Columbia **Law School**

SABIN CENTER FOR CLIMATE CHANGE LAW

June 11, 2021

The Honorable Gary Gensler
U.S. Securities and Exchange Commission
100 F Street, NE
Washington, DC 20549

Re: Public Input on Climate Change Disclosures

The Sabin Center for Climate Change Law ("Sabin Center") submits these comments in response to the SEC's request for information on whether current disclosures adequately convey climate change information to investors, registrants, and other market participants.

These comments focus on the science of climate attribution, detection, and prediction—the body of research drawing on multiple lines of evidence that describes the role of human activity in climate change—addressing questions two (2) and fourteen (14) in Commissioner Lee's March 15, 2021 request for public input.[1] The goal of these comments is to explicate the quantifiable information that climate science makes available to private companies for the particular purpose of projecting localized impacts of climate change on infrastructure, operations, and supply chains, and the potential adverse consequences that might result from disruptions caused by those impacts. The sections below further explain these key points:

- Observed physical impacts of climate change—including, among others, sea level rise and rising average temperatures—can be attributed to anthropogenic climate change with high confidence.
- There is also a robust body of studies finding a causal connection between anthropogenic influence on climate and immediately-felt consequences of climate change such as heat-related mortality, freshwater availability, agricultural productivity, wildfire risk, and more.
- Impacts that have been attributed to anthropogenic climate change can be attributed to specific emission sources in a variety of ways, including on a proportional basis.
- The degree of confidence with which scientists can attribute climate impacts to anthropogenic influence frequently meets or exceeds the level of evidence required in legal and regulatory contexts.
- Information about regional and local climate impacts is available to private companies.

[1] Allison Herren Lee, *Public Input Welcomed on Climate Change Disclosures*, SEC.GOV (March 15, 2021), https://www.sec.gov/news/public-statement/lee-climate-change-disclosures.

Attribution Science's Scope, Data Sources, and Limitations

Attribution science refers to the body of research that explores the link between human activity and climate change.[2] The field seeks to identify the contributions of specific entities, sectors, and activities to changes in the global climate, and whether (and to what extent) those changes have impacts on human activities. As further detailed below, a robust body of attribution studies explains and quantifies the role of human activity in climate change to date and can provide a means of quantifying valuable information about the scope of an entity's contribution to global climate change as well as the ways in which extreme events and other climate change-related phenomena may affect a company's assets and operations.

A. Scope of Attribution Research

The body of existing climate attribution research can be broken down into four conceptual areas: climate change attribution, impact attribution, extreme event attribution, and source attribution.

- Climate change attribution studies explore how human activities have changed and continue to change the global climate system broadly defined. These studies explain, for example, how burning fossil fuels alters atmospheric concentrations of carbon dioxide.[3]
- Impact attribution studies examine the role that climate change plays in, as noted by the Intergovernmental Panel on Climate Change ("IPCC"), "effects on lives, livelihoods, health, ecosystems, economies, societies, cultures, services, and infrastructure due to the interaction of climate changes or hazardous climate events occurring within a specific time period."[4]
- Extreme event attribution is the body of research that investigates the links between climate change and extreme weather events. For example, several studies have assessed the role of climate change in Hurricane Harvey.[5]
- Source attribution is a distinct but related body of research that aims to quantify the contributions that specific industries, entities, and activities have made to climate change overall. Leading source attribution work assesses, for example, the cumulative greenhouse

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[2] *See* Michael Burger, Jessica Wentz, and Radley Horton, *The Law and Science of Climate Change Attribution*, 45 COLUM. J. ENVTL. L. 57, 64 (2020).

[3] Climate change attribution studies examine many different aspects of the global climate system. *See, e.g.*, Yang Chen et al., *Future Increases in Arctic Lightning and Fire Risk for Permafrost Carbon*, 11 NAT. CLIM. CHANGE 404 (2021); Lauren J. Vargo et al. *Anthropogenic Warming Forces Extreme Annual Glacier Mass Loss*, 10 NAT. CLIM. CHANGE 856 (2020); Qiaohon Sun et al., *A Global, Continental, and Regional Analysis of Changes in Extreme Precipitation*, 34 J. CLIMATE 243 (2020).

[4] IPCC: CLIMATE CHANGE 2014: SYNTHESIS REPORT. CONTRIBUTION OF WORKING GROUPS I, II AND III TO THE FIFTH ASSESSMENT REPORT OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE 5 (2015), https://www.ipcc.ch/report/ar5/syr/.

[5] *See* Kevin Trenberth et al., *Hurricane Harvey Links to Ocean Heat Content and Climate Change Adaptation*, 6 EARTH'S FUTURE 730 (2018); S-Y Simon Wang et al., *Quantitative Attribution of Climate Effects on Hurricane Harvey's Extreme Rainfall in Texas*, 13 ENVTL. RES. LETTERS 1 (2018); Geert Jan van Oldenborgh et al., *Attribution of Extreme Rainfall from Hurricane Harvey, August 2017*, 12 ENVTL. RES. LETTERS 1 (2017); Mark Risser & Michael Wehner, *Attributable Human-Induced Changes in the Likelihood and Magnitude of the Observed Extreme Precipitation During Hurricane Harvey*, 44 GEOPHYSICAL RES. LETTERS 12457 (2017).

gas emissions attributable to specific oil, natural gas, coal, and cement producers.[6] Comparable studies explore the impact of certain political jurisdictions, including nations[7] and cities,[8] and other studies aim to quantify impacts of specific industries, such as tourism or agriculture.[9]

B. Data Sources

With the partial exception of source attribution, attribution studies share a common set of data sources and overlapping analytical techniques. The key sources of data on which all these studies rely are summarized here. Attribution studies frequently rely on a combination of observational data; understanding of how climate processes function and relate to human systems; and statistical analyses that are used to measure and understand data.

1. Observation and Analysis of Measured Climate Variables

Observational data includes, among others, measurements of carbon dioxide concentrations in the atmosphere, surface temperatures, sea levels throughout the world, water vapor, precipitation, sea ice, and wind speed. Observational data is used both to create baselines against which future changes can be measured, and in conjunction with statistical analysis to detect changes in the climate system. Those changes include more frequent and severe extreme events, as well as non-event changes like higher average temperatures and sea level rise. Trend analyses of historical data can allow scientists to determine whether there has been a statistically significant change in a variable.

Physical understanding refers to scientific understanding of physical properties and climate-related processes. Examples include the heat trapping effects of greenhouse gases, which can be tested using laboratory and modeling experiments.[10] Understanding the physical properties of climate processes provides a basis for developing experiments and models that can evaluate how variables in the climate system interact with each other and with human systems.

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[6] *See, e.g.*, RICHARD HEEDE, CARBON MAJORS: ACCOUNTING FOR CARBON AND METHANE EMISSIONS 1854–2010: METHODS & RESULTS REPORT (2014), https://climateaccountability.org/pdf/MRR%209.1%20Apr14R.pdf.

[7] *See, e.g.*, Sourish Basu et al., *Estimating US fossil fuel CO2 emissions from measurements of 14C in atmospheric CO*, 24 PROC. NAT'L ACAD. SCI. 117 (2020).

[8] C40 CITIES CLIMATE LEADERSHIP GROUP, CONSUMPTION-BASED GHG EMISSIONS OF C40 CITIES (2018), https://www.c40.org/researches/consumption-basedemissions.

[9] *See, e.g.*, Emrah Koçak et al., *The Impact of Tourism Developments on CO2 Emissions: An Advanced Panel Data Estimation*, 33 TOURISM MGMT. PERSPECTIVES (2020) (tourism in the most visited countries 1995 to 2014); Dario Caro et al., *Greenhouse Gas Emissions Due to Meat Production in the Last Fifty Years, in* QUANTIFICATION OF CLIMATE VARIABILITY, ADAPTATION AND MITIGATION FOR AGRICULTURAL SUSTAINABILITY 27 (Mukhtar Ahmed & Claudio O. Stockle eds., 2017) (production of beef cattle, pork and chickens).

[10] Additional examples include experiments that explore the reflectivity of sea ice, *see* Bonnie Light, Regina C. Carns, and Stephen G. Warren, *'Albedo Dome': A Method for Measuring Spectral Flux-Reflectance in a Laboratory for Media with Long Optical Paths*, 54 APPLIED OPTICS 5260 (2015), and the effect of increased soil temperatures on specific plant species, *see* Anne Marie Panetta et al., *Climate Warming Drives Local Extinction: Evidence from Observation and Experimentation*, SCI. ADVANCES 4, eaaq1819 (2018).

Statistical analysis refers to formulas, models, and techniques that researchers use to analyze data. These analyses are used both to detect and attribute climate change. Statistical analysis provides a means of detecting climate change by measuring whether observed changes are statistically significant departures from historical baselines. In attribution studies, statistical analysis can quantify the likelihood that an observed change would have occurred with or without human influence on the climate. Both observational data and physical understanding of climate processes provide the basis for calibrating and verifying climate models.

2. Modeling

Modeling allows researchers to simulate interactions between variables within the climate system using quantitative methods. Models allow scientists to explore the effect of changes to specific climate variables—greenhouse gas concentrations, temperatures, sea ice, and more—to evaluate the effect of changing one or more of those climate drivers. Attribution modeling generally involves running a model that reflects a world without anthropogenic influences on climate, then re-running the same model with actual greenhouse gas concentrations as an input and seeing what changes.

Scientists have developed standard climate simulations that are specifically designed for detection and attribution. These simulations can evaluate the probability that an event or impact would have occurred with its observed characteristics, with or without certain observed changes in the climate. These experiments leverage the same models that have been used to project future climate changes. These tools, outputs, and the models themselves are increasingly being made available to the public.

3. Documentary Evidence

Documentary evidence is particularly relevant to source attribution and refers to information contained in documents and reports that relates to human emissions of greenhouse gases. Paradigmatic examples of this type of information include historical records of fossil fuel producers and consumers that show the amount of fossil fuels that have been consumed over the course of an entity, project, or activity's existence. These records allow researchers to calculate an individual entity's contribution to global climate change by, for example, determining the amount of carbon dioxide emitted by burning a known quantity of coal, comparing that figure to the total concentration of anthropogenic carbon dioxide in the atmosphere, and accounting for factors that have an effect on the translation of emissions to atmospheric carbon dioxide concentrations.[11] Key sources of documentary evidence include national greenhouse gas inventories, securities disclosures, and reports prepared by governments and private actors that quantify emissions or sequestration impacts of particular activities.

4. Overcoming Challenges and Uncertainties

Attribution science is sufficiently robust to assess the likelihood of certain extreme weather events, describe some of the consequent impacts those events will have on companies'

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[11] *See, e.g.*, CARBON MAJORS REPORT, supra *note* 7.

operations and infrastructure, accurately identify human fingerprints on the changing climate, and quantify the impact particular entities have had to date; but there are limitations in how attribution science can be used and some remaining uncertainties. As explained in this section, researchers have techniques and language to manage these challenges, so that climate attribution science remains a robust source of useful climate information.

First, attribution is increasingly challenging as the focus of research moves from long-term, broad-scale changes in the climate towards more discrete, local events. Attribution studies that focus on specific climate impacts have to manage the role of confounding (also called "exogenous") variables, which are more difficult to isolate at fine scales. Separating climate change from other variables is made harder by the fact that natural and anthropogenic variables may relate in a non-linear way, and because multiple different human activities have changed climate variables in the past, often simultaneously.

Because of the difficulty of managing confounding variables, most impact attribution studies focus on a single link in the causal chain of climate change. This approach, often called single-step attribution, provides a way for researchers conducting an impact attribution study to manage the uncertainties that confounding variables create. A study of this kind will focus on the relationship between climate impacts and an observed change in mean climate variables or extremes without drawing conclusions about every causal step between anthropogenic influence and a climate impact. Examples of these studies include research linking local sea level rise to increased global average temperature, or research that links increased global average temperature to changes in atmospheric concentrations of greenhouse gases. Single-step attribution studies assume that human influence is a primary driver of climate change. Thus, when a particular impact can be attributed to climate change, we can infer that the impact was at least in part caused by anthropogenic causes.

Because single-step attribution studies do not account for every step in the causal chain that produces a climate impact, they are not able to isolate the proportional contribution of human influence on that impact. As a result, single-step attribution studies typically communicate results in terms of whether there is human influence on a particular impact rather than quantifying the magnitude of the influence. This approach has the advantage of being simpler than accounting for every relevant variable, and can still generate robust, quantitative attribution findings where an impact study can be linked to other studies establishing the role of human influence in the change in climate variable that gave rise to the climate impact.

In addition, there is a growing body of multi-step attribution studies aiming to combine the two steps described above: linking a climate impact to a changing climate variable, and then linking the changing climate variable to human activity. Multi-step attribution theoretically provides a more complete picture of the causal relationships in the climate system, but must contend with the potential for additional, "cascading" uncertainty with each new step that is added to the analysis.

Finally, researchers undertaking an impact attribution study can manage the difficulty of untangling confounding variables from climate forcing by communicating a qualitative description of impacts rather than quantitative analyses of impacts. Describing impacts in a qualitative way can provide valuable insight into climate change impacts for which uncertainty makes quantitative analysis impossible. Those impacts include ones that have not received a great deal of scientific or public attention to date. Qualitative results are useful climate information because they alert investors to risks that are significant but incompletely understood.

Second, models must overcome uncertainties and manage the challenges associated with attributing climate impacts at a fine scale. By comparing models to observational data scientists can assess how well a model functions, but even after checking a model against reality some dimensions of uncertainty linger. Observational measurements themselves may not be perfect. And, for many systems and places, standardized long term data sets are simply not available. Moreover, when models are used to assess extreme events at finer scales than the models themselves operate, downscaling or bias correction is needed and introduces additional uncertainties.

Researchers making use of climate models can address those challenges by articulating the nature and extent to which local climate predictions may differ from regional predictions modeled at a larger scale. The results of a study of likely future climate impacts on a particular city, for example, may be that while regional modeling suggests that North America will experience increased average surface temperature, factors like land use, local aerosol concentrations, and small scale natural variability may cause a particular city in North America to experience more or less warming than elsewhere on the continent. Moreover, uncertainties about observational data can be reported as well. The IPCC concludes, for example, that there is low confidence in Antarctic surface air temperature changes but that a key reason for that level of confidence is the scarcity of temperature measurements, and the fact that most are limited to the coasts.[12] So while some uncertainties about modeling persist, researchers can frame results at an appropriate scale and use language that clearly communicates the extent to which modeling does produce results with a high level of confidence. Those techniques allow a company using this information to effectively use the results of models and have already been demonstrated in the case studies below.

Third, the results of individual studies are typically conveyed in terms of degrees of confidence, rather than absolute certainty. A study may conclude, for example, that a result is "virtually certain (>99% probability)"[13] or a conclusion is reached "with high confidence."[14] But some degree of probabilistic language is common across many fields of scientific study.

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[12] Nathaniel L. Bindoff et al., *Detection and Attribution of Climate Change: from Global to Regional, in* CLIMATE CHANGE 2013: THE PHYSICAL SCIENCE BASIS. CONTRIBUTION OF WORKING GROUP I TO THE FIFTH ASSESSMENT REPORT OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (T.F. Stocker et al. eds., 2013), https://www.ipcc.ch/report/ar5/wg1/.

[13] *See, e.g.*, R. F. Stuart-Smith et al., *Increased Outburst Flood Hazard from Lake Palcacocha Due to Human-Induced Glacier Retreat*, 14 NATURE GEOSCIENCE 85–90 (2021).

[14] Thomas Frölicher, et al., *Marine Heatwaves Under Global Warming*, 560 NATURE 360, 362 (2018).

Language of this kind is used to manage uncertainties in a systematic way and should not be taken to mean that the conclusions a study reaches are unreliable.[15]

C. Information Available to Reporting Entities

As the sections above describe, attribution science makes available information about a company's contribution to climate change and its exposure to acute and slow-developing climate impacts. Several types of information are further discussed below, but these examples are not exhaustive, and available climate information will vary across different industries.

First, documents, reports, and other records that reflect a company's contribution to climate change. Internal records and other documents that describe the amount of fossil fuels used, energy purchased from outside suppliers, and related information would provide a means for investors to assess the degree to which a reporting entity is contributing to climate change overall.

Second, information about where climate impacts are likely to be felt. That information may allow a company to assess which of its physical assets, operations, and supply chains are located in areas known to be vulnerable to climate impacts and extreme events, and may enable the company to better understand the nature and extent of those vulnerabilities. Companies can use the output of climate models and climate impact models that produce a probabilistic assessment of impacts within a region to identify risks to assets in the effected region.[16] Using model outputs at a smaller scale than the model itself operates requires an acknowledgement that the local risk of an extreme event may differ from what the model predicts at a larger scale. A company could disclose, for example, that its principal place of business is within a geographic area that scientists have concluded is highly likely to experience climate-worsened flooding.

Third, information on how specific climate impacts are predicted to change in frequency or severity. Those impacts include both extreme events and longer term changes to the environment. Impact attribution studies that explore the linkages between climate change and specific impacts can provide insight into how those impacts will change over time, which may change the way those impacts affect particular assets or opportunities a company holds.

Case Studies

A pair of case studies highlights how private companies can make use of the data and analytical techniques highlighted in this letter to communicate useful information about those companies' contributions to climate change and their exposure to its impacts.

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[15] *See* Elisabeth A. Lloyd et al., *Climate Scientists Set the Bar of Proof Too High*, 165 CLIMACTIC CHANGE 55 (2021) ("[C]limate scientists have set themselves a higher level of proof in order to make a scientific claim than law courts ask for in civil litigation in the USA, the UK, and virtually all common law countries.").
[16] *See, e.g.*, INTER-SECTORAL IMPACT MODEL INTERCOMPARISON PROJECT, https://www.isimip.org/ (last visited June 11, 2021).

A. Con Ed's Climate Vulnerability Study

Consolidated Edison Company of New York's ("Con Ed") Climate Change Vulnerability Study provides an example of how companies can conduct (and ultimately disclose) an assessment of climate risk.[17] In the wake of Superstorm Sandy in 2013 the company undertook a comprehensive study to analyze the likelihood and consequences of a range of climate change scenarios. A copy of the study is attached to this letter.

Con Ed's study used customized downscaled projections to analyze five key climate variables over seven time periods from 2020 through 2080. The modeling that Con Ed used was only able to produce future climate projections at fairly large resolution—grid cells approximately 100km on a side. But by using historical weather station data from several stations in its service area to adjust the simulations to bring them closer to observed data, the study was able to achieve a somewhat more accurate picture of local climate projections for the New York City area.

The Con Ed study revealed significant, actionable information about the impacts of climate change on its assets and operations. The study's downscaled climate projections describe significant changes in climate in Con Ed's service territory. Those changes include a significant (575%) increase in the number of days with temperatures above 95ºF, a twenty-percent decrease in cold weather days, and extended heat wave events occurring twenty-five to seventy times more frequently by 2050. Hydrological changes in Con Ed's service territory are similarly expected to increase the company's vulnerability to climate change. As sea levels rise, the study forecasts 500-year floods occurring every ten years by 2100, and water-depth of present-day 100-year floods to increase by up to fifty percent. These projected changes have important implications for Con Ed's operations including, for example, allowing the company to identify specific assets at risk and plan for which of those assets need to be replaced or better prepared for climate change impacts.

Where quantitative results are not available, the study conveys qualitative information. The study notes, for example, that "the percentage of very strong and destructive (i.e., Categories 4 and 5) hurricanes is projected to increase in the North Atlantic basin. It can therefore be argued that climate change could make it more likely for one of these storms to impact the New York Metropolitan Region, although the most dominant factor will remain unpredictable climate and weather variability."[18]

In sum, the Con Ed study provides a good example of the kinds of climate information that a company can use and describe, and it demonstrates how using several of the techniques described in this letter—for example, combining observational data and modeling, articulating

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[17] CONSOLIDATED EDISON, CLIMATE CHANGE VULNERABILITY STUDY (2019), https://www.coned.com/-/media/files/coned/documents/our-energy-future/our-energy-projects/climate-change-resiliency-plan/climate-change-vulnerability-study.pdf?la=en%23:~:text=Con%20Edison%20recognizes%20the%20global,occurring%20at%20an%20accelerating%20rate.&text=This%20Study%20evaluates%20present%2Dday,vulnerability%20to%20climate%2Ddriven%20risks.

[18] *Id.* at 24–25.

model-based probabilistic results, and describing qualitative narratives where quantitative data is unavailable—can produce useful information on a company's climate risk.

B. Rio Grande Project EIS

The Bureau of Reclamation's Final Environmental Impact Statement (the "EIS") for the Rio Grande Project provides another example of how private companies can use climate science to understand and communicate climate change risk.[19] The EIS highlights how downscaled climate projections and models can be used to predict climate and hydrologic conditions in a discrete area—in this case, the Rio Grande River basin. A copy of the EIS is attached to this letter.

The EIS assesses the impacts of continuing to operate (through 2050) the Rio Grande Project, which furnishes a full irrigation water supply for about 178,000 acres of land and electric power for communities and industries in the area. About sixty percent of the lands receiving water are in New Mexico; 40 percent are in Texas; and water is also provided for diversion to Mexico. The project's physical features include the Elephant Butte and Caballo Dams, hundreds of miles of canals and associated infrastructure, as well as a hydroelectric powerplant.

The project's climate impact analysis was designed to understand how the water management system would operate under future climate conditions (through 2050) and the corresponding effects on the environmental impacts of water management options. To do so, the study authors used projected climate conditions developed based on an ensemble of 112 statistically downscaled climate projections. Using those projections, the EIS developed three possible scenarios—a drier scenario, a median or "central tendency" scenario, and a wetter scenario. Hydrology models were then used to simulate changes in runoff and streamflow in the Rio Grande River basin based on the three climate scenarios.

The study authors were then able to evaluate potential environmental effects based on these scenarios.[20] The wetter scenario, for example, represents a worst case for species in Elephant Butte reservoir; the drier scenario is the worst case for species downstream of the Caballo Dam.

The EIS provides another good example of the kinds of climate information that a private company can develop and describe, and it demonstrates how using techniques outlined in this letter—notably here, employing qualitative narratives as appropriate and exploring multiple climate scenarios—can produce useful information on a company's climate risk.

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[19] BUREAU OF RECLAMATION, CONTINUED IMPLEMENTATION OF THE 2008 OPERATING AGREEMENT FOR THE RIO GRANDE PROJECT, NEW MEXICO AND TEXAS (2016), https://cdxnodengn.epa.gov/cdx-enepa-II/public/action/eis/details?eisId=218219.

[20] *Id.* at 55.

Conclusion

Climate attribution studies combine observational data, physical understanding, statistical analysis, and detailed models to generate useful findings. By clearly communicating those findings, the assumptions made, the confidence with which conclusions are reached, and potential areas of uncertainty or bias, researchers produce climate information that should be useful to investors in a broad range of sectors.

Sincerely,

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Attachments (3):

1. Michael Burger, Jessica Wentz, and Radley Horton, The Law and Science of Climate Change Attribution, 45 Columbia Journal of Environmental Law 57, 67 (2020).

2. Consolidated Edison, Climate Change Vulnerability Study (2019).

3. Bureau of Reclamation, Final EIS: Continued Implementation of the 2008 Operating Agreement for the, New Mexico and Texas (Sept. 30, 2016).

The Law and Science of Climate Change Attribution

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This paper has benefited from presentations at the University of Oregon School of Law Environmental and Natural Resources Law Center's Fall 2017 Works-in-Progress Conference and Princeton University's David Bradford Energy and Environmental Policy Seminar. Special thanks to Michael Gerrard and Corey Lesk for their comments on early drafts, and to the editorial board and staff at CJEL for their extraordinary assistance.

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I. INTRODUCTION

There is overwhelming scientific agreement that human activities are changing the global climate system and these changes are already affecting human and natural systems. The observational record shows that the planet is getting significantly warmer, with eighteen of the nineteen warmest years on record occurring since 2001.[1] Other observed changes include rising sea levels, ocean warming and acidification, melting sea ice, thawing permafrost, increases in the frequency and severity of extreme events, and a

1. *State of the Climate: National Climate Report for January 2019,* NOAA NAT'L CENTERS FOR ENVTL. INFO., https://www.ncdc.noaa.gov/sotc/national/ [https://perma.cc/8BDB-CUP9] (last visited Nov. 30, 2019).

variety of impacts on people, communities, and ecosystems. There are multiple lines of evidence linking these changes to anthropogenic influence on climate.[2]

The consequences of climate change have received increasing attention in recent years, as communities around the world have been hit hard by climate-related natural disasters. The 2017 Atlantic hurricane season was the costliest on record: seventeen named storms, including six major hurricanes, pummeled the Caribbean and southern United States, causing unprecedented flooding and devastation totaling approximately $370 billion (USD) in worldwide damages.[3] That same year, Southeast Asia experienced unusually heavy monsoon rains which killed over 1,200 people and affected over 45 million people across Bangladesh, India, and Nepal.[4] There were also a number of record-breaking wildfires in 2017 and 2018, which claimed hundreds of lives, thousands of structures, and millions of acres in the Western United States, British Columbia, Europe, and Siberia.[5] Other disasters include chart-topping heat waves throughout the Northern Hemisphere, severe droughts in Central and South America and the Middle East, and record-breaking rainfall and flooding events across all continents.[6] Significant advances in

2. U. S. GLOBAL CHANGE RESEARCH PROGRAM (USGCRP), FOURTH NATIONAL CLIMATE ASSESSMENT: VOLUME II, 25–26 (2018).

3. Brian K. Sullivan, *The Most Expensive U.S. Hurricane Season Ever: By the Numbers*, BLOOMBERG (Nov. 26, 2017), https://www.bloomberg.com/news/articles/2017-11-26/the-most-expensive-u-s-hurricane-season-ever-by-the-numbers [https://perma.cc/VM95-LVU6].

4. *Press Release: 16 Million Children Affected by Massive Flooding in South Asia, with Millions More at Risk*, UNICEF (Sep. 2, 2017), https://www.unicef.org/infobycountry/media_100719.html [https://perma.cc/L285-MNNH].

5. *See, e.g.*, Luis Gomez, *California Wildfires: New Records Set by 2018 Fires*, SAN DIEGO UNION-TRIBUNE (Nov. 12, 2018), https://www.sandiegouniontribune.com/opinion/the-conversation/sd-california-2018-wildfires-burn-with-historic-impact-20181112-htmlstory.html [https://perma.cc/E5PV-V6YF]; Dale Kasler, *Worst Wildfire Year Since When? More California Acres Have Burned in 2018 Than the Past Decade,* SACRAMENTO BEE, Nov. 16, 2018, https://www.sacbee.com/latest-news/article221788220.html; *Facts and Statistics: Wildfires*, INS. INFO. INST. (2019), https://www.iii.org/fact-statistic/facts-statistics-wildfires [https://perma.cc/FJ5C-2R8N]; Melissa Etehad, *Wildfires Rage Across Europe as Countries Battle Intense Heat Wave*, L.A. TIMES (Jul. 28, 2018), https://www.latimes.com/world/la-fg-wildfires-europe-20180728-story.html [https://perma.cc/B56L-GBFM]; Andrew Freedman, *Heat Records Fall in the Arctic as Fires Erupt in Sweden and Siberia*, AXIOS (Jul. 19, 2018), https://www.axios.com/heat-wave-records-wildfires-sweden-norway-siberia-b351dce3-b3ef-41ee-b94e-e7833bd224e2.html [perma.cc/KQP2-2V9K].

6. *See* Daniel Levitt et al., *Deadly Weather: The Human Cost of 2018's Climate Disasters—Visual Guide,* THE GUARDIAN (Dec. 21, 2018), https://www.theguardian.com/environment/ng-interactive/2018/dec/21/deadly-weather-the-human-cost-of-2018s-climate-

climate change detection and attribution science—the branch of science which seeks to isolate the effect of human influence on the climate and related earth systems—have continued to clarify the extent to which anthropogenic climate change causes both slow onset changes and extreme events.[7]

The spike in deaths and costs associated with extreme events and the prospect for slow onset changes with irreversible impacts has inspired a marked increase in the number of lawsuits seeking to hold different actors—particularly governments and fossil fuel companies—accountable for their contribution to or failure to take action on climate change. For example, state and local governments across the United States have filed over a dozen lawsuits against major oil and gas producers, alleging that they knowingly contributed to climate change by extracting and selling fossil fuels, obscuring the science of climate change, and fighting policies aimed at mitigating climate change.[8] In Germany, a Peruvian farmer has brought a lawsuit against RWE, the German utility, seeking compensation for damages associated with a melting glacier the farmer alleges are in part attributable to the defendant's direct GHG emissions.[9] Lawsuits have also been filed against various national governments seeking to compel regulations aimed at curtailing the production and use of fossil fuels and otherwise reducing national GHG emissions.[10] These are among the first, not the last, of these types of cases.

Attribution science is central to the recent climate litigation, as it informs discussions of responsibility for climate change. Indeed, detection and attribution science has long been central to climate litigation, from the lawsuit filed in 1986 by New York City and Los

disasters-visual-guide [https://perma.cc/LCE7-JCYF]; Jason Samenow, *Red-hot Planet: All-time heat Records Have Been Set All Over the World During the Past Week*, WASH. POST (July 5, 2018), https://www.washingtonpost.com/news/capital-weather-gang/wp/2018/07/03/hot-planet-all-time-heat-records-have-been-set-all-over-the-world-in-last-week/ [https://perma.cc/JY6A-DQAU].

7. U. S. GLOBAL CHANGE RESEARCH PROGRAM, CLIMATE SCIENCE SPECIAL REPORT, FOURTH NATIONAL CLIMATE ASSESSMENT (2017) [hereinafter NCA4]. For a more detailed definition, see Section II(A), *infra*.

8. Michael Burger & Jessica Wentz, *Holding Fossil Fuel Companies Accountable for their Contribution to Climate Change: Where Does the Law Stand?*, 74 BULL. OF THE ATOMIC SCIENTISTS 397 (2018).

9. Lliuya v. RWE AG, VG Essen 15.12.2016 (2 O 285/15) (Germany).

10. MICHAEL BURGER & JUSTIN GUNDLACH, U.N. ENV'T PROGRAMME, THE STATUS OF CLIMATE CHANGE LITIGATION 10–26 (2017).

Angeles challenging the National Highway Transportation Safety Administration's decision not to prepare an environmental impact statement for the model year 1989 Corporate Average Fuel Economy standard, despite the standard's potential global warming impacts,[11] through the lawsuit filed in January 2019 by traditional cultural leaders from the Ksanka Band of the Ktunaxa Nation and various conservation groups challenging the U.S. Fish and Wildlife Service's decision to approve a silver and copper mine project in Montana without considering new data concerning the threats climate change poses to threatened grizzly bear and bull trout populations.[12] Climate science also plays a central role in policymaking and planning, particularly where decisions need to be made about how to allocate the costs of mitigating and adapting to climate change. Recently, researchers have been developing methodologies to link harmful impacts that were caused or exacerbated by climate change to specific emitters, with an eye towards holding emitters and other responsible parties accountable in court for their contribution to the harms.[13] As the science evolves, so too will its role in the courtroom and in policymaking.

This Article offers a comprehensive, of-the-moment survey of the roles attribution science plays in climate change law and litigation. Our purpose is to provide legal researchers and climate scientists alike with a roadmap and a rundown of the dynamic interactions between attribution science and climate change law, and to indicate some of the ways the fields might influence one another. Part II reviews the current state of attribution science with respect to both slow- and sudden-onset events. Part III describes the role that attribution science has played in recent litigation as well as policy-making and planning activities, focusing primarily on examples from the United States but also drawing on international examples. Part IV discusses future directions in the law and science of climate change attribution, addressing questions such as how attribution science can better support policy-making, planning and litigation; and how plaintiffs and courts can engage with attribution

11. City of L.A. v. Nat'l Highway Transp. Safety Admin., 912 F.2d 478 (D.C. Cir. 1990).

12. Complaint for Declaratory and Injunctive Relief, Ksanka KUPAQA XAʾȽȻIN v. U.S. Fish and Wildlife Serv., No. 9:19-cv-00020-DWM (D. Mont. Jan. 25, 2019).

13. *See, e.g.*, CLIMATE ACCOUNTABILITY INST., THE CARBON MAJORS DATABASE: CDP CARBON MAJORS REPORT 2017 (July 2017); B. Ekwurzel et al., *The Rise in Atmospheric CO_2, Surface Temperature, and Sea Level from Emissions Traced to Major Carbon Producers*, 144 CLIMATIC CHANGE 579 (2017).

science to help resolve questions of liability and responsibility for climate change.

II. SCIENTIFIC UNDERPINNINGS

Since the onset of the Industrial Revolution more than two centuries ago, human activities—especially fossil fuel combustion, land use change, and industrial production—have dramatically impacted earth's climate. As a result of human activities, concentrations of radiatively important agents such as GHGs and aerosols have increased significantly. Carbon dioxide (CO_2) concentrations, for example, have increased by more than 40 percent to levels not seen in at least 3 million years.[14] These changes in atmospheric chemistry have triggered widespread warming and other impacts. Global surface air temperature has increased by approximately 1.8° F since 1900, and ocean heat content has increased by approximately $33.5 \pm 7.0 \times 10^{22}$ joules.[15] As the planet has warmed, Arctic sea ice volume in late summer has decreased by more than 50 percent, mass loss from land-based ice sheets has accelerated, and sea levels have risen by approximately 8 inches since 19001 foot.[16] Warming is also leading to phenological changes, such as longer growing seasons, and impacting all human and natural systems.[17] The frequency, intensity and duration of many types of extreme events are changing dramatically as well. For example, record breaking high temperatures are now far more common than record breaking low temperatures, high water levels on coastlines are increasing dramatically, and the frequency of hydrometeorological extremes—both droughts and floods—is also increasing in many regions.[18]

As climate change has become more and more manifest, our understanding of the climate system has advanced dramatically.

14. WMO Greenhouse Gas Bulletin, No. 13 (Oct. 30, 2017).

15. NCA4 (2017), *supra* note 7, at 11, 82, 365. As a point of reference, the increase in ocean heat content is approximately 580 times larger than world total primary energy supply (TPES). *See* INT'L ENERGY AGENCY [IEA], KEY WORLD ENERGY STATISTICS (2018) (finding that world TPES in 2016 was 13,761 Mtoe, which is equivalent to 5.76×10^{20} joules).

16. *See* NCA4 (2017), *supra* note 7.

17. INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE [IPCC], SPECIAL REPORT: GLOBAL WARMING OF 1.5°C (Valerie Masson-Delmotte et al. eds., 2018).

18. IPCC, WORKING GROUP II CONTRIBUTION TO THE FIFTH ASSESSMENT REPORT OF THE IPCC, CLIMATE CHANGE 2014: IMPACTS, ADAPTATION, AND VULNERABILITY 982 (Fields et al eds., 2014) [hereinafter IPCC AR5 WGII].

Multiple lines of evidence, including increasingly robust observational data sets, paleoclimate data, process-models of increasing complexity, and physical understandings all point to the central role of human activity in the climate changes described above. For example, it has become clear that the spatial pattern of observed warming generally matches our theoretical understanding and model projections; specifically, high latitude regions are warming faster than the tropics, and the lower stratosphere is cooling.[19] The spatial pattern, or fingerprint, of the warming is thus consistent with increases in GHG concentrations, not alternative explanations such as volcanoes, incoming solar radiation, or internal climate variability. Our ability to link anthropogenically-induced global warming to local impacts has also improved dramatically. The leading scientific body for climate assessment, the Intergovernmental Panel on Climate Change (IPCC), periodically publishes a synthesis of existing research on climate change detection and attribution. In its most recent assessment, the IPCC concluded that "there is new or stronger evidence for substantial and wide-ranging impacts of climate change" across all climate zones and continents.[20] Similarly, the Fourth National Climate Assessment (NCA4) prepared by the U.S. Global Change Research Program (USGCRP) states that "[e]vidence for a changing climate abounds, from the top of the atmosphere to the depths of the oceans."[21]

Overall, the existing body of detection and attribution research is now quite large and the findings are sufficiently robust to support a wide variety of applications, including many of the policy, planning, and legal functions outlined in Section III. But there are also constraints to this research, such as data gaps and uncertainty about model projections, which make it difficult to identify a clear causal chain between a particular emitter or activity and specific impacts or harms associated with climate change.

Below, we summarize the current state-of-the-art in climate change detection and attribution science. We begin by defining core concepts and explaining the basic data sources and analytical techniques used in this research. Next, we discuss the status of

19. Gabriele Hegerl, Francis Zwiers & Claudia Tebaldi, *Patterns of Change: Whose Fingerprint Is Seen in Global Warming?*, 6 ENVTL. RES. LETTERS 4 (2011).

20. IPCC AR5 WGII at 982.

21. NCA4 (2017), *supra* note 7, at 36.

research with respect to different attribution questions and different types of observed impacts. For each attribution category, we discuss the areas where findings are relatively robust and then identify key challenges and takeaways for the utilization of this research in climate change law and litigation.

A. Core Concepts and Terminology

Generally speaking, detection and attribution is a two-step process used to identify a causal relationship between one or more drivers and a responding system. The first step—detection of change—involves demonstrating that a particular variable has changed in a statistically significant way without assigning cause.[22] This is typically accomplished using observational data and historical records. The second step—attribution—involves sifting through a range of possible causative factors to determine the role of one or more drivers with respect to the detected change. This is typically accomplished by using physical understanding, as well as models or statistical analysis, to compare how the variable responds when certain drivers are changed or eliminated entirely.

1. Scope of Detection and Attribution Research

Detection and attribution with regards to climate change can be broadly defined to encompass a range of research aimed at linking human activities to observed changes in the climate system and corresponding impacts on natural and earth systems. This area of research can be broken down into several interrelated parts or research streams:

Linking climate change to anthropogenic drivers: How are human activities affecting the global climate system?

Linking impacts to climate change: How do changes in the global climate system affect other interconnected natural and human systems?

Identifying the relative contribution of various emission sources and land use changes: To what extent have different sectors, activities, and entities contributed to anthropogenic climate change?

22. David R. Easterling et al., *Detection and Attribution of Climate Extremes in the Observed Record,* 11 WEATHER CLIMATE EXTREMES 17 (2016); Gabriele C. Hegerl et al., *Good Practice Guidance Paper on Detection and Attribution Related to Climate Change, in* MEETING REP. OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE EXPERT MEETING ON DETECTION AND ATTRIBUTION OF ANTHROPOGENIC CLIMATE CHANGE 2 (Thomas Stocker et al. eds., 2010).

For the purposes of brevity, we refer to these three areas of research as *climate change attribution*, *impact attribution*, and *source attribution*, recognizing that these terms may be defined differently in other papers. This approach is roughly consistent with that taken by the IPCC in past assessments, specifically the division between Working Group I (WGI), which synthesizes research on the physical science basis for anthropogenic climate change, and Working Group II (WGII), which synthesizes research on the observed and predicted impacts of climate change. However, there is no IPCC analog for "source attribution" as that term is defined in this paper,[23] and this third research stream is commonly viewed as a field distinct from the "detection and attribution" research covered in the IPCC reports. Nonetheless, source attribution deals with a fundamental attribution question relevant to some of the law and policy issues described in Section III and therefore warrants discussion in this paper.

We also discuss *extreme event attribution* as a separate category of attribution research. This is because extreme events do not fit neatly into the "climate change attribution" or "impact attribution" categories. Weather is part of the climate system, but extreme events are often discussed as "impacts" of climate change, and there are unique challenges associated with efforts to ascertain the effect of climate change on a particular extreme event. (These challenges bear similarities to the challenges associated with impact attribution).[24]

The line between "changes in the climate system" and "the impacts of climate change" is not always clear. The IPCC defines the *global climate system* as "the highly complex system consisting of five major components: the atmosphere, the hydrosphere, the cryosphere, the lithosphere, and the biosphere, and the interactions between them."[25] This broad definition is necessary to

23. The IPCC does compile some of this data in the WGI report but there is no systematic effort to synthesize research on the relative contributions of different actors or activities to climate change. There is also a third IPCC Working Group (WGIII) that assesses literature on the scientific, technological, environmental, and social aspects of mitigation of climate change.

24. E.g., extreme weather events are discussed in the IPCC WGI report as a source of evidence for climate change attribution, but also in the IPCC WGII report as an example of how climate change will affect human and natural systems.

25. IPCC, WORKING GROUP I CONTRIBUTION TO THE FIFTH ASSESSMENT REPORT OF THE IPCC, CLIMATE CHANGE 2013: THE PHYSICAL SCIENCE BASIS 1451 (Stocker et al. eds., 2013) [hereinafter IPCC AR5 WGI].

capture the highly interconnected nature of these components: changes in ocean heat content (hydrosphere), sea ice (cryosphere), carbon sequestration (biosphere), and volcanic eruptions (lithosphere) can all affect the atmosphere and vice versa. The variables studied in this research are often referred to as *essential climate variables.*[26]

The IPCC defines *impacts* or *effects* to include *physical impacts* such as floods, droughts, and local sea level rise, as well as any other "effects on lives, livelihoods, health, ecosystems, economies, societies, cultures, services, and infrastructure due to the interaction of climate changes or hazardous climate events occurring within a specific time period."[27] In many cases, a change in an essential climate variable (e.g., sea level rise) could be viewed as a "physical impact" of climate change. For the purposes of this paper, we classify studies on regional changes in essential climate variables as "climate change attribution" where the primary goal of the study is to better understand how humans are affecting the global climate system, and we classify studies on floods, droughts, and local sea level rise as "impact attribution" where the primary goal of the study is to better understand how climate change is affecting a particular region or locale.

It is also important to note that the IPCC uses a different definition of "attribution" when discussing research on climate change attribution (WGI) and impact attribution (WGII): whereas "attribution in WGI quantifies the links between observed climate change and human activity, as well as other external climate drivers," attribution in WGII "generally links responses of natural and human systems to observed climate change, *regardless of its cause*."[28] This reflects standard practice in impact attribution studies, wherein scientists focus exclusively on the relationship between global climate change and observed impacts without seeking to identify the relative contribution of human activity as compared with other external climate drivers.

These different streams of attribution science have begun to converge in recent years. There have been further advances in

26. *The Global Observing System for Climate Essential Climate Variables Data Access Matrix,* NOAA NAT'L CENTERS FOR ENVTL. INFO, https://www.ncdc.noaa.gov/gosic/gcos-essential-climate-variable-ecv-data-access-matrix [https://perma.cc/4ZSH-CMGX] (last visited Dec. 19, 2019).

27. IPCC AR5 WGII, Summary for Policy Makers, *supra* note 20, at 5.

28. *Id.* at 4.

attribution of climate change to anthropogenic activity, as well as burgeoning studies that go beyond the analysis of essential climate variables to examine adverse effects on human systems and public health.[29] Simultaneously, other researchers have been compiling data and developing techniques to identify the relative contribution of different sectors, activities, and entities to changes in atmospheric GHG concentrations.[30] Building on all three research streams, there is now a body of research which aims to link specific entities and/or activities to specific climate change impacts.[31] Below, we bring the streams together, contextualizing them within a broader climate science and risk management context.

2. Data Sources and Analytical Techniques

a. Climate Change, Extreme Event, and Impact Attribution

There are several key sources of information and analytical techniques which are used in the climate change, impact, and extreme event attribution studies. These include: physical understanding, observational data, statistical analysis, and models.[32]

Physical understanding refers to scientific understanding of physical properties and processes. A good example would be the heat trapping effects of GHGs, which can be tested using laboratory and modeling experiments. Physical understanding serves as the basis for developing experiments to evaluate potential interactions across variables in the climate system and related human and natural systems.

Observational data is data which can be observed and measured. Examples include in situ measurements of CO_2 concentrations, surface temperatures, and sea levels; satellite measurements of sea

29. Below, we use the phrase "attribution of harm" to describe studies seeking to link specific harmful impacts on public health and human systems to anthropogenic climate change. This is discussed as a subset of "impact attribution."

30. *See, e.g.*, B. Ekwurzel et al., *supra* note 13, at 579.

31. *See, e.g.*, Richard Heede, *Tracing Anthropogenic Carbon Dioxide and Methane Emissions from Fossil Fuel and Cement Producers, 1854–2010*, 122 CLIMATIC CHANGE 229 (2014).

32. *See, e.g.*, Sophie Marjanac & Lindene Patton, *Extreme Weather Event Attribution Science and Climate Change Litigation: An Essential Step in the Causal Chain?*, 36 J. ENERGY & NAT. RES. L. 265, 271–72 (2018) (noting that the "3 pillars of attribution science" are "(i) the quality of the observational record; (ii) the ability of models to simulate the event; and (iii) our understanding of the physical processes that drive the event and how they are affected by climate change.").

surface temperature, water vapor, precipitation, and sea ice; and aircraft measurements of cyclone wind speed. Observational data is primarily used in conjunction with statistical analysis to detect changes in the climate system, including changes in the frequency and severity of extreme events, and corresponding changes in natural and human systems—specifically, by comparing historical observational data sets with contemporary observations of a particular variable and determining whether there has been a statistically significant change in that variable. A statistically significant change would be detected in observations if the likelihood of occurrence by chance alone is determined to be small (e.g., less than 10%).[33]

Statistical analysis refers to mathematical formulas, models, and techniques that are used in empirical analysis of data. Statistical analysis is used in both the detection and attribution of climate change. For attribution, statistical analysis is used to quantify the probability of an observed change occurring with and without anthropogenic forcing on the climate. For example, scientists use linear regression methods[34] and variants such as "optimal fingerprinting" to determine whether a change in a climate variable is statistically significant or simply part of natural variability.[35] This analysis is part of the detection of climate change and corresponding impacts, but it can also be used to support attribution statements (e.g., a finding that the spatial pattern of warming in the atmosphere was likely caused by anthropogenic emissions because it is statistically unlikely that the spatial pattern would have occurred in the absence of anthropogenic forcing on the climate). This is sometimes referred to as "observation-based" attribution.[36]

In practice, there are very few studies that focus exclusively on observation-based statistical analysis for attribution due to short observation records and complex forcing changes over the

33. IPCC, CLIMATE CHANGE 2014: SYNTHESIS REPORT 121–22 (Rajendra K. Pachauri & Leo Meyer eds., 2014) [hereinafter IPCC AR5 SYR].

34. Linear regression is a statistical method used to summarize and study relationships between two continuous (quantitative) variables.

35. K. Hasselmann, *Optimal Fingerprints for the Detection of Time-Dependent Climate Change*, 6 J. CLIMATE 1957, 1957 (1993).

36. NAT'L ACAD. OF SCI., ENG'G, AND MED., ATTRIBUTION OF EXTREME WEATHER EVENTS IN THE CONTEXT OF CLIMATE CHANGE 51 (2016).

historical period.[37] Model approaches (below) are typically used because: (i) models allow scientists to separate out the effects of different forcings on the observed variable, and (ii) the observed record for many variables is too short to support reliable conclusions, especially given the large variability in the systems being analyzed. That said, observation-based attribution findings can serve as a useful supplement to model-based findings.[38]

Models use quantitative methods, including predictive equations and statistical techniques, to simulate interactions within the climate system. Scientists can thus set up different model experiments to evaluate the effect of one or more climate drivers (like greenhouse gases, aerosols, and solar flux) on one or more variables. For the purposes of attribution, experiments with climate models generally involve at least two sets of simulations, differing only in that one is meant to reflect the world that is, and the other is meant to reflect a "counterfactual" world without anthropogenic climate change (or without some component of anthropogenic climate change). These model simulations are typically run multiple times and for long duration, allowing scientists to better understand the most likely outcomes, as well as a fuller range of potential outcomes. Observational data and physical understanding provide the basis for calibrating and verifying models.

Several modeling centers have now developed standardized climate simulations designed for detection and attribution specifically, based on different parameters (e.g., researchers can evaluate the probability of an event or impact occurring both with and without certain observed changes in the climate, such as changes in sea surface temperature). Due to advances in parallel computing and model simplifications, these can be run rapidly and at high spatial resolution, yielding quick results. Indeed, when the above packages are combined with forecasts of variables with high predictability, such as sea surface temperature, results can be made available *in advance* of actual events. Furthermore, the tools and outputs, and models themselves, are increasingly being made publicly available. This has furthered the proliferation of

37. *Id.*

38. Andrew D. King et al., *Attribution of the Record High Central England Temperature of 2014 to Anthropogenic Influences*, 10 ENVTL. RES. LETTERS, May 1, 2015, at 1; Gabriele C. Hegerl, *Use of Models and Observations in Event Attribution*, 10 ENVTL. RES. LETTERS July 2, 2015, at 1.

attribution research in recent years, as well as an enormous amount of media coverage and public interest in the topic.[39]

Model-based approaches can support more robust attribution statements than the use of observational data and statistical analysis alone. However, models have limitations that should be kept in mind when considering their use in attribution studies. The usefulness of a model for attribution depends on how well the model can reproduce patterns associated with each climate forcing. However, there are uncertainties in our knowledge about how individual climate forcings affect the climate system. While comparing models to observations helps assess model skill, observations cannot tell us all we need to know, for three reasons. First, there is some uncertainty in observational measurements. Second, internal climate variability, unrelated to climate forcing, is difficult to disentangle from climate forcing. Third, because multiple anthropogenic and natural forcings have occurred simultaneously in the past, unpacking the relative contribution of each forcing is nontrivial.

The above challenges exist to a certain degree even for variables like global average temperature where the relationship between rising GHG concentrations and average temperatures is fairly direct. Inevitably, there will be some degree of uncertainty and room for error in model results due to the complexity of the physical systems being modeled.[40] But this does not mean that model results are unsound. To the contrary, uncertainty is prevalent across many scientific disciplines, including disciplines that are frequently relied upon in policy, planning, and litigation,[41] and scientists have tools for managing and communicating uncertainty. The IPCC, for example, uses (i) probabilistic language to describe the assessed likelihood of an outcome or result (very likely, likely, etc.);[42] (ii) terms to describe the availability of evidence to support particular findings (limited, medium,

39. See, e.g., Jane C. Hu. *The Decade of Attribution Science*, SLATE (Dec. 19, 2019).

40. E.g., models may underestimate variability, which can lead to overestimation of the effect of human influence on extreme events, and models may under-sample the range of plausible outcomes.

41. E.g., epidemiology and forensic science.

42. The IPCC defines these probabilistic terms as follows: virtually certain 99–100% probability, very likely 90–100%, likely 66–100%, about as likely as not 33–66%, unlikely 0–33%, very unlikely 0–10%, exceptionally unlikely 0–1%. In some instances, the IPCC also uses the following terms: extremely likely 95–100%, more likely than not > 50–100%, and extremely unlikely 0–5%. IPCC AR5 WGI, *supra* note 25, at 4.

robust); (iii) terms to describe the level of agreement about findings (low, medium, or high); and (iv) language describing its confidence in the findings (very low, low, medium, high, very high).[43] In individual attribution studies, uncertainty is typically managed and communicated using similar statements about confidence levels and intervals. For example, a study may conclude with 90% confidence that climate change made an extreme event at least twice as likely to occur.[44] Scientists are also constantly refining the techniques used to reduce uncertainty in their analyses, such as through additional and lengthened observational datasets, improvements to models, new analytical methods, and expert judgment.

The most robust attribution approaches combine good observations, physical understanding, rigorous statistical analysis, and detailed models to generate findings, along with clear communication and transparency with respect to research parameters, assumptions made, confidence in findings, and potential areas of uncertainty or bias. Studies that combine sound science with clear communication can generate findings that are sufficiently robust to support a wide variety of applications, but the confidence in and precision of those findings depends on the nature of the change, event, or impact being studied.

b. Special Considerations for Extreme Event and Impact Attribution

Attribution becomes increasingly complex and challenging as the focus of research moves away from long-term, broad-scale changes in the climate system and towards more localized, discrete extreme events and climate impacts. One key challenge is conducting the analysis at the appropriate *spatial and temporal scale*. Whereas climate change attribution as defined in Part II(A)(2)(a) above deals with change at a global or regional scale, typically over a long period of time, extreme event and impact attribution deal with more geographically and temporally distinct forms of change (e.g., how much has sea level risen in a particular city in the past twenty years). Natural variability, unrelated to changes in climate forcing, is larger at fine spatial and temporal scales, making it harder to

43. *Id.*

44. In this statement, the confidence level is 90% and the confidence interval starts at "twice as likely" and has no defined upper bound.

identify signals associated with anthropogenic or other forcings. Some climate forcings, such as aerosols, also differ both in concentration and forcing strength at subregional and subannual scales. Additionally, when models are used to assess extreme events that occur at finer spatial and temporal scales than the models themselves, some type of downscaling or bias correction is needed, which can introduce additional uncertainties.

Impact attribution studies must also account for *non-climate variables*—that is, characteristics of human and natural systems that are not part of the climate system. There are sometimes referred to as *exogenous variables* (i.e., phenomena that are not part of the climate system).[45] Consider a study examining the relationship between climate change, a heat wave, and public health impacts: the study would need to account for both climate variables (e.g., temperature and humidity) as well as non-climate variables (e.g., population risk factors for heat-related morbidity, access to air-conditioned facilities and emergency services) to ascertain the extent to which climate change caused or contributed to observed health outcomes. *Confounding variables*, which influence both dependent and independent variables in a study, are of special concern as they can lead to spurious associations between a driver and an event or impact.[46] The number of exogenous and confounding variables increases as attribution research moves towards an analysis of discrete impacts on humans, communities, and ecosystems.

Due to the difficulty of managing many exogenous variables, most attribution studies focus on just one "link" in the causal chain of anthropogenic climate change. This is often referred to as *single-step attribution*. Examples of single-step attribution include research linking increases in global average temperatures to changes in the atmospheric concentration of GHGs, and research linking increases in local sea level rise to increases in global average temperature. This focus on single-step attribution is apparent in IPCC WGII's approach to impact attribution (which, as noted

45. This may be somewhat of an oversimplification, as many variables which may appear to be "outside" of the climate system are still, to some extent, interdependent with that system.

46. In an impact or event attribution study, the dependent variable would be the impact or event under examination, and the independent variable would be the climate change-related driver of the impact or event (e.g., increases in GHG concentrations or, in some studies, increases in climate variables such as mean temperature).

above, examines how observed climate change is affecting natural and human systems, regardless of its cause).[47]

There is also a growing body of *multi-step attribution* studies. Such studies combine the two inquiries described above: scientists will first seek to identify how one or more core climate variables has changed in response to human activities, and then explore the implications of that change with respect to one or more specific impacts.[48] Multi-step attribution is useful for examining causal relationships in complex systems, but one potential drawback of this approach is that additional, "cascading" uncertainty and potential for error is introduced with each new "step" that is added to the analysis.

c. Source Attribution

Above, we note that source attribution is a distinct field of research that employs different methods and is subject to different constraints. There is some overlap in terms of the data collection and analytical techniques used for source attribution: scientists will use observational data to identify sources of GHGs, as well as physical understanding, statistical analysis, and models to ascertain the relative contribution of GHGs from a particular source or source category to anthropogenic climate change. But source attribution studies also rely on different types of evidence, particularly documentary evidence of GHG emissions and carbon sequestration impacts.[49]

Documentary evidence refers to information contained in documents and reports. For the purposes of source attribution, key sources of documentary evidence include national GHG emissions inventories, corporate GHG disclosures, securities disclosures, and other reports prepared by governments and private actors detailing GHG emissions or carbon sequestration impacts from a particular activity or source. Because such reports are prepared by humans, sometimes pursuant to a political or social agenda, they may

47. IPCC AR5 WGII, *supra* note 20, at 4 n.5.

48. IPCC AR5 WGI, *supra* note 25, at 867–952; Gabriele Hegerl et al., *Good Practice Guidance Paper on Detection and Attribution Related to Anthropogenic Climate Change, in* MEETING REPORT OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE EXPERT MEETING ON DETECTION AND ATTRIBUTION OF ANTHROPOGENIC CLIMATE CHANGE 3 (Thomas F. Stocker et al. eds., 2010).

49. For a more detailed discussion of the methods and techniques used in source attribution, see *infra* Part II(B)(4).

contain biases or errors of a different type than those found in raw data.

Source attribution also involves questions that cut across different social and scientific disciplines. Certainly, there is a physical science component to source attribution, as the ultimate goal is to ascertain the physical contribution of the source to anthropogenic climate change. But there are also social and normative questions that come into play when attributing emissions (or sequestration) to a particular source, particularly when trying to assign "responsibility" for emissions. Consider the many different ways that emissions can be "divvied up" across different lines—by stage of economic development, global region, country, sector, company, consumer, etc. Even within these categories, there are different ways of assigning emissions responsibility. For example, when assessing national responsibility for climate change, some have argued that we should not only look at emissions which are directly generated within the country ("territorial emissions") but also consider emissions embodied in products consumed within the country ("consumption-based emissions").[50] Similarly, when assessing corporate responsibility for climate change, there are important questions about the relative responsibility of upstream entities (e.g., fossil fuel producers) and downstream entities (e.g., manufacturers of carbon-intensive products and consumers of fossil fuels) in addition to the entities that directly generate emissions.

Granted, it is entirely possible to avoid such normative questions when publishing information about source attribution. For example, a study could simply provide a breakdown of emissions across different countries (perhaps both CO_2 exporters and CO_2 importers), sectors, etc., without reaching any conclusions about the *responsibility* of different actors or source categories. But in practice, when attribution science is related to law and policy, the question of responsibility is of paramount importance.

50. *See, e.g.*, C40 CITIES CLIMATE LEADERSHIP GROUP, CONSUMPTION-BASED GHG EMISSIONS OF C40 CITIES (2018), https://www.c40.org/researches/consumption-based-emissions [https://perma.cc/9XVC-MCRX]; Zeke Hausfather, *Mapped: The World's Largest CO2 Importers and Exporters*, CARBON BRIEF (May 7, 2017, 11:52 AM), https://www.carbonbrief.org/mapped-worlds-largest-co2-importers-exporters [https://perma.cc/3K2V-EFNE]; DANIEL MORAN ET AL., THE CARBON LOOPHOLE IN CLIMATE POLICY: QUANTIFYING THE EMBODIED CARBON IN TRADED PRODUCTS (2018), https://buyclean.org/media/2016/12/The-Carbon-Loophole-in-Climate-Policy-Final.pdf [https://perma.cc/FS95-N9W4].

B. Survey of Research to Date

1. Climate Change Detection and Attribution

Climate change detection and attribution research examines the effect of human activities on the global climate system, which is broadly defined to include the atmosphere, hydrosphere, cryosphere, lithosphere, biosphere, and the interactions between these components. The primary research question is: how do human-induced changes in the chemical composition of the atmosphere affect other essential climate variables such as temperature, precipitation, sea level, and sea ice? To answer this question, researchers must demonstrate that a detected change is "consistent with the estimated responses to the given combination of anthropogenic and natural forcing" and "not consistent with alternative, physically plausible explanations of recent climate change that exclude important elements of the given combinations of forcings."[51]

The existing body of research leaves little room for doubt that the global climate system is changing and human activities are at least partially responsible for that change; thus, there is no real question as to *whether* anthropogenic climate change is occurring. Scientists have also made considerable progress towards quantifying the effect of human activities on different components of the climate system. However, there is still some amount of uncertainty about the magnitude of the observed changes in the climate system that are due to different climate forcings—such as GHGs, aerosols, and solar radiation.[52] In this section, we

51. IPCC, WORKING GROUP I CONTRIBUTION TO THE THIRD ASSESSMENT REPORT OF THE IPCC, CLIMATE CHANGE 2001: THE SCIENCE OF CLIMATE CHANGE 56 (John T. Houghton et al eds., 2001). While in one sense attribution is easy to define, complex philosophical questions lurk in the background, including the question of how one defines causation. Deterministic causation is a simple binary framing ("A caused B") whereas probabilistic causation has a lower threshold of "A made B more likely than in otherwise would have been." Mike Hulme, *Attributing Weather Extremes to 'Climate Change': A Review*, 38 PROGRESS IN PHYSICAL GEOGRAPHY 499, 500 (2014). Even within the sub-branch of probabilistic causation, emphasized here, it should be noted that the way a problem is framed can influence the findings. See for example, the description of necessary vs. sufficient causality in Alexis Hannart et al., *Causal Counterfactual Theory for the Attribution of Weather and Climate-Related Events*, 97 BULL. AM. METEOROLOGICAL SOC'Y 99, 103–04 (2016).

52. These uncertainties primarily concern: 1) the magnitude of change in other possible drivers of climate changes (such as solar radiation changes); 2) the signature of change expected in the climate system due to human activities and '1' above; and 3) the magnitude of internal climate variability. IPCC AR5 WGI, *supra* note 25, at 867–952.

summarize the state of the terms of observed climate changes and the attribution of those changes to human activities. We focus here on mean changes in essential climate variables on a global and regional scale; changes in extremes and changes in local weather and climate are discussed in subsequent sections.[53]

a. Methods and Parameters

Scientists detect changes in the climate system through in situ measurements, such as the CO_2 readings from the Mauna Loa Observatory in Hawaii, and remote sensing from satellites and other platforms. Some of the key types of data collected through observations include measurements of GHG emissions and concentrations, atmospheric and surface temperature, water vapor (humidity), precipitation, sea ice, and sea levels. Scientists have also developed techniques to better understand past climatic conditions—for example, scientists can reconstruct paleoclimate conditions by studying the patterns in tree rings and gas bubbles trapped in ice cores.[54] This information offers important insights, including: 1) how sensitive different aspects of the climate system are to different climate forcings at various timescales, and 2) more robust estimates of natural variability than can be gleaned from the relatively short observational record.

Once change has been detected, the next step is attribution. Physical understanding of how the climate system reacts to different forcings is the foundation of climate change attribution. Examples of external forcings include GHGs, atmospheric aerosols, solar radiation, and reflectivity (albedo), all of which influence the balance of energy in the global climate system. Scientists must also have physical understanding of natural variability within the global climate system in order to ascertain whether an observed change in the system is the result of changes in forcings or natural variability.

Drawing on this physical understanding, scientists have developed global climate models that reproduce physical processes in the atmosphere, ocean, cryosphere, and land surface. One of

53. *See infra* Part II(B)(2) ("Extreme Event Attribution") and Part II(B)(3) ("Impact Attribution").

54. For more information on the development of observational techniques and datasets, see IPCC, WORKING GROUP I CONTRIBUTION TO THE FOURTH ASSESSMENT REPORT OF THE IPCC, Climate Change 2007: The Physical Science Basis 93–127 (Susan Solomon et al. eds., 2007).

the most important modeling initiatives is the Coupled Model Intercomparison Project (CMIP), which was launched by the World Climate Research Programme in 1995 to foster collaboration on and ongoing improvement of climate models and to provide a standard set of model simulations to facilitate comparison across models. Leveraging ongoing advances in physical understanding, observations, and computational power, climate models now operate at finer and finer spatial scales, include interactions across more and more components of the climate system, and generate thousands of years of model output under different forcings and initial conditions. As models have grown in sophistication, their utility for climate attribution has grown—models driven by historical greenhouse gas emissions and natural forcings (e.g., volcanoes and solar variability) can now "reproduce observed continental-scale surface temperature patterns and trends over many decades, including the more rapid warming since the mid-20th century and the cooling immediately following large volcanic eruptions."[55]

As noted above, there are challenges associated with "downscaling" from a global to a regional or local focus. These challenges are most prevalent in extreme event and impact attribution, but they also appear, to a lesser extent, in climate change attribution studies. This is because many of the observed changes in the global climate system vary on a regional basis—both due to differences in forcings and the higher natural variability at finer spatial scales.[56]

b. Status of Research

The observational record shows that significant changes in the global climate system are occurring. As noted in the IPCC's Fifth Assessment Report (AR5):

55. The IPCC issued this statement with *very high confidence*. IPCC AR5 WGI, Summary for Policymakers, *supra* note 25, at 15.

56. Above, we define "climate change attribution" as research aimed at determining "how human activities are affecting the *global* climate system." Thus, this section is concerned only with studies seeking to understand and attribute regional changes in essential climate variables in order to better understand changes in the global climate change. This section does not discuss studies that evaluate how climate and weather has changed in a region or locale in order to ascertain the effect on that region or locale (e.g., how much have sea levels risen in New York City?)—rather, those are discussed in the extreme event and impact attribution sections.

> Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased.[57]

AR5 contained similarly conclusive findings about climate change attribution, particularly with respect to the link between human influence on climate and global warming:

> Human influence on the climate system is clear. This is evident from the increasing greenhouse gas concentrations in the atmosphere, positive radiative forcing, observed warming, and understanding of the climate system.[58]

The report also found strong evidence that human activity had contributed to changes in other essential climate variables, such as sea level rise and the loss of sea ice, with different levels of confidence for different variables.[59]

Since AR5 was published in 2014, the observational record of changes in the global climate system has become even more robust, and the rate of observed change has accelerated for many essential climate variables. The body of research attributing these changes to anthropogenic influence on climate change has likewise become more robust, with more recent attribution studies further reinforcing some of the key messages from AR5. Below, we summarize the latest findings in terms of observed changes and attribution to human activity.[60]

i. Chemical Composition of Global Climate System

AR5 found, with *very high confidence*, that atmospheric concentrations of CO_2, methane (CH_4), and nitrous oxide (N_2O)

57. IPCC AR5 WGI, Summary for Policymakers, *supra* note 25, at 4.
58. *Id.* at 15.
59. *Id.*
60. There have been additional advances in the detection and attribution of long-term, time averaged climate variables that do not fit neatly into the five directly societally-relevant categories described here. Examples include fingerprinting of sea level pressure, Nathan P. Gillett, Francis W. Zwiers, Andrew J. Weaver & Peter A. Stott, *Detection of Human Influence on Sea-level Pressure*, 422 NATURE 292, 292–94 (2003), and water vapor, Benjamin D. Santer et al., *Incorporating Model Quality Information in Climate Change Detection and Attribution Studies*, 106 PROC. OF THE NAT'L ACAD. OF SCI. 14778, 14778–83 (2009).

are higher than they have been in 800,000 years, and that the rate of change in GHG concentrations over the past century is unprecedented in the past 22,000 years.[61] This was based on observations from 2011 (the latest data relied upon in AR5), showing that CO_2 concentrations had increased 40% to 391 parts per million (ppm), methane (CH_4) concentrations had increased 150% to 1803 parts per billion (ppb), and nitrous oxide (N_2O) concentrations had increased 20% to 324 ppb, as compared with pre-industrial levels.[62] This trend has continued since AR5 was published, with the latest in situ measurements putting CO_2 concentrations at 410.5 ppm, methane concentrations at 1862.8 ppb, and nitrous oxide concentrations at 332.4 ppb.[63]

Not all of these GHGs remain in the atmosphere, which is part of why it is necessary to look at multiple interconnected systems when detecting and attributing global climate change. AR5 found that the ocean had absorbed about 30% of the emitted anthropogenic CO_2, approximately 125–185 gigatons of carbon (GtC).[64] The uptake of carbon has caused ocean acidification: the pH of the ocean surface has decreased by 0.1 since the beginning of the industrial era, which corresponds with a 26% increase in hydrogen ion concentration (the measure of ocean acidity).[65] This acidification is relatively straightforward to attribute to anthropogenic carbon dioxide emissions specifically.[66] Terrestrial

61. IPCC AR5 WGI at 385. The IPCC also expressed medium confidence that the rate of GHG change was unprecedented in the past 800,000 years. These findings were based on paleoclimate observations from ice cores. *Id.* At the time AR5 was published, ice core records only extended back 800,000 years, so it was not possible to reach conclusions about GHG concentrations before this time. In 2017, scientists extracted a record-breaking 2.7-million-year-old ice core which indicated that CO_2 levels were also well below current levels during that time period. Paul Voosen, *2.7-million-year-old Ice Opens Window on Past*, 357 SCIENCE 630 (2017).

62. IPCC AR5 WGI at 678.

63. *Trends in Atmospheric Carbon Dioxide*, NOAA NAT'L CENTERS FOR ENVTL. INFO., https://www.esrl.noaa.gov/gmd/ccgg/trends/gl_trend.html [https://perma.cc/JKJ5-5GSV] (last visited Dec. 5, 2019); *Global CH_4 Monthly Means*, NOAA NAT'L CENTERS FOR ENVTL. INFO., https://www.esrl.noaa.gov/gmd/ccgg/trends_ch4/ [https://perma.cc/8AE3-RWTJ] (last visited Dec. 5, 2019); *Nitrous Oxide (N2O)—Combined Data Set*, NOAA NAT'L CENTERS FOR ENVTL. INFO., https://www.esrl.noaa.gov/gmd/hats/combined/N2O.html [https://perma.cc/K483-DBHR] (last visited Dec. 5, 2019).

64. IPCC AR5 WGI, Summary for Policymakers, *supra* note 25, at 11–12.

65. *Id.* at 12.

66. *Id.* Bindoff describes it as 'very likely.' *Id.* at 870. In the same report, another ocean chemistry change, a global decrease in dissolved oxygen especially in near-coastal waters, was assessed with medium confidence to be attributable "in part to human influences." *Id.*

ecosystems are also absorbing CO_2, but there is significant uncertainty as to the actual quantity sequestered: research indicates that anywhere from 70–250 GtC have accumulated in terrestrial systems.[67] Accounting for these different absorption pathways is critical in all aspects of climate change detection and attribution (including extreme event and impact attribution) because the effect of GHGs is dependent on where those gases are stored. Uncertainties about historical storage, or sinks, leads to some uncertainty about the magnitude of total historical effect of anthropogenic sources on climate change. More importantly, a changing climate could weaken important sinks. For example, a warming ocean is able to absorb less CO_2, melting permafrost and hydrates could release ancient CO_2 and methane to the atmosphere, and changes in vegetation could increase or decrease the terrestrial carbon sink.

ii. Atmospheric and Surface Temperature

As noted above, AR5 found "unequivocal" evidence that the climate system is warming, concluding that it was "certain" that global mean surface temperature (GMST) had increased since the late 19th century, and "virtually certain" that the global troposphere had warmed since the mid-20th century.[68] With regards to attribution, AR5 noted that observed warming trends were consistent with physical understanding and models of how rising atmospheric GHG concentrations would affect the climate system, and that the trends could not be explained by other forcings or natural variability alone.[69] AR5 quantified the potential contribution of human influence as follows:

67. *Id.* at 12.

68. *Id.* at 4, 161–62. At that time, the observational record showed that: (i) each of the last three decades had been successively warmer, in terms of global surface temperatures, than any preceding decade since 1850, and the first decade of the 21st century was the warmest on record; and (ii) globally averaged combined land and ocean surface temperature had increased by 0.85 [0.65–1.06]°C from 1880 through 2012. *Id.* at 161–62.

69. *Id.* at 869. For example, in terms of natural variability, Atlantic Multidecadal Oscillation (AMO) variability can influence trends, but does not explain 1951–2010 warming. In terms of the magnitude of other possible forcings, only solar radiation changes have been in the direction that would be expected to lead to warming, but the magnitude of change over the period is too low to have contributed to much of the warming. Furthermore, the spatial pattern of the observed warming (e.g., lower tropospheric warming and stratospheric cooling) was also consistent with increases in GHG concentrations, but not other possible forcings. *Id.* at 867–952.

> GHGs contributed a global mean surface warming likely to be between 0.5°C and 1.3°C over the period 1951–2010, with the contributions from other anthropogenic forcings likely to be between –0.6°C and 0.1°C, from natural forcings likely to be between –0.1°C and 0.1°C, and from internal variability likely to be between –0.1°C and 0.1°C.[70]

Based on these estimates, AR5 concluded that "[i]t is *extremely likely* that more than half of the observed increase in global average surface temperature from 1951 to 2010 was caused by the anthropogenic increase in greenhouse gas concentrations and other anthropogenic forcings together."[71]

Since then, the warming trend has continued and a number of temperature-related records have been broken.[72] NCA4 found, with *very high confidence*, that: (i) global surface air temperature had increased by 1.8°F (~1°C) between 1901 and 2016, and (ii) "[m]any lines of evidence demonstrate that it is *extremely likely* that human influence has been the dominant cause of the observed warming since the mid-20th century."[73] With regards to this attribution finding, USGCRP noted that there are "no convincing alternative explanations" for the observed warming in the past century.[74] USGCRP further found, with *high confidence*, that the likely range of human contribution to global mean temperature increase from 1951–2010 was 1.1° to 1.4°F (0.6° to 0.8°C) and that the likely contributions from natural forcing and internal variability to observed warming are minor.[75] There are a number of other recent studies which have reinforced and strengthened the evidentiary basis for human-induced warming. Analyses of global and regional warmth in 2014, 2015, 2016, and 2017 all found significant anthropogenic influence on record-breaking annual

70. *Id.* at 869.

71. *Id.* at 17.

72. Nineteen of the twenty hottest years on record have occurred since 2000 (with 1998 being the other hottest year), and 2016 was the hottest year on record with an average land and sea temperature that was 0.94°C above the 20th century average of 13.9°C. *See* NOAA, Climate Monitoring, https://www.ncdc.noaa.gov/climate-monitoring/global/globe/ytd/201911.

73. NCA4, *supra* note 7, at 13–14.

74. *Id.*

75. *Id.*

temperatures.[76] One noteworthy study compared observed temperatures in 2016 to annual global temperatures calculated in an ensemble of more than 24,000 years of CMIP5 simulations serving as a "control" for atmosphere (e.g., simulations in which greenhouse gases are kept at pre-industrial levels) and found that the observed 2016 temperatures were roughly 1.3°C higher than the historical average from 1881–1920, whereas the most extreme heat event in the control simulations was only 0.5°C above the historical average.[77] The scientists concluded that the record-breaking heat in 2016 could not have occurred in the absence of anthropogenic forcing on climate.[78]

iii. Oceans and Sea Level Rise

Just as the atmosphere has warmed, so too have the oceans. Two key detection findings in AR5 were that: (i) "[o]cean warming dominates the increase in energy stored in the climate system, accounting for more than 90% of the energy accumulated between 1971 and 2010 (*high confidence*)";[79] and (ii) "[i]t is *virtually certain* that the upper ocean (0–700 m) warmed from 1971 to 2010 . . . and it *likely* warmed between the 1870s and 1971."[80] With regards to attribution, AR5 found that "[i]t is *very likely* that anthropogenic forcings have made a substantial contribution to increases in global upper ocean heat content (0–700 m) observed since the 1970s."[81]

NCA4, which contained more recent measurements of ocean temperature, found that total ocean heat content has increased by approximately $33.5 \pm 7.0 \times 10^{22}$ joules since 1960 and that average sea surface temperature (SST) has increased by about 1.3°F ± 0.1°F (0.7°C ± 0.08°C) per century from 1900 through 2016.[82] USGCRP noted that the effect of anthropogenic forcing on this warming

76. *Explaining Extreme Events of 2017 from a Climate Perspective*, 100 BULL. AM. METROLOGICAL SOC'Y (SPECIAL SUPPLEMENT) S1 (2019) [hereinafter BAMS 2017]; *Explaining Extreme Events of 2016 from a Climate Perspective*, 99 BULL. AM. METROLOGICAL SOC'Y (SPECIAL SUPPLEMENT) S1 (2018) [hereinafter BAMS 2016]; *Explaining Extreme Events of 2015 from a Climate Perspective*, 97 BULL. AM. METROLOGICAL SOC'Y (SPECIAL SUPPLEMENT) S1 (2016) [hereinafter BAMS 2015]; *Explaining Extreme Events of 2014 from a Climate Perspective*, 96 BULL. AM. METROLOGICAL SOC'Y (SPECIAL SUPPLEMENT) S1 (2015) [hereinafter BAMS 2014].

77. BAMS 2016, *supra* note 76, at S11–14.

78. *Id.*

79. IPCC AR5 WGI, Summary for Policy Makers, supra note 25, at 8.

80. *Id.*

81. *Id.* at 17.

82. NCA4, *supra* note 7, at 364–65.

trend was clear but did not attempt to quantify that effect, possibly due to uncertainties about the actual magnitude of ocean warming stemming from a lack of long-term data (particularly with respect to deep ocean warming).[83] A recent study on heat content in the upper 2000 meters of the ocean found ocean warming approximately 40–50% faster than what was reported in the IPCC AR5 report.[84]

The increase in ocean heat content has been accompanied by observed increases in sea levels (and rates of sea level rise) since the 1800s. The observational record shows that, between 1901 and 2010, global mean sea level rose by approximately 0.19 meters (~7.5 inches).[85] AR5 found with *high confidence* that the rate of sea level rise since the mid-19th century has been larger than the mean rate during the previous two millennia, and that sea level rise has been accelerating quite substantially during this time period (with the most rapid rate of rise occurring since 1993).[86] The primary drivers of rising sea levels to date are thermal expansion of the ocean (caused by increases in ocean heat content) and glacier mass loss. AR5 found *high confidence* in anthropogenic influence on these two drivers in the past half-century, which supported its conclusion that "[i]t is very likely that there is a substantial anthropogenic contribution to the global mean sea level rise since the 1970s."[87] NCA4 contained similar findings.[88]

iv. Cryosphere: Sea Ice, Glaciers, Permafrost, and Snowpack

The observational record has shown a substantial decline in northern hemisphere sea ice, terrestrial glaciers, and snowpack in the past century.[89] But there is considerable geographic variation in the magnitude and rate of the decline, as not all areas are warming at the same rate, and there has actually been a small

83. *Id.* at 366, 367, 381.

84. Lijing Cheng et al., *How Fast Are the Oceans Warming?*, 363 SCIENCE 128 (2019).

85. IPCC AR5 WGI, Summary for Policy Makers, *supra* note 25, at 11.

86. *Id.* For example, AR5 found that it is "*very likely* that the mean rate of global averaged sea level rise was 1.7 [1.5 to 1.9] mm yr^{-1} between 1901 and 2010, 2.0 [1.7 to 2.3] mm yr^{-1} between 1971 and 2010, and 3.2 [2.8 to 3.6] mm yr^{-1} between 1993 and 2010." *Id.*

87. *Id.* at 19.

88. NCA4, *supra* note 7, at 333 (finding that GMSL had risen by approximately 7–8 inches since 1900, and that human forcings had made a "substantial contribution" (*high confidence)* to observed sea level rise).

89. IPCC AR4 WGI, *supra* note 25, at 319–20; NCA4, *supra* note 7, at 303.

observed increase in Antarctic sea ice,[90] which is not fully understood.[91] Setting aside that uncertainty, one clear finding of AR5 was that there are "multiple lines of evidence [which] support very substantial Arctic warming since the mid-20th century."[92] There has also been a "considerable reduction in permafrost thickness and areal extent" in certain northern regions observed over the period 1975 to 2005.[93]

AR5 concluded that anthropogenic influences "very likely contributed to Arctic sea ice loss since 1979 . . . [,] likely contributed to the retreat of glaciers since the 1960s and the increased surface mass of the Greenland ice sheet since 1993 [,] . . . [and] likely [contributed] to observed reductions in Northern Hemisphere spring snow cover since 1970."[94] Similarly, NCA4 found with *high confidence* that it is very likely that human activities have contributed to sea ice loss, glacier mass loss, and northern hemisphere snow extent decline.[95] However, AR5 noted that there is *low confidence* in our scientific understanding of the extent to which anthropogenic influences have driven the aforementioned changes in the Antarctic, and both AR5 and NCA4 noted that there had actually been a small observed increase in Antarctic sea ice in the early 2000s, which would most likely be explained by localized natural variability.[96]

Research shows that these trends have continued and accelerated since AR5 was published. One recent study found that the

90. At least through approximately the middle of the 2010s, at which point a decline appears to have commenced. Claire L. Parkinson, *A 40-y Record Reveals Gradual Antarctic Sea Ice Increases Followed by Decreases at Rates Far Exceeding the Rates Seen in the Arctic*, 116 PROC. NAT'L ACAD. OF SCI. 14414, 14414–23 (2019).

91. Proposed explanations for the increase have included freshening of the waters near Antarctica (thereby facilitating sea ice formation) such as: Richard Bintanja et al., *The Effect of Increased Fresh Water from Antarctic Ice Shelves on Future Trends in Antarctic Sea Ice,* 56 ANNALS OF GLACIOLOGY 120 (2015); decreasing stratospheric ozone (inducing local cooling through changes in atmospheric circulation); and natural variability, John Turner et al., *Non-annular atmospheric circulation change induced by stratospheric ozone depletion and its role in the recent increase of Antarctic sea ice extent*, 36 GEOPHYSICAL RES. LETTERS 1 (2009).

92. IPCC AR5 WGI, Summary for Policy Makers, *supra* note 25, at 9.

93. *Id.*

94. *Id.* at 19.

95. NCA4, *supra* note 7, at 333. *See also* Noah Diffenbaugh et al., *Quantifying the Influence of Global Warming on Unprecendented Extreme Climate Events,* 114 PROC. NAT'L ACAD. OF SCI 4881 (2017), (finding "extremely high statistical confidence that anthropogenic forcing increased the probability of record-low Arctic sea ice extent").

96. IPCC AR5 WGI, Summary for Policy Makers, *supra* note 25, at 19; NCA4, *supra* note 7, at 39, ch. 11.

Greenland Ice Sheet is melting much faster than previously believed: the pace of ice melt has accelerated four-fold since 2003, with Greenland losing approximately 280 billion tons of ice per year between 2002 and 2016—enough to raise the worldwide sea level by 0.03 inches annually.[97]

v. Hydrologic Cycle and Precipitation

Ascertaining the effect of anthropogenic forcings on the hydrologic cycle and precipitation is one of the most challenging areas of climate change attribution. Part of the challenge is detecting change—in some regions spatial gradients of precipitation are large, while historical rainfall records are incomplete and contain mixed findings about the extent to which precipitation patterns have (or have not) changed since the early 1900s. Precipitation is also characterized by large natural variability across a range of timescales ranging from the intra-annual to the centennial. The detection findings in AR5 are therefore mixed: AR5 notes that there is high confidence that average precipitation in mid-latitude land areas has increased since 1951.[98] However, there is only medium confidence in precipitation change averaged over global land areas since 1951, and low confidence in precipitation change prior to 1951.[99]

With respect to attribution, AR5 found that anthropogenic forcings had likely accelerated the hydrologic cycle, primarily through increases in temperature which can induce more rapid evaporation and support heavier rain events. However, the effect on annual mean regional precipitation was unclear. Specifically, AR5 found that:

> It is *likely* that anthropogenic influences have affected the global water cycle since 1960. Anthropogenic influences have contributed to observed increases in atmospheric moisture content in the atmosphere (*medium confidence*), to global-scale changes in

97. Michael Bevis, *Accelerating Changes in Ice Mass Within Greenland, and the Ice Sheet's Sensitivity to Atmospheric Forcing,* 116 PROC. NAT'L ACAD. OF SCI 1934, 1934 (2019).

98. IPCC AR5 WGI, Summary for Policy Makers, *supra* note 25, at 4.

99. *Id.* at 5, 40. A recent paper that integrated climate models, observations, and reconstructions of climate over the past 1000 years detected an elevated risk of hydroclimatic drought (a blend of precipitation deficit and greater evaporation potential associated with warming) consistent with anthropogenic activities as early as the first half of the 20th century. Kate Marvel et al., *Twentieth-Century Hydroclimate Changes Consistent with Human Influence*, 569 NATURE 59 (2019).

> precipitation patterns over land (*medium confidence),* to intensification of heavy precipitation over land regions where data are sufficient (*medium confidence*), and to changes in surface and sub-surface ocean salinity (*very likely*).[100]

The changes in surface and subsurface ocean salinity are noted here due to the link between precipitation and salinity: the observational record shows that regions of high salinity (where evaporation is prevalent) have become more saline, whereas regions of low salinity (where precipitation is prevalent) have become fresher since the 1950s, and these regional trends provide "indirect evidence that evaporation and precipitation over the oceans have changed."[101]

NCA4 also contained mixed findings about the effect of rising GHG concentrations and temperatures on global precipitation patterns. NCA4 noted that there had been a modest rise in annual average precipitation across global land areas, but that this increase could not be deemed statistically significant due to a lack of data coverage in early rainfall records.[102] However, NCA4 did note that there had been an observed increase in arctic precipitation of approximately 5 percent since the 1950s, which had been detected and attributed to human activities.[103]

2. Extreme Event Attribution

Extreme event attribution is a branch of climate change attribution that seeks to understand how human-induced changes in the global climate system are affecting the frequency, severity, and other characteristics of extreme events, such as abnormally hot days, heat waves, tropical cyclones, abnormally heavy rainfall events, and meteorological droughts.[104] This can be contrasted with the

100. IPCC AR5 WGI, Summary for Policy Makers, *supra* note 25, at 17 (emphasis in original).

101. *Id.* at 8.

102. NCA4, *supra* note 7, at 46.

103. *Id.* at 47 (citing Seung-Ki Min et al., *Human-Induced Arctic Moistening*, 320 SCIENCE 518 (2008)).

104. Meteorological drought is defined based on climate variables, especially precipitation and temperature (and to a lesser extent solar radiation at the surface, wind, and atmospheric humidity). Hydrological drought, in contrast, is defined by shortages of available freshwater resources, such as reservoirs, groundwater, and rivers/streams. Hydrological drought, in contrast to meteorological drought, is thus linked more closely to freshwater usage and freshwater needs.

climate change attribution research described above, which focuses on changes in long-term mean variables rather than changes in extremes.

Since 2011, the Bulletin of the American Meteorological Society (BAMS) has been publishing annual reports on *Explaining Extreme Events from a Climate Perspective*.[105] The 2016 and 2017 BAMS reports both contained studies finding that certain extreme events could not have been possible in a pre-industrial climate, all of which were heat-related events.[106] Below, we summarize some of the methods used in this research and the confidence with which scientists have been able to attribute different types of extreme events to climate change.

a. Methods and Parameters

Extreme event attribution is rapidly advancing due to improved understanding of extreme events, improved modeling (including standardized sets of simulations that can be used by a broad research community), lengthening observational datasets and re-analyses (blends of observations and models), some of which now incorporate paleoclimate data like tree rings to develop pre-observational historical reconstructions,[107] more robust remote sensing data sets, and new analytical techniques.[108] Climate and weather models, in particular, are indispensable to most event attribution studies.[109] But statistical analysis can also be used in lieu of, or as a supplement to, models for locations with high quality observational records.[110]

105. *Explaining Extreme Events from a Climate Perspective,* BULL. AM. METEOROLOGICAL SOC'Y, https://www.ametsoc.org/ams/index.cfm/publications/bulletin-of-the-american-meteorological-society-bams/explaining-extreme-events-from-a-climate-perspective/ [https://perma.cc/7P25-68HT] (last visited Nov. 17, 2019).

106. *Id. See also* BAMS 2016, *supra* note 76; BAMS 2017, *supra* note 76.

107. *E.g.*, Marvel et al., *supra* note 99.

108. NAT'L ACAD. OF SCI., ENG'G AND MED., ATTRIBUTION OF EXTREME WEATHER EVENTS IN THE CONTEXT OF CLIMATE CHANGE 1 (2016) [hereinafter NAS 2016].

109. *Id.* at 44.

110. *See, e.g.*, IPCC AR5 WGI, *supra* note 25; Stefan Rahmstorf & Dim Coumou, *Increase of Extreme Events in a Warming World,* 108 PROC. NAT'L ACAD. OF SCI. 17905 (2011); Geert Jan van Oldenborgh, *How Unusual Was Autumn 2006 in Europe?*, 3 CLIMATE PAST 659 (2007); R. Vautard et al., *Extreme Fall 2014 Precipitation in the Cevenees Mountains, in* BAMS 2014, *supra* note 76, at S56; Geert Jan van Oldenborgh et al., *Climate Change Increases the Probability of Heavy Rains Like Those of Storm Desmond in the UK—An Event Attribution Study in Near-Real Time,* 12 HYDRO. EARTH SYST. SCI. DISCUSSIONS 13197 (2015).

Generally speaking, attribution of extremes is more challenging than attribution of means for a variety of reasons, including: 1) the local nature and short duration of many extremes (which makes them difficult to model given the coarse resolution of climate models); 2) the relative rarity of extreme events at a given location (which makes it difficult to detect and attribute a climate change "signal" amidst the large "noise" of natural variability); and 3) the cause-and-effect chains for extremes are often highly nonlinear and may include instantaneous and delayed effects.[111] There are also some modeling challenges that are particularly relevant for extreme event attribution. Christiansen (2015) notes models may be too Gaussian in their extreme events (that is, they don't produce enough of them). Furthermore, skewness—a statistical measure that is sensitive to the tails of the distribution—may vary by season. Scientists have devised statistical approaches to avoid the problems and limitations associated with climate models but all rely on simplifying assumptions.[112] Statistical approaches also tend to make the potentially faulty assumption that historical relationships will persist as the climate changes further.[113] Nonetheless, for many

111. Sebastian Sippel et al., *Warm Winter, Wet Spring, and an Extreme Response to Ecosystem Functioning in the Iberian Peninsula*, *in* BAMS 2016, *supra* note 76, at S80 (citing D.A. Frank et al., *Effects of Climate Extremes on the Terrestrial Carbon Cycle: Concepts, Processes, and Potential Future Impacts*, 21 GLOBAL CHANGE BIOLOGY 2861 (2015) and J.A. Arnone et al., *Prolonged Suppression of Ecosystem Carbon Dioxide Uptake After an Anomalously Warm Year*, 455 NATURE 383 (2008)).

112. For example, a study may assume that climate change can be represented by a polynomial trend and that any residual represents natural variability.

113. NAS 2016, *supra* note 108; Bo Christiansen, *The Role of the Selection Problem and Non-Guassianity in Attribution of Single Events to Climate Change*, 28 J. CLIMATE 9873 (2015). The above is one example of a much broader collection of approaches to addressing climate model limitations. Two other examples include: (1) Hannart proposed using (observed) data assimilation techniques to go beyond climate model ensembles (Hannart et al., *supra* note 51); (2) Numerous authors used optimal fingerprinting techniques (Gabriel Hegerl & Frank Zwiers, *Use of Models in Detection and Attribution of Climate Change*, 2 WIRES CLIMATE CHANGE 570 (2011); Nikolaos Christadis & Peter A. Stott, *Changes in the Geospatial Height at 500 hPa Under the Influence of External Climatic Forcings*, 42 GEOPHYSICAL RES. LETTERS 10798 (2015)) to develop approaches tailored to specific climate models. Based on some historical measure of skill by region and extreme event type, individual models can then be included or rejected in analyses (Andrew D. King et al., *The Timing of Anthropogenic Emergence in Simulated Climate Extremes*, 10 ENVTL. RES. LETTERS 1 (2015)). While such approaches offer advances relative to simple bias correction or using climate model output directly, there remains the possibility that (1) the "winning models" miss key processes/succeed for the wrong reasons, and (2) that they may miss emerging behavior as the planet warms. In both instances, prior strong performance by an individual model might not be indicative of skill in the emerging climate.

variables and locations, extreme event studies can generate reasonably reliable results.

The results of extreme event studies are sensitive to how the research question is framed,[114] and what methodological approaches and datasets are used. Studies may focus on a class of events, such as the 2017 Atlantic hurricane season, or an individual event. This second research area, sometimes called *single-event attribution*, is growing fast, and there are now hundreds of studies seeking to identify the "human fingerprint" on major storms, floods, heat waves, and other events.[115]

One critical framing question is how to define the "extreme event" (or event class) for the purposes of the study. This involves defining physical thresholds for what constitutes an "extreme" and determining the appropriate timeframe and spatial scale of the study, all of which have implications for the results of the study. For example, if in analyzing a heat extreme scientists select as their temperature threshold the maximum temperature achieved, and focus their analysis on the location that reached the highest temperatures during the heat event, the event may appear more exceptional, and the study less broadly relevant, than if the temperature threshold and spatial scale were selected in a more generic way. More fundamentally, there are often multiple metrics that could be used to define an extreme event. For example, a heat wave could be defined based on maximum temperature over the course of the heat wave, heat wave duration, a combination of temperature and moisture in the air, or atmospheric circulation associated with the event. Along similar lines, scientists may tend to study those events where attribution statements are easiest to make and/or where data availability and societal interest are high. These are just a few examples of how event framing can introduce selection bias into an attribution study, thus compromising the study results. Fortunately, selection bias is not an insurmountable obstacle: efforts are underway to standardize how extreme events are defined and selected for analysis, and this would have the

114. Framing includes how the event is defined, what conditioning is included, and how the results are presented (frequency vs. intensity, FAR vs. RR, etc.). NAS 2016, *supra* note 108, at 37.

115. *See, e.g.*, WORLD WEATHER ATTRIBUTION PROJECT, https://www.worldweatherattribution.org/ [https://perma.cc/5US8-M5ST] (last visited Dec. 29, 2019).

added benefit of facilitating more systematic comparison between extreme event studies.[116]

Scientists also have different options for how to go about analyzing the effect of anthropogenic climate change on the event. There are two approaches that dominate extreme event attribution studies.[117] The first is a "risk-based" approach, which focuses on the extent to which climate change has increased the probability (or risk) of an extreme event threshold (such as temperatures of 95°F) being crossed. The second is a "storyline" approach, which focuses on how a variety of factors, including climate change, have affected the characteristics and magnitude of an individual extreme event in its entirety. These approaches both have benefits and drawbacks, as described below.

The risk-based approach to extreme event attribution involves evaluating the extent to which human influence on climate has changed the probability of occurrence of an event at or below a particular threshold (e.g., a heavy rain event of five inches or less).[118] One key concept in such research is the "fraction of attributable risk" (FAR), which can be defined as the relative risk (or risk ratio)[119] of an extreme event or class of events occurring with and without anthropogenic climate change. The risk-based approach typically involves the use of two or more simulations from

116. NAS 2016, *supra* note 108, at 15.

117. The binary classification of risk-based vs. storyline approaches in the main text obscures some other approaches in the literature. As one example, Mann et al. suggested a modification to traditional frequentist statistical inference approach, that builds in prior physical understanding and updates based on experience. Michael E. Mann et al., *Assessing Climate Change Impacts on Extreme Weather Events: The Case for an Alternative (Bayesian) Approach*, 144 CLIMATIC CHANGE 131 (2017). Mann et al. equate it to the conditional storylines approach (for example: surface air temperature increase means more extreme temperatures, and means more moisture in the air), but goes on to propose something quite different. Mann et al. propose to use our full knowledge and expectations (through Bayesian statistics) rather than overweighting avoidance of type 1 errors (claiming a relationship where none exists). Mann et al. note that fear of type one error yields underestimates of risk and of human contributions to extremes (citing Stefan Rahmstorf et al., *Recent Climate Observations Compared to Projections*, 316 SCIENCE 709 (2007)). Mann et al. note that such a precautionary approach to risk is common in other fields where 'do no harm' prevails (citing Gerd Gigerenzer & Adrian Edwards, *Simple Tools for Understanding Risks: from Innumeracy to Insight*, 327 BRIT. MED. J. 741 (2003) (discussing this approach in the context of pharmaceuticals)). So, he says you get more accurate results and *additionally*, from a risk management and ethical perspective, more policy sound results.

118. Myles Allen, *Liability for Climate Change*, 421 NATURE 891, 891 (2003); Hannart et al., *supra* note 51.

119. Risk ratio/relative risk = the ratio of the probability of an outcome in an exposed group to the probability of an outcome in an unexposed group.

a climate model or models which differ in that 1) one simulation is meant to represent the "world that is"—that is with the greenhouse gas concentrations (and sometimes other forcings and changes in boundary conditions like a warming ocean as well) as they have evolved since an earlier reference period, and 2) the other simulation reflects a "counterfactual world" without anthropogenic forcing. Because climate models generally cannot reproduce the observed statistics of the extreme event in question, a corresponding percentile threshold is often used. For example, if a location experiences a five-inch rainfall event, and that is estimated based on observed data to be a once per year event, the precipitation threshold amount in the model that occurs once per year is used for the model comparisons. In mathematical terms:

$$FAR = 1 - P0/P1$$

Where P1 equals the probability of a climatic event (such as a heat wave) occurring in the presence of anthropogenic forcing of the climate system, and P0 equals the probability of the event occurring if the anthropogenic forcing were not present. If FAR equals zero, it means that anthropogenic climate change had no effect on the probability of the event occurring; if FAR equals one, it means that the event could not have happened in the absence of anthropogenic climate change; if FAR equals 0.5, it means that anthropogenic climate change doubled the probability of the event occurring. In multi-event studies, a FAR of 0.5 can be interpreted as meaning that half of the events would not have happened in a world without anthropogenic climate change.

This approach was pioneered by Myles Allen in a 2003 study in which he introduced the concept of FAR as a potential basis for liability for climate damages.[120] Many other studies have since replicated Allen's approach, estimating the FAR for a range of extreme events including heat waves, droughts, and floods. While the term FAR is almost exclusively used in extreme event attribution, probabilistic analysis is prevalent across all forms of attribution,[121] and the concept of "attributable risk" can in principle

120. Allen, *supra* note 118.

121. The prevalence of probabilistic analysis in both climate change and impact attribution is evident in the IPCC's frequent use of terms such as "likely" and "very likely" when describing human influence on observed changes and impacts.

be applied to both mean changes in climate[122] and a variety of climate change impacts. Indeed, the methodology derives from common approaches used in public health and other risk-focused research.[123] The advantages of this approach are that it is relatively well-established, understood, and accepted by the scientific community,[124] and it provides quantitative (probabilistic) findings similar to the sort of epistemological and environmental data that is often dealt with by policy-makers, planners, and courts. Drawbacks include: 1) overreliance on climate models, which as noted earlier, may not be able to simulate some types of extremes with fidelity in a baseline climate, and could have blind spots with respect to how climate change may be modifying key processes influencing the extreme event, and 2) susceptibility to Type II errors (i.e., false negatives) where the signal-to-noise ratio for an event is small due to large internal variability of the atmosphere, which is often the case for dynamically-driven events such as extreme precipitation and storms especially.[125] As such, it can

122. *See, e.g.*, Thomas Knutson et al., *CMIP5 Model-Based Assessment of Anthropogenic Influence on Record Global Warmth During 2016, in* BAMS 2016, *supra* note 76, at S13.

123. The concept of "attributable risk" actually originated in epidemiological studies (e.g., studies seeking to identify the extent to which smoking increases the risk of lung cancer) and is therefore well-suited for evaluating health-related risks. Some efforts have been made to quantify "attributable risk" for climate change-related health impacts, but most of these studies are forward-looking, and there is only a small body of research seeking to determine the attributable risk of observed public health impacts. There is still a strong need for more quantitative analysis on this topic. *See infra* Section II(B)(3); Kristie L. Ebi et al., *Monitoring and Evaluation Indicators for Climate Change-Related Health Impacts, Risks, Adaptation, and Resilience*, 15 INT'L. J. ENVTL. RES. PUB. HEALTH 1943 (2018) (discussing the need to develop quantitative indicators of climate change-related health risks); Wei W. Xun et al., *Climate Change Epidemiology: Methodological Challenges,* 55 INT'L. J. PUB. HEALTH 85 (2010) (discussing challenges in attributing epidemiological risks to climate change); Maud M.T.E. Huynen & Pim Martens, *Climate Change Effects on Heat- and Cold-Related Mortality in the Netherlands: A Scenario-Based Integrated Environmental Health Impact Assessment*, 12 INT'L. J. ENVTL. RES. PUB. HEALTH 13295 (2015) (quantifying the population attributable fractions (PAF) of mortality due to heat and cold, but projecting future impacts rather than attributing current impacts); S.J. Yoon et al., *Measuring the Burden of Disease Due to Climate Change and Developing a Forecast Model in South Korea,* 128 PUB. HEALTH 725 (2014) (quantifying influence of climate change on disease burden in South Korea).

124. *See* NAS 2016, *supra* note 108, at 3.

125. Kevin Trenberth et al., *Attribution of Extreme Climate Events,* 5 NATURE CLIMATE CHANGE 725 (2015).

underestimate the extent to which anthropogenic influence has increased the probability of an event.[126]

Some probabilistic approaches have adopted conditional risk-based analyses, both to simplify the modeling and to control for factors other than anthropogenic effects (such as natural variability, as discussed above).[127] Conditional analyses can in some respects be thought of as a logical outgrowth of the tension between risk based and storyline conceptualizations,[128] since they attempt to isolate the component of extreme events due to anthropogenic warming by treating other components as a control. For example, natural variability of the ocean surface could be treated as a control through a climate model experiment that used the same observed sea surface temperature *patterns* (on the assumption that patterns are due to natural variability) to drive both the counterfactual and anthropogenic forcing simulations, while universally increasing the SSTs by the amount assumed to correspond to anthropogenic forcing. By comparing the results, scientists can largely avoid the criticism that natural variability in ocean temperatures may have led to differences between the two sets of results. However, one price paid is that by simplifying the experiment, full probabilistic attribution is no longer possible, since the experiment was designed so as to ignore the question of how sea surface temperature patterns may be impacted by anthropogenic forcing. Also unaddressed is the possibility that the estimated magnitude of SST warming assumed with the anthropogenic forcing in the experimental design could be wrong. As models become more interactive and experimental designs grow more complex, the problem of what parts to condition become more and more vexing. Harrington summarized conditioning this way:

> More conditioning on the observations of the event will result in an attribution statement with higher confidence (as some possible sources of uncertainty will have been eliminated (Shepherd 2016)), but it will have less relevance to other extreme events which may occur in the future (Otto et al. 2016), and may only quantify the

126. FAR is not well defined when the baseline risk is very low; it also is not designed to be applied to situations with decreasing risk. NAS 2016 , *supra* note 108, at 28. Furthermore, when there are multiple causes, FAR can exceed 1.

127. *See supra* Section II(B)(1).

128. For further discussion of the storyline approach, see *infra* page 32.

> human influence on one part of a causal chain of physical phenomena contributing to the severity of a given event. From the perspective of an in-depth attribution study, multiple perspectives using varying levels of conditioning may therefore be complimentary.[129]

The "storyline" approach to extreme event attribution provides an alternative method for evaluating how climate change affected some or all of the components that come together to form an individual extreme event.[130] This approach is conditional in the sense that it takes the unique extreme event as given; rather than asking whether it could have happened without anthropogenic forcing, it asks how anthropogenic forcing may have modified the given event.[131]

The storyline approach was first introduced by Trenberth et al. (2015) as an alternative to the risk-based approach. The approach begins with the idea that some aspects of climate change are better understood than others, with warming temperature and thermodynamics emerging as first order aspects of climate change that are relatively straightforward to model and understand. Proponents of the approach have emphasized that, by contrast, changes in dynamics, or motion, with climate change are poorly understood and poorly simulated by models.[132] The storyline approach, focusing only on components that are well understood, like thermodynamics, allows for higher confidence statements about a portion of the event that science understands well, albeit it at the expense of having to forsake complete, quantitative statements.[133] A typical finding from a storyline approach might be

129. Luke James Harrington, *Novel Approaches to Quantify the Emergence of Anthropogenic Climate Change* (2017), (unpublished Ph.D. dissertation, Victoria University of Wellington) (on file with New Zealand Climate Change Research Institute School of Geography, Environment and Earth Sciences).

130. The storyline approach was first introduced by Kevin Trenberth. *See* Trenberth et al., *supra* note 125, at 726.

131. Theodore G. Shepherd, *A Common Framework for Approaches to Extreme Event Attribution*, 2 CURRENT CLIMATE CHANGE REP. 28, 28 (2016).

132. The National Academies explained: "Changes in atmospheric circulation and dynamics are generally less directly controlled by temperature, less robustly simulated by climate models, and less well understood." NAS 2016, *supra* note 108, at 6.

133. The reader may note similarities between conditional probabilistic attribution and the storylines approach. Conditional attribution starts by saying 'given this . . .'. The "given" in this context is often sea surface temperatures or sea ice extent, but it can also be a certain type of atmospheric circulation. The idea is to move part of the conditions, often the most vexing part, out of the attribution question. This approach still leaves the question open

"warming of the upper ocean and atmosphere associated with climate change enabled more rainfall during event Y than otherwise would have been experienced." In some studies, quantitative statements are included as well based on certain limited assumptions. In the above example, it might be stated that the warming of the upper ocean and atmosphere due to climate change—the thermodynamics—were responsible for an X percent increase in rainfall. Critically though, any quantitative statements, rather than being comprehensive, are linked to specific aspects of the climate system identified by the authors, such as water temperatures in the example above. Furthermore, most storyline approaches do not endeavor to assess what percentage of the driver—ocean temperature in the example above is due to human activity.

As with the probabilistic or risk based approach, several criticisms have been raised of the storyline approach.[134] First, focusing on a single event in its entirety (as opposed to the risk-based approach, in which events that are defined solely based on their exceedance of a threshold such as 95°F, or air pressure at a given height) and emphasizing changes across only a portion of the event drivers (e.g., focusing on thermodynamics rather than dynamics) limits the utility of the storylines approach for traditional policy and legal applications. Since each event is treated as unique, the applications for a class of events is unclear, and emphasis on a portion of the event's drivers, often in a qualitative way, immediately begs the question of how to address remaining drivers or summarize the event in toto. Second, the storyline approach has been criticized as oversimplistic due to the compartmentalization of an event into discrete components. More specifically the basic premise that within the context of climate change thermodynamics are well understood, and dynamics are not (or are unlikely to change in important ways for extreme events), has been challenged, with some arguing that there is a smooth gradient of understanding across system components such as thermodynamics

though of whether anthropogenic warming has impacted the part being taken as given. The storyline approach takes a full, specific event as the given; tries to initially identify all aspects and drivers; but then focuses on backing out how some of the better understood aspects of climate change—generally the thermodynamics, may have impacted the event magnitude.

134. Friederike E. Otto et al., *The Attribution Question*, 6 NATURE CLIMATE CHANGE 813 (2016).

and dynamics.[135] Furthermore, thermodynamics and dynamics interact. For example, a thermodynamic change, such as warming of the upper ocean, induces changes in the dynamics of atmospheric circulation such as rising air, which can feed back on thermodynamics, for example by changing cloud cover and thus solar radiation received at the surface. Neglecting dynamics thus inevitably misses ways that thermodynamics can be impacted by dynamics, thus rendering the thermodynamics analysis incomplete.[136] Another potential drawback of this approach is that it generates more qualitative findings that may be less useful for certain applications than the quantitative findings of the risk-based approach.[137]

While there is some debate about the relative merits of these two approaches, the reality is that they are complementary—they each provide different insights on the effect of anthropogenic climate change on event characteristics, and one approach can be used to fill gaps where the other is unsuitable. For example, the probabilistic/risk-based approach may be more justifiable for analyzing all events below a threshold, for a class of events that are

135. For example, Mann et al. (2017) notes that dynamical changes with warming are starting to come into focus: more specifically, a growing body of work based on observations and simple models supports the idea that the latitudinal pattern of mean temperature changes (including Arctic amplification) may support changes in atmospheric dynamics that supports wave resonance and 'stuck' weather, which enhances the magnitude and duration of extremes. It should be noted that global climate models generally do not reproduce this pattern of wave resonance and 'stuck' weather with warming. Michael E. Mann et al., *Influence of Anthropogenic Climate Change on Planetary Wave Resonance and Extreme Weather Events*, 7 SCI. REPORTS 45242 (2017).

136. Otto shows how the dynamics and thermodynamics counteracted each other in 2013 German floods. *See* Otto et al., *supra* note 134, at 815. Similarly, a study in Western Australia found dynamics/circulation changes that favor less rain, but thermodynamic (specifically sea surface temperature) changes that favor increase in rain. Thomas L. Delworth & Fanrong Zeng, *Regional Rainfall Decline in Australia Attributed to Anthropogenic Greenhouse Gases and Ozone Levels*, 7 NATURE GEOSCIENCE 583 (2014).

137. For example, the quantitative findings from risk-based studies may be more suitable to answering questions about apportioning liability for climate change. A related criticism is that individual extreme events are complicated, and the storyline approach, through its lack of a clear methodology, opens doors to claims of cherrypicking. For example, Trenberth et al. note that during the "Snowmaggendon event" unusually high sea surface temperatures led to more moisture being available. Trenberth et al., *supra* note 125, at 727. The authors are silent on other drivers of snowfall amount, such as storm location and availability of cold air. In this instance, the approach is arguably justified given the "thermodynamic" links between sea surface temperature and warming, but especially in the hands of less knowledgeable researchers, the lack of a clear, replicable methodology may open the door to perceptions of cherrypicking of event components.

relatively well simulated by climate models (e.g., 99% temperature extremes), whereas the storylines approach may be more appropriate for complex, iconic, multivariate events such as Hurricane Sandy, which combine everything from extreme storm surge and snowfall to high winds.[138] Granted, even with both approaches there is still a fair amount of uncertainty about the human fingerprint on certain events and certain event classes.[139] This is evident from the fact that the risk-based and storyline approaches can produce very different findings about the magnitude of the human influence on certain events, as highlighted in our discussion of specific event studies below.[140]

A recent development in this field is the emergence of and growing focus on "rapid" and "advance" (or "predictive") event attribution. The World Weather Attribution (WWA) project, founded in 2014, is at the forefront of these efforts: it conducts "real-time" (i.e., rapid) attribution analysis of extreme weather events that happen around the world.[141] To accomplish this, WWA and other like entities use seasonal forecasts rather than observations to simulate extreme weather events under current climate conditions before the events actually occur. The goals of this approach are twofold: first, to demonstrate the feasibility of using forecast for reliable attribution findings, and second, to make it possible to issue attribution findings for extreme weather events as they occur.[142] This second function can help facilitate engagement with the media, policy-makers, and the public while events are still fresh in everyone's mind. However, some scientific rigor may be lost when research is conducted with such alacrity. For example, there may be less opportunity to test the model's ability to simulate the actual event, and there may be little or no time for traditional peer-review. Nevertheless, as attribution research continues to mature, and standardization of experiments

138. Elisabeth Lloyd & Naomi Oreskes, *Climate Change Attribution: When Is It Appropriate to Accept New Methods?,* 6 EARTH'S FUTURE 311 (2018).

139. To help address uncertainty, the National Academies has noted a need for more research on: (i) the role of natural variability in extreme events; (ii) the characterization of uncertainty; (iii) why it is that different approaches have yielded very different findings; (iv) what methods are used for event section; and (v) how the counterfactual (no anthropogenic climate change) world is framed. NAS 2016, *supra* note 108, at 12.

140. *See infra* section II(B)(2)(b).

141. WORLD WEATHER ATTRIBUTION PROJECT, *supra* note 115.

142. About World Weather Attribution, https://www.worldweatherattribution.org/about/ (last visited Jan. 14, 2020).

enables more multi-model evaluations, rapid—and even predictive—event attribution will grow in prominence and robustness.

b. Status of Research

IPCC AR5 summarized the status of observations on extreme events as follows:

> Changes in many extreme weather and climate events have been observed since about 1950. It is very likely that the number of cold days and nights has decreased and the number of warm days and nights has increased on the global scale. It is likely that the frequency of heat waves has increased in large parts of Europe, Asia and Australia. There are likely more land regions where the number of heavy precipitation events has increased than where it has decreased. The frequency or intensity of heavy precipitation events has likely increased in North America and Europe. In other continents, confidence in changes in heavy precipitation events is at most medium.[143]

143. IPCC AR5 WGI, Summary for Policymakers, *supra* note 25, at 5.

NCA4 contained similar findings.[144] With respect to attribution, both AR5 and NCA4 recognized that the evidence of human influence on extreme events varies depending on the event and, in many cases, is difficult to ascertain. Generally speaking, the confidence with which scientists have been able to attribute extreme events to climate change has been highest for events that are directly related to temperature.[145] Extreme events that are the result of more complex interactions between variables (e.g., drought) are more difficult to attribute. There is moderate confidence about extreme precipitation increases. While there is relatively low confidence about precipitation deficits alone in the context of drought, there is higher confidence in the combined impacts of higher temperature and precipitation on drought risk. For other classes of severe weather, such as tropical cyclones, mid-latitude storms, and smaller scale convective events and tornadoes, confidence is generally lower. However, these generalizations mask substantial nuance across space and time; for example, high temperature extremes at individual highly continental locations in the mid and high latitudes (where internal variability is large) may

144. NCA4, *supra* note 7, at 207–76.
145. NAS 2016, *supra* note 108, at 2.

be difficult to attribute, and high water level extremes may be difficult to attribute in places where large storm surges are relatively frequent, rendering the sea level rise signature on coastal high water levels relatively less prominent.

Table SPM.1 | Extreme weather and climate events: Global-scale assessment of recent observed changes, human contribution to the changes, and projected further changes for the early (2016–2035) and late (2081–2100) 21st century. Bold indicates where the AR5 (black) provides a revised* global-scale assessment from the SREX (blue) or AR4 (red). Projections for early 21st century were not provided in previous assessment reports. Projections in the AR5 are relative to the reference period of 1986–2005, and use the new Representative Concentration Pathway (RCP) scenarios (see Box SPM.1) unless otherwise specified. See the Glossary for definitions of extreme weather and climate events.

Phenomenon and direction of trend	Assessment that changes occurred (typically since 1950 unless otherwise indicated)	Assessment of a human contribution to observed changes	Likelihood of further changes	
			Early 21st century	Late 21st century
Warmer and/or fewer cold days and nights over most land areas	*Very likely* (2.6) *Very likely* *Very likely*	***Very likely*** (10.6) *Likely* *Likely*	*Likely* (11.3)	*Virtually certain* (12.4) *Virtually certain* *Virtually certain*
Warmer and/or more frequent hot days and nights over most land areas	*Very likely* (2.6) *Very likely* *Very likely*	***Very likely*** (10.6) *Likely* *Likely* (nights only)	*Likely* (11.3)	*Virtually certain* (12.4) *Virtually certain* *Virtually certain*
Warm spells/heat waves. Frequency and/or duration increases over most land areas	***Medium confidence*** on a global scale *Likely* in large parts of Europe, Asia and Australia (2.6) *Medium confidence* in many (but not all) regions *Likely*	***Likely***[a] (10.6) Not formally assessed *More likely than not*	Not formally assessed[b] (11.3)	*Very likely* (12.4) *Very likely* *Very likely*
Heavy precipitation events. Increase in the frequency, intensity, and/or amount of heavy precipitation	*Likely* more land areas with increases than decreases[c] (2.6) *Likely* more land areas with increases than decreases *Likely* over most land areas	***Medium confidence*** (7.6, 10.6) *Medium confidence* *More likely than not*	*Likely* over many land areas (11.3)	***Very likely*** over most of the mid-latitude land masses and over wet tropical regions (12.4) *Likely* over many areas *Very likely* over most land areas
Increases in intensity and/or duration of drought	***Low confidence*** on a global scale *Likely* changes in some regions[d] (2.6) *Medium confidence* in some regions *Likely* in many regions, since 1970[e]	***Low confidence*** (10.6) *Medium confidence*[f] *More likely than not*	*Low confidence*[g] (11.3)	***Likely*** *(medium confidence)* on a regional to global scale[h] (12.4) *Medium confidence* in some regions *Likely*[e]
Increases in intense tropical cyclone activity	***Low confidence*** in long term (centennial) changes *Virtually certain* in North Atlantic since 1970 (2.6) *Low confidence* *Likely* in some regions, since 1970	***Low confidence***[i] (10.6) *Low confidence* *More likely than not*	*Low confidence* (11.3)	***More likely than not*** in the Western North Pacific and North Atlantic[j] (14.6) *More likely than not* in some basins *Likely*
Increased incidence and/or magnitude of extreme high sea level	*Likely* (since 1970) (3.7) *Likely* (late 20th century) *Likely*	***Likely***[k] (3.7) *Likely*[k] *More likely than not*[k]	*Likely*[l] (13.7)	***Very likely***[l] (13.7) *Very likely*[m] *Likely*

* The direct comparison of assessment findings between reports is difficult. For some climate variables, different aspects have been assessed, and the revised guidance note on uncertainties has been used for the SREX and AR5. The availability of new information, improved scientific understanding, continued analyses of data and models, and specific differences in methodologies applied in the assessed studies, all contribute to revised assessment findings.

Notes:

[a] Attribution is based on available case studies. It is *likely* that human influence has more than doubled the probability of occurrence of some observed heat waves in some locations.
[b] Models project near-term increases in the duration, intensity and spatial extent of heat waves and warm spells.
[c] In most continents, confidence in trends is not higher than *medium* except in North America and Europe where there have been *likely* increases in either the frequency or intensity of heavy precipitation with some seasonal and/or regional variation. It is *very likely* that there have been increases in central North America.
[d] The frequency and intensity of drought has *likely* increased in the Mediterranean and West Africa, and *likely* decreased in central North America and north-west Australia.
[e] AR4 assessed the area affected by drought.
[f] SREX assessed *medium confidence* that anthropogenic influence had contributed to some changes in the drought patterns observed in the second half of the 20th century, based on its attributed impact on precipitation and temperature changes. SREX assessed *low confidence* in the attribution of changes in droughts at the level of single regions.
[g] There is *low confidence* in projected changes in soil moisture.
[h] Regional to global-scale projected decreases in soil moisture and increased agricultural drought are *likely (medium confidence)* in presently dry regions by the end of this century under the RCP8.5 scenario. Soil moisture drying in the Mediterranean, Southwest US and southern African regions is consistent with projected changes in Hadley circulation and increased surface temperatures, so there is *high confidence* in *likely* surface drying in these regions by the end of this century under the RCP8.5 scenario.
[i] There is *medium confidence* that a reduction in aerosol forcing over the North Atlantic has contributed at least in part to the observed increase in tropical cyclone activity since the 1970s in this region.
[j] Based on expert judgment and assessment of projections which use an SRES A1B (or similar) scenario.
[k] Attribution is based on the close relationship between observed changes in extreme and mean sea level.
[l] There is *high confidence* that this increase in extreme high sea level will primarily be the result of an increase in mean sea level. There is *low confidence* in region-specific projections of storminess and associated storm surges.
[m] SREX assessed it to be *very likely* that mean sea level rise will contribute to future upward trends in extreme coastal high water levels.

Figure Source: IPCC, *Summary for Policy Makers, in* CLIMATE CHANGE 2014: IMPACTS, ADAPTATION, AND VULNERABILITY 7 (C.B. Field et al. eds, Cambridge University Press 2014).

Since AR5 was published in 2013, the world has seen a growing number of record-breaking extreme events and hundreds of new event attribution studies have been published. The majority of these studies deal with heat, precipitation, and storm-related impacts, but a growing number of studies are assessing more novel types of extremes—as one example, a recent study looked at "extreme winter sunshine" in the United Kingdom.[146] Notably, of the 146 studies published in the BAMS reports since 2011, approximately 70% have found that anthropogenic climate change

146. Nikolaos Christidis et al., *Human Contribution to the Record Sunshine of Winter 2014/15 in the United Kingdom, in* BAMS 2015, *supra* note 76, at 47.

was a significant driver of the event studied.[147] The 2016 and 2017 BAMS reports also contained several studies in which the authors concluded that the event *could not have happened* in the absence of anthropogenic climate change. Another meta-analysis of extreme event attribution studies, published in 2018, found that forty-one of fifty-nine papers published in 2016 and 2017 found a positive signal of climate change, and that thirty-two of forty-three papers published in 2018 found that climate change had increased the event's likelihood or intensity.[148] That meta-study also noted that the only four studies published in 2018 which found that climate change decreased the likelihood or intensity of the event all dealt with snow and/or cold temperatures.[149] With all this new research, the evidentiary basis for attributing extreme events to climate change is growing rapidly.

i. Extreme Heat

The core characteristics of extreme heat events (magnitude, frequency, and duration) are all highly sensitive to changes in mean temperatures at a global scale.[150] Thus, an increase in the magnitude, frequency, and duration of extreme temperature events is a direct and foreseeable consequence of a warming climate. Not surprisingly, confidence in attribution findings is generally greatest for extreme heat events, as compared with other types of extreme events.[151] NCA4 found, with *very high confidence*, that the frequency and intensity of extreme heat events are increasing in most continental regions around the world, consistent with the expected physical responses to a warming climate.[152]

One of the earliest extreme event attribution studies dealt with the European heat wave of 2003. Applying the risk-based approach, Stott et al. (2004) found that it was very likely (confidence level >90%) that human influence had at least

147. *See* Stephanie C. Herring et al., *Abstract*, *in* BAMS 2016, *supra* note 76, at Sii.

148. RICHARD BLACK & RUSSEL BAUM, ENERGY & CLIMATE INTELLIGENCE UNIT, EVEN HEAVIER WEATHER 6 (2018).

149. *Id.*

150. Radley M. Horton et al., *A Review of Recent Advances in Research on Extreme Heat Events*, 2 CURRENT CLIMATE CHANGE REP. 242, 242 (2016).

151. NAS 2016, *supra* note 108, at 7; *see* Stephanie C. Herring et al., *Introduction to Explaining Extreme Events of 2016 From a Climate Perspective*, *in* BAMS 2016, *supra* note 76, at S2.

152. NCA4, *supra* note 7, at 19.

doubled the risk of a heat wave of the sort experienced that summer.[153] Since then, scientists have developed a robust body of research linking unusually warm temperatures and heat waves to anthropogenic climate change.[154] One meta-analysis of unprecedented extremes on a global level found that:

> [H]istorical warming has increased the severity and probability of the hottest month and hottest day of the year at >80% of the available observational area. For the most protracted hot and dry events, the strongest and most widespread contributions of anthropogenic climate forcing occur in the tropics, including increases in probability of at least a factor of 4 for the hottest month and at least a factor of 2 for the driest year.[155]

The studies contained in recent BAMS reports further reinforce this conclusion. The BAMS reports covering 2014 through 2017 contained a total of thirty-five studies examining anthropogenic influence on extreme heat (including terrestrial and marine heat), and thirty-three of those studies (91%) found that anthropogenic climate change had increased either the likelihood or the severity of the heat event.[156] Notably, there were several studies in the two most recent reports (from 2016 and 2017) which concluded that heat-related events would have been "virtually impossible" in the absence of anthropogenic influence on climate. One of these studies focused on record-breaking global annual *mean* surface temperatures in 2016,[157] while others focused on phenomena that more closely fit the definition of an "extreme" event, specifically:

153. Peter Stott et al., *Human Contribution to the European Heatwave of 2003,* 432 NATURE 610, 610 (2004).

154. IPCC AR5 WGI, Summary for Policymakers, *supra* note 25, at 19 ("There has been further strengthening of the evidence for human influence on temperature extremes since the SREX. It is now very likely that human influence has contributed to observed global scale changes in the frequency and intensity of daily temperature extremes since the mid-20th century, and likely that human influence has more than doubled the probability of occurrence of heat waves in some locations.").

155. Diffenbaugh et al., *supra* note 95, at 4881. The researchers noted that the framework they used in this study was capable of systematically evaluating the role of dynamic and thermodynamic factors such as atmospheric circulation patterns and atmospheric water vapor, lending much greater statistical confidence their findings.

156. BAMS 2014, *supra* note 76; BAMS 2015, *supra* note 76; BAMS 2016, *supra* note 76; BAMS 2017, *supra* note 76.

157. Thomas Knutson et al., *CMIP5 Model-Based Assessment of Anthropogenic Influence on Record Global Warmth During 2016, in* BAMS 2016, *supra* note 76, at S11.

extreme heat in Asia,[158] and marine heat waves off the coast of Alaska[159] and Australia.[160] All three studies employed the risk-based approach and found that FAR equals one, meaning the event could not have happened without anthropogenic influence. The BAMS editors noted these findings were novel and significant for two reasons: (i) they show that the influence of anthropogenic climate change can, at some point, become sufficiently strong to cause an extreme event which is beyond the bounds of natural variability alone; and (ii) because of the small sample size of events shown in the report, it is possible that many other temperature-related extreme events from recent years also could not have occurred in the absence of anthropogenic climate change.[161]

Dozens of other studies have found that climate change very likely influenced the probability and/or magnitude of heat-related events around the world. One study focused on two heat waves in India and Pakistan in 2015 which are estimated to have caused approximately 3,200 deaths.[162] Looking at both heat and humidity (such compound assessments of multiple variables are becoming more common), the researchers found that anthropogenic forcing had substantially increased the likelihood of the observed heat indices (by approximately 800–100,000%).[163]

Another compound extremes study focused on heat and drought in Thailand, specifically examining the causal forcings behind a severe drought, which affected forty-one Thai provinces and caused an agricultural loss of approximately $500 million, and a corresponding heat wave which resulted in an estimated six-fold increase in heat stroke cases as well as extensive forest fires throughout the country.[164] There, researchers found that record temperatures could not have occurred without the influence of anthropogenic influence on climate, and that this increased the

158. Yukiko Imada et al., *Climate Change Increased the Likelihood of the 2016 Heat Extremes in Asia, in* BAMS 2016, *supra* note 76, at S97.

159. John Walsh et al., *The High Latitude Marine Heat Wave of 2016 and Its Impacts on Alaska, in* BAMS 2016, *supra* note 76, at S39.

160. S.E. Perkins-Kirkpatrick et al., *The Role of Natural Variability and Anthropogenic Climate Change in the 2017/18 Tasman Sea Marine Heatwave, in* BAMS 2017, *supra* note 76, at S105.

161. Herring et al., *supra* note 151, at S1.

162. Michael Wehner et al., *The Deadly Combination of Heat and Humidity in India and Pakistan in Summer 2015*, *in* BAMS 2015, *supra* note 76, at S81.

163. *Id.* at S85.

164. Nikolaos Christidis et al., *The Hot and Dry April of 2016 in Thailand*, *in* BAMS 2016, *supra* note 76, at S128.

likelihood of low rainfall in the region.[165] A third study looking at anomalous Arctic warmth in the winter of 2016 concluded that it "most likely" would not have been possible without anthropogenic forcing (the FAR ranged from 0.96-0.99 across five observational datasets).[166]

While the above studies provide compelling evidence of human influence on extreme heat events, it is important to recognize that quantitative estimates of risk ratios can differ considerably depending on the method used in the research. This was one key finding from a study examining the role of anthropogenic warming in the 2015 central and eastern European heat waves.[167] There, researchers used a combination of statistical analysis of observational data and model simulations for attribution purposes. They found that both approaches provided "consistent evidence that human-induced climate change has contributed to the increase in the frequency and intensity of short-term heat waves and heat stress" in the region, but that risk ratio (or FAR) estimates at local scales differ considerably depending on the exact methodology applied.[168] It should be noted that the fact that more heat attribution studies rely on models than rely on observations does not indicate that models overestimate anthropogenic influence relative to observations. For example, Sippel and Otto, using a high resolution climate model simulation, found that observed upward trends in heat extremes were three times larger between 1901–2015 than the trend in the climate model driven by historical forcings, suggesting that using observations would have produced a change in relative risk that was three times larger than the model yielded.[169] Another study relying exclusively on statistical analysis of observations to examine the 2010 Russian heat wave found that the warming in the region observed since the 1960s had

165. *Id.*

166. Jonghun Kam et al., *CMIP5 Model-based Assessment of Anthropogenic Influence on Highly Anomalous Arctic Warmth During November–December 2016*, *in* BAMS 2016, *supra* note 76, at S34, S36.

167. Sebastian Sippel et al., *The Role of Anthropogenic Warming in 2015 Central European Heat Waves*, *in* BAMS 2015, *supra* note 76, at S51.

168. *Id.* at S55.

169. *See id.* at S53–S55. As noted earlier, however, use of observations without models is somewhat fraught, for reasons including the difficultly of isolating natural variability in models and (in some cases) data limitations.

increased the risk of a heat wave of the magnitude observed in 2010 by a factor of approximately five, corresponding to a FAR of 0.8.[170]

ii. Drought

While drought is closely connected to increases in temperature, it is typically more challenging to isolate the effect of anthropogenic climate change on dryness and drought conditions because droughts are such highly complex meteorological events (with many factors affecting their probability, severity, and duration) and because large internal variability in precipitation makes it more difficult to identify a climate change signal.[171] Nonetheless, researchers have made significant advances in drought attribution in recent years. Of the twelve studies on drought and dryness that were included in the 2015, 2016, and 2017 BAMS reports, eleven (92%) found clear evidence of anthropogenic influence on the severity or probability of the observed event.[172]

One persistent finding is that it is easier to attribute the heat-related aspects of drought to anthropogenic activities than it is to attribute reductions in rainfall, due to the dynamic nature of the hydrologic cycle.[173] For example, a study of the 2014 drought in the Horn of Africa found no evidence of anthropogenic influence on the likelihood of low rainfall, but "clear signals in other drivers of drought" (namely, higher temperatures and increased net incoming radiation).[174] One assessment of observed "flash droughts"[175] in southern Africa found that these events had increased by 220% from 1961–2016, and that there had also been a

170. Rahmstorf & Coumou, supra note 110, at 17905.

171. In this section, we use the term "drought" to refer to meteorological drought—that is, drought brought about by dry weather patterns. Studies examining hydrologic drought—that is, drought brought about by low water levels—would more properly be classified as "impact attribution studies."

172. BAMS 2015, *supra* note 76; BAMS 2016, *supra* note 76; BAMS 2017, *supra* note 76.

173. *See, e.g.*, NCA4, *supra* note 7, at 22: "The human effect on recent major U.S. droughts is complicated. Little evidence is found for a human influence on observed precipitation deficits, but much evidence is found for a human influence on surface soil moisture deficits due to increased evapotranspiration caused by higher temperatures. (*High confidence*)".

174. T. R. Marthews et al., *The 2014 Drought in the Horn of Africa: Attribution of Meteorological Drivers*, *in* BAMS 2014, *supra* note 76, at S83; *see also* Eduardo S. P. R. Martins et al., *A Multimethod Attribution Analysis of the Prolonged Northeast Brazil Hydrometeorological Drought (2012–16)*, *in* BAMS 2016, *supra* note 76, at S65.

175. The term "flash drought" refers to a rapid-onset drought, typically caused by very dry and hot weather conditions.

decreasing trend in precipitation from 1948–2016, but also recognized that "simulations of surface air temperature change are much more reliable than those for soil moisture and precipitation."[176] A model based study which also focused on drought in southern Africa found that climate change likely increased the intensity of the 2015–2016 El Niño which in turn contributed to decreases in precipitation in the region.[177]

The numerous studies on the 2011–2017 California drought also reflect the complexity and dependency of results on methodological choices. Swain 2014 focused on geopotential heights (the heights of pressure surfaces above mean sea level) because droughts are associated with high atmospheric pressure and blockage of moisture-laden storms, and found that high heights were attributable to anthropogenic warming.[178] Funk 2014, focusing on warming of ocean temperatures off a portion of the US West coast, found that the ocean warming did not contribute to drought risk.[179] And Wang and Schubert found conflicting results: circulation anomalies associated with anthropogenic forcing did increase drought risk, but humidity increases associated with anthropogenic warming reduced drought risk.[180] However, a more recent study found that anthropogenic warming *had* increased drought risk in California—specifically, that the precipitation deficits in California were more than twice as likely to yield drought years if they occurred when conditions were warm.[181]

176. Xing Yuan et al., *Anthropogenic Intensification of Southern African Flash Droughts as Exemplified by the 2015/16 Season*, *in* BAMS 2016, *supra* note 76, at S86.

177. Chris Funk et al., *Anthropogenic Enhancement of Moderate-to-Strong El Niño Events Likely Contributed to Drought and Poor Harvests in Southern Africa During 2016*, *in* BAMS 2016, *supra* note 76, at S91.

178. Daniel L. Swain et al., *The Extraordinary California Drought of 2013-2014: Character, Context, and the Role of Climate Change*, 95 BULL. AM. METEOROLOGICAL SOC'Y (SPECIAL SUPPLEMENT) S3, S7 (2014) [hereinafter BAMS 2013].

179. Chris Funk et al., *Examining the Contribution of the Observed Global Warming Trend to the California Droughts of 2012/13 and 2013/14*, *in* BAMS 2013, *supra* note 178, at S11.

180. Hailan Wang & Siegfried Schubert, *Causes of the Extreme Dry Conditions Over California During Early 2013*, *in* BAMS 2013, *supra* note 178, at S7.

181. Noah Diffenbaugh et al., *Anthropogenic Warming Has Increased Drought Risk in California,* 112 PROC. NAT'L ACAD. SCI. 3931, 3931 (2015).

iii. Heavy Precipitation

Both AR5 and NCA4 found clear evidence that extreme rainfall events are increasing around the world, and this is generally consistent with expected physical responses to a warming climate.[182] However, as noted above, the dynamic nature of extreme precipitation events—which can be very local and brief in nature, and thus characterized by large variability and difficult to model—can make it more difficult to attribute specific precipitation events to anthropogenic climate change than temperature extremes, particularly where scientists use the risk-based approach to attribution. In the BAMS reports published for 2014 through 2017, ten out of eighteen studies on heavy precipitation (56%) identified an anthropogenic influence on event frequency or magnitude.[183] But to the extent that studies have found a link to anthropogenic activities, some of the results have been quite striking.

One study of extreme rainfall in China in 2016 found that anthropogenic forcings, combined with the 2015–2016 strong El Niño cycle, had increased the risk of the rainfall event tenfold.[184] Other studies looking at extreme rainfall events in China have similarly found evidence of anthropogenic forcing on extreme rainfall and flood events in that region.[185] Meredith et al. (2015) used a high-resolution regional climate model to assess how water temperature increases in the Black Sea affected a highly-local "convective" precipitation event.[186] They found a 300% increase in extreme precipitation associated with a non-linear transition in the

182. NCA4, *supra* note 7, at 19 ("The frequency and intensity of . . . heavy precipitation events are increasing in most continental regions of the world (*very high confidence*)"); IPCC AR5 WGI, Summary for Policymakers, *supra* note 25, at 7. With each additional degree Celsius of warming, the atmosphere is capable of holding an additional 7% more water vapor. Dim Coumou & Stefan Rahmstorf, *A Decade of Weather Extremes,* 2 NATURE CLIMATE CHANGE 491 (2012).

183. BAMS 2014, *supra* note 76; BAMS 2015, *supra* note 76; BAMS 2016, *supra* note 76; BAMS 2017, *supra* note 76.

184. Qiaohong Sun & Chiyuan Miao, *Extreme Rainfall (R20mm, RX5day) in Yangtze–Huai, China, in June–July 2016: The Role of ENSO and Anthropogenic Climate Change*, *in* BAMS 2016, *supra* note 76, at S102.

185. Claire Burke et al., *Attribution of Extreme Rainfall in Southeast China During May 2015, in* BAMS 2015, *supra* note 76, at S92; Chunlüe Zhou et al., *Attribution of the July 2016 Extreme Precipitation Event Over China's Wuhang, in* BAMS 2016, *supra* note 76, at S107.

186. Edmund P. Meredith et al., *Evidence for Added Value of Convection-Permitting Models for Studying Changes in Extreme Precipitation*, 120 J. GEOPHYSICAL RES. ATMOSPHERE 12500, 12500 (2015).

stability of the atmosphere.[187] A lower resolution model would not be able to resolve this non-linear precipitation change associated with higher sea surface temperatures.[188]

As noted above, the "storyline" approach to attribution was developed in part to improve attribution for difficult to model events like extreme precipitation. Researchers used this approach to examine the effect of anthropogenic climate change on the 2013 floods in Boulder, Colorado, and found that anthropogenic drivers increased the magnitude of the rainfall for that week by approximately 30%.[189] The scientists also conducted a probabilistic analysis of potential impacts on flooding and found that this 30% increase in rainfall approximately doubled the likelihood of flood-inducing rainfall occurring during that event.[190] In contrast, researchers evaluating the Boulder floods under the risk-based framework found no evidence that anthropogenic climate change had increased the probability of the event occurring.[191] This underscores the sensitivity of results to methodological choices made in extreme event attribution.

iv. Tropical and Extratropical Cyclones

Climate change can fuel tropical cyclones in several ways. Although key uncertainties remain with respect to how anthropogenic forcing has influenced some tropical cyclone determinants (e.g., wind shear and atmospheric aerosols), other drivers are quite clear. First, sea surface temperatures have warmed in most places, which—all things being equal—allows the most intense storms to strengthen, leading to non-linear increase in storm impacts. Second, a warmer atmosphere can hold more moisture and thus can lead to heavier rainfall and flooding.

187. *See* Edmund P. Meredith et al., *Crucial Role of Black Sea Warming in Amplifying the 2012 Krymsk Precipitation Extreme*, 8 NATURE GEOSCIENCE 615, 615 (2015). This increase was related to the change in temperature with height; warming water warmed the lower atmosphere above it, making the lower atmosphere less dense and thereby facilitating rainfall-conducive rising of air. *Id.* at 618.

188. *See id.* at 616. Note that the paper itself did not directly attribute the increasing sea surface temperatures to anthropogenic forcing.

189. Pardeep Pall et al., *Diagnosing Conditional Anthropogenic Contributions to Heavy Colorado Rainfall in September 2013,* 17 WEATHER AND CLIMATE EXTREMES 1, 1 (2017).

190. *Id.* at 5.

191. *See* Martin Hoerling et al., *Northeast Colorado Extreme Rains Interpreted in a Climate Change Context*, in BAMS 2013, *supra* note 178, at S17.

Finally, higher sea levels exacerbate coastal flooding and high-water levels during storms.

Attribution studies on tropical and extratropical cyclones have generated mixed results. Many early studies performed using the risk-based approach found no clear evidence that anthropogenic forcings altered the probability or severity of the cyclones examined therein.[192] But more recently, there have been numerous studies in which researchers have identified a fairly large anthropogenic "fingerprint" on select storm characteristics. One such study examined 2015 tropical cyclone activity in the western North Pacific Ocean—looking specifically at the level of accumulated cyclone energy (ACE)—and found that anthropogenic forcing largely increased the odds of the ACE values that were observed (FAR = 0.81).[193]

There have also been a number of studies on individual tropical cyclones. Unsurprisingly, for Hurricane Harvey there have been several studies focused on the storm's prodigious rainfall totals, which reached approximately sixty inches. Risser and Wehner, using a statistical approach known as extreme value analysis, found anthropogenic forcing led to 37% more precipitation over land;[194] van Oldenborgh et al. 2017 found a 15% increase using a model and without considering possible changes in atmospheric dynamics.[195] Allowing for dynamical changes in addition to thermodynamics, Wang et al. 2018 found a ~25% increase.[196] A recent Trenberth 2018 paper showed large positive upper ocean heat content anomalies in advance of Harvey. Upper ocean heat content anomalies are straightforward to link to anthropogenic warming, in so far as the authors note that ~92% of

192. *See, e.g.*, Frauke Feser et al., *Hurricane Gonzalo and Its Extratropical Transition to a Strong European Storm*, *in* BAMS 2014, *supra* note 76, at S54; Lei Yang et al., *Anomalous Tropical Cyclone Activity in the Western North Pacific in August 2014*, *in* BAMS 2014, *supra* note 76, at S124.

193. Zhang et al., *Influences of Natural Variability and Anthropogenic Forcing on the Extreme 2015 Accumulated Cyclone Energy in the Western North Pacific, in* BAMS 2015, *supra* note 76 at S133.

194. Mark Risser & Michael Wehner, *Attributable Human-Induced Changes in the Likelihood and Magnitude of the Observed Extreme Precipitation During Hurricane Harvey*, 44 GEOPHYSICAL RES. LETTERS 12457, 12457 (2017).

195. Geert Jan van Oldenborgh, *Attribution of Extreme Rainfall from Hurricane Harvey, August 2017,* 12 ENVTL. RES. LETTERS 1, 1 (2017).

196. S. Wang et al., *Quantitative Attribution of Climate Effects on Hurricane Harvey's Extreme Rainfall in Texas*, 13 ENVTL. RES. LETTERS 1, 1(2018).

anthropogenically induced warming has gone towards heating the ocean. The authors go on to note that Hurricane Harvey was able to tap the anomalous heat in the nearby upper ocean, ultimately converting the energy into extreme rainfall.[197] While this last paper is not focused on attribution per se, it is emblematic of how broader science advances, past and present, help inform attribution studies—much as attribution studies can advance broader physical understanding. The Trenberth (2018) paper also makes a critical point about non-linearity and threshold crossing of impacts; the authors note that even if precipitation increase with climate change in a storm like Harvey is only 5–15%, that incremental increase could conceivably generate the bulk of all costs. Impacts of hurricane winds have also been shown to increase non-linearly with stronger winds. In the case of the three major landfalling 2017 Atlantic hurricanes, costs were hundreds of billions of dollars.[198]

In contrast to tropical cyclone findings, few attribution studies to date have found an anthropogenic signal in extra-tropical cyclones. One example, Feser et al. (2014), relied on sixty-seven years of observed data and found a recent storm experiencing extra-tropical transition was unexceptional in the context of the long-term observational dataset.[199]

3. Impact Attribution

Impact attribution focuses on the consequences and outcomes of climate change. Many of the phenomena discussed above (e.g., loss of sea ice, increases in sea levels, and changes in precipitation) can certainly be described as "impacts" of a changing climate[200]—but, as noted at the outset of this section, for the purposes of this paper, we use the IPCC AR5 definition of "impacts":

In this report, the term impacts is used primarily to refer to the

197. Kevin Trenberth et al., *Hurricane Harvey Links to Ocean Heat Content and Climate Change Adaptation*, 6 EARTH'S FUTURE 730, 730 (2018).

198. Willie Drye, *2017 Hurricane Season Was Most Expensive in U.S. History,* NAT'L GEO. (Nov. 30, 2017).

199. Feser et al., *supra* note 192, at S54.

200. For example, an "impact" of climate change can be defined as "any change in a physical, biological, or human system that is driven by a long-term climate trend." Cynthia Rosenzweig & Peter Neofotis, *Detection and Attribution of Anthropogenic Climate Change Impacts*, 4 WIREs CLIMATE CHANGE 121, 121 (2013).

> effects on natural and human systems of extreme weather and climate events and of climate change. Impacts generally refer to effects on lives, livelihoods, health, ecosystems, economies, societies, cultures, services and infrastructure due to the interaction of climate changes or hazardous climate events occurring within a specific time period and the vulnerability of an exposed society or system. Impacts are also referred to as consequences and outcomes. The impacts of climate change on geophysical systems, including floods, droughts and sea level rise, are a subset of impacts called physical impacts.[201]

Impact attribution gets closer to what people really care about in the liability and policy context, and, in particular, the question of who will be harmed by climate change and to what extent. But because impact attribution deals with consequences that are farther along the causal chain, it is harder to issue robust findings about the connection between anthropogenic influence on climate and specific on-the-ground impacts.

a. Methods and Parameters

Impact attribution, like climate change attribution, relies on physical understanding, observational data, statistical analysis, and models. However, impact attribution also involves unique challenges that can make the attribution of impacts more difficult than the attribution of climate change and extreme weather events.

The most fundamental challenge is that, as research moves further down the causal chain from human influence on climate change to discrete impacts on human and natural systems, researchers must account for an increasing number of non-climate and exogenous variables which complicate the attribution analysis (sometimes referred to as "confounding factors"). For example, in a study seeking to link public health impacts from a heat wave to anthropogenic forcing, researchers would need to account for land use decisions, access to cooling, and other adaptations affecting public health, as well as baseline vulnerability of subsets of the population to heat impacts (based on factors such as age, pre-existing health conditions, and outdoor activity) in order to ascertain the extent to which anthropogenic climate change was responsible for those impacts.

The relationship between two variables can also be complex and non-linear. For example, while the relationship between increasing

201. IPCC AR5 SYR, *supra* note 33, at 124.

mortality and each additional degree of warming may be well understood at moderately high temperatures, there may be limited knowledge, or observational basis, of just how steeply mortality may rise with temperature once extreme temperatures occur.[202] Furthermore, there is typically not a linear cause-and-effect relationship, but rather there is an interconnected web of variables where a change in any one variable can create cascading effects and feedback loops. As one example, it has been argued that anthropogenically-enhanced droughts in agricultural breadbaskets, such as Russia in 2010,[203] had cascading impacts on grain prices that disproportionately affected food insecure populations around the globe, ultimately contributing both to malnutrition and civil unrest in regions far away from the original extreme climate event.[204]

Researchers must also account for internal system dynamics in impact attribution studies. For example, a study of how a species' population was impacted by anthropogenic forcing might need to consider the amplitude of long-term population variability due to natural cycles of predator-prey interactions that could in principle be independent of climate. For many systems, and places, standardized long term data sets simply are not available. Furthermore, establishing causation, as opposed to simply observing correlation, can present another challenge, especially for impacts systems where robust models do not exist that allow for simulation of counterfactual worlds, i.e. realizations other than the single realization actually experienced in the real world. In the absence of long-term impact datasets and strong impact models, attribution impact researchers have had to make assumptions. For example, across many impact sectors, short-term weather fluctuations that happened to align with the time period when impacts data were available have been used to estimate sensitivity to climate change,[205] or impacts of earlier events for which data was

202. Ebi et al., *supra* note 123, at 085004-3.

203. Rahmstorf & Coumou, *supra* note 110.

204. *See* Troy Sternberg, *Chinese Drought, Bread and the Arab Spring*, 34 APPLIED GEOGRAPHY 519 (2012).

205. *See Oliver* Deschênes & Michael Greenstone, *The Economic Impacts of Climate Change: Evidence from Agricultural Output and Random Fluctuations in Weather*, 102 AM. ECON. REV. 3761 (2012); Oliver Deschênes & Michael Greenstone, *Climate Change, Mortality, and Adaptation: Evidence from Annual Fluctuations in Weather in the US*, 3 AM. ECON. J.: APPLIED ECON. 152 (2011).

not available.[206,207] This may be problematic, either because long-term responses inherently differ from short-term responses, or because of changes in the various state variables over time (e.g., long term changes in confounding factors like technological innovation or population change).[208]

Treatment of antecedent climate conditions not being included in the formal attribution analysis requires care as well. For example, a study of flooding damages along a river due to a specific heavy rain event might have to consider how prior meteorological/climate conditions impacted soil moisture, water levels, and even vegetation, as these prior conditions would affect flood extent and damage.

Finally, some of the challenges discussed in the extreme events section apply here as well. For example, the spatial and temporal scale of an impact—and the driving extreme event—may be too fine to capture with existing models. In these instances, large natural variability relative to any anthropogenic signal, absence of representative local data, and the aforementioned modeling challenges may hinder impact attribution.

There are a variety of approaches taken in impact attribution studies. Roughly speaking, most impact attribution studies can be characterized as either "single-step" or "multi-step" studies (also known as "direct" and "joint" attribution, respectively). The single-step studies focus on the relationship between impacts and observed changes in mean climate variables or extremes, without going so far as to draw a complete causal connection from the impact to anthropogenic influence on climate. This is similar to the approach taken in the IPCC reports: impacts are discussed in the WGII report but are generally not explicitly linked to human forcings. One key idea underpinning this approach is that human

206. Maximilian Auffhammer et al., *Integrated Model Shows that Atmospheric Brown Clouds and Greenhouse Gases Have Reduced Rice Harvests in India*, 103 PROC. NAT'L ACAD. SCI. 19668, 19670 (2006).

207. To be sure, there are some examples of studies where long-term impact data enabled assessment of long-term changes in impacts. *See* Kristie L. Ebi et al., *Detecting and Attributing Health Burdens to Climate Change*, 125. ENVTL. HEALTH PERSP. 085004-1, 085004-2 (2017) (noting a 2014 study by Bennett et al. on temperature-related mortality in Australia from 1968 to 2007. Charmian Bennett et al. *Shifts in the Seasonal Distribution of Deaths in Australia, 1968–2007*, 58 INT'L J. BIOMETEOROLOGY 835 (2014)).

208. Ebi 2017 provide a strong example: "on a time scale of decades, local food production may shift successfully to new heat-tolerant technologies or be abandoned altogether." Ebi et al, *supra* note 207, at 085004-2 (internal citations omitted).

influence is a primary driver of climate change, so we can infer that many of the impacts where attribution is well advanced are ultimately caused by anthropogenic climate change—especially those linked to climate variable, like mean temperature at a continental scale. This approach has the advantage of simplicity, but can only generate robust, quantitative findings where the impact attribution study can be linked to one or more external studies of an appropriate scale and scope, which establish the role of human influence in the change in climate variable giving rise to the impact. In the absence of such studies, scientists may be able to infer that an impact was "caused" by climate change, but they will not be able to isolate the proportional contribution of human influence on that impact. Due to this limitation, many single-step attribution studies tend to communicate results in a conservative fashion, focusing on whether there is *any* human influence on a particular impact rather than quantifying the magnitude of the influence.[209]

The multi-step or "joint" impact attribution studies, which are less common, involve at least two attribution steps: first, linking a change in a mean climate variable or extreme to anthropogenic influence and second, linking impacts to that change.[210] For example, a study could link mortality to temperature increases, and then link temperature increases to greenhouse gas emissions. This second approach is sometimes referred to as "end-to-end" attribution.[211] The multi-step approach is preferable in principle, but in practice the complexity of multi-step attribution analysis, with its potential for cascading uncertainty, can lead to weak and/or heavily-caveated attribution statements.

A distinction can also be drawn between impact attribution studies that contain quantitative analysis of impacts, and impact attribution studies which only contain a qualitative description of impacts. In quantitative studies, the analysis often mirrors that of extreme event studies—the emphasis being on determining the extent to which climate change increased the risk of certain impacts. Quantitative impact assessments do not always rely on

209. IPCC AR5 WGI, *supra* note 25, at 878.

210. For a more detailed explanation of these two approaches, *see* Dáithi Stone et al., *The Challenge to Detect and Attribute Effects of Climate Change on Human and Natural Systems,* 121 CLIMATIC CHANGE 381, 390–91 (2013).

211. *See, e.g.*, Cynthia Rosenzweig et al., *Attributing Physical and Biological Impacts to Anthropogenic Climate Change* 453 NATURE 353, 354 (2008).

models—sometimes they rely on more simple methods, like extrapolation of observations or historical statistical relationships to estimate impacts such as changes in crop yield. In the qualitative studies, scientists will look at a change like increases in surface temperature, attribute those changes to anthropogenic influence, and then simply describe how the change in the climate variable affected other variables.[212] The advantage of the qualitative approach is that it can provide useful insights into the nature of possible climate change impacts that have not received a great deal of scientific or public attention to date.[213] But the qualitative approach would not be as effective at supporting certain applications, such as liability claims, precisely because it does not generate quantitative data.

b. Status of Research

The WGII report for AR5 found strong evidence that "changes in climate have caused impacts on natural and human systems on all continents and across all oceans" in recent decades.[214] However, it also found that evidence of climate-change impacts was "strongest and most comprehensive" for natural systems, whereas evidence linking impacts on human systems to climate change was more limited.[215] Most of the attribution findings in the WGII report are the product of "single-step attribution" although the report does cite to some studies that have conducted multi-step attribution. In recent years, the BAMS reports have also been expanded to encompass impacts attribution in addition to extreme event attribution, and most of the studies in those reports employ single-step attribution.[216] Two key areas of focus in impact attribution studies include the Arctic and the oceans, where changes are occurring more rapidly and impacts are therefore more apparent.

212. *See, e.g.*, Michael Jacox et al., *Forcing of Multiyear Extreme Ocean Temperatures that Impacted California Current Living Marine Resources in 2016*, *in* BAMS 2016, *supra* note 76, at S27.

213. BAMS annual extreme event attribution reports, for example, are increasingly weighing in on impacts *after* assessing whether the extreme event can be linked to anthropogenic forcing. The majority of the papers address the link between the impact and the extreme event in a qualitative way, with a few exceptions.

214. IPCC AR5 WGII, Summary for Policymakers, *supra* note 20, at 4.

215. *Id.*

216. Herring et al., *supra* note 151, at S3. As noted earlier, in the BAMS reports, the single-step tends to be the link between anthropogenic warming and climate or extreme events, with the link to impacts treated less rigorously.

Impacts from extreme events, particularly heat waves, are also a major focus of impact attribution studies.

i. Ecosystems, Species, and Ecological Indicators

Much of the existing impact attribution research focuses on ecological impacts, seeking to understand how climate change is affecting individual species, ecosystems, and ecological functioning. The focus of such studies is on natural systems, but there are clear implications for human systems, insofar as we rely on natural systems, such as fisheries, for food as well as other ecosystem services, such as water and air filtration. There is robust evidence of impacts in this category. In particular, IPCC AR5 found with *high confidence* that "[m]any terrestrial, freshwater, and marine species have shifted their geographic ranges, seasonal activities, migration patterns, and abundances, and species interactions in response to ongoing climate change."[217] IPCC AR5 also expressed *high confidence* in findings that several recent species extinctions can be attributed to climate change,[218] and *very high confidence* that climate-related extremes such as heat waves, droughts, floods, and cyclones were altering ecosystems.[219] IPCC AR5 expressed *high* and *medium confidence* about a number of other region-specific impacts, such as changes in the timing of critical biological events, increased tree mortality, pest outbreaks, and other ecosystem disturbances.[220]

There are many examples of both single-step and multi-step attribution of ecological impacts. Most of the multi-step studies focus on the impact of increasing temperatures on biological systems.[221] In one of the earliest and most comprehensive meta-analyses, Rosenzweig et al. 2008 conducted a broad assessment of observed changes in natural systems.[222] The researchers demonstrated that: (i) regional climate changes were caused by human forcing, and (ii) observed changes in natural systems were

217. IPCC AR5 WGII, Summary for Policymakers, *supra* note 18, at 4. Note the absence, though, of direct attribution of the climate change to anthropogenic forcing, rather than other possible factors, like natural variability.

218. *Id.*

219. *Id.* at 6.

220. IPCC AR5 WGII, Technical Summary, *supra* note 18, at 44–46.

221. *See, e.g.*, Terry Root et al., *Human-Modified Temperatures Induce Species Changes: Joint Attribution*, 102 PROC. NAT'L ACAD. SCI. 7465 (2005); Ebi et al., *supra* note 207.

222. Cynthia Rosenzweig et al., *Attributing Physical and Biological Impacts to Anthropogenic Climate Change*, 453 NATURE 353, 354 (2008).

consistent with the estimated responses of physical and biological systems to regional climate change and not consistent with alternative explanations that exclude regional climate change. Specifically, they found that approximately 95% of 829 documented physical changes (e.g., glacier reduction and earlier spring peak of river discharge) and that 90% of 28,800 documented changes in biological systems (e.g., earlier blooming) were in directions consistent with warming.[223] The researchers endeavored to explicitly account for confounding variables such as land use change, management practices, pollution and human demography shifts.

Many other impact studies have been conducted since 2008 to improve understanding of exactly how climate change is affecting biological systems. The 2016 BAMS report contained several examples of such studies, including three studies finding that increases in sea surface and ocean temperatures were harming ocean ecosystems through impacts such as coral reef bleaching and reduced fish stocks,[224] and a study on terrestrial impacts which found that anthropogenic influence on climate change was actually driving higher ecosystem productivity on the Iberian Peninsula through warmer winters coupled with wet springs and increases in CO_2 availability.[225] These studies exemplified the diversity of approaches in impact attribution: one of the marine studies focused on the role of anthropogenic forcing in causing ocean temperatures that had resulted in certain ecological impacts without taking a detailed look at the impacts themselves;[226] another focused on the extent to which coral reef and seabird communities were disrupted by record-setting sea surface temperatures and made an "indirect two-step link to human-induced climate change" by referencing findings from a companion paper attributing the record-setting temperatures to anthropogenic forcing;[227] and the

223. *Id.* While those key findings were presented in quantitative terms, each documented change was handled in a qualitative way (looking at direction of change and not amount changed).

224. Sophie C. Lewis & Jennie Mallela, *A Multifactor Risk Analysis of the Record 2016 Great Barrier Reef Bleaching, in* BAMS 2016, *supra* note 76, at S144; Jacox et al., *supra* note 212; Russel E. Brainard et al., *Ecological Impacts of the 2015/16 El Niño in the Central Equatorial Pacific, in* BAMS 2016, *supra* note 76, at S21.

225. Sippel et al., *supra* note 111, at S80.

226. Jacox et al., *supra* note 212.

227. Stott et al., *Future Changes in Event Attribution Methodologies, in* BAMS 2016, *supra* note 76, at S156 (referencing Brainard et al., *supra* note 224).

third was a multi-step attribution study in which scientists attributed abnormally warm SST to anthropogenic forcing and then qualitatively examined the respective role of the abnormally warm SST on coral bleaching.[228] The multi-step attribution study of the Iberian Peninsula was noteworthy for the complexity of the model design, which included counterfactual simulations for both the climate model and the ecosystem model. The experimental design supported attribution of ecosystem impacts not only to observed changes in climate associated with anthropogenic forcing, but also to direct impacts of higher CO_2 concentrations on vegetation.[229]

As evident from these and other studies, impacts on marine ecosystems are a key topic in impact attribution. One reason for this is ocean temperatures are rising quickly in many regions relative to natural variability (indicating a high signal to noise ratio).[230] Not coincidentally, the impacts on marine resources are more evident, in some cases, than terrestrial impacts, as more and more species and ecosystems approach climate thresholds that may not have occurred during their evolutionary history. The effect of climate change on fishery productivity is also a major concern throughout the world and a key focus of many studies.[231]

ii. Inland Flooding and Hydrologic Impacts

A fair amount of research has also been conducted on the impacts of climate change on inland or riverine floods, hydrologic droughts, and changes in streamflow. Above, we discuss meteorological droughts as a type of extreme climate event—hydrologic droughts are more properly classified as "impacts" of climate change because there are so many confounding factors that affect their characteristics. The same can be said for floods. While these are often discussed as "extreme events" in common parlance, they are more properly classified as impacts of climate change due to the number of non-climate related confounding factors that

228. Lewis & Mallela, *supra* note 224.

229. Sippel et al., *supra* note 111.

230. Thomas Frölicher, et al., *Marine Heatwaves Under Global Warming*, 560 NATURE 360, 360 (2018).

231. *See, e.g.,* NAT'L OCEANIC AND ATMOSPHERIC ADMIN., WHAT CAUSED THE SACRAMENTO RIVER FALL CHINOOK STOCK COLLAPSE? (2009); Jonathan A. Hare et al., *Cusk (Brosme brosme) and Climate Change: Assessing the Threat to a Candidate Marine Fish Species Under the US Endangered Species Act*, 69 ICES J. MARINE SCI. 1753 (2012); Kyle Meng et al., *New England Cod Collapse and the Climate*, PLOS ONE, July 27, 2016.

affect flood characteristics.[232] It is also worth bearing in mind that floods and other hydrologic impacts can be affected by slow-onset changes such as temperature increases as well as extreme events. IPCC AR5 found, with *medium confidence,* that changes in precipitation, snow melt, and ice are altering hydrological systems and affecting water resources (both in terms of quality and quantity).[233] However, IPCC AR5 did not find evidence that, on a global scale, surface water and groundwater drought frequency had changed in the last few decades,[234] but did discuss research linking regional drought conditions to climate change.[235] IPCC AR5 also found with *very high confidence* that climate-related extremes were disrupting water supply.[236]

Flood attribution studies follow the same pattern as other impact attribution studies—single-step attribution, as well as storyline approaches dominate existing studies to date.[237] The climate variables that are most relevant to inland flood impact analysis include precipitation, storms, and temperature (which can cause flooding through, e.g., snowmelt and permafrost thawing). Some multi-step analyses have also been performed for hydrologic droughts and other hydrologic impacts.[238] For example, a 2008 study of human-induced changes in the hydrology of the western United States found that up to 60% of the climate-related trends in river flow, winter air temperature, and snow pack between 1950 and 1999 were human-induced.[239]

232. These include, for example, geography, topography, hydrology, water infrastructure, land use decisions, and building design. Note though that precipitation associated with a flood would be treated as an "extreme event" under our nomenclature.

233. IPCC AR5 WGII, *supra* note 18, at 44.

234. *Id.*

235. *See, e.g.*, *id.* (expressing *medium confidence* that climate change had increased soil moisture drought in the Sahel since 1970).

236. *Id.* at 6.

237. *See, e.g.*, Trenberth et al., *supra* note 125.

238. *See, e.g.*, Sebastian Sippel & Friederike E. L. Otto, *Beyond Climatological Extremes—Assessing how the Odds of Hydrometeorological Extreme Events in South-East Europe Change in a Warming Climate*, 125 CLIMATIC CHANGE 381 (2014); Pardeep Pall et al., *Anthropogenic Greenhouse Gas Contribution to Flood Risk in England and Wales in Autumn 2000,* 470 NATURE 382 (2011); Geert Jan van Oldenborgh et al., *The Absence of a Role of Climate Change in the 2011 Thailand Floods, in* EXPLAINING EXTREME EVENTS OF 2011 FROM A CLIMATE PERSPECTIVE 1047 [hereinafter BAMS 2011] (2012).

239. Tim Barnett et al., *Human-Induced Changes in the Hydrology of the Western United States*, 319 SCIENCE 1080, 1080 (2008).

iii. Coastal Impacts

Climate change is affecting coastlines through sea level rise, changes in the severity and frequency of storms and extreme rainfall events, temperature changes (particularly marine temperatures), and ocean acidification. IPCC AR5 found that many coastal areas are already experiencing adverse impacts such as submergence, coastal flooding, coastal erosion, and saltwater intrusion, all of which are exacerbated by sea level rise, but found also that the impacts of anthropogenic climate change on coastlines are difficult to tease apart from human-related drivers such as land use change and in situ adaptations such as sea walls.[240] Studies attributing coastal impacts to anthropogenic influence on climate may focus exclusively on physical impacts or may seek to link physical impacts to economic or public health outcomes.

Findings from recent coastal impact studies suggest that some coastal areas are already undergoing dramatic transformations driven primarily by sea level rise. For example, one single-step study of flooding in Southeast Florida focused on the role of sea level rise in monthly high tides and found that the probability of a 0.57-meter tidal flood within the Miami region had increased by more than 500% since 1994 due to a 10.9-centimeter increase in sea levels.[241] The findings from this study are compelling—indeed both the link between 1) anthropogenic warming and sea level rise and 2) sea level rise and the frequency of coastal flooding are two of the most robust aspects of climate change. Nevertheless, this and similar studies are limited insofar as they do not quantify the anthropogenic influence on the observed changes in sea level rise and corresponding impact on floods, nor do they speak to specific impacts on human systems (e.g., economic damages or public health outcomes).

iv. Wildfires

Climate change primarily exacerbates wildfire risk through hotter and drier conditions. Perhaps counterintuitively, in water-limited regions, an unusually wet growing season, during which time more vegetation grows which can later become fuel, can set

240. IPCC AR5 WGII, *supra* note 18, at 364.

241. William V. Sweet et al., *In Tide's Way: Southeast Florida's September 2015 Sunny-day Flood, in* BAMS 2015, *supra* note 76, at S25.

the stage for a large fire season once the vegetation dries out. Winds, atmospheric humidity, solar radiation, and lightning strikes also influence fire risk. While wildfires are sometimes characterized as "extreme events" related to climate change, they are far from purely meteorological events; rather, they are a product of both climatological and terrestrial conditions. For example, the expansion of human development and electrical systems into previously-remote forest zones leads to an increase in ignition, and forest management and fire suppression decisions affect fire frequency and intensity.[242] As such, the link between climate change and wildfires is less direct than the link between climate change and events such as heat waves. IPCC AR5 expressed *medium* and *low confidence* in various studies linking increases in the severity or frequency of wildfires to climate change,[243] with the higher confidence for wildfires in data-rich North America. Research performed since then has generated more robust evidence of a link between *anthropogenic* climate change and wildfires in North America and Australia.[244]

One of the earliest studies on this topic, published in 2004, found that human-induced climate change had a detectable influence on Canadian forest fires in recent decades[245] A 2016 end-to-end study on wildfires in the western United States found that, while there were numerous factors that aided the recent rise in fire activity, observed warming and drying had significantly increased fuel aridity during the fire season, fostering a more favorable environment for wildfires.[246] They found that anthropogenic climate change caused over half of the documented increases in fuel aridity since the 1970s and doubled the cumulative forest fire

242. A. Park Williams et al., *Observed Impacts of Anthropogenic Climate Change on Wildfire in California*, 7 EARTH'S FUTURE 892, 892 (2019) (recognizing that the effects of climate change on wildfire can vary greatly across space and time due to confounding factors such as fire suppression and ignitions from humans).

243. *See, e.g.*, IPCC AR5 WGII, *supra* note 18, at 44 (*low confidence* that climate change had increased wildfires on Mt. Kilamanjaro); *id.* at 45 (*medium confidence* that climate change increased wildfire frequency in subarctic conifer forests and tundra, and *medium confidence* that climate change increased wildfire activity, fire frequency, and duration in forests of Western U.S. and boreal forests in Canada).

244. NCA4, *supra* note 7, at 242-245.

245. N.P. Gillett et al., *Detecting the Effect of Climate Change on Canadian Forest Fires*, 31 GEOPHYSICAL RES. LETTERS 1, 1 (2004).

246. John Abatxoglou & A. Park Williams, *Impact of Anthropogenic Climate Change on Wildfire Across Western US Forests,* 113 PROC. NAT'L ACAD. SCI. 11770, 11770 (2016).

area since 1984.[247] The same researchers published a subsequent study focused on California which found that human-induced warming had already significantly enhanced wildfire activity in the state, particularly in the forests of the Sierra Nevada and North Coast.[248] Another end-to-end study focusing on the role of extreme vapor pressure deficits (VPD) in wildfire risk found that anthropogenic influences quintupled the risk of extreme VPD for western North America and had doubled the risk of extreme VPD in extratropical Australia.[249]

Again, the findings from these studies are compelling, but like many impact studies, they rely on proxies for wildfire risk such as fuel aridity in order to attribute impacts. Further studies can help continue to provide answers to help quantify the extent to which anthropogenic climate change has caused an increase in wildfires as compared with other confounding factors such as fire suppression and development in wildfire-prone areas.

v. Air pollution

There have been relatively few attribution studies of air pollution. Vautard 2018 looked indirectly at air pollution in Europe.[250] Rather than modeling actual air pollution, they modeled changes in the occurrence of "flow analogues" (i.e. wind and air pressure patterns associated with observed historical pollution events), finding that anthropogenic forcing had produced a 10% increase in the frequency of such events. As climate models become more able to model air pollution directly, and as awareness grows of how harmful fire and directly anthropogenic sources of air pollution (e.g., factories and vehicle emissions) are, we may see more attribution work on air pollution. Such studies will have to address the correlation between climate and air pollution, which differs by region, season, and type of pollutant.

247. *Id.*

248. A. Park Williams et al., *supra* note 242, at 892 (more specifically, the authors found that anthropogenic climate change had contributed to an eightfold increase in summertime forest-fire area, which in turn had contributed to a fivefold increase in California's annual wildfire extent).

249. Simon F.B. Tett et al., *Anthropogenic Forcings and Associated Changes in Fire Risk in Western North America and Australia During 2015/16, in* BAMS 2016, *supra* note 76, at S60–64.

250. *See* Robert Vautard et al., *Attribution of wintertime anticyclonic stagnation contributing to air pollution in Western Europe, in* BAMS 2016, *supra* note 76, at S70–75.

vi. Public Health

Public health impacts are another important topic in attribution research. Here, again, many studies focus on how extreme heat affects health because the link between climate change and extreme heat is relatively direct. There has been much discussion of how other climate-related events and impacts, such as floods and wildfires, can affect public health, but there is little research linking anthropogenic forcings to health impacts from those types of events in a robust, quantitative fashion. As noted in IPCC AR5, evidence of impacts on public health is not as robust as evidence of other impacts, and "[a]t present the worldwide burden of human ill-health from climate change is relatively small compared with effects of other stressors and is not well quantified."[251] However, IPCC AR5 did find more robust evidence of specific types of health impacts, expressing *medium confidence* in findings of increased heat-related mortality and decreased cold-related mortality in some regions as a result of warming, *medium confidence* that local changes in temperature and rainfall have altered the distribution of some water-borne illnesses and disease vectors,[252] and *very high confidence* that climate-related extremes were affecting morbidity, mortality, mental health, and human well-being.[253]

Attribution of public health impacts, like other impacts, is challenging due to data requirements and the complexity of isolating causal factors that contribute to health outcomes. As noted by Ebi et al. 2017, robust detection and attribution of health impacts requires reliable long-term datasets, in-depth knowledge of the many drivers and confounding factors that affect public health outcomes, and refinement of analytic techniques to better capture the effect of anthropogenic forcing on health outcomes.[254] Two key challenges are the fact that high-quality, long-term public health data is not available for many parts of the world, and there are many confounding factors that influence public health outcomes in any given region.

Despite the limitations, Ebi et al. 2017 found that "advances are possible in the absence of complete data and statistical certainty: there is a place for well-informed judgments, based on

251. IPCC AR5 WGII, Summary for Policymakers, *supra* note 18, at 6.
252. *Id.*
253. *Id.*
254. Ebi et al., *supra* note 207, at 085004-1.

understanding of underlying processes and matching of patterns of health, climate, and other determinants of human well-being."[255] To illustrate this point, the researchers discuss several contexts in which it is possible to show that a "proportion of the current burden of climate-sensitive health outcomes can be attributed to climate change": (i) heat waves, (ii) the emergence of tick vectors of Lyme disease in Canada, and (iii) the emergence of *Vibrio* in northern Europe. For heat waves, the researchers described several approaches for estimating the number of heat wave deaths attributable to anthropogenic climate change. These included two variants on multi-step attribution that would combine either the risk-based or storyline approach to extreme event attribution with an assessment of how changes in exposure to heat waves affect mortality, as well as a single-step attribution approach which would combine observations of the changes in the incidence and severity of heat waves with the exposure analysis. For *Vibrio*, the researchers found that it was possible to attribute increases in the incidence of *Vibrio* to incremental increases in sea surface temperatures, which could then be attributed to climate change. For tick vectors and Lyme disease, the researchers found that there was indirect evidence that higher temperatures were one of the forces leading to the expansion of these vectors, but that more detailed analyses of longer-term surveillance data was needed to actually quantify the relationship between climate change and tick vectors. One key takeaway from the authors of that study was that there are many different approaches to health impact attribution but no standard practice at this time.

Single-step attribution is still routinely used in health impact assessments. One such study looked at heat-related mortality in Sweden and found that mortality from heat extremes in 1980–2009 was double what would have occurred without climate change.[256] As noted, the key limitation to these studies is that they do not answer the question of how *anthropogenic* climate change is affecting public health.

255. *Id.*

256. Daniel Oudin Åström et al., *Attributing Mortality from Extreme Temperatures to Climate Change in Stockholm, Sweden*, 3 NATURE CLIMATE CHANGE 1050, 1051. (2013). The researchers accounted for confounding variables such as urbanization and the urban heat island effect, but did not attempt to quantify human influence on observed increases in extreme heat events.

The first fully quantitative end-to-end attribution analysis of heat-related morality from climate change was published in 2016.[257] This study combined a climate model with a health impact assessment model to attribute deaths from the 2003 European heat wave and found that anthropogenic climate change increased the risk of heat-related mortality by approximately 70% in Central Paris and 20% in London, and that approximately 506 (± 51) deaths were attributable to climate change in Paris, and 64 (± 3) deaths were attributable in London.[258]

Where data on public health outcomes is lacking, researchers may use changes in climate variables as proxies for health impacts. For example, a study on public health impacts from extreme temperatures in California's Central Valley used a temperature threshold of 40°C as a proxy for heat stress, and found that anthropogenic forcing had more than doubled the probability of a prolonged period (13+ days) during which temperatures exceeded that threshold).[259] Another study took a similar approach to examining health impacts from the 2015 Egyptian heat wave, using wet bulb globe temperature as a proxy for human discomfort caused by high heat and humidity, and found that the wet bulb temperatures observed during the heat wave were 69% more likely due to anthropogenic climate change.[260] This indirect approach to impact attribution is essentially the same as extreme event attribution but with a greater focus on implications for health outcomes. By construction, such studies assume a fixed relationship between the climate or climate extreme metric being calculated (e.g., a wet bulb temperature threshold) and the societal impact (additional mortality). This fixed approach may limit the applicability of the findings across places, subpopulations, and adaptation/policy contexts.

vii. Agriculture

Agricultural impacts, like public health impacts, are challenging to attribute to anthropogenic climate change due to gaps in data

257. Daniel Mitchell et al., *Attributing Human Mortality During Extreme Heat Waves to Anthropogenic Climate Change* 11 ENVTL. RES. LETTERS 1, 1 (2016).

258. *Id.*

259. Roberto Mera et al., *Climate Justice and the Application of Probabilistic Event Attribution to Summer Heat Extremes in the California Central Valley*, 133 CLIMATIC CHANGE 427, 435 (2015).

260. Daniel Mitchell, *Human Influences on Heat-Related Health Indicators During the 2015 Egyptian Heat Wave, in* BAMS 2015, *supra* note 76, at S72.

and the number of confounding factors that influence agricultural productivity.[261] One important finding from the research thus far is that climate change is having both positive and negative effects on agriculture depending on the region examined. Based on multiple studies covering a wide range of regions and crops, IPCC AR5 found with *high confidence* that "negative impacts of climate change on crop yields have been more common than positive impacts."[262] IPCC AR5 also found with *very high confidence* that climate-related extremes were disrupting the food supply.[263]

Attribution studies on agricultural impacts focus on linking observed changes in crop productivity to observed changes in temperature, rainfall, atmospheric greenhouse gas concentrations, and extreme events. Some of the earliest studies on this topic demonstrated that declining crop yields co-occurred with anthropogenic summer warming at regional scales.[264] A more recent end-to-end study on how anthropogenic climate change affected drought and poor harvests in South Africa during 2016 found that anthropogenic forcings had likely contributed to a decrease in rainfall corresponding with a decrease in production, but did not go so far as to quantify precise impacts on crop productivity or economic damages.[265]

viii. Economics and Development

All of the changes in weather, extreme events, and impacts caused by climate change have implications for the economic

261. Agriculture and ecosystems are directly impacted by CO_2 concentrations. There is also growing research on how other pollutants associated with anthropogenic emissions (or byproducts of those emissions), like low-level ozone, may impact crops, ecosystems, and human health. For example, one recent study found a 10% decrease in soy production associated with and elevated ozone concentrations linked to anthropogenic ozone precursors. The fact that these chemical reactions are highly sensitive to temperature and other climate factors points at the challenges of quantifying results. Wolfgang Cramer et al., *Detection and Attribution of Observed Impacts*, in CLIMATE CHANGE 2014: IMPACTS, ADAPTATION 979-1037 (Christopher B. Fields et al eds., 2014).
and Vulnerability

262. IPCC AR5 WGII, Summary for Policymakers, *supra* note 18, at 4.

263. *Id.* at 6.

264. *See* David B. Lobell & Christopher B. Field, *Global Scale Climate-Crop Yield Relationships and the Impacts of Recent Warming*, 2 ENVTL. RES. LETTERS 1, 1 (2007); Lianzhi You et al., *Impact of Growing Season Temperature on Wheat Productivity in China*, 149 AGRIC. FOREST METEOROLOGY 1009, 1009 (2007); David B. Lobell et al., *Climate Trends and Global Crop Production Since 1980*, 333 SCIENCE 616, 616 (2011).

265. Chris Funk et al., *supra* note 177, at S91.

health, stability, and social development of communities and nations. The primary drivers of these economic and development impacts include: 1) physical impacts on infrastructure and human settlements (e.g., from sea level rise and storms); 2) impacts on public health and human productivity; and 3) impacts on food production.[266] Quantifying these impacts is particularly challenging, as this requires quantification of all the different types of impacts discussed above, and more. But some initial efforts have been made to do so. IPCC AR5 highlighted several examples of studies drawing a qualitative link between observed climate changes and/or impacts and the corresponding effect on regional or national economic outcomes. For example, IPCC expressed *high confidence* in the fact that "extreme weather events currently have significant impacts in multiple economic sectors" in Europe.[267] IPCC AR5 also cited some specific examples of economic and social impacts from climate-related events, such as the 2008 Zambezi River flooding in Mozambique which displaced 90,000 people.[268] IPCC also highlighted research linking higher temperatures to declines in economic growth and per capita income in low-income countries,[269] and linking declining rainfall to the slower growth of Sub-Saharan economies,[270] but this research did not address the extent to which anthropogenic influence was responsible for observed impacts.

4. Source Attribution

We use the term "source attribution" in this paper to describe efforts to identify and attribute climate change to specific sources. A "source" could be a particular actor (e.g., a country or a company), a sector, or an activity. As one step in the longer chain

266. For example, the 2017 and 2018 wildfires in California caused billions of dollars of damage. Facing the prospect of liability for many of those fires, Pacific Gas and Electric (PG&E), one of the largest utilities in the United States, has filed for bankruptcy. While there has not yet been a formal attribution study establishing the causal link between anthropogenic climate change and those fires, initial analyses suggest that unusually warm temperatures did play a role. Kurtis Alexander, *Scientists See Fingerprints of Climate Change All Over California's Wildfires*, S.F. CHRON (Aug. 3, 2018), https://www.sfchronicle.com/science/article/Scientists-see-fingerprints-of-climate-change-all-13128585.php. [https://perma.cc/TUK4-TMW6].

267. IPCC AR5 WGII, *supra* note 18, at 42.

268. *Id.*

269. *Id.* at 997.

270. *Id.*

to source attribution, we include efforts to unpack the relative contributions of different sources to greenhouse gas emissions and concentrations. As noted above, source attribution has been, and remains, a distinct discipline from what is commonly labeled "detection and attribution" in the climate science community.[271] However, the distinction is beginning to blur, as recent studies have endeavored to apply climate change and extreme event attribution to individual sources. This research is thus a critically important data point for societal questions about how we should allocate *responsibility* for climate change and its impacts among different actors—and these questions are at the heart of many policy, planning, and legal debates.

a. Methods and Parameters

As discussed above, the key sources of data used in source attribution come from direct measurements of emissions, which can be performed *in situ* or remotely from satellites, as well as documentary evidence of emissions contained in corporate reports,[272] government inventories, and other sources. Where direct emissions data is lacking, scientists can use indirect methods, such as models, to estimate emissions from sources and activities. Indirect methods are particularly important for estimating emissions from land use changes and non-point sources such as agricultural operations.

As with other areas of attribution, it is challenging to establish a complete causal chain linking a source's contribution to climate change to specific changes in the global climate system and corresponding impacts on natural and human systems. Establishing such a causal chain involves going beyond merely quantifying the emissions contribution of the source and ascertaining the proportional contribution of those emissions to: (i) concentrations of greenhouse gases and other forcings, and (ii) ultimately how those changes in concentrations impact for example sea level rise, extreme weather events, and the resultant impacts on ecosystems and/or communities. There are some recent studies linking specific sources to certain changes in the global climate system but most of the existing research on "source attribution"

271. *See supra* Section II(A)(1).

272. These are most often emissions reports, although some historical emissions have been estimated based on production reports.

focuses on quantifying emissions from sources and determining the proportional contribution to increases in atmospheric greenhouse gases.[273]

One complicating factor is that climate change is not a product of a single pollutant or polluting activity, and different GHGs and other forcing agents have different effects on climate in terms of magnitude, duration, location, and type of effect.[274] For example, aerosols typically reflect sunlight, and to generalize due to this and other aerosol properties, aerosols tend to offset some of the heat-trapping effects of greenhouse gases. Data gaps are a major issue here: there are no known industry-aerosol databases, although there have been efforts to estimate national aerosol contributions.[275] This is important because large uncertainty about the emissions or climate effects of a single important forcing agent (like aerosols) affects our estimates for other forcing agents.

There is also a good deal of uncertainty about the extent and timing of historical land use changes and their impact on atmospheric concentrations of greenhouse gases. Some of these land use changes, like deforestation, also impact climate in other ways. For example, land use decisions which change the amount of sunlight absorbed at the surface can have an important or negligible effect on climate, depending on factors such as the latitude at which the deforestation occurs, and the reflective properties of the surface underneath the previously-forested area. Another complicating factor is that climate change itself directly impacts the magnitude of sources and sinks for greenhouse gases. For example, a warmer ocean is less able to uptake carbon dioxide, and changes in vegetation with climate change could switch some natural systems from net sources to net sinks, and vice versa.

Nonetheless, scientists can and have endeavored to calculate the relative contributions of emissions and land use change, and, within the category of emissions, of different pollutants. In climate change attribution studies, scientists can bolster emissions data with actual measurements of atmospheric greenhouse gases (such as those taken at Mauna Loa) to determine the overall effect of human activity on climate, with the aforementioned caveats. In

273. *See infra* Section II(B)(4)(b)(ii).
274. *See supra* Section II(B)(1).
275. *E.g.*, Ragnhild B. Skeie et al., *Perspective Has a Strong Effect on the Calculation of Historical Contributions to Global Warming*, 12 ENVTL. RES. LETTERS 1 (2017).

source attribution, an estimate of total anthropogenic emissions is the denominator against which a specific source's emissions contribution can be compared. Consider the following equation as an illustration of this concept:

$$Cs = Gs/Gg$$

Here, *Cs* equals the source's proportional contribution to climate change, *Gs* equals greenhouse gases generated by the source (including any releases or loss in carbon sequestration caused by the source), and *Gg* equals total global greenhouse gases from all anthropogenic sources. The measurements of atmospheric greenhouse gases help scientists quantify *Cs*, but they do not provide much if any insight on the magnitude of the source's emissions.

Another complicating factor is how to account for historical emissions when ascertaining the proportional contribution of a source to climate change. Given that greenhouse gases accumulate over time, stay in the atmosphere, and can even have lasting climate effects that extend beyond the time that the added gas is in the atmosphere, it makes sense to include historical emissions in source attribution studies. But data about historical emissions is much more limited, given the absence of satellite-based observations and other data sources, less rigorous reporting requirements, and disappearance over time of some emitting entities and documents.

The steps from 1) emissions estimates to concentration estimates, and from 2) concentration estimates to climate effects like warming surface temperature and sea level rise, require the use of models. Although full climate models are beginning to be applied to attribution based on individual source estimates, most of the research described below relies on simplified climate models that can conduct rapid simulations based on differing source emissions. These simplified models enable sundry experiments for example based on individual country emissions, but some fidelity is sacrificed for the greater speed and simplicity. These models include assumptions about certain climate parameters (e.g., *equilibrium climate sensitivity*—which can be loosely defined as the final global warming associated with a certain amount of additional forcing, often defined as a doubling above preindustrial CO_2

equivalent; and *transient response*, a measure of more rapid climate system response).

This question of how to account for historical emissions brings us back to an earlier point about the role of social science in source attribution. As explained above, physical sciences alone cannot fully answer the question of who is "responsible" for emissions because responsibility can be apportioned in many different ways. There are presently two primary approaches—assigning responsibility to national governments and assigning responsibility to private actors—but there are also questions about how to apportion responsibility under each approach.[276]

International climate negotiations have historically focused on using national responsibility as the basis for allocating emission reduction burdens.[277] This focus is evident in the United Nations

276. *See supra* Section II(A)(2)(c) (national emissions contributions could be calculated based on emissions generated within national boundaries or emissions embedded within consumed products; private sector emissions from fossil fuel consumption could be apportioned to fossil fuel production companies, power plants, or consumers).

277. A Brazilian proposal taken up by the UNFCCC Subsidiary Body for Scientific and Technical Advice (SBSTA) said national historical emissions impacts on temperature should determine the burden of addressing climate change. A rationale provided was that these countries had benefitted economically and geopolitically from their emissions. For more information about the Brazilian proposal and the underlying rationale for this approach, *see* Emilio L. La Rovere et al., *The Brazilian Proposal on Relative Responsibility for Global Warming, in* BUILDING ON THE KYOTO PROTOCOL: OPTIONS FOR PROTECTING THE CLIMATE (Kevin A. Baumert et al. eds., 2002); BENITO MULLER ET AL., DIFFERENTIATING (HISTORIC) RESPONSIBILITIES FOR CLIMATE CHANGE (2007); M.G.J. DEN ELZEN ET AL., DUTCH MINISTRY OF ENV'T, RESPONSIBILITY FOR PAST AND FUTURE GLOBAL WARMING: TIME HORIZON AND NON-LINEARITIES IN THE CLIMATE SYSTEM (2002); Nathan Rive et al., *Climate Agreements Based on Responsibility for Global Warming: Periodic Updating, Policy Choices, and Regional Costs,* 16 GLOBAL ENVTL. CHANGE 182 (2006); Kevin A. Baumert & Nancy Kete, *Introduction: An Architecture for Climate Protection,* in BUILDING ON THE KYOTO PROTOCOL: OPTIONS FOR PROTECTING THE CLIMATE (Kevin A. Baumert et al. eds., 2002); Stephen Gardiner, *Ethics and Global Climate Change*, 114 ETHICS 555 (2004). More recently, Underdal and Wei reference "accumulated competitive advantages" via technological innovation and economic growth as the source of Annex 1 higher wealth today. Arild Underdal & Taoyuan Wei, *Distributive Fairness: A Mutual Recognition Approach*, 51 ENVTL. SCI. POL'Y 35, 37 (2015). The Annex 1 countries have argued against apportionment of responsibility based on historical emissions, on the grounds that, they were not aware of the effects of greenhouse gas emissions until ~1990, when the IPCC described these effects in detail. *See* JYOTI PARIKH & KIRIT PARIKH, CLIMATE CHANGE: A PARKING PLACE MODEL FOR A JUST GLOBAL COMPACT (2009). Others have countered that there were many earlier warnings about the perils of greenhouse gas emissions. *See, e.g.*, PRESIDENT'S SCI. ADVISORY COMM., RESTORING THE QUALITY OF OUR ENVIRONMENT (1965); Wallace S. Broeker, *Climatic Change: Are We on the Brink of a Pronounced Global Warming?,* 189 SCIENCE 460–64; WORLD METEOROLOGICAL ORGANIZATION, PROCEEDINGS OF THE WMO/IAMAP SYMPOSIUM ON LONG-TERM CLIMATIC FLUCTUATIONS, WMO Doc. 421 (Aug. 1975); NAT'L ACAD. OF SCI., CARBON DIOXIDE AND CLIMATE: A SCIENTIFIC ASSESSMENT (1979).

Framework Convention on Climate Change (UNFCCC), which places the responsibility for reporting on and reducing emissions on national governments;[278] the so-called "Brazilian Proposal" which emerged from UNFCCC negotiations in the mid-1990s and holds that greenhouse gas emission reduction targets should be set according to each country's historical contribution to climate change;[279] and the Paris Agreement which relies on nationally determined contributions (NDCs) as the primary basis for mitigating emissions.[280] The UNFCCC reporting framework has also historically focused on territorial emissions rather than consumption-based emissions as the metric for gauging national responsibility.

That said, in recent years there has been a strong push both in international and domestic fora to: (i) account for consumption-based emissions as well as territorial emissions at the national level, and (ii) impose direct responsibility on private actors for emissions and to impose corresponding obligations on those actors.[281] Much of the focus has been on imposing regulatory requirements or liability for climate change on fossil fuel producers and electric generating companies. This brings us to another question about divvying up responsibility for emissions, which is whether it is appropriate to assign responsibility for emissions to entities that extract and sell fossil fuels. Erickson and Lazarous 2013 illustrate how extraction-based emissions accounting can be contrasted to "territorial" and "consumption-based" accounting methods in the following figure:[282]

Based on this record, Mattoo and Subramanian (2012) argued for 1970 as the start year. Aaditya Mattoo & Arvind Subramanian, *Equity in Climate Change: An Analytical Review*, 40 WORLD DEV. 1083 (2012).

278. United Nations Framework Convention on Climate Change, May 9, 1992, S. Treaty Doc No. 102-38, 1771 U.N.T.S. 107 [hereinafter UNFCC].

279. La Rovere et al., *supra* note 277.

280. Paris Agreement to the United Nations Framework Convention on Climate Change, Dec. 12, 2015, T.I.A.S. No. 16-1104 [hereinafter Paris Agreement].

281. *See infra* Section III(C)(5) for an overview of cases filed against private actors for their contribution to climate change.

282. PETER ERICKSON & MICHAEL LAZARUS, STOCKLHOLM ENV'T INST., ACCOUNTING FOR GREENHOUSE GAS EMISSIONS ASSOCIATED WITH THE SUPPLY OF FOSSIL FUELS (2013).

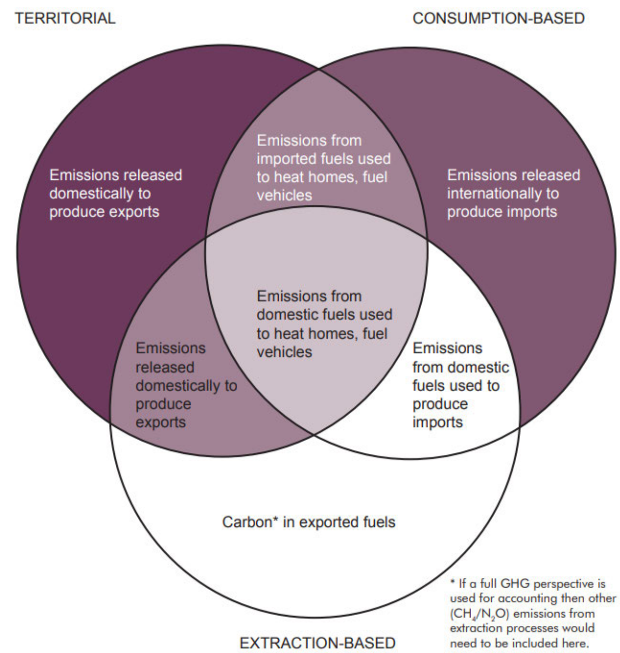

Figure 1: Comparison of territorial, consumption, and extraction-based GHG accounting

One might argue that imposing responsibly on upstream producers, or even midstream electric generators, is unfair because it lets consumers off the hook, but there are pragmatic and ethical reasons for focusing on upstream producers and electric generators. As a practical matter, it is easier to regulate a smaller group of well-informed companies than a very large group of poorly informed consumers, and some of the costs imposed on upstream and midstream entities will flow down to consumers, thus sending the appropriate price signals.[283] As an ethical matter, fossil fuel producers and energy companies have long known about the climate risks posed by use of their products, have lobbied against regulation, and ultimately profit most from the consumption of fossil fuels.

While most national emissions inventories currently focus on territorial emissions, researchers have found that it would be

283. *See, e.g.*, JONATHAN RAMSEUR & JANE LEGGETT, CONG. RES. SERV., R45625, ATTACHING A PRICE TO GREENHOUSE GAS EMISSIONS WITH A CARBON TAX OR EMISSIONS FEE: CONSIDERATIONS AND POTENTIAL IMPACTS (Mar. 22, 2019).

relatively easy for countries to produce extraction-based and consumption-based inventories based on readily available data.[284] In other words, pursuing these alternative accounting methodologies would not be significantly more expensive or technically challenging than the territorial approach. These alternative accounting methodologies also provide valuable insights that are not captured in the territorial approach—for example, the consumption-based approach accounts for "leakage" of GHG emissions to other countries via trade and helps countries understand the importance of developing policies aimed at reducing consumption of carbon-intensive products. Ultimately, though they may carry different legal weight, all three methodologies are useful in addressing the question of who is "responsible" for climate change.

b. Status of Research

i. National Emissions Estimates

Countries have been developing and refining national greenhouse gas emission inventories since the early 1990s, pursuant to emission reporting requirements laid out in the United Nations Framework Convention on Climate Change (UNFCCC). The original agreement called upon developed countries (the "Annex I" parties) to prepare and periodically update national emission inventories listing all emissions and removals of direct GHGs from five sectors—energy; industrial processes and product use; agriculture; land use, land-use change, and forestry (LULUCF); and waste—in a standardized format.[285] The parties to

284. Glen P. Peters, *From Production-Based to Consumption-Based National Emissions Inventories*, 65 ECOLOGICAL ECONOMICS 13 (2008); Steven J. Davis & Ken Caldeira, *Consumption-Based Accounting of CO2 Emissions*, 107 PROC. NAT'L ACAD. SCI. 5687 (2010); Manfred Lenzen et al., *Building EORA: A Global Multi-Region Input–Output Database at High Country and Sector Resolution*, 25 ECON. SYS. RES. 20 (2013); Stavros Afionis et al., *Consumption-Based Carbon Accounting: Does It Have a Future?,* 8 WIRES CLIMATE CHANGE 1 (2017); Glen P. Peters, et al., *A Synthesis of Carbon in International Trade,* 9 BIOGEOSCIENCES 3247 (2012); Kirsten S. Wiebe & Norihiko Yamano, *Estimating CO2 Emissions Embodied in Final Demand and Trade Using the OECD ICIO 2015,* (OECD Sci., Tech. Indus., Working Paper 2016/05); Steven J. Davis et al., *The Supply Chain of CO2 Emissions*, 108 PROC. NAT'L ACAD. SCI. 18554 (2011); THOMAS MICHAEL POWER & DONOVAN S. POWER, THE ENERGY FOUNDATION, THE IMPACT OF POWDER RIVER BASIN COAL EXPORTS ON GLOBAL GREENHOUSE GAS EMISSIONS (2013).).

285. UNFCCC, Reporting Requirements, https://unfccc.int/process-and-meetings/transparency-and-reporting/reporting-and-review-under-the-

the UNFCCC eventually introduced emission reporting requirements for non-Annex I countries as well, accompanied by programs aimed at addressing capacity and resource constraints in those countries.[286] The UNFCCC secretariat compiles all emissions inventory data in an online database,[287] and many other organizations use that data to analyze emissions trends.[288]

Due to this international emissions reporting system, there is a good deal of data on national emissions dating back to the 1990s, and the dataset has become more comprehensive through the 2000s as developed country parties have also begun reporting emissions. However, there are still significant gaps in the UNFCCC data, particularly with respect to historical emissions and developing country emissions through the mid-aughts. Governmental agencies, scientific organizations, and researchers have helped to fill gaps in UNFCCC data through independent research on topics such as historical fossil fuel use by country,[289] but there is still a fair amount of uncertainty on national emissions estimates, especially prior to the 1990s.

The UNFCCC reporting approach focuses on emissions produced within a country. As noted above, another way to apportion emissions among countries is to focus on embedded emissions—that is, the emissions embedded within products consumed in the country. This more downstream approach to calculating national emissions has gained considerable traction in recent years. In 2010, researchers constructed a global database of

convention/greenhouse-gas-inventories-annex-i-parties/reporting-requirements [perma.cc/66SQ-5LNT] (last visited Sep. 11, 2019).

286. UNFCCC, *National Reports from Non-Annex I Parties*, UNITED NATIONS CLIMATE CHANGE, https://unfccc.int/process/transparency-and-reporting/reporting-and-review-under-the-convention/national-communications-non-annex-i-parties/national-reports-from-non-annex-i-parties [https://perma.cc/P7E4-ZXAS] (last visited Sep. 11, 2019).

287. UNFCCC, *GHG Data from UNFCCC*, UNITED NATIONS CLIMATE CHANGE, https://unfccc.int/process/transparency-and-reporting/greenhouse-gas-data/ghg-data-unfccc [https://perma.cc/Q7FD-EKQY] (last visited Sep. 11, 2019).

288. *See, e.g.*, *CAIT Climate Data Explorer*, WORLD RES. INST. http://cait.wri.org/ [https://perma.cc/K784-6M28] (last visited Dec. 30, 2019).

289. *See, e.g.*, *Carbon Dioxide Information Analysis Centre (CDIAC)*, U.S. DEPT. OF ENERGY, https://cdiac.ess-dive.lbl.gov/ [https://perma.cc/2W7H-HYZ7] (last visited Dec. 30, 2019); *ESS Dive*, U.S. DEP'T OF ENERGY, https://ess-dive.lbl.gov/ [https://perma.cc/5Y72-QV8L] (last visited Dec. 30, 2019); CAIT Climate Data Explorer, *supra* note 288; KEVIN A. BAUMERT ET AL., NAVIGATING THE NUMBERS: GREENHOUSE GAS DATA AND INTERNATIONAL CLIMATE CHANGE POLICY 3139 (2005); CLIMATE EQUITY REFERENCE CALCULATOR, https://calculator.climateequityreference.org/ [https://perma.cc/T5XU-89HM] (last visited Dec. 31, 2019).

CO_2 imports and exports.[290] The Global Carbon Project has since developed a similar database that looks at both domestically produced emissions ("CO_2 Production") and emissions once CO_2 embodied in both imports and exports have been included ("CO_2 Consumption").[291] Other research institutions have since published their own analyses of emissions embedded in trade products.[292] Some efforts have also been made to evaluate consumption-based emissions at sub-national levels.[293] Indeed, new approaches continue to emerge. For example, Matthews 2016 proposed and applied the notion of national carbon debts and credits, based on per capita cumulative emissions, relative to a benchmark.[294]

Several efforts have been made to link these national emissions to specific changes in climate and corresponding impacts. Li et al. 2016 focused on Chinese emissions and found that China contributes 10 ± 4% of the current global radiative forcing, and that the relative contribution to global mean surface temperature (GMST) increase was 12 ± 2%.[295] Skeie et al. 2017 used a climate model to link the relative emissions contribution from multiple countries to GMST change, taking into account historical emissions and focusing on the largest emitters, and found that China was responsible for 6–13% and the United States was responsible for 15%–26% of the observed GMST increase.[296] Skeie et al. noted, however, that these findings were very sensitive to the parameters of the study, including technical decisions such as the timeframe for the analysis, as well as more normative decisions about the basis for attributing emissions (e.g., place of extraction vs. place of burning vs. place of final consumption) and about whether to look at per capita or total emissions. They also emphasized that, in non-

290. Steven J. Davis et al., *The Supply Chain of CO2 Emissions*, 108 PROC. NAT'L ACAD. SCI. 18554 (2011).

291. *Global Carbon Budget,* GLOBAL CARBON PROJECT, https://www.globalcarbonproject.org/carbonbudget/ [https://perma.cc/Q8LU-92FE] (last visited Dec. 31, 2019). *See also* Glen Peters et al., *Growth in Emission Transfers Via International Trade from 1990 to 2008*, 108 PROC. NAT'L ACAD. SCI. 8903 (2011); Hausfather, *supra* note 50.

292. *See, e.g.*, Moran et al., *supra* note 50.

293. *See, e.g.*, C40 Cities, *supra* note 50.

294. H. Damon Matthews, *Quantifying Historical Carbon and Climate Debts Among Nations*, 6 NATURE CLIMATE CHANGE 60 (2016).

295. Bengang Li et al., *The Contribution of China's Emissions to Global Climate Forcing*, 531 NATURE 357, 357 (2016).

296. Skeie et al., *supra* note 275.

linear systems, the proportional contribution to emissions will differ from the proportional contribution to impacts.

Otto et al. 2017 was the first study to apply the nation-based emissions framework to individual extreme event attribution, focusing on an Argentina heat wave.[297] A motivation was to quantify the proportional contribution of nation states to a phenomenon—specifically a damaging extreme event—that is closer to impacts and "losses" than phenomena to which source emission approaches had previously been applied, such as changes in global mean surface temperature.

The approach makes the simplifying assumption that each country's contributions to GMST can be linearly transferred to the Argentine heat wave. GMST is used as a responsibility indicator partly on the grounds that it is used in climate policy. Otto et al. uses two alternate methods to extract the relative contributions to GMST reported in Skeie et al., each of which has large uncertainties.[298] One major finding is that the sequence in which nations are summed in the cumulative approach is hugely important. It also means that when focusing on one entity's emissions, results may be quite different if you remove the entity of interest from a full account, as opposed to adding that entity only to a counterfactual experiment. That is: the "How would the likelihood of the event change if only the region in question has emitted?" versus "How would the likelihood of the event change if the region of interest had not emitted?" questions yield very different results.

Finally, building on efforts to develop national emissions inventories and link these to climate change impacts, a fair amount of work has gone into developing "carbon budgets" both on a global level and for individual countries. Such budgets provide one possible foundation for holding governments accountable for mitigating their impact to climate change. The IPCC assessments and UNFCC targets (limiting warming to 2°C or 1.5°C) are, in turn, often used as the foundation for establishing budgets. Starting in the mid-aughts, the UNFCCC COP issued several decisions based

297. Friederike E.L. Otto et al., *Assigning Historic Responsibility for Extreme Weather Events*, 7 NATURE CLIMATE CHANGE 757 (2017).

298. The distribution method assessed the US contribution as 34% (with a 20–54% uncertainty range), whereas the second approach, known as the gradient method, assessed the US at 28% (19–45% uncertainty range). *Id.* at 758.

on IPCC findings which recognize that industrialized countries must reduce emissions 25–40% below 1990 levels by 2020 to limit global warming to 2°C.[299] Academic researchers and organizations like the Global Carbon Project have since put a significant amount of work into developing more specific national budgets that correspond with the UNFCCC targets.[300] This work on carbon budgets is complemented by research examining the adequacy of national pledges under the Paris Agreement in light of temperature goals.[301]

ii. Corporate Emissions Estimates

There have been a number of efforts to attribute emissions to corporate actors and business sectors in recent years. Many of these efforts have focused on tracing emissions to the companies producing fossil fuels and other carbon-intensive products. Heede 2013 looked at historic production records from ninety producers of oil, natural gas, coal, and cement found that the emissions from these sources totaled 914 $GtCO_2e$, equivalent to 64% of cumulative worldwide emissions of industrial CO_2 and methane from 1751–2010.[302] Heede dubbed these producers the "carbon majors" based on their disproportionately large contribution to global emissions. He also found that approximately half of the emissions were generated since 1986—a piece of data which could be used to contradict claims about unforeseeability (since it is difficult to argue that companies were unaware of the risks of climate change by that time). Another noteworthy finding was that substantial

299. *See, e.g.*, Bali Action Plan, U.N. DOC. FCCC/CP/2007/6/ Add.1; UNFCCC, Draft Resolution, Outcome of the Work of the Ad Hoc Working Group on Long-Term Cooperative Action under the Convention, Cancun, Mex. Nov. 29–Dec.10, 2010, U.N. DOC. FCCC/AWGLGA/2010/6.7 (Dec. 10, 2010); Report of the Conference of the Parties on its Eighteenth Session, held in Doha from 26 November to 8 December 2012, 2013; UNFCCC; FCCC/CP/2012/8, February 28, 2013.

300. *See, e.g.*, GLOBAL CARBON PROJECT, *supra* note 291.

301. *See, e.g.*, Yann Robiou de Pont & Malte Meinshausen, *Warming Assessment of the Bottom-Up Paris Agreement Emissions Pledges*, 9 NATURE COMMUNICATIONS 4810 (2018). Scholars from legal, policy, and social sciences disciplines have also written on the topic of how carbon budgets should be allocated to reflect normative considerations such as justice and equity, reflecting the fact that this is one area where the law and science interact in significant ways. *See, e.g.*, Cass Sunstein & Eric Posner, *Climate Change Justice* (John M. Olin Program in Law and Economics Working Paper No. 354, 2007); Catriona McKinnon, *Climate Justice in a Carbon Budget*, 133 CLIMATIC CHANGE 375 (2015).

302. Heede, *supra* note 31. These included fifty investor-owned, thirty-one state-owned, and nine nation-state producers of fossil fuels and cement. *Id.*

emissions had come from fossil fuels sourced from non-Annex I countries such as China, India, Saudi Arabia, South Africa, Iran, Brazil, Mexico, Nigeria, Venezuela, Kuwait, Angola, Malaysia, and Libya, and that this called into question the UNFCCC's differential treatment of such countries at that time.[303] Heede's research eventually became the basis of the well-known *Carbon Majors* report, first published in 2014 and updated in 2017, and an accompanying online database.[304] Notably, the 2017 update found that one hundred fossil fuel producers were linked to 71% of industrial greenhouse gas emissions since 1988.[305]

Researchers from the Union of Concerned Scientists (UCS) have continued research on the carbon majors. Ekwurzel et al. 2017 took Heede's work a step further, applying his emission findings to a simplified climate model to assess the impacts of those emission contributions on global temperature change and sea level rise.[306] They found that emissions from the ninety carbon majors were responsible for approximately 57% of the observed rise in atmospheric CO_2, approximately 42–50% of the rise in global mean surface temperature (GMST), and 26–32% of the global sea level rise over the historical period from 1880–2010.[307] Taking a closer look at the past few decades, they find that the carbon majors were responsible for approximately 43% of the rise in atmospheric CO_2, 29–35% of the rise in GMST, and 11–14% of the global sea level rise from 1980–2010.[308]

These efforts have been complemented by initiatives such as the Climate Disclosure Project (CDP), a voluntary system whereby companies report on emissions in exchange for reputational

303. Heede, *supra* note 31, at 231.

304. RICHARD HEEDE, CARBON MAJORS: ACCOUNTING FOR CARBON AND METHANE EMISSIONS 1854–2010: METHODS & RESULTS REPORT (2014); PAUL GRIFFIN ET AL., THE CARBON MAJORS DATABASE: CDP CARBON MAJORS REPORT 2017 (2017); PAUL GRIFFIN ET AL., THE CARBON MAJORS DATABASE: METHODOLOGY REPORT 2017 (2017).

305. GRIFFIN ET AL., CDP CARBON MAJORS REPORT, *supra* note 304, at 8.

306. Ekwurzel et al., *supra* note 13. This approach was similar to that applied by Otto et al., *supra* note 297, insofar as the researchers went beyond merely estimating the contribution of sources to global emissions and also looked at the effect on temperature change and sea level rise (whereas Otto et al. focused on an extreme event).

307. Ekwurzel et al., *supra* note 13, at 579.

308. *Id.* The authors note that the calculations are incomplete at this moment in time since the CO_2 already emitted will continue to impact the dependent climate variables in the future. Along similar lines, growing abatement of aerosol emissions associated with fossil fuel combustion leads to more warming and sea level rise per unit of fossil fuel combustion.

credit,[309] as well as new legal mandates calling for companies to report emissions to national and in some cases sub-national governments.[310] The IPCC also compiles emissions data for specific sectors (energy, transport, buildings, industry, forestry, agriculture, and waste) and uses this data to help frame discussions on effective mitigation approaches.[311]

III. LEGAL AND POLICY APPLICATIONS

The ability to detect and attribute environmental changes to anthropogenic greenhouse gas emissions is useful for a variety of different law and policy applications. In the broadest sense, detection and attribution are the scientific tools that policy-makers and lawyers can use to show the existence, causes, and effects of climate change. This information can help inform critical policy decisions, such as the appropriate level for an emissions cap or a carbon tax. It can also help plaintiffs pursue certain types of legal actions, such as cases against government actors for failure to act on climate change. However, attribution science is not a panacea—the evidence generated by this field is not always effective at persuading or compelling policy-makers, courts, or the public to take action on climate change.[312] This is in part due to the complexity of and limitations in the science, but there are also barriers to policy and legal action on climate change that inhere in the nature of political decision-making and legal doctrine, unrelated to the quality of detection and attribution data.[313] This

309. CLIMATE DISCLOSURE PROJECT (CDP), https://www.cdp.net [https://perma.cc/RA5A-K6VX] (last visited Sep. 11, 2019).

310. *See, e.g.*, *GHG Reporting Program*, EPA, https://www.epa.gov/ghgreporting [https://perma.cc/U42K-ZMAZ] (last visited Sep. 11, 2019); *Mandatory GHG Emissions Reporting*, CAL. AIR RES. BOARD, https://ww2.arb.ca.gov/our-work/programs/mandatory-greenhouse-gas-emissions-reporting [https://perma.cc/V32L-GG4H] (last visited Sep. 11, 2019).

311. *See* IPCC, WORKING GROUP III CONTRIBUTION TO THE FIFTH ASSESSMENT REPORT OF THE IPCC, CLIMATE CHANGE 2014: MITIGATION OF CLIMATE CHANGE 351–413 (Ottmar Edenhofer et al. eds., 2014) (drawing most emissions data from the Emissions Database for Global Atmospheric Research (EDGAR) project).

312. *See, e.g.*, COMMUNICATING CLIMATE CHANGE INFORMATION FOR DECISION-MAKING (Silvio Serrao Neumann et al. eds, 2018); Ishani Mukherjee & Michael Howlett, *Communicating about Climate Change with Policymakers*, *in* OXFORD RESEARCH ENCYCLOPEDIA OF CLIMATE SCIENCE (2016); Sabrina McCormick et al., *Science in Litigation, the Third Branch of U.S. Climate Policy*, 357 SCIENCE 979, 979–980 (2017).

313. These include political, social, and economic barriers to policies and programs aimed at addressing climate change, as well as judicial doctrines that prevent courts from

section addresses the salience of attribution science to policy-making at various scales of governance, its role in planning and environmental impact assessment, and the critical role it has played and will play in climate change litigation.

A. Policy-Making

Attribution science plays a critical role in policy-making. It helps to build support for actions to address the causes and impacts of climate change by: (i) demonstrating that anthropogenic climate change is already underway and resulting in adverse impacts, and (ii) lending confidence to model projections of how the climate will change in response to greenhouse gas emissions and how these changes will affect people and the environment in the decades to come.[314] Indeed, as the body of detection and attribution evidence has grown, an increasing number of jurisdictions have adopted greenhouse gas reduction targets and have commenced adaptation planning activities.[315] The greater this body of evidence, the greater the justification for imposing stringent greenhouse gas reduction requirements, incentivizing the transition away from fossil fuels, and making large expenditures to prepare for the effects of climate change. Having a clear justification is important both for political reasons and for the purpose of defending mitigation and adaptation programs in court.

Attribution science can also contribute to more effective mitigation and adaptation policies. Information about source attribution is particularly helpful for informing mitigation policy, as it can be used to determine which actors, activities, or sectors should be targeted for regulation or to determine the appropriate level of regulation for any given source category. Meanwhile, information about impact attribution can help policy-makers

adjudicating climate change-related disputes. *See, e.g.*, Susanne C. Moser, *Communicating Climate Change: History, Challenges, Process and Future Directions*, 1 WIREs CLIMATE CHANGE 31 (2010); Richard J. Lazarus, *Super Wicked Problems and Climate Change: Restraining the Present to Liberate the Future*, 94 CORNELL L. REV. 1153 (2009).

314. Easterling et al., *supra* note 22.

315. *See* Michal Nachmany & Joana Setzer, *Global Trends in Climate Change Legislation and Litigation: 2018 Snapshot,* GRANTHAM RES. INST. ON CLIMATE CHANGE & ENV'T, http://www.lse.ac.uk/GranthamInstitute/wp-content/uploads/2018/04/Global-trends-in-climate-change-legislation-and-litigation-2018-snapshot-3.pdf [https://perma.cc/B672-822Q]; *Climate Change Laws of the World Database,* GRANTHAM RES. INST. ON CLIMATE CHANGE & ENV'T, http://www.lse.ac.uk/GranthamInstitute/climate-change-laws-of-the-world/ [https://perma.cc/HJ26-3U7A] (last visited Dec. 31, 2019).

identify the most significant climate change-related risks and make prudent decisions about how to allocate resources for adaptation.[316] For example, the IPCC, the USGCRP, and other authoritative bodies rely on quantitative detection and attribution studies to develop and refine their impact assessments, and this information feeds directly into national and sub-national adaptation planning efforts.[317] Regional modeling, downscaled analyses, and the use of local impact, adaptation, and vulnerability ("IAV") studies is particularly important in this context.

A related function of attribution science is that it can help decision-makers better understand the cost of unabated climate change, thus informing decisions about the appropriate level of regulation (e.g., the right price of a carbon tax) and also aiding in the justification of regulations. Consider the greenhouse gas emission and energy efficiency standards promulgated in the United States by the Obama Administration: for many of these rules, the U.S. Environmental Protection Agency ("EPA") conducted a cost-benefit analysis in which it monetized the effects of greenhouse gas emission reductions using the federal Social Cost of Carbon ("SC-CO_2")—a metric developed by the U.S. government that reflects the potential damages that can be attributed to the addition of one ton of CO_2 into the atmosphere in a particular year, expressed as a range of possible costs.[318] Using this metric, the Administration concluded that the total monetized benefits of the economic, environmental, and public health impacts from these standards significantly outweighed the costs.[319]

316. *See* Easterling et al., *supra* note 22; Sebastian Sippel et al., *Stakeholder Perspectives on the Attribution of Extreme Weather Events: An Explorative Enquiry,* 7 WEATHER, CLIMATE, SOC'Y 224, 229 (2015).

317. *See* NCA4, *supra* note 7, at 114–32; IPCC AR5 WGI, *supra* note 25, at 867–952; IPCC AR5 WGII, *supra* note 18, at 979–1038.

318. *See, e.g.*, EPA, EPA-452-R-15-003, REGULATORY IMPACT ANALYSIS FOR THE CLEAN POWER PLAN FINAL RULE (Aug. 2015); EPA, EPA-420-R-12-016, REGULATORY IMPACT ANALYSIS: FINAL RULEMAKING FOR 2017–2025 LIGHT-DUTY VEHICLE GREENHOUSE GAS EMISSION STANDARDS AND CORPORATE AVERAGE FUEL ECONOMY STANDARDS (Aug. 2012); Energy Conservation Program: Energy Conservation Standards for Commercial Refrigeration Equipment Final Rule, 79 Fed. Reg. 17,726 (Mar. 28, 2014) (codified at 10 C.F.R. pt. 431(c)).

319. Energy Conservation Program: Energy Conservation Standards for Commercial Refrigeration Equipment Final Rule, 79 Fed. Reg. at 17,730.

This finding served as a key justification for issuing the standards.[320] While the SC-CO_2 and similar metrics for other gases are primarily based on predictions of future impacts, detection and attribution studies provide information about present impacts which can help to improve predictive models and also lend confidence to impact projections.

Finally, attribution science provides a framing mechanism for international negotiations, including those conducted under the United Nations Framework Convention on Climate Change ("UNFCCC") and the Paris Agreement. There are several ways in which attribution science is useful in this context. First, the growing body of evidence linking emissions and land use changes to harmful impacts helps build political support for ambitious action on climate change, and also provides a basis for critiquing countries that do not go far enough with their emission reduction pledges (referred to in the Paris Agreement as "nationally determined contributions").[321] Second, attribution science can help improve decision-making about how to allocate funds for adaptation insofar as it provides insight into which countries, regions, sectors, and population groups have the greatest risk of harm due to anthropogenic climate change. Third, attribution science can help countries reach agreement on the highly contentious "loss and damage" framework whereby the countries that are least responsible for climate change are compensated by more responsible countries for harmful impacts caused by climate change.[322]

320. Zero Zone Inc. v. Dep't of Energy, 832 F.3d 654, 678–79 (7th Cir. 2016) (upholding use of the SC-CO_2 in rulemaking establishing energy conservation standards for commercial refrigeration equipment).

321. Paris Agreement, *supra* note 280, at art. 14, ¶ 1 (establishing a "global stocktake" whereby the parties to the agreement "shall periodically take stock of the implementation of this Agreement to assess the collective progress towards achieving the purpose of this Agreement and its long-term goals."). For information about how emission budgets would serve as benchmarks in the global stocktake, *see generally* Christian Holz & Xolisa Ngwadla, *The Global Stocktake Under the Paris Agreement: Opportunities and Challenge*, EUROPEAN CAPACITY BUILDING INITIATIVE (Anju Sharma ed., 2016), http://www.eurocapacity.org/downloads/GST_2016%5B1%5D.pdf [https://perma.cc/ER2Y-DGKE]; *see also* IPCC, SPECIAL REPORT: GLOBAL WARMING OF 1.5°C (Valerie Masson-Delmotte et al. eds., 2018), https://www.ipcc.ch/sr15/ [https://perma.cc/9959-GSRB] (providing a recent example of how information about climate change impacts can build considerable political support for climate action).

322. For more on this topic, see Christian Huggel et al., Commentary, *Loss and Damage Attribution*, 3 NATURE CLIMATE CHANGE 694 (2013); Rachel James et al., *Characterizing Loss*

This third area—loss and damage—is where attribution science could potentially play the biggest role. To develop a functional loss and damage framework, countries would need to answer two types of questions that can only be answered through a combination of attribution science and predictive modeling: first, which countries have already suffered harmful impacts as a result of climate change and are most certain to do so in the future, and second, to what extent are other countries responsible for those impacts.[323] As discussed above, one complicating factor is that there are often multiple drivers behind harmful impacts linked to climate change—for example, construction and development practices within a coastal community can increase the vulnerability of people and structures in that area to the effects of storms and sea level rise, and numerous factors, including degree of community cohesion and economic development, can decrease resilience to them. In most cases, even the most sophisticated attribution studies cannot fully resolve the question of how much of the harm incurred by a community is due to anthropogenic climate change as opposed to confounding risk factors. The complex and multi-causal nature of harms related to climate change may therefore make it difficult to reach consensus on loss and damage issues. As discussed in further detail below, it may also prove to be an obstacle to lawsuits seeking compensation from emitters for climate-related damages.

B. Planning and Environmental Impact Assessment

Attribution science also facilitates on-the-ground planning for the effects of climate change by providing more robust data about how climate change is already affecting landscapes, ecosystems, and human systems such as cities, infrastructure, and food production. This information can feed into scenario planning, informing the likely and possible ranges of outcomes under different greenhouse

and Damage From Climate Change, 4 NATURE CLIMATE CHANGE 938 (2014); Daniel Farber, *The Case for Climate Compensation: Justice for Climate Change Victims in a Complex World*, 2008 UTAH L. REV. 377 (2008).

323. For a more detailed discussion of how attribution science can inform the development of a loss and damage framework, *see* Christian Huggel et al., *Reconciling Justice and Attribution Research to Advance Climate Policy,* 6 NATURE CLIMATE CHANGE 901 (2016); Roda Verheyen, *Loss and Damage Due to Climate Change: Attribution and Causation—Where Climate Science and Law Meet*, 8 INT'L J. GLOBAL WARMING 158 (2015); Christian Huggel et al., *Potential and Limitations of the Attribution of Climate Change Impacts For Informing Loss and Damage Discussions and Policies,* CLIMATIC CHANGE (SPECIAL ISSUE) 10.1007 (2015).

gas emission trajectories.[324] Finally, attribution studies that focus on regional or localized impacts can be used to develop and refine downscaled projections of climate change impacts within a particular geographic region, and to improve the accuracy and precision of the models that are used to develop those projections.[325] All of this can feed into a more robust analysis of how climate change is affecting and will affect proposed and planned actions.

We see this type of analysis being performed in regional resource management planning, state and local planning, environmental reviews, and corporate disclosures. For example, during the Obama Administration, the federal agencies that manage public lands and natural resources began using detection and attribution science to better understand how climate change is affecting water resources, ecosystems, and biodiversity in the United States and to develop appropriate response strategies.[326] Federal, state, and local agencies are also now using data on observed impacts such as sea level rise, melting permafrost, and extreme heat events to better understand natural hazards and to inform planning decisions.[327]

324. Easterling et al., *supra* note 22. *See generally Observed and Projected (Longer-term) Changes in Weather and Climate Extremes*, 11 WEATHER CLIMATE EXTREMES (SPECIAL ISSUE) A1 (2016).

325. *See, e.g.*, Mohammad Reza Najafi et al., *Attribution of the Observed Spring Snowpack Decline in British Columbia to Anthropogenic Climate Change,* 30 J. CLIMATE 4113 1 (2017); Beena Balan Sarojini et al., *Detection and Attribution of Human Influence on Regional Precipitation,* 6 NATURE CLIMATE CHANGE 669 (2016); Peihua Qin & Zhenghui Xie, *Detecting Changes in Future Precipitation Extremes Over Eight River Basins in China Using RegCM4 Downscaling,* 121 J. GEOPHYSICAL RES. ATMOSPHERES 6802 (2016); Chunzhen Liu & Jun Xia, *Detection and Attribution of Observed Changes in the Hydrological Cycle under Global Warming,* 2 ADVANCES IN CLIMATE CHANGE RES. 31 (2011); Tim P. Barnett et al., *supra* note 239, at 1080.

326. *See, e.g.*, PETER BACKLUND ET AL., U.S. CLIMATE CHANGE SCI. PROGRAM, THE EFFECTS OF CLIMATE CHANGE ON AGRICULTURE, LAND RESOURCES, WATER RESOURCES, WATER RESOURCES, AND BIODIVERSITY IN THE UNITED STATES (Margaret Walsh et al. eds., 2008); LEVI D. BREKKE, U.S. GEOLOGICAL SUR., CLIMATE CHANGE AND WATER RESOURCES MANAGEMENT: A FEDERAL PERSPECTIVE, CIRCULAR 1331 (2009); JESSICA WENTZ, SABIN CTR. FOR CLIMATE CHANGE L., CONSIDERING THE EFFECTS OF CLIMATE CHANGE ON NATURAL RESOURCES IN ENVIRONMENTAL REVIEW AND PLANNING DOCUMENTS: GUIDANCE FOR AGENCIES AND PRACTITIONERS (2016).

327. *See, e.g.*, *Sea Level Rise,* CAL. ADAPT., https://cal-adapt.org/tools/slr-calflod-3d/ [https://perma.cc/5BQD-2EJL] (last visited Sep. 11, 2019); Press Release, NYS Dep't of Envt'l Conservation, DEC Announces New Sea Level Rise Projection Regulation for New York (Feb. 6, 2017), http://www.dec.ny.gov/press/109195.html [https://perma.cc/7XAY-BZWJ]; *Sea Level Rise Viewer*, NOAA, https://coast.noaa.gov/slr/ [https://perma.cc/X48G-QFBT] (last visited Nov. 21, 2019); *Flood Map Revision Process,* FEMA, https://www.fema.gov/flood-map-revision-processes [https://perma.cc/YZQ5-CU5A] (last

Attribution science can also help decision-makers better understand a proposed or planned action's contribution to global climate change. Currently, environmental impact assessments ("EIAs") and other planning documents express this contribution by quantifying the anticipated greenhouse gas emissions that will be generated as a result of the action, and then providing a brief qualitative description of the types of impacts which can be expected as a result of climate change. Because the overall contribution of the action to global greenhouse gases is typically quite small, no attempt is made to draw a direct link between the action's greenhouse gas emissions and specific on-the-ground impacts of climate change. Improvements in detection and attribution could facilitate the development and refinement of metrics that could be used to better explain how a project will contribute to global climate change. The SC-CO_2 and cost metrics for nitrous oxide ("SC-N_2O") and methane ("SC-CH_4") are good examples: EIA documents can use these metrics to translate greenhouse gas emissions into a specific dollar value which serves as a proxy for on-the-ground impacts (and as discussed above, improved attribution data can be used to justify and refine these metrics).

C. Litigation

Evidence linking human influence on climate to the harmful impacts of climate change plays an important role in lawsuits seeking to compel action on climate change as well as the legal defense of programs and regulations aimed at reducing greenhouse gas emissions or advancing adaptation objectives. The manner in which such evidence is utilized and the extent to which it influences case outcomes will depend on the type of case and the stage of litigation. Below, we present a detailed breakdown of legal issues and cases involving climate change-related claims and how attribution science is used in different contexts: 1) establishing standing to sue; 2) introducing expert scientific testimony and reports as evidence; 3) challenges to government failures to regulate GHG emissions; 4) the legal defense of existing GHG emission standards; 5) lawsuits seeking to hold emitters liable for

visited Nov. 21, 2019). *See also* ADITI KAPOOR, CLIMATE DEVELOPMENT KNOWLEDGE NETWORK AND WORLD WEATHER, POLICY BRIEF: CLIMATE ATTRIBUTION SCIENCE: A USEFUL TOOL TO PLAN FOR EXTREME HEAT EVENTS (2017).

damages from climate change impacts; and 6) lawsuits involving climate change adaptation, impact assessment, and disclosures.[328]

1. Establishing Standing to Sue Sources of GHG Emissions for Climate-Related Harms

Standing doctrines address the question of who should have access to courts to adjudicate a particular claim.[329] Whether a plaintiff has standing is a jurisdictional question that is addressed at the outset of litigation before the merits are adjudicated.[330] Standing requirements vary considerably by jurisdiction. Here, we will focus on the standing jurisprudence of U.S. federal courts—since this is the context where attribution science has played the most significant role—recognizing that these federal standards are among the most restrictive in the world.[331]

Federal standing doctrine arises from the Supreme Court's determination that Article III of the Constitution limits the jurisdiction of the federal courts to cases or controversies where the

328. There are certain legal doctrines that may control the outcome of these cases but more indirectly implicate questions of attribution, such as the political question doctrine, the foreign affairs preemption doctrine, and the doctrine of legislative displacement. *See* discussion *infra* Section III(C)(5).

329. There is large body of scholarship on the question of standing for climate change-related damages. *See, e.g.*, Bradford C. Mank, *Standing and Future Generations: Does* Massachusetts v. EPA *Open Standing for Generations to Come?*, 34 COLUM. J. ENVTL. L. 1 (2009); Bradford C. Mank, *Standing and Global Warming: Is Injury to All Injury to None?*, 35 ENVTL. L. 1 (2005); Blake R. Bertagna, Comment, *"Standing" Up for the Environment: The Ability of Plaintiffs to Establish Legal Standing to Redress Injuries Caused by Global Warming*, 2006 BYU L. REV. 415 (2006); Christopher L. Muehlberger, Comment, *One Man's Conjecture is Another Man's Concrete: Applying the "Injury-in-Fact" Standing Requirement to Global Warming*, 76 UMKC L. REV. 177 (2007); Joseph M. Stancati, Note, *Victims of Climate Change and Their Standing to Sue: Why the Northern District of California Got it Right*, 38 CASE W. RES. J. INT'L L. 687 (2006–2007); Nigel Cooney, Note, *Without a Leg to Stand on: The Merger of Article III Standing and Merits in Environmental Cases*, 23 WASH. U. J. L. & POL'Y 175 (2007).

330. While standing is a jurisdictional issue, the issues implicated in the standing analysis may go directly to the merits of the case, which may lead a court to defer its standing analysis under the case has been fully briefed and all evidence reviewed.

331. *See* John Dimanno, *Beyond Taxpayers' Suits: Public Interest Standing in the States*, 41 CONN. L. REV. 639 (2008); Christopher S. Elmendorf, *State Courts, Citizen Suits, and the Enforcement of Federal Environmental Law by Non-Article III Plaintiffs*, 110 YALE L.J. 1003 (2001); J. Michael Angstadt, *Securing Access to Justice Through Environmental Courts and Tribunals: A Case in Diversity,* 17 VT. J. ENVTL. L. 345 (2016); Matt Handley, *Why Crocodiles, Elephants, and American Citizens Should Prefer Foreign Courts: A Comparative Analysis of Standing to Sue*, 21 REV. LITIG. 97, 117 (2002); Niran Somasundaram, *State Court Solutions: Finding Standing for Private Climate Change Plaintiffs in the Wake of* Washington Environmental Council v. Bellon, 42 ECOLOGY L.Q. 491 (2015).

plaintiff has a concrete and personal stake in the outcome of the litigation.[332] Based on this understanding, the Supreme Court has held that Plaintiffs must establish that (i) they have suffered an injury-in-fact—that is, "an invasion of a legally protected interest which is (a) concrete and particularized and (b) actual or imminent, not conjectural or hypothetical;"[333] (ii) the injury-in-fact is fairly traceable to the defendants' allegedly unlawful actions;[334] and (iii) the injury could be redressed by a favorable court decision.[335] Attribution science is central to standing contests over each of these prongs.

a. Standing Elements

i. Injury-in-Fact

The types of harms giving rise to standing include injuries to economic, physical, spiritual, aesthetic, and recreational interests.[336] There is no threshold requirement for the size of the injury—any "identifiable trifle" is sufficient to establish standing.[337] However, injury must be "particularized," meaning that it is not a "generalized grievance" shared by the public at large.[338] The requirement of particularized injury has been viewed as a potential barrier for plaintiffs seeking standing based on injuries caused by climate change, since such injuries are often shared by the public. However, some plaintiffs have successfully used impact attribution research to persuade the courts that their injuries are sufficiently particularized for standing purposes.[339]

It is more difficult to establish an injury-in-fact based on the risk of future harm. The general rule is that the future harm must be

332. Lujan v. Defs. of Wildlife, 504 U.S. 555, 556 (1992).

333. *Id.* at 560 (internal citations and quotations omitted).

334. *Id.*

335. *Id.* at 561.

336. Ass'n of Data Processing Serv. Orgs. Inc. v. Camp, 397 U.S. 150, 152, 154 (1970).

337. United States v. Students Challenging Regulatory Agency Procedures (SCRAP), 412 U.S. 669, 689 n.14 (1973).

338. United States v. Richardson, 418 U.S. 166, 171 (1974); Schlesinger v. Reservists Comm. To Stop the War, 418 U.S. 208, 217 (1974).

339. *See* Massachusetts v. EPA, 549 U.S. 497, 525 (2007) (finding state had standing due to loss of land resulting from sea level rise), Connecticut v. Am. Elec. Power Co., 582 F.3d 309 (2d Cir. 2009), *rev'd*, 564 U.S. 410 (2011) (finding state had standing due to loss of snow pack, the corresponding effect on water supplies and flooding, and the effect of sea level rise and coastal erosion on coastal property).

"imminent, not conjectural or hypothetical."[340] The term can be interpreted as entailing a temporal element, a probabilistic element, or both.[341] The Supreme Court has conceded that this is an "elastic concept"[342] and has defined it differently in different cases. Most recently, the Court has held that the imminence requirement is met where the harm is "certainly impending" or where there is a "substantial risk" of the harm occurring.[343] To establish standing based on the prospect of future environmental damage, plaintiffs must demonstrate either: (i) a substantial risk of direct harm (e.g., physical health impacts), or (ii) that they visit the affected area or use the affected resources for recreational, spiritual, or aesthetic purposes and/or have concrete plans to do so in the future.[344]

ii. Causation and Redressability

The second and third elements of standing (causation and redressability) are closely related, sometimes referred to as "two sides of the same coin."[345] These requirements have proven to be the most difficult to prove in cases involving climate-related harms. For causation, the plaintiff must establish that the injury is "fairly traceable" to the challenged action "and not the result of the independent action of some third party not before the court."[346] Courts often look for factual causation, typically expressed as a "but for" test: would the plaintiff not have been injured but for the defendant's action.[347] In cases brought against governments and private actors for failure to regulate or abate emissions, the Supreme Court has found sufficient causation where the emissions

340. *Lujan*, 504 U.S. at 560.

341. Evan Tsen Lee & Josephine Mason Ellis, *The Standing Doctrine's Dirty Little Secret*, 107 NW. U.L. REV.169, 179–80 (2012) (noting cases where courts have found a lack of imminence because the alleged injury would not happen immediately, and cases where courts have found a lack of imminence because the injury was too "conjectural" and there was insufficient probability that it would ever occur).

342. *Lujan,* 504 U.S. at 565 n.2.

343. Clapper v. Amnesty Int'l USA, 568 U.S. 398, 414 n.5 (2013); Susan B. Anthony List v. Driehaus, 573 U.S. 149, 158 (2014).

344. *Lujan*, 504 U.S. 555; Summers v. Earth Island Inst., 555 U.S. 488 (2009).

345. Ctr. For Biological Diversity v. EPA, 90 F.Supp.3d 1177, 1190 (W.D. Wash. 2015). *See also* Gonzales v. Gorsuch, 688 F.2d 1263, 1267 (9th Cir. 1982); Duke Power Co. v. Carolina Envtl. Study Grp., 438 U.S. 59, 74 (1978).

346. *Lujan*, 504 U.S.at 560 (internal citations and quotation marks omitted).

347. *See, e.g., Duke Power Co*, 438 U.S. at 74–75; Allen v. Wright, 468 U.S. 737, 758 (1984).

represent a "meaningful contribution" to global climate change.[348] What constitutes a "meaningful contribution" to global climate change is a question that at this point will be determined on a case-by-case basis.[349]

Finally, the redressability prong requires that it is likely and not "merely speculative" that the injury would be redressed by a favorable decision.[350] The prospect of even partial redress may be sufficient.[351]

iii. Procedural Injury

Standing requirements are somewhat relaxed for cases that involve "procedural injuries."[352] Such injuries occur when agencies undertake actions without adhering to legally mandated procedures, such as when a federal agency undertakes a major action without preparing an environmental impact statement ("EIS"), promulgates a final rule without adhering to the Administrative Procedure Act ("APA")'s notice and comment requirements, or otherwise fails to implement a process that is required by statute.[353] Courts will sometimes refer to these cases as involving "procedural rights."[354]

348. *See Massachusetts*, 549 U.S. at 525 (emissions from all U.S. motor vehicles made a "meaningful contribution" to global climate change).

349. *See, e.g.*, Wash. Envtl. Council v. Bellon, 732 F.3d 1131, 1135 (9th Cir. 2013) (emissions from Washington power plants amounting to 6% of state's total GHG emissions not a "meaningful contribution" to climate change), *reh'g en banc denied*, 741 F.3d 1075 (9th Cir. 2014); Amigos Bravos v. U.S. Bureau of Land Mgmt., 816 F. Supp. 2d 1118, 1136 (D.N.M. 2011) (254,730 metric tons of GHGs per year that might result from the approval of 92 oil and gas leases were not a "meaningful contribution" to global climate change); Juliana v. United States, 217 F.Supp.3d 1224 (D. Or. 2016) (Motion to Dismiss denied because U.S. agencies had regulatory authority over at least 14% of global GHGs and this was sufficient for standing).

350. *Lujan*, 504 U.S. at 561.

351. *See Massachusetts*, 549 U.S. 497; *Am. Elec. Power Co.*, 582 F.3d 309 (2d Cir. 2009), *rev'd*, 564 U.S. 410 (2011).

352. *Lujan*, 504 U.S. at 571–72.

353. Christopher T. Burt, Comment, *Procedural Injury Standing After* Lujan v. Defenders of Wildlife, 62 U. CHI. L. REV. 275, 276 (1994); F. Andrew Hessick, *Probabilistic Standing*, 106 NW. U. L. REV. 55, 69 (2012) (citing *Summers*, 555 U.S. at 496–97).

354. *Lujan*, 504 U.S. at 572 n.7; *Massachusetts*, 549 U.S. at 498 (citing APA § 7607(b)(1)) (noting that that the "right to challenge agency action unlawfully withheld" is a procedural right created by the APA). In *Lujan*, the Supreme Court affirmed that procedural rights are "special" and that "[t]he person who has been accorded a procedural right to protect his concrete interests can assert that right without meeting all the normal standards for redressability and immediacy." 504 U.S. at 572 n.7. The Court further explained, "Thus, under our case law, one living adjacent to the site for proposed construction of a federally

iv. Standing for States and Associations

Adding an additional layer to the standing analysis is the fact that states have special standing to sue, both by virtue of their sovereign status and the breadth of their interests, which encompass the state's direct interests, e.g., state property, as well as the interests of their residents.[355] Large associations may also have an easier time establishing standing than private individuals due to the number of members in those associations. This holds true in cases involving the risk of future harm: an association with many members may be able to establish that, in aggregate, its members face a "substantial risk" of harm, where an individual plaintiff would not be able to make this showing.

Consider the case of *Natural Resources Defense Council v. EPA*, a case involving a challenge to the adequacy of an ozone pollution standard decided by the D.C. Circuit Court of Appeals in 2007. The ozone standard was expected to result in a very small increase in the risk of cancer—one in 200,000, according to NRDC's experts. This might not have sufficed as an "imminent" threat to an individual plaintiff's interest, but NRDC was able to establish standing by presenting evidence of the aggregated risk across all of its 490,000 members.[356] The D.C. Circuit Court of Appeals explained:

> The lifetime risk that an individual will develop nonfatal skin cancer as a result of EPA's rule is about 1 in 200,000 by the intervenor's lights. Even if a quantitative approach is appropriate—an issue on which we express no opinion—this risk is sufficient to support standing. One may infer from the statistical analysis that two to four of NRDC's nearly half a million members will develop cancer as a result of the rule.[357]

licensed dam has standing to challenge the licensing agency's failure to prepare an environmental impact statement, even though he cannot establish with any certainty that the statement will cause the license to be withheld or altered, and even though the dam will not be completed for many years." *Id.* Notably, the plaintiff must still show that they will suffer a concrete injury-in-fact that is linked to the procedural injury. *Summers*, 555 U.S. at 496 (citing *Lujan*, 504 U.S. at 572 n. 7); *Massachusetts*, 549 U.S. at 518 (noting that the plaintiff needs to show that the "procedural step was connected to the substantive result" and that there is "some possibility that the requested relief will prompt the injury-causing party to reconsider the decision that allegedly harmed the litigant."). For more on this topic, see Burt, *supra* note 353, at 280–81.

355. *Massachusetts*, 549 U.S. 497; Georgia v. Tenn. Copper Co., 237 U.S. 474 (1915).

356. Nat. Res. Def. Council v. EPA, 464 F.3d 1, 7 (D.C. Cir. 2006).

357. *Id.*

However, in *Summers v. Earth Island Inst.*, five Supreme Court justices rejected a similar argument in the public lands context. There, the Sierra Club sought standing to challenge U.S. Forest Service regulations based on potential injury to its members' use and enjoyment of national forests. The majority denied standing because the Sierra Club had failed to establish that any member had concrete plans to visit a site where the regulations would be applied.[358] The dissent argued that, because the Sierra Club had 700,000 members, there was a statistical probability that one of their members would be adversely affected by the regulations,[359] but the majority held that "such speculation does not suffice" for standing purposes.[360]

v. Concluding Notes on Standing

As may be evident from the above discussion, standing jurisprudence is viewed by many as "incoherent"[361] and inevitably subjective.[362] The lack of a coherent approach is particularly apparent in cases involving the risk of future harm, where courts typically conduct a qualitative rather than quantitative assessment of the risk to determine whether it rises to a level of imminence.[363] Hessick notes that as a likely consequence of their qualitative analyses, courts have "[g]enerally proven themselves incapable of applying [this standard] in a rigorous way,"[364] and explains that

358. *Summers*, 555 U.S. at 496.

359. *Id.* at 505–07.

360. *Id.* at 499. *Summers* does not totally foreclose the possibility of standing based on a probabilistic injury. The probabilistic inquiry in *Summers* was whether one of the association members might visit a forest that was affected by the regulation in the near future—this question is much easier to answer through affidavits than through statistical analysis, since it depends on the members' intent. In contrast, the probabilistic inquiry in *Nat. Res. Def. Council v. EPA* was whether one of the association members might be harmed by involuntary exposure to pollution—statistical analysis is both necessary and well-suited to making such predictions. Faced with a situation more analogous to *Nat. Res. Def. Council v. EPA,* the Court may have reached a different conclusion about the statistical probability of injury.

361. Lee & Ellis, *supra* note 341, at 169, 200; William A. Fletcher, *The Structure of Standing,* 98 YALE L. J. 221, 231 (1988).

362. Cass Sunstein, *What's Standing After Lujan? Of Citizen Suits, "Injuries," and Article III,* 91 MICH. L. REV. 163, 188–89 (1992); Albert Lin, *The Unifying Role of Harm in Environmental Law,* 3 WIS. L. REV. 897, 938 (2006); Lee & Ellis, *supra* note 341, at 200; Hessick, *supra* note 353, at 73.

363. Hessick *supra* note 353, at 73.

364. *Id.*

"[u]ncertainty about probability forces courts to forego precise calculations of probabilities and instead to evaluate probability on a gestalt feeling of the likelihood of a harm occurring. Assessments of this sort, however, are vulnerable to biases."[365] As a result of these factors, it is very difficult to predict whether or how federal courts will grant standing in climate change cases, particularly where plaintiffs allege an increased risk of future harm rather than a present injury. One way or the other, the state of attribution science is and will be central.

b. Case Law on Standing to Sue for Climate Change-Related Harms

The role of attribution science in establishing standing, then, is to determine whether plaintiffs have suffered an injury, or risk of an injury, that can be linked to anthropogenic climate change, and therefore linked to emissions that were generated by a private entity or inadequately regulated by a government entity. Attribution data is a valuable complement to impact projections as it can be used to establish an existing injury while also lending credibility to projections of future harm. This section reviews key decisions which illustrate how attribution of impacts to anthropogenic climate change factors into standing analysis.

i. *Massachusetts v. EPA*

The Supreme Court first addressed the issue of standing to bring climate change-related claims in *Massachusetts v. EPA*. There, a group of states, cities, and environmental organizations brought a lawsuit challenging the EPA's decision not to regulate greenhouse gas emissions from motor vehicles under the Clean Air Act. One of the key questions in the case was whether EPA could decline to exercise its regulatory authority because there was too much uncertainty about the causes and effects of climate change.[366] The question of uncertainty was also relevant to the question of standing—the issue being whether plaintiffs could establish a sufficiently certain causal link between the failure to regulate and harms that they had incurred and would incur as a result of climate

365. *Id.* at 75.

366. *Massachusetts*, 549 U.S. at 497, 513–14 (citing EPA, Control of Emissions from New Highway Vehicles and Engines: Notice of Denial of Petition for Rulemaking, 68 Fed. Reg. 52922, 52929–31 (Sept. 8, 2003)).

change. Because this case involved a procedural right—specifically, the right to challenge agency action unlawfully withheld—the immediacy and redressability requirements were relaxed.[367]

In their briefs, the plaintiffs supported their standing and merits claims by describing the many harms that they would incur as a result of climate change—for example, the states were experiencing and would continue to experience a "loss of state-owned property to rising sea levels. . . added costs to deal with emergency response measures caused by more frequent intense storm surge flooding events . . . damage to state-owned historic, archeological, and natural resources including state forests . . . [and] damage to state-owned facilities and infrastructure along the coast."[368] These assertions were supported by numerous expert declarations[369] as well as an amicus brief filed by climate scientists in support of the plaintiffs.[370]

In its initial review of the case, the U.S. Court of Appeals for the D.C. Circuit proceeded directly to the merits without resolving the standing issues separately, noting that this was a case where the standing inquiry and the merits inquiry clearly overlapped and that it would be "exceedingly artificial to draw a distinction between the two."[371] One concurring judge commented on standing, asserting that he would have dismissed the case because the plaintiffs only alleged what he viewed as a "generalized grievance" shared by all U.S. residents rather than the sort of "particularized grievance" required under standing law.[372]

On review, a five justice majority held that at least one of the plaintiffs—the state of Massachusetts—had presented sufficient evidence of actual and imminent harms to establish standing in the case, specifically the fact that it would suffer serious loss of coastal

367. *Id.* at 518.

368. Petitioners' Reply Brief in Support of Petition for Mandamus at 2, Massachusetts v. EPA, 549 U.S. 497 (2007) (No. 05-1120).

369. *See, e.g.*, Final Brief for the Petitioners at 2–3, Massachusetts v. EPA, 415 F.3d 50 (D.C. Cir. 2005) (Nos. 03-1361, consolidated with Nos. 03-1362 through 03-1368).

370. Brief of Amici Curiae Climate Scientists David Battisti, et. al. in Support of Petitioners at 10–18, Massachusetts v. EPA, 549 U.S. 497 (2007) (No. 05-1120).

371. Massachusetts v. EPA, 415 F.3d 50, 56 (D.C. Cir. 2005), *rev'd*, 549 U.S. 497 (2007). Interestingly, on the merits the court held that there was sufficient uncertainty about the causes and effects of climate change such that EPA had reasonably declined to exercise its authority. *Massachusetts*, 415 F.3d at 58.

372. *Id.* at 60–61 (Sentelle, J., concurring).

property as a result of sea level rise.[373] The Court noted that Massachusetts had a "special position and interest" in the case, in part because "it actually owns a great deal of the territory alleged to be affected" by climate change, and in part because of its status as a sovereign state.[374] The Court referred to data in the petitioners' affidavits showing that "global sea levels rose between 10 and 20 centimeters over the 20th century as a result of global warming and have already begun to swallow Massachusetts' coastal land" and that "[r]emediation costs alone . . . could reach hundreds of millions of dollars."[375] It held that this was a sufficiently particularized injury. Responding to EPA's assertion that Massachusetts' injury was "conjectural because the land loss that the state expected could not be quantified," the Court said that it was unnecessary to determine "the precise metes and bounds of [the state's] soon-to-be-flooded land" because the general trend was clear: Massachusetts was losing land and would continue to lose land to sea level rise.[376]

Turning to the causation and redressability prongs of standing, the court rejected EPA's assertion that its decision not to regulate would contribute "so insignificantly to petitioners' injuries" and thus there was "no realistic possibility that the relief sought would . . . remedy petitioners' injuries, especially since predicted increases in emissions from China, India, and other developing nations will likely offset any marginal domestic decrease EPA regulation could bring about."[377] First, the Court noted that, judged by any standard, U.S. motor vehicle emissions make a "meaningful contribution" to greenhouse gas concentrations and global warming (in 1999, they accounted for more than 6% of worldwide carbon dioxide emissions, or 1.7 billion metric tons).[378] The Court acknowledged that EPA could not by itself reverse global warming through motor vehicle standards but this did not mean that the court lacked jurisdiction to decide "whether EPA has a duty to take steps to *slow* or *reduce* it."[379] The majority explained that while a favorable decision would not totally remedy the problem, Massachusetts would not lose as much land as it otherwise

373. *Massachusetts*, 549 U.S. at 517.
374. *Id.* at 523.
375. *Id.* at 521–23.
376. *Id.* at 523, n.21.
377. *Id.* at 523–24.
378. *Id.* at 525.
379. *Id.* at 525.

would.[380] Thus, the majority treated redressability "as a matter of degree rather than an all-or-nothing proposition."[381]

ii. *Connecticut v. Am. Elec. Power Co.*

In subsequent cases, federal courts have raised questions about whether to grant standing to petitioners who are: (i) not states (and therefore have fewer interests of a different nature that could be affected by climate change), (ii) seeking regulation of emission sources with a much smaller greenhouse gas footprint than the U.S. motor vehicle fleet, or (iii) not alleging a procedural injury.

Connecticut v. American Electric Power Company was a case that involved state plaintiffs but lacked a procedural injury claim. There, a group of state, city, and non-governmental plaintiffs sued five power companies, alleging that their contribution to climate change constituted a public nuisance under both federal and state common law. The plaintiffs alleged a combination of existing and future injuries associated with climate change. For example, the states cited studies showing that climate change was already causing sea level rise and snowpack melt and that this had an adverse effect on their interests and their residents.[382]

The U.S. Court of Appeals for the Second Circuit, responding to a motion to dismiss, held that at least some of the plaintiffs had standing, finding that both the existing and future harms were sufficient to establish injury-in-fact. The court began its standing analysis by explaining that "[t]he procedural posture of a case is important when assessing standing", and that when considering a motion to dismiss, courts should "presume that general factual allegations embrace those facts necessary to support the claim."[383] The court further noted that defendants "may certainly test [plaintiffs'] standing as the litigation progresses by requesting an evidentiary hearing or by challenging [plaintiffs'] standing on summary judgment or even at trial" but that the "allegation of a credible risk" is sufficient at the pleading stage, as "[a]dopting a more stringent view of [standing requirements] would essentially collapse the standing inquiry into the merits."[384]

380. *Id.* at 525–26.
381. Lee & Ellis, *supra* note 341, at 192.
382. *Am. Elec. Power Co.*, 582 F.3d 309, 318 (2d Cir. 2009), *rev'd*, 564 U.S. 410 (2011).
383. *Id.* at 333.
384. *Id.* (internal citations omitted).

With regards to existing injuries, the court found that that California's alleged injuries from sea level rise and snowpack melt "far exceed the 'identifiable trifle' required by Article III."[385] With regards to whether the future harms were sufficiently imminent, the court cited precedent holding that, in cases involving exposure to a harmful substance, it is the exposure that must be imminent and not the onset of disease.[386] The court then explained that the plaintiffs' future injury claims in the present case were even "more compelling" because, according to plaintiffs, the "defendants are currently emitting large amounts of carbon dioxide and will continue to do so in the future" and the adverse impacts to the plaintiffs were "certain to occur because of the consequences, based on the laws of physics and chemistry, of the documented increase in carbon dioxide in the atmosphere."[387] Thus, the "future injuries they predict are anything but speculation and conjecture."[388]

Turning to the questions of causation and redressability, the court briefly noted plaintiffs' allegations that the defendants were the "five largest emitters of carbon dioxide in the United States" and that their emissions accounted for 2.5% of global emissions, but did not examine whether this constituted a "meaningful contribution" to global climate change.[389] The court explained that the fact that the defendants "contribute to" climate change was sufficient to allege causation in the context of a motion to dismiss, and that the significance of the contribution was "an issue best left to the rigors of evidentiary proof at a future stage of the proceeding, rather than dispensed with as a threshold question of constitutional standing."[390] In other words, the court determined that this issue should be addressed as part of its evaluation of the factual merits of the nuisance claim.[391] The court concluded that, "[f]or purposes of Article III standing, [the Plaintiffs] are not required to pinpoint which specific harms of the many injuries they assert are caused by particular Defendants, nor are they required to

385. *Id.* at 342.
386. *Id.* at 344.
387. *Id.*
388. *Id.*
389. *Id.* at 345–47.
390. *Id.* at 347.
391. For more information about how the causation requirement differs in the standing and nuisance context, *see* Section III(C)(5).

show that Defendants' emissions alone cause their injuries. It is sufficient that they allege that Defendants' emissions contribute to their injuries."[392] Citing *Massachusetts*, the court also held that the possibility of partial redress in this context was sufficient for standing purposes.[393]

On appeal, the Supreme Court announced that the eight justices hearing the case were equally divided on the standing issue and thus affirmed the Second Circuit's decision.[394] Four justices would have granted standing cited *Massachusetts* and did not perform any additional analysis, indicating that they viewed that case as controlling even where a procedural injury was not at stake.[395] Ultimately, the Court unanimously held that the case was non-justiciable because the federal common law claims had been displaced by the Clean Air Act's grant of authority to EPA to regulate greenhouse gas emissions.[396] The Court did not address the state law claims.

iii. *Kivalina v. Exxon Mobil*

In *Native Village of Kivalina v. Exxon Mobil* (*Kivalina*), a Native Alaskan village sued approximately two dozen fossil fuel and energy generation companies for their contribution to climate change and the corresponding damages to the village (specifically, the cost of relocation), alleging a public nuisance under federal common law.

The district court reviewing this case had a very different perspective on standing than the Second Circuit in *American Electric Power*. It found that Kivalina lacked standing because it had not demonstrated that its injuries were "fairly traceable" to the defendants' actions because there were many other actors responsible for the emissions leading to damages in the village.[397] The court reached this conclusion even though the emissions at issue were significantly larger than those at issue in *American Electric Power*—specifically, Kivalina alleged that the defendant companies were jointly responsible for more than 1.2 billion tons of direct greenhouse gas emissions annually, as well as an unspecified

392. *Am. Elec. Power Co.*, 582 F.3d at 347.
393. *Id.* at 348.
394. *Id.*
395. *Id.*
396. *Id.* at 429.
397. Native Vill. of Kivalina v. Exxon Mobil Corp., 663 F. Supp. 2d 863, 880–81 (N.D. Cal. 2009), *aff'd on other grounds*, 696 F.3d 849 (9th Cir. 2012).

quantity of indirect (downstream) greenhouse gas emissions generated by the combustion of fossil fuels extracted and sold by these companies.[398] As Kivalina put it, the defendants were responsible for a "substantial portion" of global greenhouse gas emissions.[399] Kivalina's complaint also included a detailed description of how greenhouse gas emissions were contributing to global climate change and, in turn, to localized impacts on Kivalina, such as melting permafrost and rising sea levels, which would force the village to relocate in the near future.[400]

The district court found that Kivalina had not alleged facts sufficient to be granted standing. On the question of whether a "contribution" to a problem may be sufficient to establish standing, it held that a contribution was not in-and-of-itself sufficient evidence of harm and that plaintiffs had failed to show a "substantial likelihood" that the conduct of any one of the defendants actually harmed the village.[401] The court explained that:

> In view of the Plaintiffs' allegations as to the undifferentiated nature of greenhouse gas emissions from all global sources and their worldwide accumulation over long periods of time, the pleadings makes clear that there is no realistic possibility of tracing any particular alleged effect of global warming to any particular emissions by any specific person, entity, group at any particular point in time. Plaintiffs essentially concede that the genesis of global warming is attributable to numerous entities which individually and cumulatively over the span of centuries created the effects they now are experiencing. Even accepting the allegations of the Complaint as true and construing them in the light most favorable to Plaintiffs, it is not plausible to state which emissions—emitted by whom and at what time in the last several centuries and at what place in the world—"caused" Plaintiffs' alleged global warming related injuries. Thus, Plaintiffs have not and cannot show that Defendants' conduct is the "seed of [their] injury." To the contrary, there are, in fact, a multitude of "alternative culprit[s]" allegedly responsible for the various chain of events allegedly leading to the erosion of Kivalina.[402]

398. Complaint for Damages and Demand for Jury Trial at paras. 18–122, Native Vill. of Kivalina v. Exxon Mobil Corp., 663 F. Supp. 2d 863 (N.D. Cal. 2009) (No. CV 08 1138).

399. *Id.* at para. 3.

400. *Id.* at paras. 123–62, 181–184.

401. *Kivalina*, 663 F. Supp. 2d 863 at 880, *aff'd on other grounds* 696 F.3d 849 (9th Cir. 2012).

402. *Id.* at 880–81.

The district court did not specifically address whether there was some threshold at which standing could be established to sue emitters based on damages caused by climate change, but the court's analysis suggests that it would have reached the same decision regardless of the magnitude of the emissions.

On appeal, the Ninth Circuit followed the Supreme Court's decision in *American Electric Power* and dismissed the case due to legislative displacement, rather than a lack of standing.[403]

iv. *Washington Environmental Council v. Bellon*

The U.S. Court of Appeals for the Ninth Circuit grappled more directly with the question of what constitutes a sufficient contribution to climate change as part of the standing causation analysis in *Washington Environmental Council v. Bellon.* There, the court, responding to an appeal of a motion for summary judgment, held that two non-profits did not have standing to challenge Washington State's failure to regulate greenhouse gas emissions from five oil refineries, because they had not shown that the refineries' emissions made a meaningful contribution to global greenhouse gas levels.[404] The non-profits alleged that their members would experience adverse health impacts and property damage as a result of climate change, as well as aesthetic and recreational injuries because changes in precipitation patterns, reductions of glaciers, changes in wildlife habitat, and forest fires would affect natural areas that they routinely visit.[405] The court held that these injuries were sufficient to satisfy the injury-in-fact prong of the standing analysis but that the plaintiff had failed to establish causation.

Specifically, the court found that the plaintiffs' causation argument "consist[ed] of a series of links strung together by conclusory, generalized statements of 'contribution,' without any

403. Native Vill. of Kivalina, 696 F.3d at 869. Justice Pro, in a concurring opinion, stated that he would have dismissed the case for lack of standing: "It is one thing to hold that a State has standing to pursue a statutory procedural right granted to it by Congress in the CAA to challenge the EPA's failure to regulate greenhouse gas emissions which incrementally may contribute to future global warming. *See* Mass. v. EPA, 549 U.S. 497, 516–20 (2007). It is quite another to hold that a private party has standing to pick and choose amongst all the greenhouse gas emitters throughout history to hold liable for millions of dollars in damages."

404. Wash. Envtl. Council v. Bellon, 732 F.3d 1131, 1135 (9th Cir. 2013), *reh'g en banc denied*, 741 F.3d 1075 (9th Cir. 2014).

405. *Id.* at 1140–41.

plausible scientific or other evidentiary basis that the refineries' emissions are the source of their injuries."[406] The court explained that:

> Greenhouse gases, once emitted from a specific source, quickly mix and disperse in the global atmosphere and have a long atmospheric lifetime. Current research on how greenhouse gases influence global climate change has focused on the cumulative environmental effects from aggregate regional or global sources. But there is limited scientific capability in assessing, detecting, or measuring the relationship between a certain GHG emission source and localized climate impacts in a given region.[407]

With regards to the defendants, the court noted that the refineries were responsible for 101.1 million metric tons of CO_2 annually (5.9% of total greenhouse gas emissions produced in the state of Washington), and that unlike the much larger quantity of emissions at issue in *Massachusetts v. EPA* (1.7 billion tons), the effect of those emissions on global climate change was "scientifically indiscernible, given the emission levels, the dispersal of GHGs world-wide, and the absence of any meaningful nexus between Washington refinery emissions and global GHG concentrations now or as projected in the future."[408] Thus, the court concluded that the causal chain was "too tenuous to support standing."[409]

The *Bellon* decision and other cases discussed above raise two important questions. First, at what threshold do emissions from a source represent a "meaningful contribution" to global climate change such that an adequate causal nexus can be found between those emissions and localized climate impacts? Or, in the words of the *Bellon* court, at what point is the effect of the emissions on global climate change sufficiently "scientifically discernible"?

406. *Id.* at 1142.

407. *Id.* at 1143.

408. *Id.* at 1145. The court noted that the *Bellon* case also differed from *Massachusetts* because no procedural right was implicated and there was no state plaintiff that should be granted "special solicitude" in the standing analysis, but found that even if it "assume[d] that the Plaintiffs' members are entitled to a comparable relaxed standard, the extension of *Massachusetts* to the present circumstances would not be tenable."

409. *Id.* at 1144. *See also* Barnes v. U.S. Dep't of Transp., 655 F.3d 1124 (9th Cir. 2011) (finding that it was not possible to establish a link between greenhouse gas emissions from an increase in aviation activities caused by airport expansion and specific harmful impacts of climate change).

Detection and attribution research can help to answer this question, but there are also legal and policy judgments embedded in any determination of what constitutes a "meaningful" or "significant" contribution. Second, should this inquiry be conducted as part of the standing analysis, or is the question so closely tied to the merits that the issue should, in all or some subset of cases, be deferred to that later stage of the litigation? We return to this question in Section IV.

v. *Comer v. Murphy Oil*

The U.S. Court of Appeals for the Fifth Circuit also grappled with the question of standing for non-governmental entities to sue fossil fuel companies in *Comer v. Murphy Oil USA*. There, residents and owners of lands and property along the Mississippi Gulf coast filed a class action lawsuit against energy, fossil fuel, and chemical companies alleging that the greenhouse gas emissions generated by these companies contributed to global warming, which in turn caused a rise in sea levels which exacerbated the effects of Hurricane Katrina.[410] The plaintiffs asserted claims for damages based on state common law actions of public and private nuisance, trespass, negligence, unjust enrichment, fraudulent misrepresentation, and civil conspiracy.[411] Unlike in *American Electric Power*, the plaintiffs did not pursue any federal common law action nor did they seek injunctive relief.[412] As in other cases, the defendants argued that the plaintiffs had not established an adequate causal connection between defendants' conduct and plaintiffs' harm.

The district court in Mississippi initially held that plaintiffs lacked standing,[413] but the Fifth Circuit reversed, holding that the landowners had Article III standing to bring their nuisance, trespass, and negligence claims.[414] The court noted that fully addressing the defendants' causation arguments would require the court to address the merits of plaintiffs' claims and was therefore

410. Comer v. Murphy Oil USA, 585 F.3d 855, 859 (5th Cir. 2009).
411. *Id.* at 859–60.
412. *Id.* at 860.
413. Comer v. Murphy Oil USA, Inc., No. 1:05-CV-436-LG-RHW, 2007 WL 6942285, at *1 (S.D. Miss. Aug. 30, 2007), *rev'd sub nom* Comer v. Murphy Oil USA, 585 F.3d 855 (5th Cir. 2009).
414. Comer v. Murphy Oil USA, 585 F.3d at 87980.

"misplaced at this thresholds standing stage of the litigation."[415] It further explained that "the Article III traceability requirement need not be as close as the proximate causation needed to succeed on the merits of a tort claim" and that "an indirect causal relationship will suffice" for the purposes of Article III standing.[416] The Fifth Circuit thus took a very different approach from the Ninth Circuit in *Bellon*, noting that it must take the plaintiff's allegations that the defendants' emissions caused their injuries as true at the pleading stage, recognizing that the plaintiffs would be required to support those assertions at a later stage in the litigation.[417]

The decision did not stand for long: the Fifth Circuit granted a rehearing en banc shortly after issuing the decision, and subsequently lost its quorum to decide the case before hearing it. The court ultimately held that it must dismiss the appeal due to lack of quorum and thus, the vacatur of the original panel decision remained in place.[418]

vi. *Juliana v. United States*

More recently, in *Juliana v. United States,* a federal district court in Oregon held that plaintiffs suing the U.S. government for affirmatively contributing to climate change and failing to control emissions from fossil fuel development and use had adequately alleged that they had standing to sue.[419] The court, responding to a motion for dismiss, noted that "general factual allegations" were sufficient to establish Article III standing.[420] The court found that the plaintiffs had established sufficiently personalized and concrete injuries—such as lost income for a ski resort employee, and harmful impacts to a family farm—that were fairly traceable to the greenhouse gas emissions resulting from U.S. fossil fuel production and use.[421] The court distinguished the case from *Bellon* on two grounds:

415. *Id.* at 864.
416. *Id.*
417. *Id.*
418. Comer v. Murphy Oil USA, 607 F.3d 1049, 1055 (5th Cir. 2010).
419. Juliana v. United States, 217 F. Supp. 3d 1224, 1248 (D. Or. 2016).
420. *Id.* at 1268.
421. *Id.* at 1267–68.

(1) The procedural posture of the case was different: *Bellon* involved a motion for summary judgment, which is typically filed after the parties have completed discovery, whereas the *Juliana* court was responding to a motion to dismiss, which is filed shortly after the complaint is filed and which can only be granted where there is no genuine issue of material fact.[422]

(2) The emissions at issue in *Juliana* (from all U.S. fossil fuels) were significantly larger than the emissions at issue in *Bellon* (from five refineries), and by no means represented a "minor contribution" to climate change.[423]

The court also rejected the idea put forth by the district court in *Kivalina*—that causation between emissions and impacts cannot be established where there are "a multitude of alternative culprits" that are also responsible for climate change—and found that "a causal chain does not fail simply because it has several links, provided those links are not hypothetical or tenuous and remain plausible."[424] It summarized the causal chain as follows:

> DOT and EPA have jurisdiction over sectors producing sixty-four percent of United States emissions, which in turn constitute roughly fourteen percent of emissions worldwide; they allow high emissions levels by failing to set demanding standards; high emissions levels cause climate change; and climate change causes plaintiffs' injuries.[425]

Finally, with regards to redressability, the court noted that the requested remedy—ordering the U.S. government to "prepare and implement an enforceable national remedial plan to phase out fossil fuel emissions"—would "slow or reduce" the harm caused to plaintiffs, and that was sufficient for standing.[426]

The court subsequently denied a motion for summary judgement, again declining to find that plaintiffs lacked standing to sue, and citing many of the considerations noted above. The court acknowledged that a different standard applies when reviewing a motion for summary judgment (which is typically filed after the

422. *Id.* at 1245.
423. *Id.*
424. *Id.* at 1268.
425. *Id.* at 1246.
426. *Id.* at 1247.

parties have completed discovery) as compared with a motion to dismiss.[427] At this stage, plaintiffs must establish that there is a "genuine question of material fact as to the standing elements."[428] The court found that the affidavits and expert testimony submitted by plaintiffs during discovery met this requirement, and noted that it would revisit all elements of standing after the factual record had been fully developed at trial.[429]

The district court's summary judgment decision was reversed by the Ninth Circuit in early 2020 based on the appellate court's determination that plaintiffs had not satisfied the redressability prong of Article III standing.[430] Specifically, the court concluded that it could not provide the redress plaintiffs were seeking—an order requiring the government to develop a plan to phase out fossil fuel emissions and reduce atmospheric CO_2—because providing such relief would implicate policy choices reserved for the elected branches of government and thus violate the separation of powers doctrine.[431] Importantly, the Court of Appeals did find that the plaintiffs had satisfied the injury and causation requirements of Article III standing, for the purposes of summary judgment, because the plaintiffs had claimed concrete and particularized injuries and there was a genuine factual dispute as to whether federal policies were a "substantial factor" in causing the plaintiffs' injury.[432] In reaching this conclusion, the court cited the U.S.'s historical and current contribution to global emissions and evidence submitted by plaintiffs that federal subsidies and leases had increased those emissions.[433] It also rejected the government's reliance on *Bellon* to argue that the causal chain is too attenuated

427. Juliana v. United States, 339 F. Supp. 3d 1062, 1086 (D. Or. 2018), *mandamus dismissed sub nom.* In re United. States, No. 18-505, 2019 WL 3462578 (U.S. July 29, 2019).

428. *Id.* at 1086–87.

429. *Id.* at 1096. *See infra* section III(C)(5) for a more detailed discussion of the expert testimony submitted during discovery.

430. Juliana v. United States, No. 18-36082 (9th Cir. Jan. 17, 2020).

431. This is similar to the separation of powers arguments cited by some judges in dismissing lawsuits brought against fossil fuel companies. See Section III(C)(5) *infra*. In *Juliana*, the plaintiffs argued that the court need not itself make policy decisions in issuing an order to the government to take action, since the court defer to the elected branches of government to decide how to implement the order. The court disagreed, finding that the plaintiff's requested relief would require it to pass judgment on the *sufficiency* of the government's implementation of the order, which would necessarily entail a broad range of policymaking. *Juliana*, No. 18-36082 at *26.

432. *Juliana*, No 18-36082 at *19-21.

433. *Id.*

for standing purposes, noting that the plaintiff's alleged injuries arose from "a host of federal policies, from subsidies to drilling permits, spanning over 50 years" (whereas *Bellon* involved a failure to regulate five oil refineries).[434] Thus, the Court of Appeals' decision was not based on any deficiencies in the underpinning science or causal chain linking government inaction to climate impacts.

vii. Foreign Jurisdictions

Some foreign courts have also grappled with the question of what constitutes a "meaningful contribution" to climate change for standing purposes. For example, in *Dual Gas Pty Ltd. v. Environment Protection Authority,* the Victorian Civil and Administrative Tribunal in Australia made the following observations when determining whether plaintiffs had standing to sue the government's approval of a new power plant:

> [D]espite the global nature of the GHG issue, there must still be a materiality threshold in relation to the type or size of the works or emissions that is relevant to whether a person's interests are genuinely affected, as opposed to being too remote or too general. The emission of a few tonnes of GHG from a small factory in Gippsland would not in our view give rise to standing under s 33B(1) to an objector in Mildura even though it represents an incremental GHG increase. It is unnecessary for us to determine where the line of materiality might be drawn. As we noted in our introduction, the DGDP is a major power station that will generate up to 4.2 million tonnes of GHG per annum over a 30 year projected life cycle and increase Victoria's GHG emissions profile by 2.5% over 2009 levels. In our view, this clearly raises potential issues of material interest or concern to all Victorians, and creates an almost unique level of "affected interests" and standing compared to the more usual sort of works approval matters that come before the Tribunal.[435]

Of course, standing requirements in states and most, if not all, foreign jurisdictions are not as stringent as standing requirements in U.S. federal courts. In some decisions, there is no standing

434. *Id.* at 20.
435. *Dual Gas Pty Ltd. v Env't Protection Authority* [2012] VCAT 308, ¶ 134. (Austl.).

analysis.[436] In others, the standing analysis is of a more general nature and does not require plaintiffs to show that they incurred a particularized harm as a result of the greenhouse gas emissions that might be controlled as a result of judicial intervention, with the result that attribution science plays a less critical role in the standing analysis.[437] Because the standards are more permissive, standing has not been a significant obstacle to climate change cases outside of the United States, nor have attribution questions factored heavily in the standing analyses.[438]

The inconsistencies within the case law on standing in the United States, and as between U.S. courts and foreign jurisdictions, reinforce the conceptual and practical difficulties that have bedeviled analysis of climate change litigation. In *Massachusetts*, 6% of global GHG emissions was found to be a "meaningful contribution" sufficient to show causation, and states were granted "special solicitude" in proving standing.[439] In *American Electric Power*, 2.5% of global GHG emissions was enough for the Second Circuit, and for at least four judges then sitting on the Supreme Court.[440] In *Kivalina*, a district court judge focused not on the quantity of emissions or the question of their significance, but the impossibility of tracing specific impacts to specific emissions.[441] In *Bellon*, the Ninth Circuit determined that 5.9% of Washington State's GHG emissions could not be effectively disaggregated from the global co-mingling of GHGs to establish causation.[442] In *Comer*, a Fifth Circuit panel found that allegations that a large number of companies had made a significant contribution were sufficient to survive a motion to dismiss. In *Juliana*, the district court noted that U.S. agencies had regulatory authority over at least 14% of global GHGs and found it sufficient.[443]

436. *See, e.g.*, Leghari v. Republic Fed'n of Pakistan (2015) W.P. No. 25501/2015. For more on standing to bring climate-related lawsuits in non-U.S. jurisdictions, see BURGER & GUNDLACH, *supra* note 10.

437. *See, e.g.*, Rb Den Haag 24 juni 20015, m.nt. C/09/00456689 HA ZA 3-1396 (Urgenda Stichting/Staat der Nederlanden) (Neth.) [hereinafter *Urgenda* District Court Decision (2015)].

438. *See* BURGER & GUNDLACH , *supra* note 10.

439. *See supra* Section III(C)(1)(b)(i).

440. *See supra* Section III(C)(1)(b)(iii).

441. *See supra* Section III(C)(1)(b)(iv).

442. *See supra* Section III(C)(1)(b)(v).

443. *See supra* Section III(C)(1)(b)(vi).

All of which leaves open a number of questions: What quantity of emissions matters? Which sources or actors are relevant for calculating contributions? What is the best, or at least an appropriate, means of aggregating the actors and their emissions for the purposes of calculating contributions? What is the state of the science in measuring the relationship between individual sources/actors and localized impacts? These questions matter for standing. As discussed further below, they matter on the merits, as well.

2. Evidentiary Standards for Scientific Testimony and Reports

A threshold consideration regarding the role of attribution science in the courtroom is whether expert testimony on attribution is admissible in court. The *Daubert* standard, first articulated by the Supreme Court in *Daubert v. Merrell Dow Pharmaceuticals*,[444] is the contemporary standard for admissibility in federal courts and many states have adopted this standard as well. That standard charges the judge with ensuring that the basis of the expert's testimony is "scientific knowledge"[445] and outlines the following factors for making this determination:

- Whether the scientific theory or technique can be (and has been) tested
- Whether it has been subjected to peer review and publication
- Whether it has a known error rate
- Whether it has a degree of "general acceptable" within a "relevant scientific community."[446]

Most states now follow the *Daubert* standard, but some adhere to the less exacting *Frye v. United States* standard (the previous federal standard),[447] which only requires "general acceptance" of the science within the relevant scientific community.[448] These

444. Daubert v. Merrell Dow Pharm., Inc., 509 U.S. 579 (1993).

445. *Id.* at 592.

446. *Id.* at 592–95.

447. 293 F. 1013 (D.C. Cir. 1923).

448. Michael Morgenstern, Daubert *v.* Frye*: A State-by-State Comparison*, THE EXPERT INST. (Apr. 3, 2017), https://www.theexpertinstitute.com/daubert-v-frye-a-state-by-state-comparison/ [https://perma.cc/5UF2-F5JQ].

standards are typically only evoked when the opposing side challenges expert testimony.

Most attribution studies accord with the *Daubert* standard insofar as they rely on scientific theories that can be tested using models, statistical analyses, and observations; they are typically published in peer reviewed journals; they typically discuss known sources of bias and the potential for Type I and Type II errors; and they are based on generally accepted techniques. However, defendants in climate lawsuits may argue that some of the more novel impact and event attribution techniques do not meet all four requirements, and in particular, the requirement of "general acceptance" within the scientific community. Defendants are also highly likely to challenge testifying scientists who draw inferences from attribution studies with respect to impacts not explicitly covered in those studies, even where the underlying studies would clearly satisfy *Daubert*.[449] This highlights the benefits of using attribution studies of an appropriate scale and scope.

One important question is whether and to what extent confidence levels will affect the admissibility of and weight given to attribution studies presented to courts. As noted in Part II, attribution findings are frequently presented in terms of confidence levels and intervals—for example, a study may find with ">90% confidence" that anthropogenic forcing on climate doubled the risk of an extreme event occurring. The National Academy of Sciences ("NAS") *Reference Manual on Scientific Evidence* notes that a 95% confidence level is the "standard" for scientific studies but does not recommend a threshold for admissibility in court, nor does it discuss how confidence levels might affect the weight afforded to a scientific study.[450] Apart from that manual, there does not appear to be any clear standard for dealing with confidence levels and intervals in courtrooms. Many, but not all, attribution studies present findings at the 95% confidence level, consistent with general scientific practice. This bodes well for the utilization of the research in courts, but there may be situations where it is also useful to discuss findings at lower confidence levels (the goal

449. For more on this topic, *see* Kirsten Engel & Jonathan Overpeck, *Adaptation and the Courtroom: Judging Climate Science*, 3 MICH. J. ENVTL. & ADMIN. L. 1 (2013).

450. FED. JUD. CTR., REFERENCE MANUAL ON SCIENTIFIC EVIDENCE: THIRD EDITION 284–85 (National Academies Press 2011) https://www.fjc.gov/sites/default/files/2015/SciMan3D01.pdf [https://perma.cc/3SEB-JN9L].

being to identify what is plausible, even if not highly certain). Part IV presents recommendations on how researchers might frame their research to satisfy the demands of the courtroom as well as other applications.

There is no single numeric standard that juries and courts rely on in assessing the weight of scientific expert testimony.[451] Generally speaking, judges and juries will consider factors such as believability, persuasiveness, thoroughness, and whether the evidence has been refuted.[452] Evidence that is indefinite, vague, or improbable will generally be given less weight than evidence that is direct and unrefuted.[453] The weight afforded to attribution findings will thus depend on the level of uncertainty underpinning those findings as well as the extent to which the findings are a subject of scientific debate.

3. Lawsuits Challenging the Failure to Regulate Greenhouse Gas Emissions

Environmental and citizen groups in the United States and other jurisdictions have brought numerous challenges seeking to compel governments to take action to curtail greenhouse gas emissions.[454] There are three types of lawsuits that fall within this category: (i) lawsuits challenging the government failure to implement statutory mandates with respect to air pollution control; (ii) lawsuits challenging the failure to protect public health pursuant to general legal mandates recognized in constitutions, public trust doctrines, human rights law, and other legal sources; and (iii) lawsuits involving administrative decisions undertaken within an existing regulatory scheme, typically decisions to grant or refuse an authorization for a particular activity (such as coal mining or the construction of an airport). In all three types of cases, attribution

451. Note the burden of proof in civil trials is the "preponderance of evidence" standard, which requires a plaintiff to convince the trier of fact that the evidence in support of her case outweighs the evidence offered by the defendant to oppose it.

452. *Weight of the Evidence*, WEST'S ENCYCLOPEDIA OF AMERICAN LAW (2d ed. 2008), https://legal-dictionary.thefreedictionary.com/weight+of+evidence [https://perma.cc/44VB-TD4W].

453. *Id.*

454. Cases involving a common law breach of a government duty owned to plaintiffs are sometimes referred to as "public liability" cases in contrast to the "private liability" cases discussed in subsequent sections. *See* Jutta Brunnée et al, *Overview of Legal Issues Relevant to Climate Change*, in CLIMATE CHANGE LIABILITY: TRANSNATIONAL LAW AND PRACTICE 23 (Richard Lord et al. eds., Cambridge University Press 2012).

science comes into play when plaintiffs need to establish a causal connection between the government's action or inaction and concrete harms caused by climate change to succeed on the merits.

a. Lawsuits Challenging the Failure to Implement Statutory Mandates With Respect to Air Pollution Control

i. *Massachusetts v. EPA*

The most noteworthy case involving a government failure to regulate greenhouse gas emissions pursuant to an existing statutory scheme for air pollution control was *Massachusetts*. In the same way that attribution science helped plaintiffs establish standing in this case, it also helped them to rebut EPA's assertion that it there was too much scientific uncertainty about climate change to regulate.[455]

The case history is illuminating. The D.C. Circuit initially dismissed the case but did not reach consensus on the basis for dismissal, in part due to disagreements about the scientific underpinnings of EPA's views about scientific uncertainty. In Judge Randel's plurality opinion, he wrote that EPA had properly declined to regulate based on its conclusions that there was too much scientific uncertainty about the causal effects of greenhouse gases on climate change.[456] In reaching this conclusion, the judge referred to EPA's reliance on a 2001 National Research Council ("NRC") report, which found that "a causal linkage" between greenhouse gas emissions and global warming "cannot be unequivocally established."[457] He summarized the NRC's findings as follows:

> The earth regularly experiences climate cycles of global cooling, such as an ice age, followed by periods of global warming. Global temperatures have risen since the industrial revolution, as have

455. Uncertainty was only one of the rationales proffered by EPA for not regulating motor vehicle emissions. EPA also argued that: (i) it did not have statutory authority to regulate greenhouse gas emissions, and (ii) even if did have authority to regulate, there were "policy considerations" which made it unwise for EPA to exercise that authority at this time. *Massachusetts*, 549 U.S. at 513–514. *See also* citing EPA, Control of Emissions from New Highway Vehicles and Engines: Notice of Denial of Petition for Rulemaking, 68 Fed. Reg. 52922, 52929–31 (Sept. 8, 2003).

456. *Massachusetts*, 415 F.3d at 58. (The court also supported EPA's determination that policy considerations weighed against regulating greenhouse gases at this time.)

457. *Id.* at 57 (citing NAT'L RES. COUNCIL, CLIMATE CHANGE SCIENCE: AN ANALYSIS OF SOME OF THE KEY QUESTIONS (2001)).

> atmospheric levels of carbon dioxide. But an increase in carbon dioxide levels is not always accompanied by a corresponding rise in global temperatures. For example, although carbon dioxide levels increased steadily during the twentieth century, global temperatures decreased between 1946 and 1975. Considering this and other data, the National Research Council concluded that "there is considerable uncertainty in current understanding of how the climate system varies naturally and reacts to emissions of greenhouse gases." This uncertainty is compounded by the possibility for error inherent in the assumptions necessary to predict future climate change. And, as the National Research Council noted, past assumptions about effects of future greenhouse gas emissions have proven to be erroneously high.[458]

In light of this perceived uncertainty, Judge Randel concluded that it was neither arbitrary nor capricious for EPA to decline to regulate greenhouse gas emissions at the time.[459] Judge Sentelle, concurring in the decision to dismiss the case, asserted that the court lacked jurisdiction to hear the case on standing grounds.[460] Judge Tatel dissented, arguing that the NRC report actually did provide a sufficient basis for a finding that greenhouse gas emissions endangered public health and welfare and should therefore be regulated under the Clean Air Act.[461] Notably, the dissenting judge provided a more detailed synthesis of the NRC report's findings, which contradicted Judge Randel's interpretation of the report. Some of the key points highlighted were that:

> The very first sentence of the NRC report stated that "Greenhouse gases are accumulating in Earth's atmosphere as a result of human activities, causing surface air temperatures and subsurface ocean temperatures to rise." The quote used by Judge Randel (that "a causal linkage" between greenhouse gas emissions and global warming "cannot be unequivocally established") had been taken out of context, and was merely a recognition that this linkage, as with many other scientific theories, could not be established with 100% certainty.[462]
>
> The NRC report made clear that uncertainties about climate change related chiefly to the scope and magnitude of impacts

458. *Id.* (internal citations omitted).
459. *Id.* at 58.
460. *Id.* at 60–61 (Sentelle, J., concurring).
461. *Id.*at 61–82 (Tatel, J., dissenting).
462. *Id.* at 63.

> caused by greenhouse gas accumulation, not whether there was a correlation between those emissions and global warming.[463] The NRC report explicitly acknowledged that "national policy decisions made now and in the longer-term future will influence the extent of any damage suffered by vulnerable human populations and ecosystems later in this century."[464]

On review, the Supreme Court acknowledged that uncertainty *might* be a reasonable basis for not regulating, but held that EPA cannot defer regulation unless it issued a formal declaration that the uncertainty was "so profound that it preclude[d] EPA from making a reasoned judgment as to whether greenhouse gases contribute to global warming."[465] While the Court did not decide the issue, it did clearly indicate that it might not uphold a determination of uncertainty from EPA—it noted the "harms associated with climate change are serious and well-recognized" and that the "Government's own objective assessment of the relevant science and a strong consensus among qualified experts indicate that global warming threatens, *inter alia,* a precipitate rise in sea levels, severe and irreversible changes to natural ecosystems, a significant reduction in winter snowpack with direct and important economic consequences, and increases in the spread of disease and the ferocity of weather events."[466]

ii. *Coalition for Responsible Regulation v. EPA*

Following the Supreme Court's decision in *Massachusetts*, EPA issued an endangerment finding for GHG emissions from motor vehicles, finding that such emissions cause or contribute to the endangerment of public health and welfare. The D.C. Circuit upheld this determination in *Coalition for Responsible Regulation v. EPA*.[467] There, an industry group argued that there was "too much uncertainty" about the science underpinning climate change and that EPA had improperly relied on external studies from the IPCC,

463. *Id.* at 64.

464. *Id.* at 64.

465. *Massachusetts*, 549 U.S. at 534.

466. *Id.* at 499.

467. Coal. for Responsible Regulation, Inc. v. EPA., 684 F.3d 102, 121 (D.C. Cir. 2012), *aff'd in part, rev'd in part sub nom* Util. Air Regulatory Grp. v. EPA., 573 U.S. 302 (2014), and *amended sub nom* Coal. for Responsible Regulation, Inc. v. EPA, 606 F. App'x 6 (D.C. Cir. 2015). *See also* Biogenic CO2 Coal. v. EPA, No. 16-1358 (D.C. Cir. filed Oct. 14, 2016) (challenging endangerment finding for GHG emissions from aircraft).

U.S. Global Change Research Program, and U.S. National Research Council in reaching its decision.[468] The court rejected these claims and held that EPA's reliance on external studies was entirely proper—noting that "EPA is not required to re-prove the existence of the atom every time it approaches a scientific question"—and held that the scientific body of evidence underpinning the endangerment finding was "substantial" and therefore legally sound.[469] In reaching this conclusion, the court explained that EPA had addressed each link in the causal chain connecting anthropogenic greenhouse gas emissions to harmful impacts on public health and welfare and that EPA had provided three lines of evidence to support the finding: (i) our "basic physical understanding" of the greenhouse gas effect, (ii) observational evidence of past climate change, and (iii) models predicting how the climate will response to greenhouse gas concentrations in the future.[470]

iii. Other Clean Air Act Cases

Above, we describe how attribution science has played a central role in the issuance and judicial review of Clean Air Act endangerment findings. This would also be the case if EPA exercised its authority to establish National Ambient Air Quality Standards ("NAAQS") for GHGs under Section 110 or if EPA developed a program to control GHG emissions as a source of international air pollution under Section 115 of the Act.[471] To establish NAAQS for GHGs, EPA would need to identify thresholds for ambient concentrations of GHGs that are sufficient to protect public health and welfare. Similarly, to establish a Section 115 program, EPA would need to establish targets for emission reductions as necessary to "prevent or eliminate the endangerment" that those emissions pose to foreign nations. In either case, it would be necessary to define the appropriate threshold for emission control based on, among other things, both

468. *Coal. for Responsible Regulation, Inc.*, 684 F.3d at 121.

469. *Id.* at 120.

470. *Id.* at 120-121.

471. See Michael Burger et al., *Legal Pathways to Reducing Greenhouse Gas Emissions under Section 115 of the Clean Air Act*, 28 GEO. ENVTL. L. REV. 359 (2016); Kassie Siegel et al., *Strong Law, Timid Implementation. How the EPA Can Apply The Full Force of the Clean Air Act To Address The Climate Crisis*, 30 UCLA J. ENVTL. L. & POLICY 185 (2012).

existing impacts as well as predictions of future impacts of climate change.

The Clean Air Act and other air pollution control statutes also provide for the establishment of technology-based emission standards (e.g., standards reflecting the "best available technology" or the "best system of emission reduction.").[472] In this context, attribution science plays a less pivotal role in the establishment and judicial review of the standards, since the standards are primarily based on considerations pertaining to statutory authority, technological feasibility, and cost. However, challenges to and defenses of these standards do involve attribution questions to some extent—for example, when defining the "best system of emission reduction" for controlling emissions from stationary sources under the Clean Air Act, EPA must take into account the public health benefits of the standards as well as technological feasibility and cost.[473] But to date, attribution science has not featured prominently in litigation over technology-based and hybrid rules and standards such as the Clean Power Plan.[474]

b. Cases Challenging the Government Failure to Protect Public Health Pursuant to Constitutional Mandates, Public Trust Doctrines, Human Rights Law, and Other Legal Sources

A number of cases have been brought challenging the failure to regulate greenhouse gas emissions and fossil fuel production on the grounds that government entities have violated more general mandates pertaining to fundamental rights. In the United States, there are at least two federal legal sources that have given or could give rise to such cases: the public trust doctrine, which holds that government actors have a duty to preserve certain "public trust" resources for future generations;[475] and the theory of substantive due process, which holds that the federal government must safeguard fundamental rights that are "implicit in the concept of ordered liberty" or "deeply rooted in this Nation's history and tradition."[476] States and other jurisdictions also have a variety of

472. *See, e.g.*, Clean Air Act § 111(a)(1), 42 U.S.C. §7411 (2018).
473. *Id.*
474. *See, e.g.*, West Virginia v. EPA, No. 15-1363 (D.C. Cir. 2015); North Dakota v. EPA, No. 15-1381 (D.C. Cir. 2015).
475. Ill. Ctr. R.R. Co. v. Illinois, 146 U.S. 387 (1892).
476. McDonald v. City of Chi., III., 561 U.S. 742, 761, 767 (2010).

different common law, constitutional, and statutory requirements that oblige government actors to protect public welfare, human rights, or the environment, which can support such claims.[477] In these cases, attribution science is primarily used to demonstrate a causal connection between the under-regulated greenhouse gas emissions and specific injuries to public health and welfare or the environment, which, in turn, give rise to the alleged breach of government duty.[478]

i. *Juliana v. United States*

In *Juliana*, the plaintiffs asserted that: (i) the U.S. government had violated "the fundamental right of citizens to be free from government actions that harm life, liberty, and property" by "approving and promoting fossil fuel development, including exploration, extraction, production, transportation, importation, exportation, and combustion" that had resulted in the degree of climate change we are now experiencing and are projected to experience in the future;[479] and (ii) the U.S. government also violated its public trust obligation to its citizens through this conduct.[480] To prove these claims, the plaintiffs would have needed to establish a causal connection between the emissions that the U.S. government had approved and/or failed to control and the alleged violations of their rights and/or the public trust doctrine.

The plaintiffs in *Juliana* emphasized the magnitude of the emissions at issue, noting that: (i) territorial emissions from the U.S. account for approximately 25.5% of the world's cumulative CO_2 emissions, and this figure would likely be higher using a consumption- or extraction-based accounting approach; (ii) emissions from U.S. energy consumption were 5.4 billion metric

477. For example, there have been a number of lawsuits filed under state constitutions and public trust doctrines due to state inaction on climate change, as well as foreign lawsuits filed pursuant to national constitutional obligations and human rights laws. *See, e.g.*, Funk v. Pennsylvania, 71 A.3d 1097 (Pa. Commw. Ct. 2013); Urgenda District Court Decision (2015); Leghari v. Pakistan (2015) WP No. 25501/201 (Lahore Hight Court) (Pak.). *See also Public Trust Doctrine*, SABIN CTR. FOR CLIMATE CHANGE L., http://climatecasechart.com/principle-law/public-trust-doctrine/ (last visited Jan. 6, 2020) [https://perma.cc/DH4B-N93K].

478. In some instances it may also be the case that attribution science plays a role in positing the efficacy or level of protection available under the alternative scenario sought by plaintiffs.

479. Juliana v. United States, 217 F. Supp. 3d 1224, 1248 (D. Or. 2016).

480. The contours of the public trust doctrine, as interpreted by the plaintiffs and court in this case, are similar to the duty of care at issue in Urgenda District Court Decision (2015).

tons of CO_2 in 2014; (iii) if the government had acted on expert recommendations on how to limit emissions issued by EPA in 1990 and the Congressional Office of Technology Assessment in 1991, then U.S. CO_2 emissions would have been reduced by 35% from 1987 levels; and (iv) instead, since 1991, the U.S. government had "knowingly allowed at least an additional 130,466 million metric tons of CO_2 emissions from fossil fuel combustion."[481] Plaintiffs also dedicated a substantial portion of their complaint to explaining precisely how climate change is affecting and will affect their lives, liberty, and property interests, to support both their standing and merits claims.[482] The overarching theme of the complaint was that the plaintiffs, all being young people, are "especially vulnerable" to the threats caused by climate change.[483] It detailed existing and projected impacts on each of the individual children, such as adverse impacts on a farm where one of the children works and intends to pursue a livelihood;[484] lost income for a family that works at a ski resort;[485] and asthma attacks from the increased frequency of forest fires in Oregon (a result of hotter and drier temperatures).[486]

In her decisions denying the U.S. government's motion to dismiss and motion for summary judgment, the district court judge in Oregon held that the plaintiffs' allegations raised colorable substantive claims under the U.S. Constitution and the public trust doctrine.[487] The judge found that the substantive due process claim was supported by plaintiff's allegations that "the government has caused pollution and climate change *on a catastrophic level*, and that if the government's actions continued unchecked, they will permanently and irreversibly damage plaintiff's property, their economic livelihood, their recreational opportunities, their health, and ultimately their (and their children's) ability to live long,

481. First Amended Complaint for Declaratory and Injunctive Relief at paras. 151–163, Juliana v. United States, 217 F. Supp. 3d. 1224 (D. Or. 2016) (No. 615-cv-01517-TC). This estimate of the U.S. emissions contribution was based on total emissions from energy production within the U.S. since 1991.

482. *Id.* at paras. 16–97.

483. *Id.* at para. 10.

484. *Id.* at paras. 23–28.

485. *Id.* at para. 38.

486. *Id.* at para. 46.

487. Juliana v. United States, 217 F. Supp. 3d. 1224 (D. Or. 2016); Juliana v. United States, 339 F.Supp.3d 1062 (D. Or. 2018).

healthy lives."[488] With this in mind, the judge stated: "I have no doubt that the right to a climate system capable of sustaining human life is fundamental to a free and ordered society" and therefore was a constitutionally protected right.[489] The judge also found that the plaintiff's allegations were sufficient to establish a breach of the public trust doctrine, which prohibits government actors from "depriving a future legislature of the natural resources necessary to provide for the well-being and survival of its citizens."[490] She noted that it was unnecessary to determine whether the atmosphere was itself a public trust resource that must be preserved for future generations, because the territorial sea owned by the federal government has already been declared a public trust resource, and plaintiffs had alleged adequate harms to that resource caused by ocean acidification and rising ocean temperatures.[491]

As discussed above, the district court's decision was overturned by the Ninth Circuit Court of Appeals in early 2020.[492] Finding that the plaintiffs had failed to establish the redressability prong of Article III standing, the Court of Appeals remanded to the district court with orders to dismiss. Nonetheless, the work the parties put into preparation for an anticipated trial—and the district court's decision on the motion for summary judgment—reveals a great deal about how detection and attribution science would likely factor into resolution of other cases involving regulatory failures.

In preparation for trial, the plaintiffs submitted more than 1,000 pages of expert reports detailing the fundamental science of

488. *Juliana*, 217 F. Supp. 3d at 1250.

489. *Id.*

490. *Id.* at 1253. *But see* Alec L. v. Jackson, 863 F. Supp. 2d 11 (D.D.C. 2012) (holding that the public trust doctrine is a matter of state, not federal, law) (citing PPL Montana, LLC v. Montana, 565 U.S. 576 (2012)).

491. *Juliana*, 217 F. Supp. 3d at 1256 (citing First Amended Complaint ¶ 16 ("An important part of Kelsey's diet includes food that comes from the marine waters and freshwater rivers, including salmon, cod, tuna, clams, mussels, and crab."); *id.* ¶ 27 ("Other food sources for Alex, including crab and seafood, are negatively impacted by ocean acidification, warming, and sea level rise caused by Defendants."); *id.* ¶ 33 ("Ocean acidification caused by Defendants has already begun to adversely impact shellfish along the coast, and is predicted to take its toll on crab, mussels, and all shelled seafood."); *id.* ¶ 45 ("On the Oregon coast, Sahara enjoys climbing rocks and sand dunes, swimming, and tidepooling to see marine life. Sahara's enjoyment of these activities is being increasingly harmed in the future by sea level rise, greater erosion, enhanced ocean acidification, and increased water temperatures.").

492. *See infra* Section III(C)(1).

climate change, observed and projected impacts, and the ways in which the United States and the fossil fuel industry have contributed to the problem.[493] In some cases, the experts linked observed impacts directly to the plaintiff's alleged injuries, but some of these linkages draw on qualitative inferences about how broader trends related to climate change have affected or may affect the plaintiffs. For example, with respect to a plaintiff who had to move from her home in Cameron, Arizona because the springs her family depended on for water were drying up, one expert noted that the "pattern of drought in places like Arizona is directly linked to climate change" without citing research specifically attributing the arid conditions in the area to climate change.[494] Similarly, experts reporting on public health impacts noted that the youth plaintiffs, like all children, are at a higher risk of certain health problems such as asthma due to climate change but did not attribute specific health problems experienced by individual plaintiffs to climate change.[495] In other cases, statements about impacts on plaintiffs were based on observed trends and impacts without reference to attribution studies like those described in Section II.[496] Arguably more robust linkages were drawn between climate change and alleged injuries based on downscaled climate impact data—for example, data on historic and projected sea level rise in the town where one plaintiff lived,[497] and attribution studies linking specific extreme events that affected plaintiffs to anthropogenic climate change.[498]

Regarding the question of source attribution and the U.S. contribution to climate change, Dr. James Hansen prepared a lengthy expert report and an accompanying paper on *Assessing*

493. *See U.S. Climate Change Litigation:* Juliana v. United States, SABIN CTR. FOR CLIMATE CHANGE L., http://climatecasechart.com/case/juliana-v-united-states/ [https://perma.cc/7DBD-37KP] (last visited Jan. 6, 2020).

494. Expert Report of Steven W. Running, Ph.D at 6, Juliana v. United States, 339 F.Supp.3d 1062 (D. Or. 2018) (No. 6:15-cv-1517).

495. Expert Report of Susan E. Pacheco, M.D. and Jerome A. Paulson, M.D., FAAP, Juliana v. United States, 339 F.Supp.3d 1062 (2018) (No. 6:15-cv-1517).

496. *See*, *e.g.*, Expert Report of Steven Running, *supra* note 494, at 9 ("Ski areas like Hoodoo Pass and Willamette Pass in Oregon, where Plaintiff Zealand recreates and his family has been employed, and Stevens Pass in Washington, where Plaintiff Aji recreates, have recently had years with so little snow the areas could not even open for business.")

497. Expert Report of Dr. Harold R. Wanless at 24, Juliana v. United States, 339 F.Supp.3d 1062 (2018) (No. 6:15-cv-1517).

498. Expert Report of Dr. Kevin Trenberth at 18-22, Juliana v. United States, 339 F.Supp.3d 1062 (2018) (No. 6:15-cv-1517).

"Dangerous Climate Change": Required Reduction of Carbon Emissions to Protect Young People, Future Generations and Nature, which he co-authored with other scientists and economists.[499] Hansen cited research finding that the U.S. is an "unambiguous leader" in cumulative GHG emissions, having generated approximately 25% of emissions since 1751 ("more than double that of China, which falls second in the ranking"), and that the United States alone is responsible for a 0.15°C increase in global temperature. Dr. Hansen discussed emission reduction targets for the U.S. based on a global climate budget.[500] Dr. Hansen also discussed impacts such as sea level rise but did not explicitly quantify the proportional contribution of the United States to those impacts.

The question of the United States' responsibility for climate change was further explored in an expert report from Peter Erickson, a scientist at the Stockholm Environment Institute. He noted that the U.S. produces a substantial quantity of "territorial" emissions but that this is an incomplete indicator of responsibility for climate change.[501] He called for consideration of the United States' consumption emissions, which are approximately 20% higher than territorial emissions in recent decades, as well as extraction-based emissions, since the country also bears some responsibility for emissions from the burning of fossil fuels produced in the United States.[502] His expert testimony contained a comparison of U.S. emissions under all three accounting approaches. Erickson also noted that the United States has contributed to climate change by leasing and subsidizing the production of fossil fuels, but did not quantify the effect of those leases and subsidies on climate change (vis-à-vis global mean temperature change) or its impacts. Notably, Erickson did not suggest that one accounting approach should dominate—but rather that all three approaches should be considered when assessing U.S. responsibility for climate change.

499. Expert Report of James E. Hansen, Juliana v. United States, 339 F.Supp.3d 1062 (2018) (No. 6:15-cv-1517).; *see also* James E. Hansen et al., *Assessing "Dangerous Climate Change": Required Reduction of Carbon Emissions to Protect Young People, Future Generations and Nature*, 8 PLOS ONE 12 (Dec. 2013).

500. Expert Report of James Hansen, *supra* note 499, at 26–27.

501. Expert Report of Peter A. Erickson at 3, Juliana v. United States, 339 F.Supp.3d 1062 (D. Or. 2018) (No. 6:15-cv-1517).

502. *Id.* ("To more fully reflect its contribution to global climate change, it is my opinion that the Federal Government should also regularly conduct both a consumption-based and an extraction-based GHG emissions inventory.").

The U.S. government also solicited numerous expert reports primarily aimed at countering the idea that plaintiffs' injuries could be traced to U.S. government conduct. With respect to impact attribution, the defense experts argued that the plaintiffs' experts have failed to establish a conclusive link between anthropogenic climate change and the plaintiffs' alleged injuries because they infered that climate change caused the injuries based on observations and general trends[503] without accounting for other confounding factors that may have been responsible for the injuries.[504] The defendants' experts also addressed the question of source attribution—that is, the question of U.S. government responsibility and ability to provide redress for climate change-related injuries. They argued that the plaintiffs' experts have failed to specify the degree to which U.S. government conduct is responsible for climate change or the plaintiffs' alleged injuries, [505]

503. *See, e.g.*, Notice of Supplemental Disputed Facts Raised By Defendants' Expert Reports In Support Of Plaintiffs' Response In Opposition To Defendants' Motion For Summary Judgment, Juliana v. United States, 6:15-cv-01517, Dkt. 338 (Aug. 24, 2018) (plaintiffs' health impact experts "never directly link[ed] any of the [psychiatric and medical consequences of climate change] to any individual plaintiffs. They remain theoretical possibilities, reported in various studies of natural disasters, but *not* conclusively identified in any of the Plaintiffs she examined."), Juliana v. United States, 339 F.Supp.3d 1062 (D. Or. 2018) (No. 6:15-cv-1517); Expert Report of Dr. Norman I. Klein at 5 ("Drs. Frumkin, Pacheco, and Paulson confuse general correlations from abstract epidemiological studies with clinical examination of specific instances of asthma and allergy symptoms), Juliana v. United States, 339 F.Supp.3d 1062 (D. Or. 2018) (No. 6:15-cv-1517).

504. *See, e.g.*, Expert Report of Norman Klein, *supra* note 503, at 3 ("[e]ven if the individual Plaintiffs' complaints of allergy and asthma symptoms were credited, an exemption of other potential contributing factors must be evaluated before climate change could be determined as a contributing, much less primarily contributing, factor to these specific Plaintiffs."); Expert Report of Dr. John P. Weyant at 10 ("By failing to analyze the potential confounding effect of local conditions, Dr. Trenberth reaches conclusions about the impacts on Plaintiffs that are unsupported and therefore unreliable."), Juliana v. United States, 339 F.Supp.3d 1062 (D. Or. 2018) (No. 6:15-cv-1517); Expert Report of Dr. John P. Weyant at 15 ("When Prof. Running makes claims about injuries to Plaintiffs, he simply presumes that human-induced climate change is the major cause of the multiple hydrological and ecological changes that he discusses, despite the fact that population growth and migration, forest and water management practices, and wildfire and flood prevention measures are also important determinants of the climate events he analyzed."), Juliana v. United States, 339 F.Supp.3d 1062 (D. Or. 2018) (No. 6:15-cv-1517); Expert Report of Dr. John P. Weyant at 18 ("Complicated interactions are emblematic of the confounding factors that scientists need to consider when examining the influence of climate change. It is the part of the reason why Prof. Running's statement that an increased wildfire season due to climate change has and will affect many of the Plaintiffs is an overbroad assertion."), Juliana v. United States, 339 F.Supp.3d 1062 (D. Or. 2018) (No. 6:15-cv-1517).

505. *See, e.g.*, Expert Report of John Weyant *supra* note 504, at 11 ("Overall, Dr. Trenberth's conclusions are not supported by analysis that allows one to determine how and

and failed to demonstrate that the U.S. government could provide adequate redress for the alleged injuries through policy and regulatory actions.[506] They also disputed the share of global emissions attributable to U.S. government action or inaction.[507] One expert estimated that the U.S. government is responsible for no more than 4% of global emissions and that the other 96% of emissions are generated by: (i) countries other than the U.S., or (ii) fossil fuel consumption by entities other than the federal government that would have occurred regardless of federal policies and regulations.[508] Another expert estimated that, even under a consumption-based accounting approach, the share of emissions attributable to the U.S. government is only 5%.[509] Notably, both experts acknowledged that total U.S. emissions are much higher than these estimates regardless of whether a territorial-, consumption-, or extraction-based methodology is used, but they

to what degree Jaime's experiences with water shortages, wildfires, droughts, or heat waves are exacerbated by human-induced climate change.").

506. *See, e.g.*, Expert Report of David G. Victor at 12 , Juliana v. United States, 339 F.Supp.3d 1062 (D. Or. 2018) (No. 6:15-cv-1517) ("US oil and gas producers extract commodities worth $245b per year. The subsidy embodied in the output is only about 1.9% of the total market value of production. In my view, subsidies worth that tiny fraction of the total value are not material to an industry whose prices can swing many multiples of this percentage in a financial quarter."); Expert Report of David G. Victor at 19, Juliana v. United States, 339 F.Supp.3d 1062 (D. Or. 2018) (No. 6:15-cv-1517) ("The effect of oil subsidy reforms on emissions will be much smaller than suggested by Erickson, because other factors have a much larger impact on production decisions, the industry is highly competitive and responsive to changes in market conditions and production costs."); Expert Report of Dr. Daniel Sumner at 8 , Juliana v. United States, 339 F.Supp.3d 1062 (D. Or. 2018) (No. 6:15-cv-1517) ("I conclude that there is considerable doubt as to whether Dr. Robertson's proposed agricultural methods can deliver the amount of GHG abatement that Dr. Robertson claims at any price."). *See, e.g.*, Expert Report of David G. Victor at 4, Juliana v. United States, 339 F.Supp.3d 1062 (D. Or. 2018) (No. 6:15-cv-1517) ("The effect of oil subsidy reforms on emissions will be small to zero.") ; Expert Report of Dr. James L. Sweeney at 13, Juliana v. United States, 339 F.Supp.3d 1062 (D. Or. 2018) (No. 6:15-cv-1517) ("If the U.S. halted its use and production of fossil fuels, the prices of these fuels would fall and other counties would increase their use of fossil fuels.").

507. *See, e.g.*, Expert Report of James Sweeney, *supra* note 506, at 66 ("Plaintiffs and their experts offer no analysis to link the failure to develop policies to the impacts on GHG emissions."); Expert Report of David G. Victor, *supra* note 506, at 5 ("Stiglitz fails to identify plausible, real-world actions that the U.S. government could have taken that would have led to appreciably different outcomes with respect to domestic and international energy systems."); Expert Report of James Sweeney, *supra* note 506, at 56 ("Only a very small fraction of these sources [of U.S. greenhouse gas emissions are] directly controlled by the federal government.").

508. Expert Report of James Sweeney, *supra* note 506, at 60.

509. Expert Report of David G. Victor, *supra* note 506, at 4.

dispute the notion that the U.S. government is responsible for all U.S. emissions.[510] This was consistent with the approach taken by defendants in their answer to the original complaint, in which they admitted key facts about the proportion of global CO_2 emissions generated within the U.S. while maintaining that the U.S. government is not responsible for those emissions.[511] Reviewing these materials in the context of the defendants' motion for summary judgment, the district court found "that plaintiffs have provided sufficient evidence showing that causation for their claims is more than attenuated," that "[t]he ultimate issue of causation will require perhaps the most extensive evidence to determine at trial," and that a "final ruling on this issue will benefit from a fully developed factual record where the Court can consider and weigh evidence from both parties."[512]

Thus, even without the "trial of the century," we can see the contours of the "battle of experts" such a trial would entail. Plaintiffs' primary goal with their expert testimony was to establish that the defendant is responsible for a meaningful contribution to climate change—an amount sufficient to prove causal relationships that satisfy the standing requirements and the even more demanding standards for showing a violation of public trust obligations and/or constitutional rights—and that climate change is the legal cause of specific injuries suffered by the plaintiffs. Defendants' primary strategy was to undermine the reliability of plaintiffs' proffers, and their tactic was to poke holes in plaintiffs' expert reports by challenging the science of source attribution and highlighting the importance of confounding factors.

ii. Other Atmospheric Trust Litigation in the U.S.

There have been a number of similar cases asking state courts to find that state governments have a public trust duty to address climate change (frequently referred to as "atmospheric trust"

510. Expert Report of James Sweeney, *supra* note 506, at 60; Expert Report of David G. Victor, *supra* note 506, at 8–10.

511. *See, e.g.*, Federal Defendants' Answer to the First Amended Complaint for Declaratory and Injunctive Relief at ¶ 151, Juliana v. United States, 339 F. Supp. 3d 1062 (D. Or. 2018) ("Federal Defendants aver that from 1850 to 2012, CO_2 emissions from sources within the United States (including from land use) comprised more than 25 percent of cumulative global CO_2 emissions").

512. *Juliana*, 339 F. Supp. 3d at 1062, 1093.

cases).[513] These cases involve the same sort of inquiry into the extent to which harmful impacts on a public trust resource can be linked to under-regulated greenhouse gas emissions. For example, in *Sanders-Reed v. Martinez*, youth plaintiffs in New Mexico sought a judgment establishing that the state had a public trust duty under state law to protect the atmosphere and that its "failure to investigate the threat posed by climate change" and to devise a plan to "mitigate the effects of climate change" was a breach of that duty.[514] The state district court initially dismissed the case, in part because it determined that New Mexico regulators had properly determined that New Mexico regulation of greenhouse gas emissions "would have no perceptible impact on climate change."[515] The appellate court took a different approach and found that Article XX, Section 21 of the New Mexico state constitution recognizes that a public trust duty exists for the protection of New Mexico's natural resources, including the atmosphere.[516] However, the court also concluded that the state had established legislative and administrative procedures for raising arguments concerning the duty to protect the atmosphere and that these arguments could not be made through a separate common law cause of action.[517] Similarly, courts in Washington State and Alaska have affirmed that those states' public trust doctrines apply to climate change but

513. *See, e.g.*, Kanuk ex rel. Kanuk v. State Dep't of Nat. Res., 335 P.3d 1088 (Alaska 2014); Sinnok v. Alaska, No. 3AN-17-09910, 2018 WL 7501030 (Alaska Super. Ct. 2018); Butler ex rel. Peshlakai v. Brewer, No. 1 CA–CV 12–0347, 2013 WL 1091209 (Ariz. Ct. App. Mar. 14, 2013); Filippone ex rel. Filippone v. Iowa Dep't of Nat. Res., 829 N.W.2d 589 (Iowa Ct. App. 2013) (declining to extend the public trust doctrine to the atmosphere because the Iowa Supreme Court had previously declined to extend the doctrine to forested areas and public alleyways); Aronow v. State, No. A12–0585, 2012 WL 4476642 (Minn. Ct. App. Oct. 1, 2012) (declining to apply the public trust doctrine to the atmosphere because no court in Minnesota or any other jurisdiction has done so, and because it had previously held that the public trust doctrine did not apply to land); Chernaik v. Kitzhaber, 328 P.3d 799 (2014); Svitak ex rel. Svitak v. State, 178 Wash. App. 1020, No. 69710–2–I, 2013, 2013 WL 6632124 (Wash. Ct. App. Dec. 16, 2013); Sanders-Reed ex rel. Sanders-Reed v. Martinez, 350 P.3d 1221 (N.M. 2015); Foster v. Wash. State Dep't of Ecology, 362 P.3d 959 (2015).

514. *Sanders-Reed*, 350 P.3d at 1223 (citing plaintiff's amended complaint to district court).

515. Order Granting Defendants' Motion for Summary Judgement and Denying Plaintiffs' Motion for Summary Judgement, Exhibit A, at TR-3, Sanders-Reed ex rel. Sanders-Reed v. Martinez, No. D-101-CV-2011-01514 (N.M. Dist. July 04, 2013).

516. *Sanders-Reed*, 350 P.3d at 1225.

517. *Id.*

deferred to existing legislation and executive processes as the appropriate means to regulate GHGs.[518]

iii. Foreign Jurisdictions

Similar types of "atmospheric trust" cases have also been brought in foreign jurisdictions to protect rights enumerated in foreign constitutions, human rights instruments, and international treaties. Perhaps most famously, the Supreme Court of the Netherlands recently upheld decisions from the Hague Court of Appeals and the District Court of the Hague in *Urgenda Foundation v. Kingdom of the Netherlands*, finding that the Dutch government had breached its obligations to its citizens by backing away from the previous administration's mitigation commitments, and ordered the government to limit GHG emissions to 25% below 1990 levels by 2020, consistent with what the court viewed as the country's fair contribution towards the U.N. goal of limiting global temperature increases to 2°C above pre-industrial conditions.[519] The Supreme Court supported its decision by referring to IPCC assessments of how climate change is affecting and will affect human and natural systems and an explanation of why the 25% reduction target is necessary to limit global warming to 2°C.[520] Detection and attribution science factored into this analysis in two ways: first, by providing evidence of the harms incurred by Dutch people as a result of climate change (impact attribution); and second, by providing information about the emissions reductions necessary to meet the 2°C target (contribution attribution).

Similar lawsuits have been brought against governments in the United Kingdom,[521] Germany,[522] Canada,[523] Belgium,[524]

518. *Foster*, 362 P.3d 959; Kanuk ex rel. Kanuk v. State Dep't of Nat. Res., 335 P.3d 1088 (Alaska 2014) (ruling that claims for relief raised nonjusticiable political questions); Sinnok v. Alaska, No. 3AN-17-09910, 2018 WL 7501030 (Alaska Super. Ct. 2018).

519. Urgenda Foundation v. Kingdom of the Netherlands, Hoge Raad, ECLI:NL:HR:2019:2007 (Dec. 20, 2019) [hereinafter *Urgenda* decision (2019)]. (English translation available at http://blogs2.law.columbia.edu/climate-change-litigation/wp-content/uploads/sites/16/non-us-case-documents/2020/20200113_2015-HAZA-C0900456689_judgment.pdf).

520. *Id.* at ¶¶ 2.1, 4.1– 4.8, 7.1–7.3.6.

521. Plan B Earth and Others v. Sec'y of State for Bus., Energy, and Indus. Strategy [2018] EWHC 1892 (Admin), (UK), http://climatecasechart.com/non-us-case/plan-b-earth-others-v-secretary-state-business-energy-industrial-strategy/ [https://perma.cc/KPY8-HPF6].

522. Bundesverfassungsgericht [BVerfG] [Federal Constitutional Court], Nov. 26, 2018, (Germany),http://climatecasechart.com/non-us-case/friends-of-the-earth-germany-assoc

Switzerland,[525] India,[526] Pakistan,[527] Colombia,[528] and Uganda,[529] as well as the European Parliament and Council.[530] At the time of this writing, most of these cases are still pending.[531] Four were

iation-of-solar-supporters-and-others-v-germany/[https://perma.cc/E3B4-9TF6];Verwaltungsgericht [VG] [Berlin Administrative Trial Court] Oct. 31, 2019, No. 00271/17 R/SP, (Germany), http://climatecasechart.com/non-us-case/family-farmers-and-greenpeace-germany-v-german-government/ [https://perma.cc/4PBK-8DNV].

523. ENVironnement JEUnesse v. Canada, 2018 QCSC 500-06 (Can.), http://climatecasechart.com/non-us-case/environnement-jeunesse-v-canadian-government/ [https://perma.cc/E9NR-EF8D].

524. Tribunal de Première Instance [Civ.] [Tribunal of First Instance] Brussels, 2016, VZW Klimatzaak v. Kingdom of Belgium, (Belg.), http://climatecasechart.com/non-us-case/vzw-klimaatzaak-v-kingdom-of-belgium-et-al/ [https://perma.cc/E3C9-JWLT].

525. Petition (Summary in English) at ¶ 1(a), Bundesverwaltungsgericht [BVGE] [Federal Administrative Court, Section 1] Nov. 27, 2018, A-2992/2017 (Switz.), http://climatecasechart.com/non-us-case/union-of-swiss-senior-women-for-climate-protection-v-swiss-federal-parliament/ [https://perma.cc/Q2SM-SCEQ].

526. Pandey v. India, (2017) National Green Tribunal, http://climatecasechart.com/non-us-case/pandey-v-india/ [https://perma.cc/VT8P-P6AX].

527. Ali v. Pakistan, Constitutional Petition No. ___ / I of (2016) (SC) (Pak.), http://climatecasechart.com/non-us-case/ali-v-federation-of-pakistan-2/ [https://perma.cc/L228-XQ8T]; Leghari v. Pakistan, (2015) W.P. No. 25501/201 (Lahore High Court) (Pak.), http://climatecasechart.com/non-us-case/ashgar-leghari-v-federation-of-pakistan/ [https://perma.cc/JBN3-XGYJ].

528. Corte Suprema de Justicia [C.S.J.] [Supreme Court], abril 5, 2018, STC4360, No. 11001-22-03-000-2018-00319-01 (Colom.), http://climatecasechart.com/non-us-case/future-generation-v-ministry-environment-others/ [https://perma.cc/53WU-NLJK].

529. Mbabazi and Others v. The Attorney General and National Environmental Management Authority, Civil Suit No. 283 of 2012 (Uganda), http://climatecasechart.com/non-us-case/mbabazi-et-al-v-attorney-general-et-al/ [https://perma.cc/J5RL-U426].

530. Armando Ferrão Carvalho and Others v. The European Parliament and the Council, Case No. T-330/18 (EU General Court 2018), http://climatecasechart.com/non-us-case/armando-ferrao-carvalho-and-others-v-the-european-parliament-and-the-council/ [https://perma.cc/JN4R-3K2Q].

531. Bundesverfassungsgericht [BVerfG] [Federal Constitutional Court], Nov. 26, 2018, (Germany), http://climatecasechart.com/non-us-case/friends-of-the-earth-germany-association-of-solar-supporters-and-others-v-germany/ [https://perma.cc/E3B4-9TF6]; Verwaltungsgericht [VG] [Berlin Administrative Trial Court] Oct. 31, 2019, No. 00271/17 R/SP, (Germany), http://climatecasechart.com/non-us-case/family-farmers-and-greenpeace-germany-v-german-government/ [https://perma.cc/4PBK-8DNV]; Pandey v. India, (2017) National Green Tribunal, http://climatecasechart.com/non-us-case/pandey-v-india/ [https://perma.cc/VT8P-P6AX]; Ali v. Pakistan, Constitutional Petition No. ___ / I of (2016) (SC) (Pak.), http://climatecasechart.com/non-us-case/ali-v-federation-of-pakistan-2/ [https://perma.cc/L228-XQ8T]; Mbabazi and Others v. The Attorney General and National Environmental Management Authority, Civil Suit No. 283 of 2012 (Uganda), http://climatecasechart.com/non-us-case/mbabazi-et-al-v-attorney-general-et-al/ [https://perma.cc/J5RL-U426]; Tribunal de Première Instance [Civ.] [Tribunal of First Instance] Brussels, 2016, VZW Klimatzaak v. Kingdom of Belgium, (Belg.), http://climatecasechart.com/non-us-case/vzw-klimaatzaak-v-kingdom-of-belgium-et-al/

dismissed by courts on procedural grounds or lack of justiciability (e.g., due to lack of standing).[532] Decisions have been issued in the Pakistan and Colombia cases holding that the government violated fundamental rights by failing to address the risks posed by climate change (in both cases, the failure to adapt was discussed along with the failure to mitigate emissions).[533] Attribution science plays the same role in these cases as it did in the *Urgenda* decision—supporting claims about impacts and the government's contribution to those impacts.

c. Cases Challenging Permitting and Licensing Decisions

Plaintiffs have also filed cases challenging permitting and licensing decisions that could increase fossil fuel production and/or GHG emissions. For example, petitioners brought a case in Austria alleging that the government's authorization of the Vienna airport expansion would run afoul of emission reductions targets set forth in Austria's Climate Protection Law as well as the country's commitments under the newly enacted Paris Agreement.[534] An administrative court initially held in favor of petitioners, but that

[https://perma.cc/E3C9-JWLT]; Armando Ferrão Carvalho and Others v. The European Parliament and the Council, Case No. T-330/18 (EU General Court 2018), http://climatecasechart.com/non-us-case/armando-ferrao-carvalho-and-others-v-the-european-parliament-and-the-council/ [https://perma.cc/JN4R-3K2Q].

532. Armando Ferrão Carvalho and Others v. The European Parliament and the Council, Case No. T-330/18 (EU General Court 2018), http://climatecasechart.com/non-us-case/armando-ferrao-carvalho-and-others-v-the-european-parliament-and-the-council/ [https://perma.cc/JN4R-3K2Q]; Plan B Earth and Others v. Sec'y of State for Bus., Energy, and Indus. Strategy [2018] EWHC 1892 (Admin), (UK), http://climatecasechart.com/non-us-case/plan-b-earth-others-v-secretary-state-business-energy-industrial-strategy/ [https://perma.cc/KPY8-HPF6]; Bundesverwaltungsgericht [BVGE] [Federal Administrative Court, Section 1] Nov. 27, 2018, A-2992/2017 (Switz.), http://climatecasechart.com/non-us-case/union-of-swiss-senior-women-for-climate-protection-v-swiss-federal-parliament/ [https://perma.cc/Q2SM-SCEQ]. ENVironnement JEUnesse v. Canada, 2018 QCSC 500-06 (Can.), http://climatecasechart.com/non-us-case/environnement-jeunesse-v-canadian-government/ [https://perma.cc/E9NR-EF8D].

533. Leghari v. Pakistan, (2015) W.P. No. 25501/201 (Lahore High Court) (Pak.) http://climatecasechart.com/non-us-case/ashgar-leghari-v-federation-of-pakistan/ [https://perma.cc/JBN3-XGYJ]; Corte Suprema de Justicia [C.S.J.] [Supreme Court], April 5, 2018, STC4360, No. 11001-22-03-000-2018-00319-01 (Colom.), http://climatecasechart.com/non-us-case/future-generation-v-ministry-environment-others/ [https://perma.cc/53WU-NLJK].

534. Verwaltungsgerichtshof [VwGH] [Administrative Court of Justice] Feb. 2, 2017, W109 2000179-1/291E (Autstria), http://climatecasechart.com/non-us-case/in-re-vienna-schwachat-airport-expansion/ [https://perma.cc/BEL8-KWXF].

decision was overruled by the Austrian Constitutional Court.[535] In Norway, plaintiffs challenged the issuance of licenses for deep-sea oil and gas exploration on similar grounds.[536] The Oslo District Court dismissed the challenge, finding, among other things, that "[e]missions of CO2 abroad from oil and gas exported from Norway are irrelevant" in analyzing the constitutionality of the lease sale;[537] petitioners have appealed that decision. Swedish plaintiffs challenged the sale of coal mines and coal-fired power plants in Germany by Vattenfall—an energy company owned by the Swedish state—again, on similar grounds.[538] The Stockholm District Court denied these requests after determining that the plaintiffs had not experienced an injury from the governmental decisions at issue.[539] Similar lawsuits have been filed in the United Kingdom and Australia.[540] In these types of cases, petitioners can use attribution data to link the emissions generated from the project to harmful effects of climate change.[541] However, as illustrated by the Stockholm District Court's dismissal on standing grounds, it may be more difficult to establish injury based on emissions from specific licensing decisions as compared with cases challenging broader government failures to act on climate change.

535. *Id.*; Verfassungsgerichtshof [VfGH] [Constitutional Court] June 29, 2017, E 875/2017, E 886/2017, http://climatecasechart.com/non-us-case/in-re-vienna-schwachat-airport-expansion/ [https://perma.cc/BEL8-KWXF].

536. Greenpeace Nordic Ass'n at 18–19, Case No. 16-166674TVI-OTIR/06, (Oslo District Court, Jan. 4, 2018), http://climatecasechart.com/non-us-case/greenpeace-nordic-assn-and-nature-youth-v-norway-ministry-of-petroleum-and-energy/ [https://perma.cc/7R8N-EW2Q].

537. *Id.* at 21.

538. Tingsrätt [TR] [Stockholm District Court] 2016-09-15 (Sweden), http://climatecasechart.com/non-us-case/push-sweden-nature-youth-sweden-et-al-v-government-of-sweden/ [https://perma.cc/MX84-N5QW].

539. *Id.*

540. *Ironstone Community Action Group Inc. v. NSW Minister for Planning and Duralie Coal Pty. Ltd.*, (2011) NSWLEC 195 (Austl.), http://climatecasechart.com/non-us-case/ironstone-community-action-group-inc-v-nsw-minister-for-planning-and-duralie-coal-pty-ltd/ [https://perma.cc/9YBF-XS5J]; Plan B Earth and Others v. Sec'y of State for Transport, [2019] EWHC 1070 (Admin) (UK),http://climatecasechart.com/non-us-case/plan-b-earth-v-secretary-of-state-for-transport/ [https://perma.cc/N9R8-JBY8].

541. *See*, *e.g.*, Complaint at 3, Tingsrätt [TR] [Stockholm District Court] 2016-09-15 (Sweden), http://climatecasechart.com/non-us-case/push-sweden-nature-youth-sweden-et-al-v-government-of-sweden/ [https://perma.cc/MX84-N5QW]; Complaint at Section 3.6.1, Verwaltungsgerichtshof [VwGH] [Administrative Court of Justice] Feb. 2, 2017, W109 2000179-1/291E (Autstria), http://climatecasechart.com/non-us-case/in-re-vienna-schwachat-airport-expansion/ [https://perma.cc/BEL8-KWXF]. Plaintiffs in these cases also argued that emissions from the proposed projects would prevent the country from achieving its fair share of emissions reductions as called for in the UNFCCC and the Paris Agreement.

4. Legal Defense of Greenhouse Gas Emission Standards and Related Actions

As governments introduce an increasing number of laws, policies, and programs aimed at addressing the causes and impacts of climate change, the number of lawsuits challenging these actions will also increase.[542] These are similar to lawsuits challenging the failure to regulate greenhouse gas emissions—the key difference being that these lawsuits involve allegations that regulations are *too* stringent or that other actions taken to curtail emissions (e.g., permit denials) are unjustified. Indeed, both types of claims could be, and often are, brought with respect to the same regulatory action, with one side arguing that emission standards are insufficient and another arguing that they are too stringent.[543]

One example of a defense case which involved considerable attention to attribution science was *Green Mountain Chrysler Plymouth Dodge Jeep v. Crombie*.[544] In a legal challenge to Vermont's Low Emission Vehicle Program, automobile manufacturers and retailers specifically challenged the scientific basis for the standards, arguing that the program would impose significant costs but "do nothing concrete to improve air quality or the health of Vermont residents."[545] To support this claim, the petitioners emphasized that CO_2 is unlike other air pollutants in that it disperses globally throughout the upper atmosphere and then cited this fact as the

542. *See, e.g.*, Société Arcelor Atlantique et Lorraine v. [EU] Parliament and Council (environment and consumers), Case T-16/04 (EU General Court 2010), http://climatecasechart.com/non-us-case/societe-arcelor-atlantique-et-lorraine-v-eu-parliament-and-council-environment-and-consumers/ [https://perma.cc/VD3V-7VTM]; Essent Belgium NV v. [Flemish region of] Vlaams Gewest, Case C-492/14 (Netherlands 2016), http://climatecasechart.com/non-us-case/essent-belgium-nv-v-flemish-region-of-vlaams-gewest/ [https://perma.cc/JNQ7-N66U]; Maia Filho v. Federal Environmental Agency (IBAMA), Special Appeal 1000.732 – RO (Brazil 2015), http://climatecasechart.com/non-us-case/maia-filho-v-environmental-federal-agency-ibama/ [https://perma.cc/AZ4L-TTM8]; Gloucester Resources Limited v. Minister for Planning, [2019] NSWLEC 7 (Australia 2019), http://climatecasechart.com/non-us-case/gloucester-resources-limited-v-minister-for-planning/ [https://perma.cc/XDW3-WLJY] (in a legal challenge appealing the denial of a company's application to construct a coal mine, an Australian court upheld the government's denial of permit on climate change grounds).

543. *See, e.g.*, Coal. for Responsible Regulation v. EPA, No. 09-1322 (D.C. Cir. Dec 23, 2009); Sierra Club v. EPA, No. 10-1215 (D.C. Cir. Aug 2, 2010) (both challenging EPA's Tailoring Rule).

544. Green Mountain Chrysler Plymouth Dodge Jeep v. Crombie, 508 F. Supp. 2d 295 (D. Vt. 2007).

545. Complaint ¶ 4, *Green Mountain Chrysler*, Dkt. 1, 508 F. Supp. 2d 295 (2:05-cv-302) filed Nov. 18, 2005.

basis for arguing that CO_2 reductions in Vermont would not have any practical impact on public health in Vermont.[546] Vermont, joined by other defendants, solicited expert testimony from scientists to contradict these claims, and the petitioners attacked the credibility of these scientists. The reviewing court issued a lengthy opinion evaluating the scientific claims and finding that the scientific basis for the emission standards was sound.[547] The court cited specific examples of climate-related harms, including potentially severe effects on Vermont, as well as language from the Supreme Court's decision in *Massachusetts* highlighting the legitimacy of small and incremental regulatory steps to address climate change.[548] The decision also contained a lengthy explanation of why expert testimony from climate scientists such as James Hansen was admissible under the *Daubert* test.[549]

5. Lawsuits to Hold Emitters Liable for Damages Caused by Climate Change Impacts

In addition to suing governments for failure to regulate greenhouse gas emissions, some plaintiffs have gone directly to the source, suing major emitters, such as utilities, as well as fossil fuel companies, in an attempt to obtain an injunction against future emissions or monetary damages for adaptation costs. To date, these lawsuits have been predominately domestic, and based on tort or tort-like theories such as public nuisance, private nuisance, and negligence.[550] In one instance, an environmental organization and Philippine citizens filed a petition with the Human Rights Commission of the Philippines claiming that fossil fuel companies' activities constitute a violation of their human rights.[551] In the future, it is possible that climate change lawsuits may be brought by foreign nations or citizens against private actors in either U.S. courts or within their domestic jurisdictions.[552] Attribution science is central to any and all such cases, as it is necessary to establish a causal connection between the defendant's emissions or activities

546. *Id.* at 9–11.

547. *Green Mountain Chrysler*, 508 F. Supp. at 339–40.

548. *See, e.g.*, *id.* at 309.

549. *Id.* at 310–33.

550. Burger & Wentz, *supra* note 8.

551. In re Greenpeace Southeast Asia and Others, Case No. CHR-NI-2016-0001 (2015).

552. *See* Michael Byers et al., *The Internationalization of Climate Damages Litigation*, 7 WASH. J. ENVTL. L. & POL'Y 264 (2017).

and plaintiffs' injuries, and that the injuries were a foreseeable result of the emissions.

Much has been written on the prospect of climate change torts.[553] As others have noted, these analyses sit along a "spectrum," ranging from "those who are optimistic about the prospects for climate damages litigation [and] argue that climate damages are not fundamentally different from other types of common law damages

553. *See* Albert C. Lin & Michael Burger, *State Public Nuisance Claims and Climate Change Adaptation*, 36 PACE ENVTL. L. REV. 49 (2018); Byers et al., *supra* note 552; R. Henry Weaver & Douglas A. Kysar, *Courting Disaster: Climate Change and the Adjudication of Catastrophe*, 93 N.D. L. REV. 295 (2017); CLIMATE CHANGE LIABILITY: TRANSNATIONAL LAW AND PRACTICE (Richard Lord et al. eds., Cambridge University Press 2012); David Weisbach, *Negligence, Strict Liability, and Responsibility for Climate Change*, 97 IOWA L. REV. 521 (2011–2012); CLIMATE CHANGE LIABILITY (Michael Faure & Marjan Peeters, eds., Edward Elgar 2011); Amy Sinden, *Allocating the Costs of the Climate Crisis: Efficiency Versus Justice*, 85 WASH. L. REV. 293, 323–39 (2010); Matthew F. Pawa, *Global Warming: The Ultimate Public Nuisance*, 39 ENVTL. L. REP. 10230 (2009); Christopher R. Reeves, *Climate Change on Trial: Making the Case for Causation*, 32 AM. J. TRIAL ADVOC. 495 (2009); Kirk B. Maag, Note, *Climate Change Litigation: Drawing Lines to Avoid Strict, Joint, and Several Liability*, 98 GEO. L.J. 185 (2009); Randall S. Abate, *Automobile Emissions and Climate Change Impacts: Employing Public Nuisance Doctrine as Part of a "Global Warming Solution" in California*, 40 CONN. L. REV. 591 (2008); Shi-Ling Hsu, *A Realistic Evaluation of Climate Change Litigation Through the Lens of a Hypothetical Lawsuit*, 79 U. COLO. L. REV. 701 (2008); Timothy D. Lytton, *Using Tort Litigation to Enhance Regulatory Policy Making: Evaluating Climate-Change Litigation in Light of Lessons from Gun-Industry and Clergy-Sexual-Abuse Lawsuits*, 86 TEX. L. REV. 1837 (2008); James R. May, *Climate Change, Constitutional Consignment, and the Political Question Doctrine*, 85 DENV. L. REV. 919 (2008); Amelia Thorpe, *Tort-Based Climate Change Litigation and the Political Question Doctrine*, 24 J. LAND USE & ENVTL. L. 79 (2008); Jonathan Zasloff, *The Judicial Carbon Tax: Reconstructing Public Nuisance and Climate Change*, 55 UCLA L. REV. 1827 (2008); Erin Casper Borissov, Note, *Global Warming: A Questionable Use of the Political Question Doctrine*, 41 IND. L. REV. 415 (2008); David A. Dana, *The Mismatch Between Public Nuisance Law and Global Warming*, 18 SUP. CT. ECON. REV. 9 (2010); David Hunter & James Salzman, *Negligence in the Air: The Duty of Care in Climate Change Litigation*, 155 U. PA. L. REV. 1741 (2007); Myles Allen et al., *Scientific Challenges in the Attribution of Harm to Human Influence on Climate*, 155 U. PA. L. REV. 1353 (2007); Daniel J. Grimm, Note, *Global Warming and Market Share Liability: A Proposed Model for Allocating Tort Damages Among CO2 Producers*, 32 COLUM. J. ENVTL. L. 209 (2007); Sarah Olinger, Comment, *Filling the Void in an Otherwise Occupied Field: Using Federal Common Law to Regulate Carbon Dioxide in the Absence of a Preemptive Statute*, 24 PACE ENVTL. L. REV. 237 (2007); Benjamin P. Harper, Note, *Climate Change Litigation: The Federal Common Law of Interstate Nuisance and Federalism Concerns*, 40 GA. L. REV. 661 (2006); Thomas W. Merrill, *Global Warming as a Public Nuisance*, 30 COLUM. J. ENVTL. L. 293 (2005); Matthew F. Pawa & Benjamin A. Krass, *Global Warming as a Public Nuisance:* Connecticut v. American Electric Power, 16 FORDHAM ENVTL. L. REV. 407 (2005); James R. Drabick, Note, *"Private" Public Nuisance and Climate Change: Working Within, and Around, the Special Injury Rule*, 16 FORDHAM ENVTL. L. REV. 503 (2005); Myles R. Allen & Richard Lord, *The Blame Game: Who Will Pay for the Damaging Consequences of Climate Change?*, 432 NATURE 551 (2004); David A. Grossman, *Warming Up to a Not-So-Radical Idea: Tort-Based Climate Change Litigation*, 28 COLUM. J. ENVTL. L. 1 (2003); Eduardo M. Peñalver, *Acts of God or Toxic Torts? Applying Tort Principles to the Problem of Climate Change*, 38 NAT. RESOURCES J. 563 (1998).

that already give rise to liability," to those who "accept that existing legal concepts could form a basis to recover climate damages, [but] they caution that such cases face a series of challenges often centered around causation," to those who "argue that climate damages claims face threshold issues that will likely prevent them from ever being argued on their merits."[554] Among these, Professor Douglas Kysar has done the most to conceptualize and articulate the problems confronting any such claim:

> Tort law seems ill-equipped to address the causes and impacts of climate change: diffuse and disparate in origin, lagged and latticed in effect, anthropogenic greenhouse gas emissions represent the paradigmatic anti-tort, a collective action problem so pervasive and so complicated as to render at once both all of us and none of us responsible. Thus, courts will have ample reason—not to mention doctrinal weaponry—to prevent climate change tort suits from reaching a jury.[555]

This leads Kysar to the conclusion that "tort law is unlikely to play a substantial role in the ultimate effort to reduce greenhouse gas emissions,"[556] placing him on the relatively skeptical end of the spectrum. At the same time, however, Kysar exposes the potential for encounters with climate change tort claims to shift "the bar for exoticism in tort":

> Various suits that have frustrated judges because of their scale, scientific complexity, and widespread policy implications—such as claims involving toxic and environmental harm, tobacco and handgun marketing, or slavery and Holocaust reparations—may come to seem less daunting and intractable when juxtaposed against "the mother of all collective action problems." Current debate over whether courts are engaging in "regulation through litigation" may come to appear miscast in the face of suits that raise at once both an ordinary pollution nuisance and a challenge to the very foundations of modern industrial life. At long last, courts and commentators may come to view tort claims in degrees of polycentricity, rather than in crude binary terms of conventional civil disputes, on the one hand, and political or regulatory matters, on the other.[557]

554. Byers et al., *supra* note 552, at 270–71.

555. Douglas A. Kysar, *What Can Climate Change Do About Tort Law*, 41 ENVTL. L. 1, 4 (2011).

556. *Id.*

557. *Id.* at 4–5.

If the bar shifts, it may well be that the bar shifts not only after but *during* the course of climate tort litigation.[558] To date, Kysar's first prediction, at least, has proved correct. While there have been quite a few successful cases brought against governments for failure to regulate greenhouse gas emissions,[559] the same cannot be said for lawsuits aimed at holding emitters liable for damages caused by climate change impacts. The authors are not aware of any such lawsuit that has been successful to date. Moreover, the influence of these cases on the shape of tort law remains to be seen. But our purposes here are more limited than Kysar's deep conceptualization of tort law: namely, to provide a summary of key issues confronting common law climate change cases and to identify the role attribution science has played, is playing, and might yet play in resolving them.

Accordingly, in this section we describe the basic elements of tort—duty, breach, causation, and harm—and how climate change insinuates itself into an analysis of them. We then assess the role attribution science might play in meeting evidentiary standards in a court of law, and ultimate persuasive outcomes on the merits. Finally, we describe the way attribution science played into a number of high-profile climate tort cases in the past, to give an inkling of what may lie ahead in the future.

a. Elements of Negligence & Nuisance

The legal elements required to prevail on different tort claims differ from one another: to prevail on a negligence claim, the plaintiff must establish that the defendant has breached a duty or standard of care, that this breach caused a personal injury to the plaintiff, and that the defendant's conduct is the "proximate cause" of the injury.[560] To prevail on a private nuisance claim, the plaintiff must establish that the defendant's conduct has caused a "substantial and unreasonable interference with plaintiff's use and enjoyment of property."[561] To prevail on a public nuisance claim,

558. Weaver & Kysar, *supra* note 553; *see also* Douglas A. Kysar, *The Public Life of Private Law: Tort Law as a Risk Regulation Mechanism*, 9 EUR. J. RISK. REG. 48 (2018).

559. *See supra* Part III(C)(3)(a)(i) (Massachusetts v. EPA); *see supra* Part III(C)(3)(c)(iii) (Foreign Jurisdictions).

560. RESTATEMENT (SECOND) OF TORTS § 281 (AM. LAW INST. 1965).

561. RESTATEMENT (SECOND) OF TORTS § 822 (AM. LAW INST. 1979).

the plaintiff must establish that the defendant's conduct has caused an "unreasonable interference with a right common to the public."[562] Despite the differences, they do all share some common elements. The concepts of duty and breach, explicit in negligence, are imported into nuisance through the concept of "unreasonable interference." Proximate causation and a resulting harm or injury are required in all three.

Below, we summarize the key elements of tort cases and briefly touch on how attribution science may help with establishing these elements. This summary is followed by a more in-depth overview of the role of attribution science in climate change cases.

i. Duty

It is a well-worn story that tort law's notion of a legal duty is a confusing, muddled concept, generally bounded by the competing opinions by Judge Cardozo and Judge Andrews set forth in *Palsgraf v. Long Island Railroad Company* some ninety years ago.[563] In Judge Cardozo's view, "antisocial conduct only triggers a duty of tort responsibility when its potential harmful effects can be attached to particular, identifiable victims" and the risk of harm is "apparent to the eye of ordinary vigilance."[564] In other words, "the risk reasonably to be perceived defines the duty to be obeyed, and risk imports relation; it is a risk to another or to others within the range of apprehension."[565] Foreseeability, then, is part of Cardozo's definition of tort duty. In contrast, Judge Andrews' dissent presents a "communal notion of responsibility in which all actors are under a duty to avoid unreasonable behavior, irrespective of whether that behavior implies a particular relation of responsibility to plaintiffs."[566] Judge Andrew explained: "Due care is a duty imposed on each one of us to protect society from unnecessary danger, not to protect A, B, or C alone."[567] For Judge Andrews, the issue of foreseeability of injury to a particular plaintiff may be relevant to the proximate cause inquiry, but not the nature of the

562. Connecticut v. Am. Elec. Power Co., 582 F.3d 309, 369–70 (2d Cir. 2009), *rev'd*, 564 U.S. 410 (2011).

563. Palsgraf v. Long Island R.R. Co., 162 N.E. 99 (N.Y. 1928).

564. Kysar, *supra* note 555, at 13; *Palsgraf*, 162 N.E. at 99.

565. *Palsgraf*, 162 N.E. at 100.

566. Kysar, *supra* note 555, at 14.

567. *Palsgraf*, 162 N.E. at 102.

defendant's duty.[568] Federal and state courts wrestling with cases sounding in negligence and nuisance fall somewhere within this range, with some courts embracing foreseeability of harm to the specific plaintiff as an element of duty[569] and others rejecting it.[570]

The identification of a legal duty under Cardozo's concept is deeply complicated by the facts of climate change. Climate change is, after all, a "geophysical problem . . . centuries in the making (and studying) with causes ranging from volcanoes, to wildfires, to deforestation to stimulation of other greenhouse gases . . . . to the combustion of fossil fuels."[571] What's more, "the range of consequences is likewise universal—warmer weather in some places that may benefit agriculture but worse weather in others, e.g., worse hurricanes, more drought, more crop failures and . . . the melting of the ice caps, the rising of the oceans, and the inevitable flooding of coastal lands."[572] Would the "eye of ordinary vigilance" demanded by Judge Cardozo[573] foresee a pathway leading from a particular activity located somewhere in the "train of industry"[574] to a particular climate change-related injury experienced by a particular person in a particular place and time? Is the duty more easily recognizable if the entity suffering the injury is a state, a city, a tribe, or a certified class? If the particularized harms that come from producing, transporting, storing, marketing, selling, combusting, and/or consuming fossil fuels so as to emit greenhouse gases are foreseeable now, at what point did they become so?

Where foreseeability is an element of tort duty, the history and current and future states of attribution science will play a role in establishing and defending against it. However, even in a case

568. *Id.* at 104.

569. *See, e.g.,* Norris v. Corr. Corp. of Am., 521 F. Supp. 2d 586, 589 (W.D. Ky. 2007).

570. *See, e.g.,* Rodriguez v. Del Sol Shopping Ctr. Assocs., L.P., 326 P.3d 465, 467 (N.M. 2014); Thompson v. Kaczinski, 774 N.W.2d 829, 835 (Iowa 2009). The decisions rejecting foreseeability as an element of duty are consistent with the Third Restatement of Torts, which notes: "Despite widespread use of foreseeability in no-duty determinations, this Restatement disapproves that practice and limits no-duty rulings to articulated policy or principle in order to facilitate more transparent explanations of the reasons for a no-duty ruling and to protect the traditional function of the jury as factfinder." RESTATEMENT (THIRD) OF TORTS: PHYS. & EMOT. HARM § 7, cmt. j (AM. LAW INST. 2010).

571. California v. BP P.L.C., No. C 17-06011 WHA, 2018 WL 1064293 (N.D. Cal. Feb. 27, 2018).

572. *Id.*

573. *Palsgraf,* 162 N.E. at 99.

574. California v. BP P.L.C., 2018 WL 1064293, at *4.

governed by Judge Andrews' more expansive view—for instance, a public nuisance case where the duty is more widely distributed—plaintiffs cannot evade the issue of foreseeability. It will come up in establishing proximate cause. As Kysar explains, "plaintiffs will face the challenge of establishing foreseeability in a way that does not strain liberal notions of limited obligation beyond the breaking point."[575] The end result could be a global duty owed by some select group of actors to people everywhere. Or it could mean that no legal duty exists to constrain these types of behaviors.

ii. Breach

Once a duty has been established, liability can only attach if there has been a breach, in some form, of that duty. The key issue in assessing a breach, under a conventional analysis, involves balancing competing values, both in negligence and nuisance. In the negligence context, a breach occurs where the plaintiff has failed to exercise reasonable care to protect others from a foreseeable risk of harm. What constitutes "reasonable care" is typically defined by what a "reasonable person" would do under similar circumstances.[576] In nuisance, the breach factors into an assessment of whether defendant's interference with plaintiff's person, property, or public goods was "unreasonable." To determine what constitutes an "unreasonable interference," courts may weigh factors such as the utility of the conduct giving rise to the alleged nuisance, the cost of abating the alleged nuisance, and the severity of the harm caused by defendant's conduct when deciding whether the conduct is indeed a nuisance.[577]

In both instances, the "reasonableness" inquiry involves something of a "social welfare cost-benefit test,"[578] with one critical factor being whether the cost of taking precautions is greater or less than the cost of potential harm.[579] Attribution science has a

575. Kysar, *supra* note 555, at 17.

576. RESTATEMENT (SECOND) OF TORTS § 283 (AM. LAW INST. 1965).

577. RESTATEMENT (SECOND) OF TORTS § 826 (AM. LAW INST. 1979). While a balancing of harm versus utility is typically required in nuisance cases seeking injunctive relief, some courts have held that such balancing is not required where plaintiffs are seeking monetary damages. *See, e.g.*, Nat'l Energy Corp. v. O'Quinn, 233 VA. 83, 86 (1982).

578. Kysar, *supra* note 555, at 21.

579. United States v. Carroll Towing Co., 159 F.2d 169, 173 (2d Cir. 1947) (liability in negligence will be found if the probability of harm multiplied by the gravity of the potential injury exceeds the cost of precaution).

role to play in calculating the costs of climate change. As discussed in Part II, attribution science is the connective tissue tying particular impacts resulting in particular costs back to climate change and anthropogenic influence on climate change, and it can help improve calculations of the social cost of greenhouse gas emissions.[580]

In some instances, attribution science may have a role to play in calculating the benefits of climate change. As has been long-recognized, climate change does produce some "winners."[581] Changes that lead to increased agricultural production in some northern latitudes may be identified through attribution science. However, many of the benefits of defendants' activities will fall outside the scope of attribution science. These include things like the economic, social, health, and welfare benefits of fossil fuel development, power production, transportation, materials manufacturing, cement, shipping, aviation, and so forth and so on.

Courts will also consider foreseeability when assessing the reasonableness of conduct (a concept that cuts across the elements of duty, breach, and proximate cause). Again, attribution science plays an obvious role in this inquiry, helping to establish that a reasonable person would anticipate that activities which generate greenhouse gas emissions or otherwise contribute to climate change[582] will eventually result in specific types of harmful impacts. But there are limitations on the extent to which attribution science can establish foreseeability with respect to specific impacts and specific plaintiffs, which we discuss in further detail below.

There are other factors underpinning the "reasonableness" analysis that do not implicate climate change attribution science—these include custom, common practice, and regulatory treatment (e.g., whether the conduct is proscribed by law). Thus, while attribution studies can give weight to the idea that major contributions to climate change are "unreasonable," a court may

580. *See also* Kysar, *supra* note 555, at 22–23 (discussing application of SC-CO_2 to *American Electric Power*).

581. *See, e.g.*, J.B. Ruhl, *The Political Economy of Climate Change Winners*, 97 MINN. L. REV. 206 (2012); Michael H. Glantz, *Assessing the Impacts of Climate: The Issue of Winners and Losers in a Global Climate Change Context*, 65 STUD. IN ENVTL. SCI. 41 (1995).

582. Deforestation and the marketing of fossil fuels would be examples of conduct which does not directly generate greenhouse gas emissions but nonetheless contributes to climate change.

nonetheless conclude that such conduct is reasonable because it is a customary pattern of behavior.

iii. Causation

In addition, the plaintiff must show that the defendant's conduct was both the factual and the proximate, or legal, cause of the injury.[583] Factual causation concerns the scientific relationship between the defendant's action or behavior and the alleged injury.[584] To show factual causation, one must show both general, or generic, causation, and specific, or individualized, causation.[585] One commentator offered this useful summary: "General causation refers to whether the action in question *could have* caused the alleged injury, while specific causation refers to whether the action in question 'more likely than not' *actually caused* the alleged injury."[586] These are separate inquiries, that raise distinct questions for attribution science.

In regards to general causation, one critical question is whether and under what circumstances courts will impose liability on an actor who is not the sole cause of the injury. Underpinning this is the question of how courts might apportion liability among multiple emitters. In failure-to-regulate cases, some courts have granted standing based on a showing that the unregulated emissions made a "meaningful contribution" to climate change.[587] Courts have devised alternative tests for apportioning liability in tort cases. Consider the example of "toxic tort" cases, which involve claims of injury caused by exposure to harmful substances, and where there are multiple potential defendants that caused the exposure (e.g., by producing or releasing the harmful substance into the environment).[588] These cases have much in common with tort actions undertaken against greenhouse gas emitters, insofar as there is a "basic problem of proving, even defining, causal relationships in an environment where multiple causation

583. Byers et al., *supra* note 552, at 279.
584. *Id.*
585. *Id.*
586. *Id.*
587. *See supra* Part III(C)(1)(b) (Case Law on Standing to Sue for Climate Change-Related Harms).
588. *See* Glen O. Robinson, *Probabilistic Causation and Compensation for Tortious Risk*, 14 J. LEGAL STUD. 779 (1985).

confounds the possibility of isolating one 'responsible' cause as the touchstone of legal liability."[589]

As in toxic tort cases, there are several ways that liability may be apportioned among potentially responsible parties in this context, including the use of statistical, probabilistic, and epidemiological studies.[590] Due to the nature of the claims in toxic tort cases, it is typically impossible to show that a particular plaintiff's health condition is directly and solely caused by exposure to a substance generated by a specific defendant.[591] To overcome this hurdle, the plaintiffs in toxic tort cases have used statistical analyses and computer modeling to present: (i) probabilistic estimates of health risks associated with chemical exposures, and (ii) relative contributions to that risk from different parties.[592] Where the probability that a particular defendant's substance caused a substantial portion of the harm reaches a certain threshold, then courts may be willing to impose liability for the harm. For example, some courts require plaintiffs to show that their injuries were "more likely than not" caused by the defendant's conduct, and this requirement has been met through showings that the behavior increased the risk of the harm occurring by a factor of 2.[593] However, other courts have held that probabilistic proof is insufficient for imposing liability and have demanded "particularistic proof" of a causal connection.[594]

In regards to specific causation, the critical question is "whether defendant's actions or behavior were 'a necessary element' in bringing about the injury."[595] Assuming one can show that climate change is responsible for a particular local climate-related phenomenon or event that produced an injury, and before one

589. *Id.* at 780.

590. Byers et al., *supra* note 552, at 279.

591. Note, *Causation in Environmental Law: Lessons from Toxic Torts,* 128 HARV. L. REV. 2256, 2259 (2015) ("Because of the nature of the substances generally involved, the harms due to exposure typically are not discovered until long after the exposure occurred. In addition, over that period of time, the injured party may have been exposed to a variety of potentially harmful substances, likely as a result of actions by a variety of different actors. As a result, identifying any responsible party, much less identifying all responsible parties, can be quite difficult.").

592. *Id.* at 2268–69 (citing Daniel Farber, *Toxic Causation,* 71 MINN. L. REV. 1219, 1220 n.7 (1987)).

593. Albert C. Lin, *Beyond Tort: Compensating Victims of Environmental Toxic Injury,*78 S. CAL. L. REV. 1439, 1450 (2005); Grossman, *supra* note 553, at 23.

594. Lin, *supra* note 593, at 1450.

595. Byers et al., *supra* note 552, at 280.

gets to issues of contributory negligence, the problem for proving climate harms here is clear: emissions of any one actor, or even any small set of actors, will be difficult to pin down as a "but-for" cause of impacts arising from anthropogenic climate change.[596]

Again, though, toxic tort law has encountered similar situations—even if at an entirely different scale—and developed approaches through which to assign liability. The "substantial factor" or "material contribution" test allows a court to find liability where a defendant's conduct was a "substantial factor" in bringing about or a "material contribution" to a plaintiff's injury.[597] The "commingled approach" offers another possible approach. In litigation over groundwater contamination from MTBE, a court held that "[w]hen a plaintiff can prove that certain gaseous or liquid products . . . of many suppliers were present in a completely commingled or blended state at the time and place that the risk of harm occurred, and the commingled product caused a single indivisible injury, then each of the products should be deemed to have caused the harm."[598] Under a market share theory of liability, defendants may be held liable for injuries caused by a product based on their respective "shares" in the manufacture and sale of the product.[599]

In contrast to the factual causation inquiry, which focuses on scientific relationships, proximate cause is intended to address whether the injury is sufficiently closely related to the allegedly wrongful conduct, such that it makes sense to impose liability on the defendant.[600] To answer this question, courts may consider factors such as the geographic and temporal proximity between the conduct and the injury (and more generally, the directness of the relationship between conduct and injury), and whether the injury was a foreseeable result of the conduct.[601] As Justice Andrews

596. *See, e.g.* Kysar, *supra* note 555, at 31; Michael Duffy, *Climate Change Causation: Harmonizing Tort Law and Scientific Probability,* 28 TEMP. J. SCI. TECH. & ENVTL. L. 185 (2009).

597. Byers et. al., *supra* note 552, at 281–82.

598. In re Methyl Tertiary Butyl Ether (MTBE) Prod. Liab. Litig., 379 F. Supp. 2d 348, 377–78 (S.D.N.Y. 2005).

599. Byers et al., *supra* note 552, at 283.

600. Another way of posing this question is to ask whether the defendant should be shielded from liability even if he or she is the cause-in-fact of the injury. *See* Luke Meier, *Using Tort Law to Understand the Causation Prong of Standing,* 80 FORDHAM Law L. REV. 1241, 1249 (2011).

601. KENNETH S. ABRAHAM, THE FORMS AND FUNCTIONS OF TORT LAW 124 (3d ed. 2007). The Supreme Court has held that defendants must establish a direct link between conduct

explained in his *Palsgraf* dissent, "open-ended concepts such as fairness, justice, policy, practical politics, and common sense" may also factor into the proximate cause analysis.[602]

We have already touched on how attribution science can be used to establish causation (in the context of standing) and foreseeability (in the context of duty and breach). A more detailed analysis of the role of attribution science with respect to these two elements is provided in Section III.C.4.b.

iv. Harm or Injury

Regardless of the tort, actual harm must be shown. For a negligence claim, breach must give rise to an injury that is similar to, but not always identical to, the sort of "injury-in-fact" required for standing purposes. Courts have yet to articulate a clear distinction between standing and negligence injuries, but there are some subtle differences in terms of how these concepts are typically defined. For example, most courts have held that negligence liability requires proof of actual harm, whereas standing can be based on a harm that has yet to occur but is imminent.[603] At the same time, the types of harms that can support a negligence claim are defined more broadly to include emotional distress, and in some jurisdictions, this has become a vehicle for imposing liability on defendants whose negligent conduct increases the risk of harm to a plaintiff, thereby causing emotional distress.[604]

and injury to satisfy proximate cause requirements under various statutory frameworks that mirror common law doctrines, and that courts should not go beyond the "first step" of the causal chain to establish that link under these statutes. *See* Bank of Am. Corp. v. City of Miami, 137 S.Ct. 1296 (2017). While directness is certainly relevant to the proximate cause inquiry for tort liability, this narrow interpretation of what qualifies as a sufficient "direct" cause has not been extended to common law cases.

602. David Owen, *Figuring Foreseeability*, 44 WAKE FOREST L. REV. 1277 (2009) (citing *Palsgraf*, 162 N.E. at 103–05 (Andrews, J., dissenting)).

603. Albert Lin, *The Unifying Role of Harm in Environmental Law*, 3 WIS. L. REV. 897, 911 (2006); Cass Sunstein, *Standing Injuries,* SUP. CT. REV. 37 (1993).

604. *See* RESTATEMENT (THIRD) OF TORTS: PHYS. & EMOT. HARM § 8, Scope Note (AM. LAW INST. 2012). Courts may require that the emotional injury be linked to some sort of physical harm or impact, such as exposure to a toxic substance, which gives rise to a "reasonable fear" of a physical harm. *See, e.g.*, Sterling v. Velsicol Chem. Corp., 855 F.2d 1188, 1205-06 (6th Cir. 1988) (holding that mental distress from a reasonable fear of cancer is an adequate injury for tort liability under Tennessee law). But some jurisdictions recognize a cause of action for negligent infliction of emotional distress absent any physical impact or injury. *See* Lin, *supra* note 603, at 903–07.

Like negligence, there is some precedent for treating risk as an injury in the context of nuisance claims. Specifically, under the doctrine of "anticipatory nuisance," courts may enjoy an anticipatory or prospective nuisance activity that has not yet caused harm but threatens to do so.[605] In most cases, to prevail on an anticipatory nuisance claim, the plaintiff must show that there is a "high probability" or "reasonable certainty" of injury.[606] Here, again, attribution science would be used in the ways described above—both as a means of characterizing the injury (interference) to the plaintiff, and as a means of explaining why the interference is unreasonable and a threat.

b. Role of Attribution Science

As noted above, attribution science can be used to establish three key elements in tort litigation: foreseeability, causation, and injury. The foregoing discussion of standing illustrates how attribution science is used to establish injury, and while there are subtle differences in how "injury" is defined in standing and on the merits of tort cases, the role of attribution science in these two contexts is roughly the same. We therefore focus here on how attribution science can support findings of foreseeability and causation.

Foreseeability and causation are closely linked—the same research that can be used to establish a causal connection between climate change and impacts can also be used to establish the foreseeability of impacts—but they are not one in the same. To the contrary, there may be circumstances where an impact may have been caused by climate change but was not foreseeable, and circumstances where an impact is a foreseeable consequence of climate change but cannot be causally linked to climate change. It is therefore important to discuss these as distinct applications of attribution science.

With regards to foreseeability: the existing detection and attribution literature highlights a wide array of impacts that are already occurring as a result of climate change and lends credibility to predictions of future impacts. A court's determination as to

605. PROSSER & KEETON ON THE LAW OF TORTS 640-41 (5th ed. 1984); George P. Smith, II, *Re-Validating the Doctrine of Anticipatory Nuisance,* 29 VT. L. REV. 687, 689 (2005).

606. Smith *supra* note 605, at 689; Charles J. Doane, *Beyond Fear: Articulating a Modern Doctrine in Anticipatory Nuisance for Enjoining Improbable Threats of Catastrophic Harm,* 17 B.C. ENVTL. AFF. L. REV. 441 (1990).

whether an impact is a foreseeable consequence of activities that increase greenhouse gas emissions would likely depend on: (i) the degree of confidence with which the impact has been attributed to climate change or projected to occur as a result of climate change; (ii) the amount of scientific research linking the impact to climate change (and level of consensus among scientists); and (iii) the timeframe in which that research was performed. If there are only a handful of studies on a particular impact or if the studies were all published after the allegedly tortious conduct, then courts might conclude that the impacts are not foreseeable.[607]

Establishing that certain physical impacts such as sea level rise and increasing temperatures are foreseeable outcomes of activities that contribute to climate change is a relatively straightforward task. However, as discussed in Part II, the actual injuries associated with climate change are often secondary or tertiary impacts that are influenced by a multitude of confounding factors in addition to anthropogenic influence on climate. The greater the number of confounding factors, the more difficult it may be to establish that a particular injury was foreseeable. It may also be challenging to establish the foreseeability of specific low-probability, high-impact events even where those events are part of a broader trend that has been attributed to or predicted to come about as a result of climate change. For instance, a catastrophic flood that is far more severe than what any climate model predicted may not be foreseeable, even where increased intensity of extreme precipitation events is generally accepted.

In most tort cases invoking climate change, it may be significantly more challenging for plaintiffs to establish causation—and in particular, specific causation—than it is to establish foreseeability. Indeed, this appears to be the most difficult element to prove across all cases. As discussed above, standing law requires a showing of factual or but-for causation. This is also required for

607. Another factor that might be considered in the foreseeability analysis is the scale of the emissions impact—the idea being that a small emissions impact will not result in foreseeable harms. However, technically speaking, even a very small emissions contribution would foreseeability contribute to all impacts associated with climate change due to the dispersion of greenhouse gases in the atmosphere. It is the authors' view that the magnitude of the emissions impact is more relevant to the analysis of harm and causation in the tort context.

negligence and nuisance cases.[608] As with standing, the challenge here is proving a counter-factual: what would have happened in the absence of defendant's conduct? Sometimes this is a relatively easy exercise, but for harms related to climate change, this is a fact-intensive inquiry that can involve a fair amount of assumption and speculation, testimonies from competing experts, and weighing of evidence.[609] Whereas this inquiry is treated as a question of law in the standing context in most cases, it is treated as a question of fact in the tort context, and would therefore be decided "only at the end of trial, after all of the evidence has been received and all of the experts have testified."[610]

The causal questions implicated by tort lawsuits against the range of likely defendants in climate cases are complex. To succeed in such a case, a plaintiff would need to establish several lines of causation:

- The plaintiff must link a specific change or event to anthropogenic climate change (e.g., sea level rise or a flooding event)—i.e., climate change and extreme event attribution.
- The plaintiff must link a specific loss to that change or event (e.g., the cost of adaptation measures or residual losses that were not or could not be avoided through adaptation)—i.e., impact attribution.
- The plaintiff must link the defendant's conduct (i.e., release of greenhouse gas emissions) to anthropogenic climate change and identify the defendant's relative contribution to the harm incurred by the plaintiff—i.e., source attribution.

Regarding the first line of causation: proving that a specific change or event is caused by climate change will be easier for long-term changes such as mean temperature increases and sea level rise—but as discussed in Part II, there are challenges to establishing

608. This is known as "factual causation," "but for causation," or the *sine qua non* test. These are basically the same concepts because "an act is a factual cause of an outcome if, in the absence of the act, the outcome would have occurred even if the defendant had acted non-negligently." RESTATEMENT (THIRD) OF TORTS: LIABILITY FOR PHYS. & EMOT. HARM § 26 Factual Cause (AM. LAW INST. 2012).

609. Luke Meier, *Using Tort Law to Understand the Causation Prong of Standing,* 80 FORDHAM L. REV. 1241, 1248–49 (2011).

610. *Id.* at 1249 (citing KENNETH S. ABRAHAM, THE FORMS AND FUNCTIONS OF TORT LAW 105–07 (3d ed. 2007).

causation even in that context. For example, plaintiffs will need to establish that flooding or saltwater inundation is caused by sea level rise even where coastal erosion and subsidence are also occurring as a result of coastal development.

Linking a specific extreme weather event to climate change poses another test. The probabilistic approach to event attribution, whereby scientists quantify the extent to which anthropogenic climate change affected the probability of the event occurring (expressed as FAR—fraction of attributable risk), would likely be the best vehicle for establishing causation for the purposes of tort litigation.[611] As discussed above, some probabilistic attribution assessments have identified a relatively strong climate signal on certain events with a relatively high level of certainty. For example, the study of the 2003 European Heat Wave found that climate change had increased the probability of this event at least a factor of two, more likely a factor of six.[612] In other studies, the climate signal is evident but less strong. For example, a study of the 2000 United Kingdom floods found that climate change increased the probability of the flood occurring by a factor of two in most simulations, but in 10% of cases, the risk increase was less than 20%.[613]

There is precedent for courts accepting this type of statistical data as evidence of causation. For example, in U.S. tort law, plaintiffs typically must show that their individual injuries were "more likely than not" caused by the behavior question, and this requirement has been met through showings that the behavior increased the risk of the harm occurring by a factor of two.[614] Applying that same standard to the 2003 European Heat Wave, a court could conclude that climate change was "more likely than not" the proximate cause of the heat wave. As discussed in the standing section, courts also consider probabilistic assessments when determining whether a future injury is sufficiently "imminent" such that plaintiffs have satisfied the injury-in-fact requirement.

611. Allen et al., *supra* note 553, at 1385 (citing Myles Allen, *Liability for Climate Change,* 421 NATURE 891, 891–92 (2003); Dáithí A. Stone & Myles R. Allen, *The End-to-End Attribution Problem: From Emissions to Impacts,* 71 CLIMATIC CHANGE 303, 303–04 (2005).

612. Allen et al., *supra* note 553, at 1393.

613. A. Kay et al., *Attribution of Autumn / Winter 2000 Flood Risk in England to Anthropogenic Climate Change; A Catchment-Based Study*, 406 J. OF HYDROLOGY 91 (2011).

614. Grossman, *supra* note 553, at 23.

Probabilistic event attribution can also be supplemented with observational evidence showing trends in the frequency of an event growing over time.[615] Observational evidence of trends probably would not, by itself, suffice for the purposes of establishing liability for a particular event for the reasons noted above. However, it is possible that such evidence could be used to establish liability for the aggregated impacts of additional extreme weather events over time—for example, a state that has experienced a 10% increase in extreme heat days may be able to establish that climate change more likely than not was responsible for that increase. This type of argument has been accepted in the context of the lawsuits noted in the previous sections (defense of government regulation and lawsuits seeking to compel regulation)[616] but has not been tested in the context of private liability lawsuits.

The storyline or mechanistic approach could also be used to link an extreme event or even a long-term change to anthropogenic influence on climate. That approach would yield different types of quantitative findings—for example, that anthropogenic climate change increased the magnitude of a storm or flood by 10%.

Even if the plaintiff is able to establish that a physical change or extreme event was caused by climate change, he or she must also establish the second and third lines of causation. The second causation challenge—establishing and quantifying the specific loss caused by the change or event—involves determining the extent to which the loss was caused by anthropogenic climate change as compared with other confounding factors. As discussed in Part II, a probabilistic approach can also be used in impact attribution to generate this sort of information. However, to date, most impact attribution studies do not produce findings that are as quantitatively robust as studies conducted on extreme events due to the number of confounding factors that influence impacts such as public health outcomes.

The third causation challenge—defining the defendant's relative contribution to the damage—is a matter of source attribution. As discussed above, courts have grappled with a related question in the context of lawsuits challenging government failure to regulate—specifically, whether the total greenhouse gas

615. *See, e.g,* S.K. Min et al., *Human Contribution to More-Intense Precipitation Extremes*, 470 NATURE 378 (2011).

616. *See* Sections III(C)(3) and III(C)(4).

contribution from the unregulated source category is sufficiently large such that: (i) the plaintiffs have standing by virtue of some actual or imminent harm caused by those emissions, and (ii) the government has violated some sort of obligation by failing to regulate those emissions.[617]

Importantly, even if a source's emissions are considered to be a "material", "substantial", or "significant" contribution to climate change, this does not mean that the source caused a specific impact and can therefore be held liable for all harms associated with that impact. Imposing liability in this context would be akin to imposing joint and several liability on all emitters that surpass a materiality threshold—something courts may be reluctant or even unwilling to do, given the possible ramifications of such a judicial policy. Recognizing this, some petitioners are now seeking to obtain monetary damages from emissions sources that are proportional to the emissions contribution from that source.[618]

One possible way to avoid some of the challenges associated with quantifying the defendants' contribution to plaintiffs' injuries is to seek injunctive relief rather than monetary damages in a tort lawsuit. Plaintiffs seeking injunctive relief have thus far faced the same challenges as those seeking monetary relief when attempting to establish causation for standing purposes, but there has not yet been a trial in which courts have fully evaluated the merits of causation claims in either context. Another option for plaintiffs seeking monetary damages would be to rely on lower bound damage estimates that can be attributed to defendants' conduct with high confidence—but this approach might require some re-framing of attribution studies—an issue which we explore in Part IV.

It may also prove easier to establish a causal nexus between defendants' conduct and plaintiffs' injuries where plaintiffs aggregate harms from multiple types of climate change-related impacts and across multiple persons. It is easier to establish, for example, that climate change (and defendants' conduct contributing to climate change) has caused injury to an entire state, city, or trade organization as opposed to an individual private plaintiff.

617. *See* Part III(C)(3)(b).

618. Lliuya v. RWE AG, VG Essen 15.12.2016 (2 O 285/15) (Germany).

c. Cases

i. *Connecticut v. American Electric Power* (Second Circuit)

The Second Circuit's review of *American Electric Power*, discussed above, provides some insights into how courts might handle tort claims pertaining to climate change. First, the court determined that whether a given quantity of emissions is a "meaningful" or "significant" contribution to global climate change is an evidentiary issue that should be addressed at a future stage of the proceedings—at least where those emissions appear on their face to potentially meet that standard.[619] Second, the court found that contributing sources of GHG emissions can be called to account, explaining that "[t]he Court has not imposed a requirement upon all federal common law of nuisance cases that the challenged pollution must be 'directly traced' or that plaintiffs must sue all sources of the pollution complained of in order to state an actionable claim. On the contrary, 'the fact that other persons contribute to a nuisance is not a bar to the defendant's liability for his own contribution.'"[620] Third, the court held that, to prevail on a public nuisance theory, plaintiffs need not demonstrate that they have suffered an actual harm or even an immediate harm—rather, a threatened harm would suffice. The court cited numerous precedents showing that federal courts have the authority to enjoin a threatened nuisance before irreparable harm results.[621] These

619. *Am. Elec. Power*, 582 F.3d at 345.

620. *Am. Elec. Power*, 582 F.3d at 356–57 (citing RESTATEMENT (SECOND) OF TORTS § 840E). (Am. Law Inst. 2008). *See also, e.g.*, Illinois ex. rel Scott v. Milwaukee, No. 72 C 1253, 1973 U.S. Dist. LEXIS 15607, (N.D. Ill. Nov. 1, 1973) ("[I]t is sufficient for plaintiffs to show that defendants' nutrient discharges [leading to eutrophication of Lake Michigan] constitute a significant portion of the total nutrient input to the lake. The correct rule would seem to be that any discharger who contributes an aliquot of a total combined discharge which causes a nuisance may be enjoined from continuing his discharge. Either that is true or it is impossible to enjoin point dischargers."), *aff'd in relevant part and rev'd in part*, 599 F.2d 151 (7th Cir. 1979), *vacated on other grounds*, Milwaukee v. Illinois, 451 U.S. 304 (1981). *Cf.* Student Pub. Interest Research Grp. of N.J., Inc. v. Tenneco Polymers, Inc., 602 F. Supp. 1394, 1397 (D.N.J.1985) (holding, in the context of finding causation for standing purposes, that pollution may derive from multiple sources and that it is not necessary to pinpoint which polluter caused a specific harm).

621. *Am. Elec. Power*, 582 F.3d at 357 (citing Mugler v. Kansas, 123 U.S. 623 (1887) (observing that courts of equity, in adjudicating public nuisance cases, can both prevent threatened nuisances, "before irreparable mischief ensues," as well as abate those in progress); United States v. Ira S. Bushey & Sons, 346 F. Supp. 145, 150 (D. Vt. 1972) ("[o]ne distinguishing feature of equitable relief is that it may be granted upon the threat of harm which has not yet occurred.") (quoting WILLIAM L. PROSSER, HANDBOOK OF THE LAW OF

conclusions would tend to support the notion that a nuisance claim can be predicated on a contribution to threatened harm, and that emitters might be held liable based on their proportional contribution to climate change.

ii. *Kivalina v. Exxon Mobil* (Northern District of California)

The district court's analysis of standing in *Kivalina* also provides some insight into how a court might address a climate nuisance claim. In particular, that the district court found an inadequate causal connection between the defendants' emissions (which were significantly more than those at issue in *AEP*—more than 1.2 billion tons per year of direct emissions) suggests that the district court would not have found adequate causation to support a nuisance claim.[622]

While not explicitly stated in the decision, the court's decision to dismiss the case may have been influenced by the fact that Kivalina was seeking damages to cover the full costs of its injuries, while defendants were only partially responsible for those injuries. In a sense, Kivalina was asking the court to impose joint and several liability on the companies.[623] Consider the following excerpt from the court's discussion of why the political question doctrine (as well as a lack of standing) barred its consideration of the case:

> Plaintiffs also fail to confront the fact that resolution of their nuisance claim requires the judiciary to make a policy decision about *who* should bear the cost of global warming. Though alleging that Defendants are responsible for a "substantial portion" of greenhouse gas emissions . . . Plaintiffs also acknowledge that virtually everyone on Earth is responsible on some level for contributing to such emissions. Yet, by pressing this lawsuit, Plaintiffs are in effect asking

TORTS 624 (3d ed. 1964)); Texas v. Pankey, 441 F.2d 236, 242 (10th Cir. 1971) (reversing district court refusing to issue injunction against pesticide spraying that was both threatened at the time the suit was instituted and had since been done); 7 STUART M. SPEISER, CHARLES F. KRAUSE & ALFRED W. GANS, THE AMERICAN LAW OF TORTS § 20.19 (Thomson West 2003) ("We deem it necessary to explain that a prospective nuisance is a fit candidate for injunctive relief. . . . One distinguishing feature of equitable relief is that it may be granted upon the threat of harm which has not yet occurred."); Andrew H. Sharp, Comment, *An Ounce of Prevention: Rehabilitating the Anticipatory Nuisance Doctrine,* 15 B.C. ENVTL. AFF. L. REV. 627, 633–36 (1988).

622. Native Vill. of Kivalina v. ExxonMobil Corp., 663 F. Supp. 2d 863, 881 (N.D. Cal. 2009), *aff'd,* 696 F.3d 849 (9th Cir. 2012).

623. However, courts might not be receptive to such claims. *See* Maag, *supra* note 553, at 187.

> this Court to make a political judgment that the *two dozen Defendants named in this action should be the only ones to bear the cost of contributing to global warming*. Plaintiffs respond that Defendants *should be* the ones held responsible for damaging Kivalina allegedly because "they are responsible for more of the problem than anyone else in the nation . . ." [] But even if that were true, Plaintiffs ignore that the allocation of fault—and cost—of global warming is a matter appropriately left for determination by the executive or legislative branch in the first instance.[624]

iii. *Lliuya v. RWE AG*

For plaintiffs seeking damages, an alternative approach to *Kivalina* is to request compensation for a proportion of damages that corresponds with the proportion of global greenhouse gas emissions emitted by the defendant. This is the strategy deployed in *Lliuya v. RWE AG*, in which a Peruvian farmer filed suit in German court against a German utility company, seeking damages to offset the costs of protecting his town from melting glaciers.[625] The farmer only sought damages proportional to the utility's relative contribution to global GHG emissions.[626] A district court in Germany dismissed the case, finding that there was no "linear causal chain" between RWE's emissions and the alleged injury because so many emitters had contributed to the risk of flooding in the farmer's town,[627] but the appellate court reversed and directed that the case move forward to an evidentiary phase to determine whether the plaintiff's home is threatened by flooding or mudslide as a result of the melting glacier, and the extent to which RWE's greenhouse gas emissions contribute to that risk.[628] The court will be reviewing expert opinions on the RWE's CO_2 emissions, the contribution of those emissions to climate change, the resulting impact on the glacier, and RWE's contributory share of responsibility for causing that impact.

624. Native Vill. of Kivalina, 663 F. Supp. 2d at 876–77.

625. *Lliuya v. RWE*, *supra* note 618.

626. *Id.*

627. FRANKFURTER ALLGEMEINE ZEITUNG [*David Loses the Fight Against Goliath*], Dec. 15, 2016, https://www.faz.net/aktuell/wirtschaft/energiepolitik/peruanischer-bauer-scheitert-mit-klage-gegen-rwe-14575835.html [https://perma.cc/3JNZ-9ADV] ("Eine Flutgefahr wäre jedoch der RWE AG nicht individuell zuzuordnen." ["A flood risk would however not be attributed singly to RWE AG."]).

628. Lliuya v. RWE AG, Landgericht Essen 30.11.2017 (I-5 U 15/17) (Germany).

Providing an accurate and precise estimate of a particular emitter's contribution to climate change remains challenging—in part due to limited information about historical and current emissions from individual sources, and in part due to uncertainty about the total amount of emissions being generated and sequestered as well as the relative contribution of different greenhouse gases to the greenhouse effect. There is also the question of how to apportion responsibility for emissions, with one critical question being whether fossil fuel production companies, electric generating units, or both should be viewed as "responsible" for emissions in the context of a private liability lawsuit. While this is an "attribution" question, it does not fall within the scope of detection and attribution science; rather, it involves social, political, and legal determinations about how to apportion responsibility.

iv. Pending U.S. Cases Against Fossil Fuel Companies

In 2017 and 2018, local governments across the United States initiated a new wave of litigation seeking to hold fossil fuel companies liable for their contribution to climate change and to recover damages for the cost of adapting to climate change.[629] Similar lawsuits have been filed by Rhode Island and the Pacific Coast Federation of Fishermen's Associations.[630] The plaintiffs in these cases allege that companies like ExxonMobil, BP, and Shell knowingly contributed to climate change by extracting and selling fossil fuels, obscuring the science of climate change, and fighting policies aimed at mitigating climate change, and should therefore

629. Complaint, City of Imperial Beach v. Chevron Corp., No. C17-01227 (Cal. App. Dep't Super. Ct. Jul. 17, 2017); Complaint for Public Nuisance, City of Oakland v. BP P.L.C., No. RG17875889 (Cal. App. Dep't Super. Ct. Sep. 19, 2017); Complaint, City of Santa Cruz v. Chevron Corp., No. 17CV03243 (Cal. App. Dep't Super. Ct. Dec. 20, 2017); Complaint, Cty. of Marin v. Chevron Corp., No. CIV1702586 (Cal. App. Dep't Super. Ct. Jul. 17, 2017); Complaint, Cty. of San Mateo v. Chevron Corp., No. 17CIV03222 (Cal. App. Dep't Super. Ct. Jul. 17, 2017); Complaint, Cty. of Santa Cruz v. Chevron Corp., No. 17CV03242 (Cal. App. Dep't Super. Ct. Jul. 17, 2017); Complaint for Public Nuisance, City of San Francisco v. BP P.L.C., No. CGC-17-561370 (Cal. App. Dep't Super. Ct. Sep. 19, 2017); Complaint, City of Richmond v. Chevron Corp., No. C18-00055 (Cal. App. Dep't Super. Ct. Jan. 22, 2018); Complaint and Jury Demand, Bd. of Cnty. Comm'rs of Boulder Cty. v. Suncor Energy (U.S.A.), No. 2018CV030349 (Colo. Dist. Ct. Apr. 17, 2018); Complaint, City of New York v. BP P.L.C., No. 1:18-cv-00182 (S.D.N.Y. Jan. 9, 2018); Plaintiff's Complaint, Mayor & City of Baltimore v. BP P.L.C., No. 24-C-18-004219 (Md. Cir. Ct. Jul. 20, 2018).

630. Complaint, Rhode Island v. Chevron Corp., No. PC-2018-4716 (R.I. Super. Ct. Jul. 2, 2018); Complaint, Pac. Coast Fed'n. of Fishermen's Ass'ns, Inc. v. Chevron Corp., No. CGC-18-571285 (Cal. Super. Ct. Nov. 14, 2018).

be held liable for some of the adaptation costs incurred by governments. They are pursuing multiple state law legal theories: public nuisance, private nuisance, negligence, trespass, failure to warn, and design defect, among others. These are not the first tort cases against emitters involving state rather than federal law claims—as noted in the above discussion of standing,[631] both *American Electric Power* and *Comer* also involved state law claims, but those decisions did not address the merits of those claims.

The complaints submitted by petitioners in these cases touch on all aspects of attribution. They discuss the basic science of climate change and attribution of climate change to increasing concentrations of greenhouse gas emissions; they identify specific extreme events and impacts of climate change that are injuring petitioners; and they examine "known causes" of those impacts, looking at the effect of anthropogenic climate change as well as other factors.[632] With regards to source attribution, petitioners quantify the cumulative emissions from the fossil fuels produced, sold, and marketed by defendant companies (e.g., "15% of global fossil fuel product-related CO2 between 1965 and 2015, with contributions currently continuing unabated"[633]) and assert that this is a "substantial" contribution to the impacts on petitioners.[634] The complaints are thus drafted in a manner which clearly anticipates that questions of climate change attribution will be at the heart of the inquiry into whether defendants have caused a nuisance or other actionable harm under common law. The attribution statements contained therein are relatively robust because: (i) petitioners represent the aggregated interests of all individuals within their jurisdiction (or trade association) and can therefore allege a broader array and greater magnitude of harms, and (ii) emissions from the combustion of fossil fuels produced by defendants constitute a relatively large (and quantifiable) share of global cumulative emissions. From the standpoint of attribution

631. *See supra* Section III (C)(1).

632. *See, e.g.*, Complaint for Public Nuisance, City of San Francisco v. BP P.L.C., *supra* note 629; Plaintiff's Complaint, Mayor & City of Baltimore v. BP P.LC., *supra* note 629; Complaint, Rhode Island v. Chevron Corp., *supra* note 630.

633. Complaint for Public Nuisance, City of San Francisco v. BP P.L.C., *supra* note 629, at 35.

634. *See, e.g.*, Complaint, Rhode Island v. Chevron Corp., *supra* note 630, at 48; Complaint for Public Nuisance, City of San Francisco v. BP P.L.C., *supra* note 629, at 35; Complaint, Maryland & Mayor of Baltimore v. BP P.L.C., *supra* note 629, at 49.

science, petitioners have made compelling arguments as to why a substantial proportion of their injuries can be traced to those emissions.

It remains unclear whether these cases will actually go to trial and whether the reviewing courts will fully evaluate the attribution questions presented therein. While plaintiffs are pursing state law theories, defendants have argued (and some judges have agreed) that all of the claims are "necessarily governed by federal law" because a "uniform standard of decision is necessary to deal with the issues raised" by plaintiffs.[635] Cases decided under federal law are more likely to be dismissed due to federal precedent in cases such as *American Electric Power*. To date, two cases have been dismissed by district court judges who held that claims were non-justiciable because they raised questions that should be resolved by the legislative and executive branches of the federal government.[636] One of these federal judges held a "climate science tutorial" in which both sides were asked to brief him on climate science. However, the opinion granting defendants' motion to dismiss explicitly recognized that "[t]he issue is not over science" but rather precedent and the separation of powers.[637]

v. Philippines Carbon Majors Inquiry

Plaintiffs in foreign jurisdictions have also begun to use human rights law and other legal sources as the basis for holding companies responsible for their contribution to climate change. In 2016, environmental and human rights advocates submitted a petition to the Philippines Commission on Human Rights requesting an investigation into the responsibility of forty-seven "Carbon Majors" (carbon producing companies) for human rights violations or threats of violations resulting from the impacts of climate change.[638] The claims raised by petitioners are similar to those raised in tort—that the companies produced and promoted the use of massive quantities of fossil fuels with full knowledge that the consumption of these fuels would contribute significantly to

635. City of Oakland v. BP P.L.C., No. C 17-06011 WHA, 2018 WL 1064293, at *3 (N.D. Cal. Feb. 27, 2018).

636. City of Oakland v. BP P.L.C., 325 F. Supp. 3d 1017 (N.D. Cal. 2018); City of New York v. BP P.L.C., 325 F. Supp. 3d 466 (S.D.N.Y. 2018).

637. City of Oakland v. BP P.L.C., 325 F. Supp. at 1022 (N.D. Cal. 2018).

638. In re Greenpeace Southeast Asia v. Chevron, Case No. CHR-NI-2016-0001 (2016).

global climate change (and the corresponding harmful impacts on lives and livelihoods), and that this knowing contribution constituted a violation of fundamental human rights.[639] The petition emphasizes the scientific basis for the claim, referring to scientific studies on climate change attribution as well studies on the emissions that can be attributed to the carbon majors. A joint summary brief submitted by a group of amici curiae in support of the petitioners contains an even more detailed overview of climate and attribution science, including the latest research on how climate change is affecting and will continue to affect the Philippines.[640] The joint summary brief was a collaboration between legal experts and climate scientists—the goal being to present a credible overview of the best available science in relatively straightforward terms. In December 2019, the Commission announced its finding that major fossil fuel companies can be held liable for climate change impacts and that existing civil law in the Philippines provided grounds for holding such companies criminally liable where there is clear proof that they have engaged in acts of obstruction, deception, or fraud.[641]

d. Concluding Notes on Tort Liability

The role of attribution science in climate torts is, at the moment, front and center in the public's eye. But our analysis is consistent with Professor Kysar's:

> Make no mistake: a conceivable set of arguments on behalf of climate change tort plaintiffs *does* exist. The problem, however, is that the winning scenario for most climate-related harms requires a court to stretch in plaintiffs' direction at nearly every stage of the traditional tort analysis: duty would have to encompass "negligence in the air," rather than more particularized relations of responsibility; nuisance would have to be interpreted as an absolute protection against significant invasions, irrespective of social welfare balancing; actual cause would have to embrace—at long last—a probabilistic, risk-

639. *Id.*

640. CENTER FOR INTERNATIONAL ENVIRONMENTAL LAW ET AL., JOINT SUMMARY OF THE AMICUS Brief CURIAE: IN RE: NATIONAL INQUIRY ON THE IMPACT OF CLIMATE CHANGE ON THE HUMAN RIGHTS OF THE FILIPINO PEOPLE (Mar. 19, 2018), https://www.ciel.org/philippines-joint-amicus [https://perma.cc/66P4-KBU7].

641. Press Release, CIEL, Groundbreaking Inquiry in Philippines Links Carbon Majors to Human Rights Impacts of Climate Change, Calls for Greater Accountability (Dec. 9, 2019).

> enhancement conception of causation; exceptional measures of apportionment would have to be invoked to address a multiple defendant problem of unprecedented magnitude; proximate cause would have to be interpreted such that the scope of foreseeable harm from greenhouse gas emissions both tracks projections from climate models that stand at the very forefront of scientific inquiry and, in many cases, applies retroactively as a form of imputed knowledge tantamount to strict liability; and harm would have to be expanded to include much more by way of anticipatory injury than courts currently recognize.[642]

Science can be used to support arguments but it does not necessarily answer fundamental questions over the appropriate logic of blame.

6. Lawsuits Involving Climate Change Impacts, Adaptation, and Risk Disclosures

Attribution science also plays a more limited role in lawsuits involving climate change impacts, adaptation, and disclosures about climate change-related risks. These include: (i) failure-to-adapt lawsuits, which involve allegations that an actor has failed to account for the effects of climate change and this resulted in an adverse outcome that would not have occurred if the actor had accounted for those effects, or else failed to develop adequate plans to prevent foreseeable adverse outcomes in the future;[643] (ii) lawsuits involving legal defense of adaptation measures;[644] (iii) lawsuits in which defendants seek to shield themselves from liability for climate-related harms by alleging that climate change, and not their own conduct, was responsible for those harms;[645] and (iv)

642. Kysar, *supra* note 555, at 44.

643. *See, e.g.*, ExxonMobil Complaint for Declaratory and Injunctive Relief and Civil Penalties at para 170; Conservation Law Found. v. Exxon Mobil Corp., No. 1:16-cv-11950 (D. Mass. Sep. 9, 2016); Complaint and Jury Demand, Conservation Law Foundation, Inc. v. Shell Oil Products US, No. 1:17-cv-00396 (D.R.I. Aug. 28, 2017). *See also* Jennifer Klein, *Potential Liability of Governments for Failure to Prepare for Climate Change*, SABIN CENTER FOR CLIMATE CHANGE LAW (2015); Jacqueline Peel & Hari M. Osofsky, *Sue to Adapt?*, 99 MINN. L. REV. 2177, 2193–95 (2015).

644. *See, e.g.*, cases cited *supra* note 643.

645. For example, utilities may cite climate change as a defense in wildfire litigation. *See* Mark Chediak, *Facing $17 Billion in Fire Damages, a CEO Blames Climate Change*, BLOOMBERG (August 13, 2018), https://www.bloomberg.com/news/articles/2018-08-13/facing-17-billion-in-fire-damages-a-ceo-blames-climate-change [https://perma.cc/9A38-YQUD].

lawsuits involving climate change-related risk disclosures in contexts, such as environmental reviews and financial statements.[646]

One critical question in such cases is whether the present or future effects of climate change are foreseeable. This bears on questions such as whether it was reasonable for a defendant to omit climate change-related risks from a security disclosure or an environmental report; whether it was reasonable for a defendant to ignore climate change-related risks in the approval, construction, or operation of a facility or development project; and whether it was reasonable for a government officer to impose new restrictions on private development due to climate change-related risks. For example, attribution science has been used in cases involving listing decisions under the U.S. Endangered Species Act ("ESA") to both justify listing decisions predicated on consideration of climate change-related risks to the species[647] and to compel consideration of climate change impacts where the government failed to do so in listing decisions.[648] Attribution science may also be used to establish

646. *See, e.g.*, AquAlliance v. Bureau of Reclamation, F. Supp. 3d 969 (E.D. Cal. 2018) (agency violated NEPA by failing to adequately assess climate change impacts on water supply); Sierra Club v. FERC, 867 F.3d 1357 (D.C. Cir. 2017) (agency violated NEPA by failing to adequately disclose GHG emissions from pipeline project); People of the State of New York v. Exxon Mobil Corp., N.Y. No. 452044 (Dec. 10, 2019) (Exxon did not violate Martin Act through public disclosures concerning how it accounted for past, present, and future climate change risks). *See also* Michael Burger & Jessica Wentz*, Downstream and Upstream Emissions: The Proper Scope of NEPA Review*, 41 HARV. ENVTL. L. REV. 109 (2017); Jessica Wentz, *Planning for the Effects of Climate Change on Natural Resources,* 47 ENVTL. L. REP. 10220 (March 2017); Jessica Wentz, *Assessing the Impacts of Climate Change on the Built Environment: A Framework for Environmental Reviews*, 45 ENVTL. L. REP. 11015 (2015).

647. *See, e.g.*, Alaska Oil & Gas Ass'n v. Pritzker, 840 F.3d 671 (9th Cir. 2016) (upholding NMFS's use of climate science in deciding to add Pacific bearded seal subspecies to endangered species list); Alaska Oil & Gas Ass'n v. Jewell, 815 F.3d 544, 558, 46 ELR 20042 (9th Cir. 2016) (upholding FWS's decision to account for climate change impacts in designating critical habitat for species); In re Polar Bear Endangered Species Act Listing & §4(d) Rule Litig., 794 F. Supp. 2d 65, 41 ELR 20318 (D.D.C. 2011), *aff'd*, 709 F.3d 1, 43 ELR 20132 (D.C. Cir. 2013) (upholding the polar bear listing); Ctr. for Biological Diversity v. Lubchenco, 758 F. Supp. 2d 945 (N.D. Cal. 2010) (upholding NMFS decision not to list ribbon seal as threatened or endangered despite climate-related threats).

648. *See, e.g.*, Defs. of Wildlife v. Jewell, No. 14-247-M-DLC, 2016 WL 1363865, at *20, 46 ELR 20070 (D. Mont. Apr. 4, 2016) (FWS failed to use best available science, including science on climate change, when deciding not to list wolverine as threatened); In re Polar Bear Endangered Species Act Listing §4(d) Rule Litig., 748 F. Supp. 2d 19, 30 (D.D.C. 2010) (holding that a species may be listed as "endangered" even if it is not in danger of imminent extinction, and remanding FWS's decision to list the polar bear as "threatened" rather than "endangered" for additional consideration of foreseeable future threats, particularly changes in future sea ice conditions); Ctr. for Biological Diversity v. Zinke, No. 3:18-cv-00064-SLG,

the extent to which anthropogenic climate change is the cause of harmful effects, which bears on the question of whether the defendant's failure to adapt actually caused or contributed to the plaintiff's alleged injury.

IV. FUTURE DIRECTIONS IN THE LAW AND SCIENCE OF CLIMATE ATTRIBUTION

As courts and policy-makers continue to grapple with appropriate responses to the increasingly urgent climate crisis, attribution science will continue to play a critical role in shaping discussions around responsibility and liability for climate change and its impacts. Here, we discuss future directions in the law and science of climate change attribution, addressing questions such as how attribution science might better support policy-making, planning and litigation; how plaintiffs might utilize attribution science in lawsuits against government and private defendants; and how defendants and courts might respond to the realities and limitations of climate attribution science. Some of these functions may be best performed by a third party organization that focuses on the synthesis and communication of scientific research, such as the Intergovernmental Panel on Climate Change.[649]

A. How Can Attribution Science Better Support Climate Law, Policy and Planning?

There are a variety of ways in which the scientific community could work towards supporting applications of attribution research, such as the use of this research to inform loss and damage negotiations and judicial determinations of liability for climate change impacts. These include: (i) continuing to lead the development of scientific knowledge and understanding by

2018 WL 8805325, at *1 (D. Alaska 2018) (challenging the determination that the listing of the Pacific walrus as endangered or threatened was not warranted).

649. The IPCC chapters on detection and attribution of climate change are a good example of how attribution research can be summarized, synthesized, and communicated in an accessible format. Krishna Mirle Achuta Rao et al., *Detection and Attribution of Climate Change: from Global to Regional*, *in* CLIMATE CHANGE 2013: THE PHYSICAL SCIENCE BASIS 867–952 (2013). Other entities that are engaged in the synthesis and communication of attribution research include the World Weather Attribution (WWA) project and the Bulletin of Atmospheric Scientists (particularly in the publication of the annual reports on extreme event attribution).

advancing detection and attribution research across the board; (ii) generating attribution findings at different confidence levels to better communicate uncertainty about the "upper bound" and "lower bound" of plausible anthropogenic influence on an observed change; (iii) communicating findings clearly and in an accessible format; (iv) engaging stakeholders; and (v) linking individual studies to other advancing research areas that helps to flesh out the causal chain from emissions to impact.

1. Continue to Conduct Attribution Research on the Full Range of Climate Change Impacts With An Eye Towards Improving Confidence Levels and Certainty In Findings.

The body of attribution research has grown considerably in recent years, increasing levels of confidence and certainty regarding a wide range of climate impacts at multiple political and geographical scales. Climate scientists pursuing their collective and independent research agendas have already established an undeniable connection between anthropogenic GHG emissions and climate change, and between climate change and slow onset impacts and the increasing frequency and intensity of certain types of extreme events, assuring that there is a sound scientific basis for collective action to address the climate crisis through mitigation and adaptation measures. More recent emphasis in relatively novel areas such as source attribution and single-event attribution has already helped inform progressive advocacy strategies. So, in an important sense, the single most important thing the scientific community can do to support applications of attribution research is *more of the same*.

Indeed, international and national policy initiatives, as well as lawsuits in the United States and elsewhere, have relied on existing attribution research to claim that climate change is responsible for a broad range of impacts, including coastal impacts from sea level rise, loss of snowmelt, declines in agricultural productivity, and declines in fishery productivity, among other things. To our knowledge, international coordination, domestic efforts, and climate change litigation have never failed due to a shortfall in the attribution science—even despite a concerted disinformation campaign that has reduced political support for ambitious climate action for the last quarter century.[650] In short, the scientific findings compiled to date are already well-suited to support climate law and policy.

Yet, there are gaps in coverage, particularly with respect to extreme events and impacts in developing countries and in areas where the observational record is not as robust and where funding for research may be more limited. Moreover, even where attribution research has been performed for a particular variable, the scope and scale of the study may be incompatible with real-world applications. Geographic and temporal scope are both relevant in this context. For example, loss and damage negotiations would benefit from research attributing impacts over a long timeframe within specific countries, whereas the plaintiffs in a case like *Juliana*[651] would benefit most from research attributing impacts on them as individuals, which requires more downscaling than a country-wide analysis and a more complete reckoning with confounding factors.

Going forward, litigants, policy-makers, and planners will benefit from attribution research on all impacts and at all scales from the global to the highly individualized, the goal being to improve confidence levels and certainty in findings. It will be helpful for scientists to generate additional findings for slow-onset impacts such as sea level rise, temperature changes, ocean acidification, and desertification, as well as extreme events such as precipitation, heat, and wildfire. It would additionally be beneficial to work towards quantifying actual impacts or harms on communities and individuals.

The scientific community could work with affected stakeholders to address the incomplete coverage of attribution science and identify priority areas for research. Granted, working with affected people to determine what variables to focus on in attribution studies could contribute to concerns about selection bias (i.e., the bias introduced when data is selected for research without proper randomization). This practice could result in a larger proportion

650. *See* Fossil Free MIT, *The Fossil Fuel Industry's Role in Hindering Climate Change Action: Lobbying and Disinformation Against Science and Scientists* (April 2014) https://www.fossilfreemit.org/wp-content/uploads/2014/08/FossilFreeMIT-Lobbying-Disinformation.pdf [https://perma.cc/X8DD-S6ED]; Union of Concerned Scientists, *Climate Disinformation*, https://www.ucsusa.org/climate/disinformation [https://perma.cc/4976-NSKS].

651. 339 F.Supp.3d 1062.

of attribution studies that focus on events or impacts with a clear connection to climate change than a purely random sampling of events and impacts. As such, scientists may need to be cautious about any overarching statements made with respect to the body of attribution research. But scientists are already cautious about making such statements,[652] and such concerns about selection bias would not undermine the credibility of the individual studies being performed.

2. Generate Findings at Different Confidence Levels

As discussed in Part II, attribution findings are often expressed in terms of probabilities and confidence levels. For example, an IPCC report might conclude with "high confidence" (80%) that a particular impact was "very likely" caused by anthropogenic climate change, or a probabilistic event attribution study might find with > 90% confidence that anthropogenic climate change quadrupled the risk of a particular storm occurring. These are compelling statistics, but depending on the application, it may also be helpful for researchers to also discuss lower-bound, higher confidence estimates (e.g., > 95% confidence that anthropogenic climate change at least doubled the risk of that same storm occurring) or higher-bound, lower confidence estimates (e.g., > 80% confidence that anthropogenic climate change made the storm at least six times more likely). Lower-bound estimates with higher confidence levels would be more useful for applications where certainty in findings is needed, such as litigation seeking to hold fossil fuel companies liable for their contribution to climate change. Upper-bound estimates with lower confidence levels would be more useful in policy and planning applications where decision-makers would benefit from understanding the potential extent of anthropogenic influence on an observed change but certainty about that data is less important.

There is an inevitable tradeoff between the level of confidence in findings and the magnitude of the "human fingerprint" identified in an attribution study. Scientists can issue higher confidence findings that anthropogenic climate change contributed "at least" a certain amount to the probability or magnitude of an event without

652. *See, e.g.*, BAMS 2016, *supra* note 76 (studies contained within these reports contain clear explanations of research parameters and uncertainty).

ruling out the possibility that the effect of anthropogenic climate change was actually much larger. Again, discussing both lower and upper bound estimates in this context is helpful for navigating uncertainty and clarifying findings. Consider the study of the 2003 European heat wave: Stott et al. (2004) found that it was very likely (confidence level > 90%) that anthropogenic climate change had at least doubled the risk of a heat wave of the sort experienced that summer (FAR = 0.5), but they also noted that the anthropogenic FAR could be substantially greater and that their "best estimate" was that climate change had increased the risk by a factor of four (FAR = 0.75) (no confidence interval was specified for this estimate, but it was clearly lower than 90%).[653] Without that additional information, a reader might assume that the FAR = 0.50 is the "best estimate" of the human fingerprint in this study, and without the more conservative FAR estimate, the findings might not hold up to scientific (or judicial) scrutiny.

This same approach could also be implemented in the context of a storyline or mechanistic study. For example, a storyline evaluation of a tropical storm might generate several findings at different confidence intervals (e.g., >95% chance that climate change increased the magnitude of a storm by at least 30%, >90% chance that climate change increased the magnitude of the storm by at least 40%, and >80% chance that climate change increased the magnitude of the storm by at least 50%).

3. Clearly Communicate Findings

Most attribution studies are written for a scientific audience, and the findings contained therein can be difficult to understand for people who lack expertise with terminology and concepts such as confidence intervals and p-values. These studies are sometimes "translated" for a broader audience, often by journalists, but when non-scientists summarize scientific findings there is a greater risk that complex topics will be over-simplified or inaccurate conclusions will be drawn from the research. For this reason, it is helpful for the scientists conducting the research to present their findings in a clear and accessible fashion, to the extent practicable.

Marjanac et al. (2017) highlight several best practices for communicating attribution science to courts, but their

653. Stott et al., *supra* note 153.

recommendations apply in equal force to communication with policy-makers, planners, companies, and the public at large:

> (i) areas of agreement should be clearly stated before discussion of areas of disagreement; (ii) methodology and results should be quantitatively and qualitatively transparent to enable interpretation and assessment of credibility by the courts; (iii) assumptions and uncertainties should be stated in a simple, concise and transparent manner; and (iv), results should discuss implications for foreseeability; that is, whether and to what extent a study can opine on the impact of anthropogenic emissions on the future likelihood of occurrence or severity of the event.[654]

An oft-lamented reality is that in communicating uncertainty, bias, and other limitations in their research, scientists risk giving the impression that the research is not credible or accurate. Careful communication of these concepts is also important to protect the credibility of the research against external attacks by parties antagonistic to climate action, or else defending themselves in lawsuits. Generally speaking, careful communication involves providing context for statements about uncertainty, bias, and limitations to help a non-scientific audience understand: (i) whether the level of uncertainty, bias, etc. is standard or unusual as compared with similar studies; and (ii) the effect of uncertainty and bias on the reliability and accuracy of the results. Scientists should also be careful not to overstate the novelty of this field—while attribution science is undergoing constant evolution, the vast majority of studies published in this field are based on well-established scientific techniques, carefully tested models, and detailed observational sets.

4. Engage with Stakeholders

Clear communication of findings is an important first step towards promoting the real-world application of attribution science; engagement is critical to successful communication, and to growing the impact of attribution research. Various researchers have already highlighted the need for dialogue between scientists and stakeholders on climate change science and attribution

654. Sophie Marjanac et al., *Acts of God, Human Influence and Litigation*, 10 NATURE GEOSCIENCE 616 (2017).

research to ensure practical relevance of this research.[655] Weaver et al. (2013) describe the importance of active-learning feedback loops—that is, processes which allow for policy-makers and other stakeholders "to communicate back to scientists any concerns, misunderstandings, relevance, or timeliness of the issues."[656] This type of co-generation of knowledge has played a central role in climate risk assessments, such as those conducted by the New York City Panel on Climate Change.[657] Some of the lessons learned from these co-generation efforts (e.g., risk management frameworks, focusing on the decision-needs of stakeholders, inclusion of social scientists and boundary spanners in the process, and working through existing, trusted networks) will help ensure attribution research is as impactful as possible. Given the expertise about impacts that resides with stakeholders, deeper stakeholder engagement can also be expected to lead to scientific advances not only in attribution science for decision-making, but also for attribution science itself, especially with respect to attribution of impacts. For example, a stakeholder engagement process with water managers encouraged attribution scientists to focus on a broader set of event metric definitions, including the duration of rain events, in order to make their research more relevant for decision-makers and sector experts.[658]

5. Link Individual Studies to Related Research To Help Flesh Out the Causal Chain from Emissions to Impact

Most attribution studies only focus on one part of the causal chain linking emissions and land use changes to impacts. To the extent that the scientists working on these studies are aware of related research, it would be helpful for them to explicitly discuss this research and explain how it ties into their own findings. For example, a study attributing specific impacts to increases in

655. *See, e.g.*, Sippel et al., *supra* note 111; Christopher P. Weaver et al., *Improving the Contribution of Climate Model Information to Decision-Making: The value and Demands of Robust Decision Frameworks*, 4 WIREs CLIMATE CHANGE 39 (2013); Hannah Parker et al., *Using a Game to Engage Stakeholders in Extreme Event Attribution Science*, 7 INT'L J. DISASTER RISK SCI. 353 (2016).

656. Sippel et al., *supra* note 111, at 225 (citing to Weaver et al., *supra* note 655).

657. *See, e.g.*, Cynthia Rosenzweig & William Solecki, New York City Panel on Climate Change, *Special Issue: Advancing Tools and Methods for Flexible Adaptation Pathways and Science Integration Policy* (The New York Academy of Sciences 2019).

658. Julie A. Vano et al., *Hydroclimatic extremes as challenges for the water management community: Lessons from Oroville Dam and Hurricane Harvey, in* BAMS 2016, *supra* note 76.

extreme heat could cite external studies demonstrating the link between increases in extreme heat and anthropogenic forcing on climate. Researchers and scientific organizations could also publish more synthesis reports linking individual studies and explaining the extent to which these studies, in aggregate, can support claims of end-to-end attribution. Where possible, it would be helpful to harmonize the scope and scale of connected studies such that the quantitative analyses conducted in one study can flow through and inform the quantitative analysis in the subsequent study, with the goal being to develop robust, quantitative findings across a larger section of the causal chain. More fundamentally, further standardization of attribution research—ranging from the selection of topics to study, to the metrics used, and the data and models brought to bear—will support cross-comparison, evaluation, and scaling up of findings across studies.

B. How Might Judges and Litigants Utilize Attribution Science in the Courtroom?

The IPCC's *Special Report on the Impacts of Global Warming of 1.5°C* highlights the necessity of achieving rapid GHG emission reductions in the immediate future.[659] With temperatures having already increased by approximately 1°C and many national governments failing to make the necessary cuts in GHG emissions, legal intervention and innovation may be necessary in order to avert catastrophic climate change. This raises the question of how judges and litigants can best utilize attribution science to help argue and decide cases, particularly those involving claims that a government or private actor should be held accountable for their contribution to or failure to regulate GHG emissions. Below, we discuss some approaches and legal innovations that could provide for a more robust assessment and application of attribution science in the courtroom.

1. Standing and Justiciability

The single greatest obstacle to the effective utilization of attribution science in the courtroom is the fact that climate cases raising complex attribution issues may be dismissed or decided

659. IPCC, SPECIAL REPORT: GLOBAL WARMING OF 1.5°C (Valerie Masson-Delmotte et al. eds., 2018).

without a trial, meaning that their scientific bases may never fully assessed and adjudicated. As discussed in Part III, the main reasons for dismissal are lack of standing, the political question doctrine, the doctrine of legislative displacement, and the doctrine of foreign affairs preemption.

With regards to standing, some courts have recognized that the questions implicated in the standing analysis are heavily fact dependent and tend to overlap with the merits of the case.[660] But other courts have denied standing based on a cursory assessment of these scientific questions, finding without trial that the causal connection between emissions and injury is too attenuated.[661] Plaintiffs should not be denied their day in court based on judicial hunches about the state of the science. Standing claims involving disputed facts should be addressed after discovery, when all issues are fully briefed and all evidence is submitted.[662] For example, the questions of what constitutes a "meaningful contribution" to GHG emissions and whether a court can provide meaningful relief should be considered factual issues to be evaluated at the merits stage.[663] The Second Circuit in *American Electric Power,* the Fifth Circuit Court in *Comer,* and the district court in *Juliana* all endorsed this approach.[664]

Some scholars have also recommended specific analytical techniques that are uniquely well-suited for assessing standing claims in cases involving climate change-related claims. For example, scholars have recommended that courts recognize that the risk of harm is itself an injury that can provide the basis for standing.[665] This would bear on how the courts interpret the

660. Juliana v. United States, 217 F. Supp. 3d 1224, 1242–1248 (D. Or. 2016). *See also* Meier, *supra* note 600, at 1248–49 (noting that the standing analysis involves many assumptions and speculation, fact-intensive inquiry, competing experts, and weighing of evidence).

661. *See, e.g.*, Native Vill. of Kivalina v. Exxon Mobil Corp., 663 F. Supp. 2d 863, 880 (N.D. Cal. 2009).

662. Causation in Environmental Law, *supra* note 591, at 2270–71; Meier, *supra* note 600, at 1265 ("the fact-specific nature of the cause in fact inquiry makes it difficult to conduct this inquiry at the threshold of litigation, and thus it is irreconcilable with the gatekeeper function of standing").

663. *See supra* Part III(C)(5).

664. *See supra* Part III(C)(1)(b).

665. Hessick, *supra* note 353, at 67–68 (arguing that all claims based on a risk of injury present an actual case or controversy that should be justiciable, no matter how small the risk, and that the "substantial risk" requirement is directly at odds with holdings that the size of the harm is irrelevant to whether a plaintiff has standing, since the risk itself is an injury);

"injury-in-fact" requirement for future harms (e.g., in cases where attribution science is primarily used to support model projections of those future harms). It may also bear on how courts interpret the causation and redressability requirements. For example, in cases involving procedural harms, the "harm" is really an increased chance of substantive harm in the future, and courts adjust their standing analysis to accommodate such harms by relaxing requirements for imminence and redressability.[666] There is some judicial precedent to support such an approach.[667]

Another approach could be to allow "fractional standing" for probabilistic injuries.[668] According to one commentator, a "fractional injury" is "one that, if manifest in one individual, would be insufficient to grant standing" but if "multiple individuals experience this injury and band together to demand relief . . . then their collective grievance would be sufficient to merit standing."[669] Fractional standing involves looking at the probability of the harm, the severity of the harm, and the number of people at risk and determining whether the aggregate harm is sufficient to grant

Lin, *supra* note 603 (involuntary risk is a harm); Sunstein, *supra* note 603 (arguing that an increased probability of harm is itself an injury-in-fact that should suffice for standing purposes in cases that involve public law claims); Claire Finkelstein, *Is Risk a Harm?* 151 U. PENN. L. REV. 963 (2003) (arguing that risk of harm is itself a harm); Meier, *supra* note 600, at 1288–91 (noting there is some precedent for this approach); Robinson, *supra* note 588, at 783 (explaining why the "basic objectives of tort law are better served if liability is based on risk of injury than if it is based on the actual occurrence of harm").

666. Burt, *supra* note 353, at 280 (citing Sierra Club v. Marsh, 872 F.2d 497, 500 (1st Cir. 1989) (Judge Breyer clarified that the underlying harm in procedural injury cases is not the "harm to procedure," but the increased risk of substantive harm (to the environment, for example) that occurs when procedures are not followed.). *See also* Hessick, *supra* note 353, at 69 (In procedural cases, "it is clear that the injury is *not* the effect of the agency action on the plaintiff" because the redress that a court could provide (making the agency follow proper procedures) will not necessarily remedy that injury. Rather "the relevant injury that is redressed in a procedural claim is the increased probability of harm.").

667. *See Duke Power Co.* 438 U.S. 59 at 73–74 (holding apprehension caused by risk of harm caused by radiation exposure was sufficient for standing); Covington v. Jefferson Cty., 358 F.3d 626, 641 (9th Cir. 2004) (holding fear that leaking hazardous material would contaminate property was sufficient for standing); Suttin v. St. Jude Med. S.C., Inc. 419 F.3d 568, 575 (6th Cir. 2005) (holding increased risk of future physical injury from the implantation of an allegedly defective device constituted injury-in-fact); Baur v. Veneman, 352 F.3d 625, 633 (2d Cir. 2003) (holding enhanced risk of disease transmission may constitute injury-in-fact); Friends of the Earth, Inc. v. Gaston Copper Recycling Corp., 204 F.3d 149, 160 (4th Cir. 2000) ("Threats or increased risk . . . constitute[] cognizable harm.").

668. Daniel E. Rauch, *Fractional Standing*, 33 YALE J. ON REG. 281 (2016).

669. *Id.* at 282.

standing.[670] The D.C. Circuit implicitly endorsed this approach in *Natural Resources Defense Council v. EPA*, discussed above.[671]

With regard to the other justiciability issues raised by courts, judges may be relying on overly broad applications of general principles, such as the separation of powers, and legal doctrines, such as political question or foreign affairs preemption, to dismiss cases involving climate claims. There are, of course, many potential reasons for judicial caution in this context. Regulation has been viewed as a more appropriate response to climate change than court intervention. It is argued that democratically elected officials and technically sophisticated bureaucrats should be making policy decisions that involve complex scientific determinations, economic tradeoffs, and difficult ethical questions. There are also concerns about opening the "floodgates" to litigation. Even with robust evidence of attribution, courts may be hesitant to adjudicate claims against governments or private actors given that the numbers of potential claimants and defendants in public trust and tort actions as well as the scope of potential court decisions and the scale of potential compensation awards are huge.

But there are important counterpoints to these arguments. First, as plaintiffs in the atmospheric trust litigation,[672] the cities' tort cases,[673] and numerous statutory cases[674] argue, these climate cases arguably fall neatly within courts' core areas of competence and well-settled legal causes of action. The scale of the problem is not a reason, in and of itself, for courts to refuse to engage in its solution. Second, there is a large gap between the level of action taken by political branches of government and the level of action needed to avert the worst impacts of climate change. Courts do have a role in policing government failures to protect people's rights, whether those be fundamental rights secured under the Constitution or a public trust inherent in our nation's and states' democracies, or substantive and procedural rights provided under statute. Finally, there is an expressive function the law can and arguably should serve. Put simply, the world will experience catastrophic climate change if we continue a business-as-usual trajectory. Judicial

670. *Id.* at 290–91.
671. *See supra* Part III(C)(1)(a)(iv).
672. *See supra* Part III(C)(3)(b).
673. *See supra* Part III(C)(5).
674. *See supra* Part III(C)(3)(a).

intervention at this time could help change our course by sending important messages to governments and private actors about responsibility for climate change, unearthing facts which will advance public discourse on this topic, and in some cases compelling action that is needed to mitigate and adapt to climate change.

2. Factual and Proximate Causation

As illustrated in Part III, some judges have expressed skepticism about whether plaintiffs pursuing climate change-related claims can establish an adequate causal nexus between the defendant's conduct and their injuries as necessary to support standing and their arguments on the merits. However, recent cases provide valuable insight into how attribution science can be used to establish both factual and proximate causation in these cases.

a. Defining Parties' Contributions to GHGs

The first step in determining whether a party is a legally relevant cause of damages associated with climate change is to define that party's contribution to increases in atmospheric GHG concentrations. Some form of quantification is necessary to establish both factual cause and proximate cause. Above, we note that there are several legal tests for determining whether a party's contribution to a larger problem is a factual cause of that problem, most of which focus on the relative size of that contribution as compared with others (e.g., whether the party made a "material contribution" to the problem).[675] Quantifying the party's GHG contribution is essential to applying these tests. As for proximate cause: the question here is whether the injury is sufficiently closely related to the allegedly wrongful conduct such that it would be reasonable to impose liability. Again, the size of the emissions contribution is relevant to this inquiry.

675. We do not mean to imply that these relative share tests are the only appropriate means of ascertaining factual causation. A court could conclude that even a small contribution to GHG emissions is a factual cause of at least some of the harmful effects of climate change. The concern, of course, is that imposing liability on small contributors would open the floodgates to litigation. But a court pursuing this approach could also rely on the proximate cause requirement to conclude that it would be unreasonable to impose liability for such a small contribution.

Defining a party's GHG contribution is not as straightforward as one might like. There may be data gaps that preclude accurate quantification. Even where adequate data exists, there are inevitably analytical questions that must be answered, such as which emissions accounting approach to use—territorial, consumption-based, or extraction-based—and how to account for historical as compared with present (and possibly even future) emissions. Lawyers and judges can turn to source attribution science to understand the relative contribution of sources under different accounting methods at different temporal scales.

Several of the cases brought to date illustrate how litigants and courts might use source attribution data to define GHG contributions:

> In *Urgenda*, the Supreme Court of the Netherlands used the Dutch national emissions inventory to define that country's GHG contribution and relied on scientific research on the global carbon budget to define its corresponding emissions reduction obligation. Specifically, the court referred to UNFCCC decisions finding that industrialized countries must reduce emissions 25–40% below 1990 levels by 2020 to limit global warming to 2°C, which was in turn based on IPCC reports outlining possible global emission reduction pathways for achieving this target.[676] The court also discussed reports which corroborated Urgenda's assertion that the Dutch government must reduce emissions by at least 25% in this timeframe, including UNEP Emissions Gap reports which found that industrialized country commitments were insufficient to limit warming to 2°C or 1.5°C, a report prepared by the PBL Netherlands Environment Assessment Agency finding that Dutch policy must be more ambitious to align it with the Paris Agreement, and data showing that Dutch per capita emissions were "relatively high" compared to other industrialized nations.[677]

The expert reports compiled in *Juliana* illustrate, among other things, how parties can disaggregate government responsibility for GHG emissions based on authorities and decisions. For example, plaintiffs provided a counterfactual scenario in which they estimated emission reductions that would have occurred if the government had pursued a certain course of action to address

676. *Urgenda* Decision (2019) at ¶¶ 7.1-7.3.6.
677. *Id.* at ¶¶ 2.2.2, 4.6, 7.3.4, 7.4.4, 7.2.9.

climate change in the past, in order to delimit the fact of government responsibility, while also presenting estimates of total emissions from energy emissions within the U.S. *and* data on potential emissions from U.S. energy exports and consumption.[678] Defendants, naturally, contested that scenario with their own experts, who argued that the U.S. government cannot be held responsible for all emissions generated within the U.S. (or by products consumed within the U.S. or fossil fuels extracted within the U.S.), and who estimated that U.S. government conduct is responsible for no more than 4–5% of total global emissions.[679] In denying the defendants' motion for summary judgement, the district court found that the pleadings submitted by both parties "make clear that plaintiffs and defendants agree that federal defendants' policies greenhouse gas emissions play a role in global climate change" even if there was a dispute as to extent of that role.[680] With regards to the quantity of emissions attributable to the U.S. government, the district court focused on the defendants' admissions regarding total U.S. emissions (e.g., defendants admitted in their answer that the U.S. is responsible for more than 25% of cumulative global CO_2 emissions from 1850 to 2012) and noted that this was much greater than the 6% of global emissions at issue in *Massachusetts*.[681] The judge did not explicitly rule on whether all cumulative U.S. emissions could be attributed to U.S. government conduct, but she did discuss the many lines of evidence demonstrating a causal connection between U.S. policies and third party emissions and found this sufficient to support causation for standing purposes at the summary judgement stage.[682]

The plaintiffs in *Juliana* also argued that territorial, consumption-based, *and* extraction-based accounting methodologies should be considered in determining the government's GHG contribution and corresponding responsibility for climate change. In their complaint, they relied primarily on estimates of cumulative

678. See *supra* Part III(C)(3)(b)(i).
679. *Id.*
680. Juliana v. United States, 339 F. Supp. 3d 1062, 1072 (D. Or. 2018).
681. *Id.* at 1092.
682. *Id.* at 1093. *See also* Juliana v. United States, 217 F. Supp. 3d 1224, 1246 (D. Or. 2016) ("DOT and EPA have jurisdiction over sectors producing sixty-four percent of United States emissions, which in turn constitute roughly fourteen percent of emissions worldwide; they allow high emissions levels by failing to set demanding standards; high emissions levels cause climate change; and climate change causes plaintiffs' injuries.").

territorial emissions to support their allegations, and then supplemented this with additional emissions attributable to U.S. consumption of fossil fuels and U.S. fossil fuel exports. As discussed in Part III, they also enlisted an expert to provide a detailed comparison of U.S. emissions under the three accounting approaches and to explain why the U.S. government should maintain consumption-based and extraction-based inventories in addition to a territorial inventory.[683] This "all-of-the-above" approach makes sense for the purposes of establishing national responsibility for climate change as a general matter or in qualitative terms. But in calculating a national and global emissions inventory and budget for the purpose of setting policy, one methodology must dominate, to avoid double and triple counting of emissions. Recognizing this, the plaintiffs in *Juliana* focused on consumption-based emissions in their requested remedy: they sought a court order compelling the U.S. government to "prepare a consumption-based inventory of U.S. CO_2 emissions" accompanied by an enforceable plan to phase out fossil fuel emissions and draw down excess atmospheric CO_2.[684] The defendants did not strongly object to a consumption-based accounting approach in their reply briefs (as their primary argument was that the U.S. government should not be held accountable for all U.S. emissions no matter what accounting approach is used), but one of their experts did express the view that transitioning to a consumption-based accounting system might be infeasible or difficult to implement.[685]

Other lawsuits rely on different emissions accounting methodologies. There is no strict requirement that different courts addressing different types of legal claims, in different jurisdictions, use the same accounting methods to impose responsibility on entities; it may well be that climate litigation results in two different parties being held responsible for the same emissions. However, while this may not strangle the litigation, it can raise concerns

683. *See* supra Part III(C)(3)(b)(i).

684. Amended Complaint, Prayer for Relief, at 94, Juliana v. United States, 217 F. Supp. 3d 1224 (D. Or. 2016) (No. 6:15-cv-01517-TC).

685. Expert Report of David G. Victor at 4, Juliana v. United States, 217 F. Supp. 3d 1224 (D. Or. 2016) (No. 6:15-cv-01517-TC) ("with respect to claims regarding the use of consumption-based accounting methods for 95 GHGs, it is my expert opinion that such methods are neither administratively, nor politically 96 straightforward to implement quickly.").

about fairness, justice, and the efficiency of the judicial system. For instance, in the lawsuits against fossil fuel companies, plaintiffs focus on extraction-based emissions, primarily relying on estimates of cumulative fossil fuel production to establish that the companies they are suing have made a "substantial contribution" to climate change.[686] In response, the defendants have argued that plaintiffs are seeking to evade precedent holding that the federal government's Clean Air Act authority displaces nuisance claims based on GHG emissions by focusing on the extraction of fossil fuels rather than consumption. The federal district court in California, in denying motions from San Francisco and Oakland to remand their cases back to state court, expressed agreement with defendants, stating that plaintiffs seek to avoid federal common law by "fixat[ing] on an earlier moment in the train of history, the earlier moment of production and sale of fossil fuels, not their combustion."[687] Relatedly, the district courts in both the Oakland case and in the New York City case dismissed the cases, in part, due to the extraterritorial implications of imposing liability for the extraction of fossil fuels and their belief that this would infringe on the foreign affairs power of the executive and legislative branches of government.[688] It remains to be seen whether other judges overseeing these lawsuits will adopt a similar perspective on the extraterritorial effects of holding fossil fuel companies liable for their contribution to climate change.

These cases also illustrate how other types of information are relevant to the analysis of proximate cause and supplement attribution data. Some of the normative considerations relevant to the proximate cause inquiry include the extent to which the company profited from the production and eventual use of fossil fuels, whether the company knew that it was producing and selling a harmful product, and whether the company engaged in unethical activities such as the obstruction of climate change science.[689]

686. *See supra* Part III(C)(5).

687. Order Denying Motion to Remand at 6, California v. BP P.L.C., (N.D. Cal. Feb. 27, 2018) (No. C 17-06011 WHA).

688. City of Oakland v. BP P.L.C., 325 F. Supp. 3d 1017 (N.D. Cal. 2018); City of New York v. BP P.L.C., 325 F. Supp. 3d 466 (S.D.N.Y. 2018).

689. The UCS publishes reports on "climate accountability" at fossil fuel companies in which it assesses companies based on these sorts of criteria. *See, e.g.*, *The Climate Accountability Scorecard,* UNION OF CONCERNED SCIENTISTS, (Oct. 23, 2018), https://www.ucsusa.org/global-

Recognizing this, plaintiffs in lawsuits against fossil fuel companies have framed the allegedly tortious conduct in their complaints broadly, focusing not only on the companies' production and sale of fossil fuels, but also the fact that they knew about the potential harms of their products many years, actively concealed that information, pursued climate change disinformation campaigns, and lobbied against climate change regulations.[690] Plaintiffs in *Juliana* also touched on some similar arguments in their complaint, noting, for example, that the U.S. government "acted with deliberate indifference" when it ignored expert reports urging it to take immediate action on climate change in the early 1990s.[691]

Countries and companies may claim that they cannot be held responsible for emissions before the early 1990s because that was when the IPCC first warned the world about climate change and the UNFCCC first committed to take action to address the problem. Recognizing this, some plaintiffs, like those in *Juliana*, have focused on emissions since 1990 as the primary basis for their claims.[692] However, scholars have compiled a wealth of evidence from the 1960s, 1970s, and 1980s that put countries and companies on notice about the harmful effects of GHG emissions and the perils of climate change.[693] Plaintiffs in tort cases against fossil fuel companies rely on evidence showing that fossil fuel companies have known about the risks of their products since the 1950s to establish that they can be held responsible for historical emissions, but the plaintiffs also emphasize the point that most fossil fuel emissions have accumulated since 1980, at which time the industry already knew that their products posed a "catastrophic" threat to the global climate.[694] Given the level of industry knowledge regarding the harms of their products and the intentional concealment of these risks, some plaintiffs in these cases have also argued that companies

warming/fight-misinformation/climate-accountability-scorecard-ranking-major-fossil-fuel-companies#.W_L31ZNKhaR [https://perma.cc/5K7X-VK9K].

690. *See supra* Part III(C)(5).

691. Complaint for Declaratory and Injunctive Relief ¶ 8, Juliana v. United States, 217 F. Supp. 3d 1224 (2015) (No. 6:15-cv-01517-TC), 2015 WL 4747094.

692. First Amended Complaint, ¶¶ 141, 151, Juliana v United States, 217 F. Supp. 3d 1224 (2015) (No. 6:15-cv-01517-TC) (plaintiffs in *Juliana* also present data on historical emissions since the 1700s and cite evidence of the U.S. government knowing about the dangers of climate change as far back as 1965 to further bolster their claims).

693. Heede, *supra* note 31.

694. *See, e.g.*, Complaint for Public Nuisance ¶ 61, State of California v. BP P.L.C., No. CGC-17-561370 (filed Cal. Super. Ct., Sep. 19, 2017).

should be held strictly liable for failure to warn and for design defect.[695]

b. Establishing Causal Connections to Impacts

The cases litigated to date demonstrate that attribution science is sufficiently robust to establish causal connections between increases in GHG concentrations, global warming, and a broad range of on-the-ground impacts and harms. This is not to say *all* impacts of climate change can be definitively linked to anthropogenic influence on climate—but there is a sufficiently large subset of impacts that can be attributed with enough confidence to support litigation in one form or another. These include, for example, sea level rise, melting snowpack, increases in average temperatures and extreme heat, and ocean acidification.

The analysis in cases like *Massachusetts* and *American Electric Power* suggests that it should be relatively easy for entities like states, tribes, and cities to establish a causal connection between climate change and at least some injuries associated with it. This is not merely because of their sovereign status—it is also because these entities represent many people and assets and will experience greater harms from climate change as a result of the breadth of their interests. The same can be said for trade organizations, environmental groups with large memberships, and other non-governmental entities that represent many individuals.

Juliana illustrates some of the challenges plaintiffs may face in establishing a causal connection to individual injuries. As discussed in Part III, the plaintiffs dedicated a large portion of their briefs and expert testimony to defining that causal nexus between climate change and specific injuries, and if the case had gone to trial, this would have been one of the key factual disputes. One critical question for courts as they begin to grapple with such factual disputes is to what extent observational evidence of local impacts (e.g., loss of snowpack at ski resorts) can be used to support claims of injury in the absence of an attribution study of a matching geographic and temporal scope showing that the observed impact was caused by anthropogenic influence on climate change. The answer to this question of course depends on context, but generally

695. *See, e.g.*, Complaint, Richmond v. Chevon et al., No. C18-00055 (filed Cal. Super. Ct., Jan 22, 2018).

speaking, such observational evidence should be interpreted in light of the larger body of attribution research and assigned weight accordingly. For example, if plaintiffs submit evidence that anthropogenic influence on climate is driving snowpack declines throughout the Northern Hemisphere, then it would be reasonable to infer that the observed declines in snowpack at particular resorts in North America have also been caused by anthropogenic influence on climate even without a radically downscaled attribution study for those resorts.

We recognize that in cases like *Kivalina* and *Bellon*, courts have expressed doubt about whether it is possible to trace emissions from a particular source to specific impacts due to the nature of climate change. But if this argument was taken to its extreme, then no one could be held responsible for climate change. From a technical standpoint, given that GHG emissions disperse throughout the atmosphere and have a relatively uniform effect, it would be more accurate to say that *all* emissions can be traced to impacts. And as discussed below, the emissions contribution of a party can be used as a proxy for its contribution to an impact.

Litigants and courts should be aware of both the strengths and limitations of attribution science when framing and analyzing arguments. Plaintiffs may prove most successful where they base their claims on impacts which can be attributed to anthropogenic climate change with high confidence, such as sea level rise, melting snowpack, increases in average temperatures and extreme heat, and ocean acidification. Plaintiffs may also prove most successful where they rely on expert reports and peer-reviewed attribution studies and avoid making causal inferences even for those impacts for which there is a very robust connection to anthropogenic climate change. Judges, meanwhile, should be mindful of the fact that there are different levels of confidence for different impacts, pay close attention to the evidence submitted, and should not dismiss claims based on generalized conclusions about the uncertainty of the science. Judges should also be aware that, when translating global or regional impacts to specific injuries, it may be necessary to accept causal inferences, as with the snowpack example presented above.

3. Proving and Defending against Obligations and Redressability

Few jurisdictions have addressed in even a preliminary way critical questions regarding the scope and extent of private and governmental obligations to address climate change. As discussed above, there is some precedent affirming national obligations in other jurisdictions (e.g., *Urgenda*), but no U.S. court has yet found that the federal government is bound to any particular level of climate ambition. Recall that *Massachusetts* held that EPA had failed to justify its decision not to issue GHG regulations for motor vehicles; it did not mandate that EPA actually issue the regulations, far less that it issue regulations achieving one or another standard.[696]

Urgenda illustrates how attribution science can be used to help establish national emission budgets. Source attribution data is constantly improving and estimates of carbon budgets are constantly being revised in light of new emissions data, so it will be important for litigants and courts to rely on the most recent data in framing carbon budgets.[697] The understanding that carbon budgets are a moving target could also factor into the remedy prescribed by courts in cases like *Urgenda*. For example, rather than mandating a government achieve a specific target on a specific date, a court could require the government to establish and periodically update its target based on the best available science. Attribution science could also be used to define more specific obligations for national governments, such as obligations pertaining to fossil fuel development and subsidies (source attribution data on extraction emissions would be particularly relevant here). For example, in the Colombian case holding that the government violated fundamental rights by failing to address the risks posed by climate change, the court relied on research showing the contribution of deforestation to climate change in determining that the Colombian government had an obligation to protect, conserve, maintain, and restore the portion of the Amazon forest located within Colombia.[698] In particular, the court cited: (i) estimates from Colombia's Institute of Hydrology, Meteorology, and Environmental Studies (IDEAM)

696. *See supra* Part III(C)(3)(a)(i).

697. *See* discussion *supra* Part II(B)(4).

698. Corte Suprema de Justicia [C.S.J.] [Supreme Court], April 5, 2018, STC4360, No. 11001-22-03-000-2018-00319-01 (Colom.), http://climatecasechart.com/non-us-case/future-generation-v-ministry-environment-others/ [https://perma.cc/53WU-NLJK].

finding that the increase in GHG emissions resulting from deforestation in the Amazon forest would generate an increase in Colombia's temperature by 0.7–1.1°C between 2011 and 2040, by 1.4–1.7°C between 2041 and 2080, and by as much as 2.7°C between 2017 and 2100; (ii) qualitative findings from IDEAM that the GHG increase from deforestation would also result in more precipitation in some areas and less precipitation in other areas, potentially exacerbating problems such and pollutant loadings (during wet periods) and drought; and (iii) a government report finding that reducing deforestation to zero by 2020 would ensure that "44 megatons of greenhouse gases would not enter the atmosphere."[699]

In establishing obligations for private actors, one critical question will be how to allocate liability and damages among multiple companies. The plaintiffs in *RWE* have already provided the courts with one possible approach: they are seeking damages that are proportionate to the company's individual GHG contribution (thus pursuing several liability). The municipal plaintiffs suing fossil fuel companies have pursued a slightly different approach, seeking to hold these companies jointly and severally liable for their aggregate contribution climate change. Judges may view joint and several liability as a slippery slope in this context, given that there are so many potential defendants who could be joined in these cases. Another alternative would be to hold upstream manufacturers liable for the production and sale of harmful products under a market share theory of liability (e.g., apportioning liability among fossil fuel companies based on their share of fossil fuel sales).[700]

Arguably, imposing several liability based on the party's proportionate contribution to GHG increases is the approach which best reflects the party's "true" contribution to climate change impacts. A market-share approach would also accomplish this if

699. *Id.* ¶¶ 11.1, 11.3.

700. For more on this topic, *see* Grimm, *supra* note 553, at 216 ("Market share liability has often been found appropriate only where products are sufficiently interchangeable such that it is either impossible or overwhelmingly burdensome to isolate individual causation among defendants."); Andrew B. Nace, Note, *Market Share Liability: A Current Assessment of a Decade-Old Doctrine*, 44 VAND. L. REV. 395, 396–97 (1991); Samantha Lawson, *The Conundrum of Climate Change Causation: Using Market Share Liability to Satisfy the Identification Requirement in* Native Village of Kivalina v. ExxonMobil Co., 22 FORDHAM ENVTL L. REV. 433 (2010); Daniel A. Farber, *Basic Compensation for Victims of Climate Change*, 155 U. PA. L. REV. 1605, 1640–55 (2007). *But see* Kysar, *supra* note 555, at 37 (critiquing the market share liability approach and recommending that several liability is the appropriate form of recovery).

the "market share" were defined as the share of GHG emissions, (in which case this would be identical to the several liability approach)—but if the "market share" is the share of fossil fuels produced or electricity generated, then this approach might overestimate the actual contribution to the injury (insofar as other GHG sources, such as agriculture and land use change, would not be accounted for in the contribution determination). Imposing joint and several liability might also result in an overestimation of a party's contribution to the injury. However, there may be compelling reasons to impose joint and several liability in certain contexts—for example, in the municipal lawsuits against fossil fuel companies, the plaintiffs note that the companies colluded in climate change misinformation campaigns, and that each company was "the agent, servant, partner, aider and abettor, co-conspirator, and/or joint venture" of the other defendants to justify their request for joint and several liability.[701]

V. CONCLUSION

In this Article, we summarize the state of the art in climate change detection and attribution science; describe how that science is being used in policy, planning, and litigation; and discuss further directions in the law and science of climate change attribution. We focus, in particular, on the use of attribution science in the courtroom. Attribution science has always been a key component of climate change litigation. But, the recent waves of cases brought against national and subnational governments, seeking increased mitigation ambition, and against fossil fuel and energy companies, seeking compensation or abatement funds for the costs of adaptation, have made the relationship between the science and law of climate change attribution all the more salient.

The political sphere in the United States continues to be clouded with false debates over the validity of climate science. Things are far clearer in the courtroom, where to our knowledge no judge has questioned the scientific basis for the global community's shared understanding of the causes and effects of climate change. But there are significant scientific issues that remain to be clarified, for

701. *See, e.g.*, Complaint ¶ 40, Imperial Beach v. Chevon et al., No. C17-01227 (filed Cal. Super. Ct., July 17, 2017); Complaint ¶ 44, Richmond v. Chevon et al., No. C18-00055 (filed Cal. Super. Ct., Jan 22, 2018).

law and policy purposes, and it may well be that litigation provides the forum for achieving that clarity.

Climate Change Vulnerability Study

December 2019

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conEdison

In partnership with:

ICF

Lamont-Doherty Earth Observatory
COLUMBIA UNIVERSITY | EARTH INSTITUTE

With contributions from O'Neill Management Consulting, LLC, The Risk Research Group, Inc., and Jupiter Intelligence Inc.

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Executive Summary

In its 2013 rate case filing after Superstorm Sandy, Con Edison proposed $1 billion in storm hardening investments to build additional resiliency into its energy systems. Con Edison worked with a Storm Hardening and Resiliency Collaborative to recommend optimal investments for the proposed storm hardening funds, including the recommendation that Con Edison conduct a Climate Change Vulnerability Study (Study). As described by the New York State Public Service Commission, the purpose of this Study is to aid in the ongoing review of the Company's design standards and development of a risk mitigation plan.[1] Over the course of the Study, Con Edison regularly convened a stakeholder group to provide feedback, consisting of many of the same participants from the Storm Hardening and Resiliency Collaborative. The findings from the Study equip Con Edison with a better understanding of future climate change risks and strengthen the company's ability to more proactively address those risks.

This Study describes historical and projected climate changes across Con Edison's service territory, drawing on the best available science, including downscaled climate models, recent literature, and expert elicitation. Con Edison recognizes the global scientific consensus that climate change is occurring at an accelerating rate. The exact timing and magnitude of future climate change is uncertain. To account for climate uncertainty, the Study considered a range of potential climate futures reflecting both unabated and reduced greenhouse gas concentrations through time and evaluated extreme event "stress test" scenarios.

This Study evaluates present-day infrastructure, design specifications, and procedures against expected climate changes to better understand Con Edison's vulnerability to climate-driven risks. This analysis identified sea level rise, coastal storm surge, inland flooding from intense rainfall, hurricane-strength winds, and extreme heat as the most significant climate-driven risks to Con Edison's systems. Con Edison has unique energy systems, and vulnerabilities vary across those systems. The utility's electric, gas, and steam systems are all vulnerable to increased flooding and coastal storms; workers across all commodities are vulnerable to increasing temperatures; and the electric system is also vulnerable to heat events.

While Con Edison already uses a range of measures to build resilience to weather events, the vulnerabilities identified in this Study guide the company to pursue additional strategies to mitigate climate risks. The Study establishes an overarching framework that can work to strengthen Con Edison's resilience over time. While many adaptation strategies focus on avoiding impacts altogether, a comprehensive resilience plan also requires a system that can reduce and recover from impacts, particularly following outages.

Over the course of 2020, Con Edison will develop and file a Climate Change Implementation Plan, which will specify a governance structure and a strategy for implementing adaptation options over the next 5, 10, and 20 years. While this Study assesses vulnerabilities within Con Edison's present-day systems to a future climate, the implementation plan must also consider the evolving market for energy services, and potential changes to services and infrastructure driven by customers, government policy and external actions over time.

[1] Cases 13-E-0030, 13-G-0031, 13-S-0032, Order Adopting Storm Hardening and Resiliency Collaborative Phase Three Report Subject to Modifications (January 25, 2016).

The Need for a Study

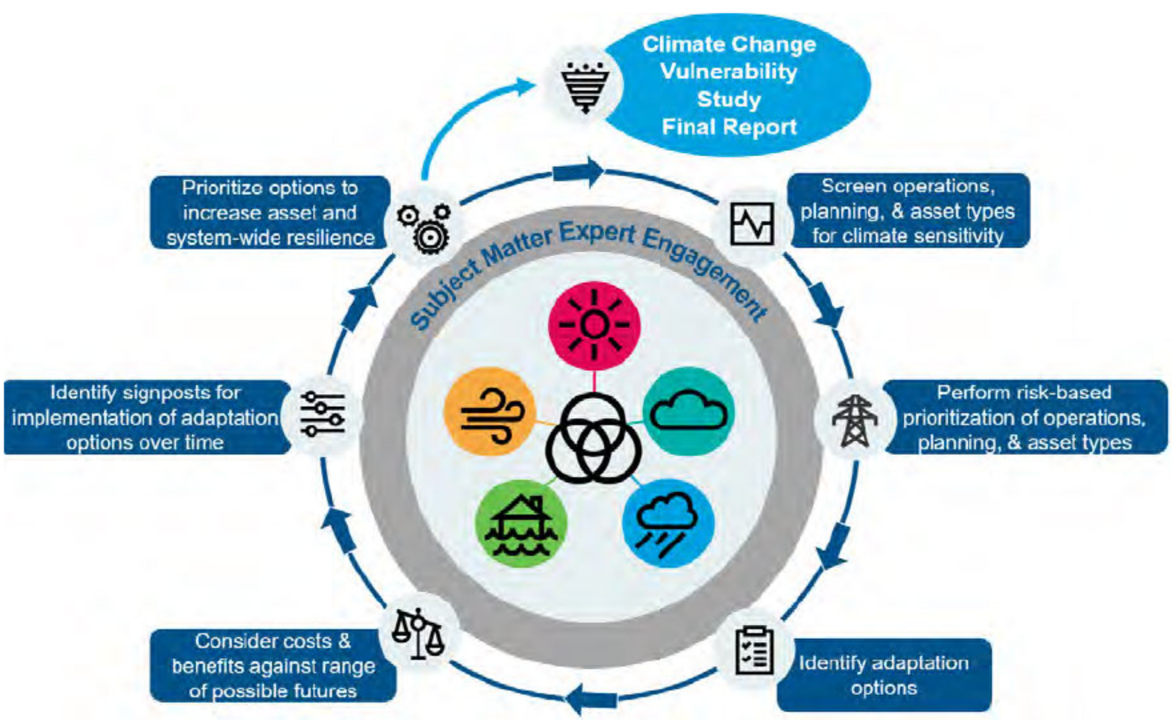
The New York State Public Service Commission approved an Order and funding for Con Edison to conduct a Climate Change Vulnerability Study, with a requirement for delivery by the end of 2019. The Con Edison Department of Strategic Planning undertook this Study with support from more than 100 subject matter experts throughout the company and in collaboration with ICF's climate adaptation and resilience experts and Columbia University's Lamont-Doherty Earth Observatory. The Study was designed to meet three primary goals:

Con Edison's resilience to climate change has important implications for increasingly interconnected societal, technological, and financial systems that the company serves.

1. Research and develop a shared understanding of new climate science and projected extreme weather for the service territory.
2. Assess the risks of potential impacts of climate change on operations, planning, and physical assets.
3. Review a portfolio of operational, planning, and design measures, considering costs and benefits, to improve resilience to climate change.

The Study used an integrated approach to achieve these goals, as shown in Figure 1.

Figure 1 ■ General approach overview: The process cycles through the steps for each climate hazard, beginning with 'Screen operations, planning, and asset types for climate sensitivity'. The process results in the Climate Change Vulnerability Study Final Report.



A New Understanding of Climate Science and Extreme Weather

Con Edison will face new challenges from a rapidly changing climate through the 21st century. To better understand these challenges, the Study characterized historical and projected changes to climate hazards within the service territory to estimate the magnitude and timing of potential climate vulnerabilities. Climate variables that present outsized impacts to Con Edison include temperature, humidity, precipitation, sea level rise, and extreme events, such as rare hurricanes and long-duration heat waves.

Temperature

Average and maximum air temperatures are projected to increase throughout the century relative to historical conditions. Assuming unabated greenhouse gas concentrations, Con Edison could experience up to 23 days per year in which maximum temperatures exceed 95°F by 2050 relative to 4 days historically. Heat waves with 3 or more days when *average* temperatures exceed 86°F in Central Park are projected to occur up to 5 and 14 times per year by 2050 and 2080, respectively, relative to 1 heat wave every 5 years historically.

Humidity

The frequency of very high heat index thresholds, which combines both temperature and humidity, is projected to increase dramatically through the century. The number of days per year where the heat index equals or exceeds 103°F could increase by 7 to 26 days by 2050, compared with only 2 days historically. In addition, Con Edison evaluates the relationship of system load to an index called temperature variable (TV), which is similar to a heat index, but considers the persistence of heat and humidity over several days. Looking forward, TV thresholds that historically occur only once per year (e.g., 86°F) are projected to become common occurrences within a generation, occurring between 4 and 19 times per year by 2050 and between 5 and 52 times per year by 2080 based on reduced and unabated greenhouse gas concentrations, respectively.

Precipitation

Con Edison's service territory experiences rainfall, downpours, snowfall, and ice. Climate change is projected to drive heavier precipitation across these event types. For example, the heaviest 5-day precipitation total could be 11.8 inches at Central Park by 2050, which represents a 17% increase over the historical reference period. Ultimately, projections point to a future defined by more frequent heavy precipitation, likely accompanied by smaller increases in the frequency of dry or light precipitation days.

Sea Level Rise

Sea levels are very likely to rise between 0.62 and 1.94 feet by 2050. In turn, rising sea levels will have profound effects on coastal flooding, as sea level rise increases both the frequency and height of future floods. For example, the flood height associated with the 1% annual chance flood (i.e., the so-called 100-year flood) in New York City is projected to increase from 8.3 feet to as much as 13.3 feet by 2100 relative to mean sea level at the Battery tide gauge. By the end of the century, today's annual chance flood could occur at every high tide.

Extreme Events

Extreme events are low-probability and high-impact phenomena, such as hurricanes and long-duration heat waves. While difficult to simulate in climate models, a growing body of evidence suggests that many extreme events will increase in frequency and intensity as a result of climate warming. This Study considers high impact "worst-case"[2] extreme event scenarios, including a prolonged heat wave, a Category 4 hurricane, and an unprecedented nor'easter, to understand these changes and their impacts on Con Edison.

Characterization of Con Edison's Vulnerabilities to Climate Risks

Heat and Temperature Variable

The core electric vulnerabilities to increasing temperature and TV include increased asset deterioration, decreased system capacity, increased load, and decreased system reliability. Since the internal temperature of electric power equipment is determined by the ambient temperature as well as the power being delivered, higher ambient temperatures increase the internal operating temperature of equipment.

Higher internal operating temperatures increase the rate of aging of the insulation of electric equipment such as transformers, resulting in decreased total life of the assets. Higher internal temperatures, resulting from higher average and maximum ambient temperatures, also reduce the delivery capacity of electric equipment such as transformers. In addition, higher ambient temperatures increase the operating temperature of overhead transmission lines, causing increased sagging. One remedy is to decrease the operational rating of the assets to reflect the new operating environment. However, derating the system due to increasing temperatures would effectively decrease the capacity of the system, and Con Edison will need to make investments to replace that capacity if it is needed.

Similarly, higher TV can cause higher peak loads due to increases in demand for cooling. Increases in load may also require investments in system capacity to meet the higher demand. The combination of decreased capacity and increased load is best addressed through Con Edison's existing 10- and 20-year load relief program. Addressing this combined risk is estimated to cost between $1.3 billion and $4.6 billion by 2050 (based on future projections using Representative Concentration Pathway (RCP) 4.5 10th and RCP 8.5 90th percentiles, respectively).

Increases in heat waves are expected to affect the electric network and non-network systems by decreasing reliability. Con Edison uses a Network Reliability Index (NRI) model to determine the reliability of the underground distribution networks. The Study's forward-looking NRI analysis found that with an increase in the frequency and duration of heat waves by mid-century, between 11 and 28 of the 65 underground networks may not be able to maintain Con Edison's standard of reliability by 2050, absent adaptation.

Outdoor worker safety may be a concern across all Con Edison commodities if heat index values rise as projected. When needed, Con Edison can implement safety protocols (e.g., shift modifications and hydration breaks) already practiced in mutual aid work that the company provided in hotter locations such as Florida and Puerto Rico. Similarly, to supply sufficient cooling in 2080, Con Edison's heating, ventilation, and air conditioning (HVAC) capacity will have to increase by 11% due to projected increases in dry bulb temperature. These systems have a roughly

[2] "Worst-case" scenarios are meant to explore Con Edison system vulnerabilities related to rare extreme weather events and formulate commensurate adaptation and resilience strategies. Scenarios represent one plausible permutation of extreme weather and the severity of actual events may exceed those considered.

15-year life span and therefore can be upgraded during routine replacements with minimal cost increases.

Flooding from Precipitation, Sea Level Rise, and Coastal Storms

All underground assets are vulnerable to flooding damage (i.e., water pooling, intrusion, or inundation) from precipitation events, sea level rise, and coastal storms. Following Superstorm Sandy in 2012, Con Edison protected all infrastructure in the floodplain against future 100-year storms and 1 foot of sea level rise (e.g., submersible infrastructure, flood walls, pumps, elevation). Sea level rise projections suggest that Con Edison's 1 foot of sea level rise risk tolerance threshold may be exceeded as early as 2030 and as late as 2080.

Electric substations, overhead distribution, underground distribution, and the transmission system are sensitive to precipitation-based hazards, although the design of Con Edison's assets already mitigates some of these risks. For example, flooding from increased intense precipitation can damage non-submersible electrical equipment, although Con Edison designs all underground cables and splices to operate while submerged in water. In addition, all underground distribution equipment installed in flood zones and all new installations are submersible.

To assess future asset vulnerability to sea level rise and storm surge, the Study team analyzed the exposure of Con Edison's assets to 3 feet of sea level rise, while keeping the other elements of Con Edison's existing risk tolerance constant (i.e., a 100-year storm with 2 feet of freeboard). Of the 324 substations (encompassing generating stations, area substations, transmission stations, unit substations, and Public Utility Regulating Stations), 75 would be vulnerable to flooding during a 100-year storm if sea level rose 3 feet. In addition, 32 gas regulators and five steam generation stations would be exposed. Hardening all of these assets would cost approximately $680 million.

Both the gas and steam distribution systems are vulnerable to water entry, which can reduce system pressure and limit distribution capacity. In the gas system, low-pressure segments[3] are particularly vulnerable to this risk. In addition, the steam system is susceptible to "water hammer" events when a high volume of water collects around a manhole, causing steam in the pipes underneath to cool and condense. Interaction between steam and the built-up condensate may cause an explosion, both damaging the steam system and putting public safety at risk.

Across all commodities, increased winter precipitation can wash salt from city roads, causing an influx of salt-saturated runoff into manholes and percolation into the ground. Salt can cause equipment degradation, arcing, manhole fires or explosions, and failure of underground assets.

Extreme and Multi-Hazard Events

The Study team reviewed the vulnerabilities of Con Edison's electric, gas and steam systems to future extreme events based on specific, worst case extreme event narratives (Category 4 hurricane, a strong nor'easter, and a prolonged heat wave) designed to stress-test these systems.

Storm surge driven by an extreme hurricane event (i.e., a Category 4 hurricane) has the potential to flood both aboveground and belowground assets. In addition, wind stress and windblown debris can lead to tower and/or line failure of the overhead transmission system and damage overhead distribution infrastructure, which could cause widespread customer outages.

[3] The Con Edison gas system contains piping operating at three pressures: low, medium, and high.

An extreme nor'easter may cause significant damage to assets across all commodities. During nor'easters, accumulation of radial ice can cause tower or line failure of the overhead transmission system. Similarly, snow, ice, and wind can damage the overhead distribution system.

Con Edison's systems are vulnerable to exceeding system capacity during extreme temperatures; gas systems may experience overloading during extreme cold, and electric systems during extreme heat.

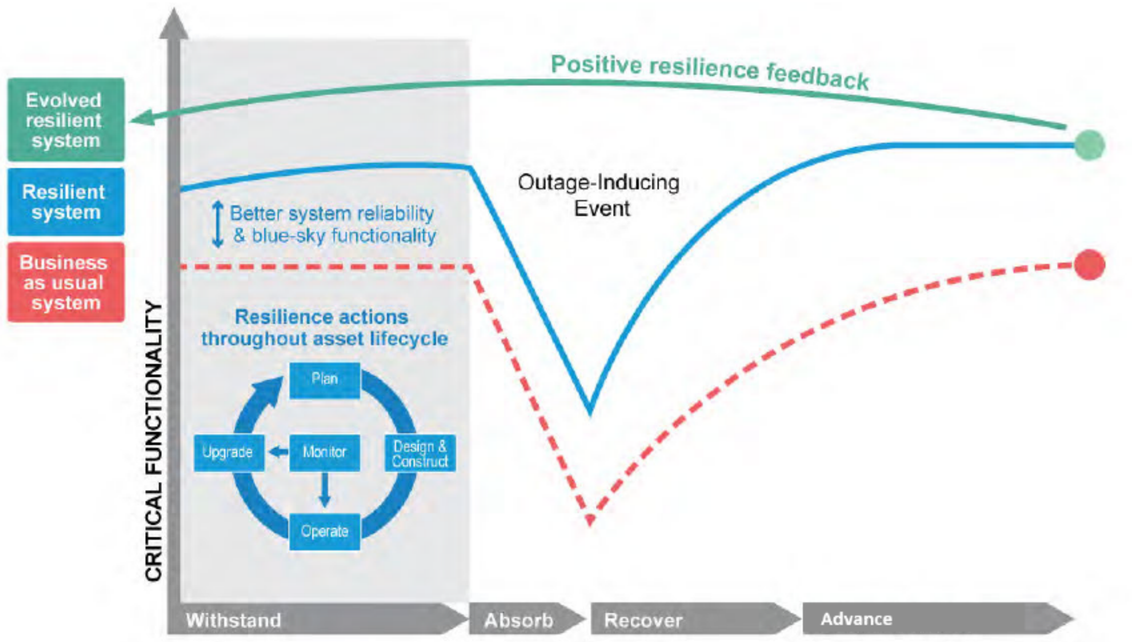
On an operational level, the increasing frequency and intensity of extreme weather events may exceed Con Edison's currently robust emergency preparedness efforts. Con Edison's current "full-scale" response, which calls for all Con Edison resources and extensive mutual assistance, is initiated when the number of customers out of service reaches approximately 100,000. However, low-probability extreme events can increase customer outages and outage durations by orders of magnitude, outpacing current levels of emergency planning and preparedness.

Resilience Management Framework

A resilience management framework will help Con Edison build resilience over time.

To conceptualize how to systematically address vulnerabilities, the Study team developed a resilience management framework (Figure 2). The framework encompasses investments to better withstand changes in climate, absorb impacts from outage-inducing events, recover quickly, and advance to a better state. The "withstand" component of this framework prepares for both gradual and extreme climate risks through resilience actions throughout the life cycle of the assets. As such, many adaptation strategies fall under this category. Investments to increase the capacity to withstand also provide critical co-benefits such as enhanced blue-sky functionality and reliability of Con Edison's systems. The resilience management framework facilitates long-term adaptation and creates positive resilience feedback so that Con Edison's systems achieve better functionality through time. To succeed, each component of a resilient system requires proactive planning and investments.

Figure 2 ■ Conceptual figure representing a resilience management framework designed to withstand changes in climate, absorb and recover from outage-inducing events, and advance to a better state. Most resilience actions should occur systematically throughout the asset life cycle to enhance the ability to withstand changes in climate, while also enhancing system reliability and blue-sky functionality. Resilient systems also adapt so that the functionality of the system improves through time (green line). Each component of a resilient system requires proactive planning and investments.



Adaptation Measures to Address Vulnerabilities

> Con Edison already has undertaken a range of measures to build resilience; this Study identified additional adaptation options to address vulnerabilities under a changing climate.

Con Edison has already undertaken a range of measures to increase the resilience of its systems. For example, lessons learned and vulnerabilities exposed during past events, including Superstorm Sandy (2012) and the back-to-back nor'easters (winter storms Riley and Quinn, 2018), resulted in significant capital investments to harden the system. Looking forward, as Con Edison is investing in the system of the future—one with greater monitoring capabilities, flexibility, and reliability—it is simultaneously building a system that is more resilient to extreme weather events and climate change. In addition to new investments, Con Edison also conducts targeted annual updates to its system to ensure capacity and reliability, which help the company keep pace with recent changes in temperature and humidity.

Withstand Gradual Changes in Climate and Extreme Events

Resilience actions should occur systematically throughout an asset's life cycle to enhance the ability to withstand changes in climate while also enhancing system reliability and blue-sky functionality. This can be accomplished through planning, designing, and upgrading assets in a resilient manner, with ongoing monitoring throughout.

Plan

Incorporating climate change projections into Con Edison's routine planning processes will help identify capital needs and help the systems gradually adjust to changes in climate. Some of the types of planning processes and tools that may benefit from consideration of climate change include the following:

- Load and volume forecasting for all commodities
- Load relief planning for the electric system, which should include reduced system capacity and higher load due to warmer temperatures
- Working with utilities in other environments to understand how they plan and design their system for the climate Con Edison will experience in the future
- Long-range planning for all commodities
- Network reliability modeling and planning

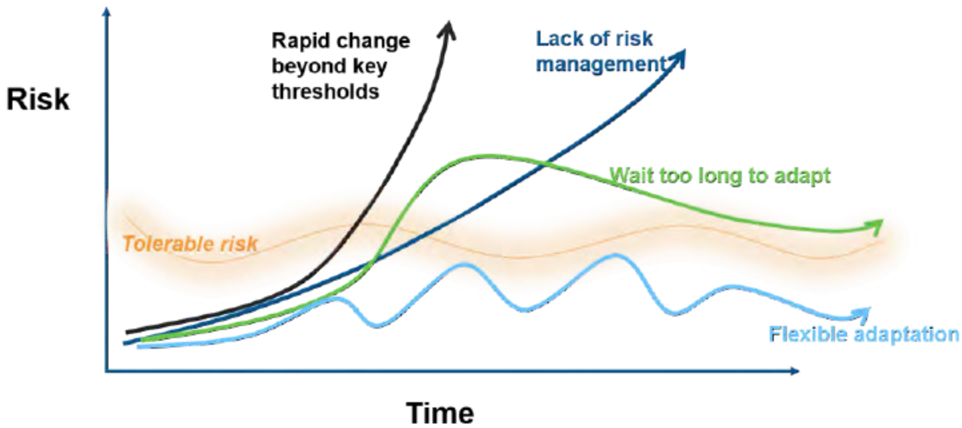
Design

The key to designing resilient infrastructure is to update design standards, specifications, and ratings to account for likely changes in climate over the life cycle of the infrastructure. While there is uncertainty as to the exact changes in climate an asset will experience, selecting an initial climate projection design pathway allows engineers to design infrastructure in line with Con Edison's risk tolerance. The Study team suggests an initial climate projection design pathway that follows the 50th percentile merged RCP 4.5 and 8.5 projections for sea level rise and high-end 90th percentile merged RCP 4.5 and 8.5 projections for heat and precipitation.

Upgrade

Changing design standards will influence the construction of new assets but does not address the vulnerability of existing assets. A flexible and adaptive approach to managing and upgrading assets will allow Con Edison to manage risks from climate change at acceptable levels, despite uncertainties about future conditions. The flexible adaptation pathways approach allows Con Edison to adjust adaptation strategies as more information about climate change and external conditions that may affect Con Edison's operations is learned over time. Figure 3 depicts how flexible adaptation pathways are based on flexible management to maintain tolerable levels of risk.

Figure 3 ■ Flexible adaptation pathways in the context of tolerable risk and risk management challenges to non-flexible adaptation. Adapted from Rosenzweig & Solecki, 2014.



As conditions change over time, Con Edison will need to consistently track these changes to identify when decision making for additional or alternative adaptation strategies is required. This approach relies on monitoring indicators, or "signposts," that provide information which is critical for adaptive management decisions. Broad categories of signposts that Con Edison should consider monitoring include climate variable observations and best available climate projections; climate impacts; and policy, societal, and economic conditions. Predetermined thresholds for these conditions signal the need for a change in action, which support decisions on when, where, and how Con Edison can take action to continue to manage its climate risks at an acceptable level. The body of this report provides many specific examples of proactive investments in resilience and their signposts; a few selected examples are provided in Table 1.

Table 1 ■ Examples of adaptation strategies to upgrade existing infrastructure and signposts to trigger action

Strategy	Signpost
Implement electric reliability strategies, such as: • Split the network into two smaller networks. • Create primary feeder loops within and between networks. • Install a distribution substation. • Incorporate distributed energy resources and non-wires solutions. • Design complex networks that consider combinations of adaptation measures.	Forward-looking network reliability index exceeds 1 per unit
Upgrade HVAC systems.	End of the existing asset's useful life
Retrofit ventilated equipment with submersible equipment to eliminate the risk of damage from water intrusion.	Expanded area of precipitation-based flooding; better maps of areas at risk of current and future precipitation-based flooding
Replace limiting wire sections with higher rated wire to reduce overhead transmission line sag during extreme heat wave events. Alternatively, remove obstacles or raise towers to reduce line sag issues.	Increased incidence of line sag; higher operating temperatures
Strategically expand program to elevate gas regulator vent line termini to include additional regulators exposed to floodplains associated with stronger storms and inland flooding.	When sea level rise exceeds 1 foot; reported or observed flooding in vicinity of asset without vent line protectors

Absorb and Recover from the Impacts of Extreme Events

It is neither efficient nor cost-effective for Con Edison to harden its systems to withstand every type of extreme event. Instead, Con Edison must use a broader suite of adaptation strategies to absorb and recover from the inevitable disruptions caused by extreme events exceeding their design standards. Con Edison currently incorporates "absorb" into its design and operations with, for example, a limited ability to control customer demand and shed load in extreme cases. A broader suite of strategies focuses on emergency preparedness, limiting customer impact and improving customer coping, including the following:

- Supporting the creation of resilience hubs (spaces that support residents and coordinate resources before, during, and after extreme weather events (Baja, 2018) and have continued access to energy services)
- Using smart meters to implement targeted load shedding to limit the impact to fewer customers during extreme events
- Strengthening staff skills for streamlined emergency response
- Planning for resilient and efficient supply chains
- Coordinating extreme event preparedness plans with external stakeholders
- Incorporating low-probability events into long-term plans
- Expanding extreme heat worker safety protocols
- Examining and reporting on the levels of workers necessary to prepare for and recover from extreme climate events
- Investing in energy storage, on-site generation, and energy efficiency programs

Advance

Advancing to a better adapted, more resilient state after an outage-inducing event (i.e., building back better/stronger) begins with effective pre-planning for post-event reconstruction. Even with proactive resilience investments, events can reveal system or asset vulnerabilities. Where assets need to be replaced during recovery, having a plan already in place for selection and procurement of assets designed to be more resilient in the future can help to ensure that Con Edison is adapting to a continuously changing risk environment. Outage-inducing events also provide important opportunities to measure the performance of adaptation investments, helping to inform additional actions that further resilience.

Next Steps

In 2020, Con Edison will develop an implementation plan that details priority actions needed in the next 5, 10, and 20 years.

As a next step from this Study, Con Edison will develop a detailed Climate Change Implementation Plan to integrate the recommendations from this Climate Change Vulnerability Study. The implementation plan will be developed in close coordination with Con Edison SMEs and will utilize quarterly meetings with external stakeholders. The implementation plan will consider updates in climate science, finalize an initial climate design pathway, integrate that pathway into company specifications and processes based on input from subject matter experts, develop a timeline for action with associated costs and signposts, and recommend a governance structure. Some key items for consideration in the implementation plan include determining the appropriate amount of proactive investment, changes in the policy/regulatory and operating environment and the establishment of a reporting structure.

Introduction

Study Background and Objectives

Con Edison's resilience to climate change has important implications for increasingly interconnected societal, technological, and financial systems that the company serves. Developing a shared understanding of Con Edison's vulnerability to climate change is critical to ensuring the continued strength of the company over the coming century. The Con Edison Climate Change Vulnerability Study (Study) has three primary goals:

1. Develop a shared understanding of new climate science and projected climate and extreme weather for the territory.
2. Assess the risks of potential climate change impacts on Con Edison's operations, planning, and physical assets.
3. Review a portfolio of operational, planning, and design measures, considering costs and benefits, to improve resilience to climate change.

The Study was conducted as an outcome of the 2013 rate case. In 2013, Con Edison worked with a Storm Hardening and Resiliency Collaborative in parallel with the rate case to provide parties with an opportunity to fully examine proposals for plans to protect against storms. In 2014, the New York State Public Service Commission approved an Order and funding for Con Edison to implement measures to plan for and protect its systems from the effects of climate change, including conducting a climate change vulnerability study. The Study was developed by the Con Edison Department of Strategic Planning, in collaboration with ICF's climate adaptation and resilience experts and Columbia University's Lamont-Doherty Earth Observatory. The members of this partnership are collectively referred to as the Study team. The Study team relied on inputs and expertise from Con Edison subject matter experts (SMEs), including engaging more than 100 SMEs through a series of in-person meetings, teleconferences, and workshops.

Guiding Principles

The Study used six key principles to efficiently meet its objectives and benefit Con Edison. The Study employed a decision-first and risk-based approach, applying the best available climate science to produce flexible and adaptive solutions and mitigate risks associated with climate change and extreme weather events. The Study process was transparent and interactive to ensure that it can be replicated and institutionalized.

Decision-first approach. The Study team used a decision-first approach, which focuses on understanding the broader vulnerabilities and constraints of the system, the objectives and needs of stakeholders, and the adaptation options available, before considering the projected changes in future climate. The Study team first identified the needs of decision makers (i.e., Con Edison leadership and SMEs) and worked from there to determine information requirements based on decision goals, instead of starting by amassing as much data as possible. This approach places a higher priority on understanding the decision-making context and providing enough information to inform those decisions, which helps to prioritize near- and long-term risks and develop effective solutions despite the existence of deep uncertainties related to future climate change.

Risk-based approach. The Study team employed a risk-based approach that considers both the likelihood and the consequence of potential changes in the climate. This involves identifying a comprehensive set of plausible future climate outcomes and assessing their probability and associated impact on Con Edison's service territory. Doing so allows Con Edison to assess its vulnerability to—and to prepare for—*high-probability and low-impact*, as well as *low-probability and high-impact*, outcomes.

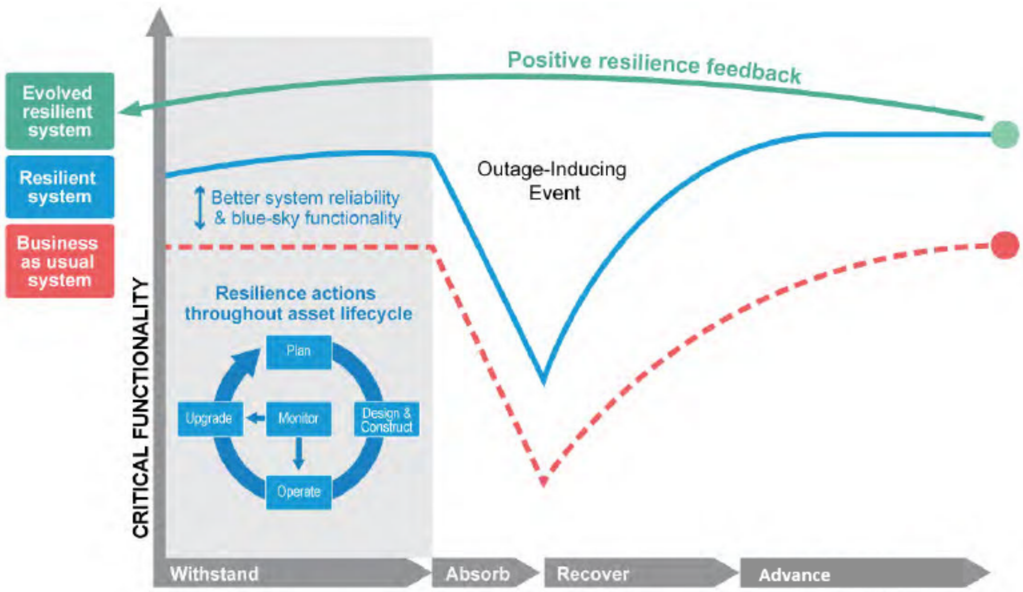
Best available climate science. The Study team prioritized continuous dialogues among climate scientists, climate adaptation specialists, and Con Edison SMEs to identify which climate scenarios, time periods, hazards, variables, and thresholds are important for Con Edison's operations, infrastructure, and planning. The Study team assessed multiple lines of evidence to capture historical climate conditions in the territory and employed a comprehensive set of Global Climate Models to identify the extent to which current climate conditions may change throughout the 21st century. Ultimately, the Study team synthesized climate information into metrics relating plausible effects of climatic changes on operations, infrastructure, and planning.

Transparent and replicable. A transparent and replicable approach allows Con Edison to institutionalize its adaptation strategy and increase its adaptive capacity over time. This will help SMEs establish their adaptation efforts into emerging policies and procedures, as well as train the next generation of SMEs in resilience building. Transparency also engenders trust with internal and external stakeholders.

Flexible solutions and adaptive implementation. A flexible and adaptive approach will allow Con Edison to manage risks from a changing climate at acceptable levels, despite uncertainties about future conditions. Adaptive implementation pathways, or flexible adaptation pathways, are a recognized approach to adaptation planning and project implementation that ensures adaptability over time in the face of uncertainty: changes in energy demand, technologies, population, and other driving factors, and refinements in the scientific understanding of future climate. Under the adaptive approach, resilience measures can be sequenced over time, allowing Con Edison to protect against near-term changes while leaving options open to protect against the wide range of plausible changes emerging later in the century.

Resilience management framework. The Study introduces a resilience management framework that allows Con Edison to mitigate risks associated with climate changes and extreme weather events most relevant to Con Edison's service territory (Figure 4). Resilient systems are composed of more than hardening measures alone, and instead consider measures that increase resilience throughout the life cycle of outage-inducing climate events. These measures include the system's capacity to "withstand," "absorb," and "recover" from climate risks and "advance" resilience. In this way, the resilient management framework is particularly important for addressing complex extreme events with significant uncertainties and extreme thresholds to build into hardening measures alone. In turn, resilient systems offer critical co-benefits, such as improved system reliability and blue-sky functionality, reduced consequences from non-climatic risks, and more resilient customers. A resilience management framework also facilitates long-term adaptation, which enhances the critical functionality of the system through time and creates positive resilience feedback. To succeed, each measure of a resilient system requires proactive planning and investments.

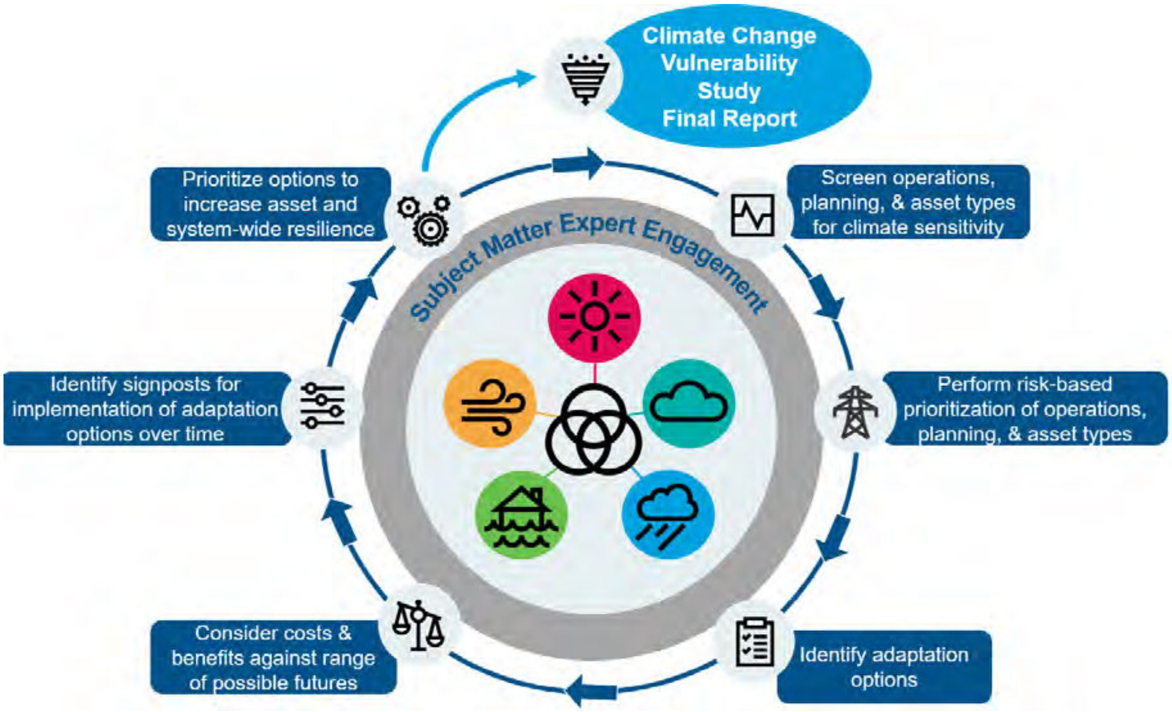
Figure 4 ■ Conceptual figure representing a resilience management framework designed to withstand changes in climate, absorb and recover from outage-inducing events, and advance to a better state. Most resilience actions should occur systematically throughout the asset life cycle to enhance the ability to withstand changes in climate, while also enhancing system reliability and blue-sky functionality. Resilient systems also adapt so that the functionality of the system improves through time (green line). Each component of a resilient system requires proactive planning and investments.



Study Methodology

The Study uses an integrated approach, with Con Edison SMEs providing support throughout the process. A rapid screen of the sensitivity of operations, planning, and assets (referred to for simplicity as "assets" throughout the rest of this document unless otherwise stated) for each climate change hazard provided the basis for a risk-based prioritization of assets. The Study team performed detailed analyses for the sensitive assets, including identifying a portfolio of adaptation options and qualitatively considering the financial costs, co-benefits, and resilience of each option. These detailed analyses will inform the development of flexible solutions and the further prioritization of assets and options to increase systemwide resilience during the creation of Con Edison's Climate Change Implementation Plan in 2020. Figure 5 depicts the Study's general approach.

Figure 5 ■ General approach overview: The process cycles through steps for each climate hazard, beginning with 'Screen operations, planning, and asset types for climate sensitivity'. The process results in the Climate Change Vulnerability Study Final Report.



Screen operations, planning, and asset types for climate sensitivity. The Study began by establishing and confirming a clear set of climate change hazards and relevant thresholds for operations, planning, and asset types. The study team engaged SMEs to identify the extent to which each climate change hazard is a factor in asset design or operation and rate sensitivities by considering impacts from previous weather events and key climate information used in design or operation. Only assets with high sensitivity were considered in the subsequent risk-based prioritization process.

Perform risk-based prioritization of operations, planning, and asset types. Following the high-level screen for sensitivity, the Study team sought to prioritize operations, planning processes, and asset types for further analysis.

- Heat and humidity: Heat and humidity design standards vary across Con Edison assets, so the Study team used a risk workbook to guide SMEs through a structured process to identify the *probability of impact* (based on the probability of exceeding thresholds and the impact of threshold exceedance) and the *consequence of impact*. Together, these components create an *overall risk score* for each relevant asset and climate change hazard combination. *Consequence* is defined as the likely impact to the overall system given the possibility for damage or failure of the particular asset, and includes reliability, safety, environmental damage, and financial costs to the company or customers. The Study team identified several asset types and variable combinations with high sensitivity and high overall climate risk to carry forward as priorities in the analysis.
- Sea level rise and storm surge: Sea level rise and storm surge is a geographically defined hazard with a common design standard across all Con Edison assets. As such, there was a need to

identify potentially exposed assets rather than prioritize among them. The Study team used Geographic Information System (GIS) modeling to evaluate the specific type and number of assets that would be exposed under various future scenarios.

- Precipitation: Very few of Con Edison's assets have design standards tied to precipitation. For the few that were identified, the Study team evaluated whether the assets would withstand future increases in the intensity of precipitation events. In addition, the Study team worked with Con Edison SMEs to identify and prioritize the operational impacts of precipitation on the various commodities.
- Extreme events: By definition, the extreme events analyzed in the study exceed all existing Con Edison design standards. As such, the Study team conducted a workshop with SMEs to prioritize extreme event risks based on the following:
  - The potential for impacts on operations, planning, and assets
  - How prior major weather events affected assets and operations
  - The preparations that Con Edison has in place for future extreme events
  - How longer or more intense events might overwhelm current preparedness efforts

Identify adaptation options. For the identified vulnerabilities, the Study team developed adaptation response options through SME engagement, review of relevant literature, and lessons learned from adaptation options implemented in regions with similar challenges. Adaptation options include strategies to withstand a changing climate, such as engineering design, operations, and planning strategies, as well as strategies to absorb and recover from extreme events. The Study team considered adaptation options that are often already in use to manage the hazard, but which may require revision or updating to deal with changing risk. The Study team also considered both short-term and long-term solutions and took steps to understand and assess the limitations of adaptation options.

Consider costs and benefits of adaptation options against a range of possible futures. The Study team worked with SMEs to develop order of magnitude costs of the various adaptation strategies, where feasible. Where possible, the Study team conducted a multi-criteria analysis of the adaptation options to compare criteria that may be difficult to quantify or monetize, or that may not be effectively highlighted in the financial analysis.

Identify signposts for implementation of adaptation options over time. Evaluation of adaptation measures in the context of a continuously changing risk environment poses a challenge to typical project planning, design, and execution. It is important to ensure that decision-making processes support flexible solutions that allow for effective risk management in the face of irreducible uncertainties in projections of future climate conditions. The Study uses an adaptive implementation pathway approach to achieve this goal. The Study team designed a framework for "signposts," which represent information that will be tracked over time to help Con Edison understand how climate, policy, and process conditions change and, in turn, trigger additional action.

Prioritize options to increase asset and systemwide resilience. Once the prior steps were completed, the Study team circulated the findings to SMEs to allow them to strike, add, or refine strategies. This process resulted in the prioritized set of strategies included in this report.

Historical and Future Climate

Con Edison in a Changing Climate

Earth's climate is not static; it changes in response to both natural and human-caused drivers. The past decade was the warmest on record, and global atmospheric warming has increased at a faster rate since the 1970s (GCRP, 2017), which the global climate science community attributes to increasing human-caused greenhouse gas emissions (IPCC, 2013).

A growing body of research reveals that a range of climate hazards will likely increase in frequency and intensity as a result of atmospheric warming (GCRP, 2017; IPCC, 2013). For example, a warmer atmosphere increases the frequency, intensity, and duration of heat waves; holds more water vapor for heavy precipitation events; and accelerates ice loss from Earth's large ice sheets, contributing to sea level rise and coastal storm surge. These climate changes highlight how changes in the global climate system affect local climatology and weather in Con Edison's service territory. Local changes include both long-term mean changes, such as gradual increases in temperature and sea level, and changes in extreme events, such as heat waves, hurricanes, and storm surge. In most cases, long-term climate change amplifies and increases the likelihood of extreme events. In turn, climate changes and baseline climate hazards cause both direct (e.g., physical damage to infrastructure) and indirect (e.g., changing customer behavior) impacts across the electric, gas, and steam systems of Con Edison's business.

Rapid climate change will bring new challenges to Con Edison through the 21st century. This Study develops climate projections to characterize these challenges. Still, conceptualizing climate change in tangible terms is notoriously difficult. Another way to describe potential climate change is through climate analogs, which match expected future climate change at a location to current climate conditions in another. Under this perspective, New York City's temperature and precipitation by 2080 could more closely resemble current conditions in southern cities such as Memphis, TN, and Little Rock, AR, if greenhouse gas emissions continue unabated (Fitzpatrick & Dunn, 2019).[4]

[4] Climate analogs are illustrative and vary depending on the choice of evaluation metrics, decade, and climate scenario. In this case, analogs are determined using metrics for seasonal minimum and maximum temperature and total precipitation.

Con Edison's Understanding and Assessment of Climate Change

The Study team developed improved, downscaled climate projections and used best available science to understand and evaluate climate change trends and potential extreme weather events across Con Edison's service territory over near- (2030), intermediate- (2050), and long-term (2080) time horizons.[5] This approach builds on methods used by the New York City Panel on Climate Change (NPCC) and introduces a range of benefits (see Table 2). The Study team focused on climate variables that could present outsized impacts to operations, planning, and infrastructure across the electric, gas, and steam segments of Con Edison's business. These include temperature, humidity, precipitation, sea level rise and coastal flooding, extreme events, and multiple—or compounding—events.

The primary tools for understanding future climate change are Global Climate Models (GCMs), which mathematically simulate important aspects of Earth's climate, such as changes in temperature and precipitation, natural modes of climate variability (e.g., El Niño and La Niña events), and the influence of human greenhouse gas emissions (GCRP, 2017). Over short timescales (i.e., years to decades), individual GCM projections can differ from one another due to unpredictable natural climate variability, differences in how models characterize small-scale climate processes, and their response to greenhouse gas emissions/concentration assumptions. For these reasons, future climate analyses often consider a large ensemble of GCMs to better discern long-term trends, account for uncertainty, and consider a fuller range of potential future climate outcomes. To this end, the Study team used a broad model ensemble (i.e., 32 GCMs) for each climate variable of interest to address the spread across models and provide a comprehensive view of future climate.

While GCMs use a finer spatial resolution than ever before, they still provide coarse-resolution estimates of future climate, with model grid cells typically extending approximately 100 kilometers on one side. To achieve a more accurate representation of local climate in the New York Metropolitan Region, the Study team bias-corrected and downscaled GCM projections (i.e., statistically adjusted simulations to bring them closer to observed data) using weather station data over a 1976–2005 historical reference period from three weather station locations spanning Con Edison's service territory, including Central Park, LaGuardia Airport, and White Plains Airport.[6]

GCM simulations are driven by a standard set of time-dependent greenhouse gas concentration trajectories called Representative Concentration Pathways (RCPs), developed by the Intergovernmental Panel on Climate Change (IPCC). RCPs consider different evolutions of fossil fuels, technologies, population growth, and other controlling factors on greenhouse gas emissions through the 21st century. To acknowledge uncertainty in future greenhouse gas concentrations, the Study team selected the commonly used RCPs 4.5 and 8.5 to drive each GCM, following precedent set by IPCC and NPCC. RCP 4.5 represents a moderately warmer future based on a peak in global greenhouse gas emissions around 2040. In contrast, RCP 8.5 represents a hotter future

[5] Columbia University's Lamont-Doherty Earth Observatory led the analysis of temperature, humidity, and precipitation projections and extreme event information. ICF provided insights into future climate conditions using localized constructed analog (LOCA) projections, analyzed sea level rise projections, and synthesized extreme event narratives. Jupiter Intelligence provided projections of extreme temperatures and the urban heat island effect.

[6] Technical information regarding bias-correction and downscaling methods used in this Study are provided in the appendices for the relevant climate variables.

corresponding to "business as usual" increases in greenhouse gas concentrations through the century.

The Study team used a model-based probabilistic framework to evaluate climate change hazards and account for model uncertainty under different RCP scenarios. Specifically, the Study team analyzed high-end estimates (e.g., the 90th percentile of projections across climate models), and mid-point (50th percentile) and low-end (10th percentile) projections for both RCPs. In doing so, the Study Team considered the range of potential climate outcomes across models and RCPs to form a comprehensive risk-based approach. Under this framework, the RCP 8.5 90th percentile approximates a stress test to characterize low probability, high-impact climate change, and its impact on Con Edison.

This Study builds on the approach used by NPCC. Table 2 provides a high-level overview of climate information advances developed as part of this Study.

Table 2 ■ Overview of climate projection methods in this Study relative to the NPCC2 (2015) climate projections of record for New York City

NPCC2 (Reference Projections)	Con Edison Study
Combined projections from two scenarios (RCPs 4.5 and 8.5)	Separate scenario projections
Four time periods (2020–2080)	Seven time periods (2020–2080) to align with planning processes
Single reference point (Central Park)	Multiple reference points tailored to the service territory (Central Park, White Plains, and LaGuardia)
Downscaling using the "delta method"	Downscaling using "quantile mapping"
Limited set of climate variables	Numerous Con Edison-specific variables and multi-variable projections (e.g., heat plus humidity)

The Study also evaluates Con Edison's vulnerability to rare and complex extreme events, such as major hurricanes and long-duration heat waves, that may increase in intensity and frequency as a result of climate change. Such events play an outsized role in shaping the public's perception of climate change vulnerability and how institutions should address its unique challenges. While the Study team uses model-based probabilistic projections to inform many climate variables, such as long-term mean temperatures and sea level, it is more challenging to project the rarest events, such as a 1-in-100-year heat wave, and multi-faceted and difficult to model events such as hurricanes. Obstacles to modeling rare and complex extreme events include the brevity of the historical record relative to the rarity of the event, and challenges associated with modeling extremes that have important features at very small space and time scales.

To address these challenges, the Study team constructed a series of extreme event narratives based on historical analogs and the best available climate science. In contrast with model-based probabilistic projections, narratives represent plausible future worst-case scenarios[7] meant to stress-test Con Edison's system. The narratives merge a decision-first and risk-based approach, blending best available science with decision maker-defined high impacts to develop a better understanding of Con Edison's vulnerability to rare, complex extreme events.

Overview of Climate Science Findings Relevant to Con Edison

The Study team's analysis characterized historical and future changes in temperature, humidity, precipitation, sea level rise, and extreme events within Con Edison's service territory. This information supports a risk-based understanding of potential climate-related vulnerabilities within the company's operations, planning, and physical assets. The sections below provide an overview of projected climate changes relevant to Con Edison. While projections were prepared for Central Park, LaGuardia, and White Plains as described above, this section commonly uses Central Park as a reference point due to its central location and because it currently serves as a reference point for many Con Edison operations. The report appendices contain detailed information on other locations and the full scope of climate projections and corresponding vulnerabilities developed for this Study.

The timing and magnitude of climate change over the coming century remains uncertain, particularly with respect to rare and multi-faceted extreme events. This uncertainty presents challenges for institutions such as Con Edison in understanding the potential effects of climate change and the associated risks to their business, operations, and financial performance.

Scenario analysis is a proven way to address these challenges. For example, Task Force on Climate-Related Financial Disclosures (TCFD) scenarios use forward-looking projections to provide a framework to help companies prepare for risks and opportunities brought about by climate change. The scenarios used in this Study are similarly hypothetical constructs, but differ from TCFD scenarios in that they provide quantitative details regarding future extreme event conditions (e.g., regarding specific storm characteristics) so that Con Edison can better plan for specific impacts to assets and infrastructure. Ultimately, this Study uses both climate science and stakeholder-driven perspectives to develop plausible, high impact worst-case scenarios designed to stress-test Con Edison's system.

Temperature

Both average and maximum air temperatures are projected to increase throughout the century relative to historical conditions (Figure 6). Climate model projections reveal significant increases in the number of days per year in which average temperatures exceed 86°F (up to 26 days per year, relative to a baseline of 2 days) and maximum temperatures exceed 95°F (up to 23 days per year from a baseline of 4 days; Figure 7) by 2050. At the same time, winter minimum temperatures are expected to fall below 50°F as many as 40 fewer times per year than in the past by mid-century, representing a 20% decrease.

[7] Worst-case scenarios are meant to explore Con Edison system vulnerabilities related to rare extreme weather events and formulate commensurate adaptation and resilience strategies. Scenarios represent one plausible permutation of extreme weather and the severity of actual events may exceed those considered.

Figure 6 ■ Historic (black line) and projected (colored bands) average air temperature in Central Park during the summer under two greenhouse gas concentration scenarios (RCPs 4.5 and 8.5)

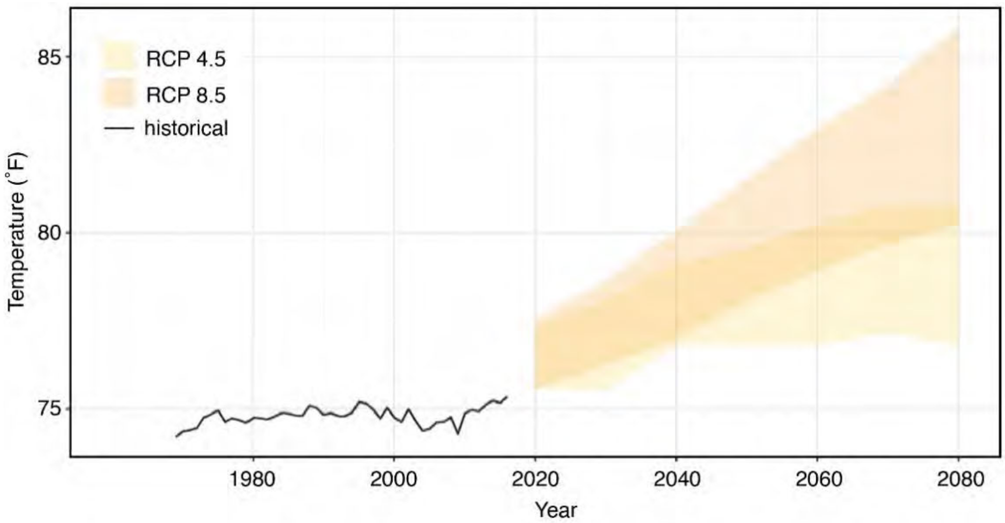
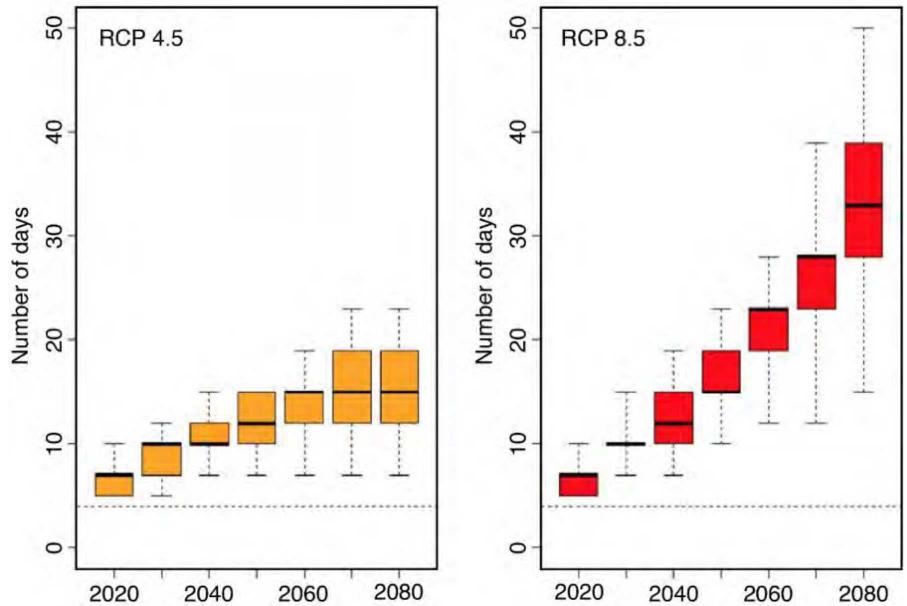


Figure 7 ■ The average number of days per year with maximum summer air temperatures exceeding 95°F in Central Park under two greenhouse gas concentration scenarios (RCPs 4.5 and 8.5). The dashed horizontal lines show the historical average number of days. Box plots correspond to the 10th, 25th, 50th, 75th, and 90th percentile projections.

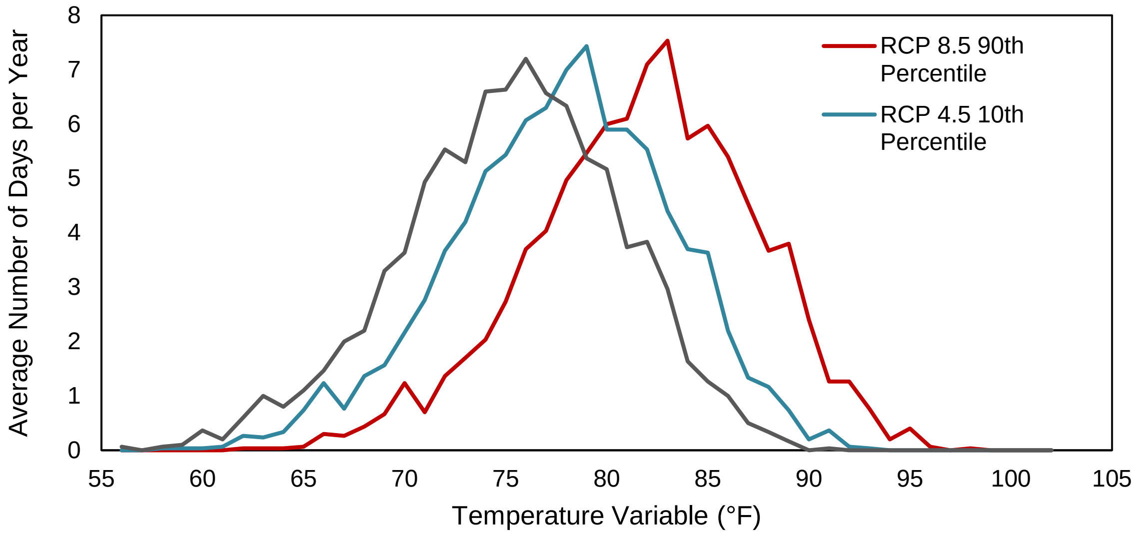


Multi-day heat events, known as heat waves, create potential risks for Con Edison as they drive demand for air conditioning and stress electrical and infrastructure systems. The number of heat waves, defined here as 3 or more consecutive days when *average* temperatures exceed 86°F in Central Park, is projected to increase up to 5 and 14 events per year by 2050 and 2080, respectively, relative to 0.2 events per year historically. The magnitudes of temperature increases are projected to be greatest at LaGuardia and Central Park and smaller at White Plains.

Humidity

The New York Metropolitan Region is susceptible to significant combinations of heat and humidity, which cannot be captured by temperature alone. The combination of temperature and humidity drives electric demand within Con Edison's service territory. To address this, the company currently evaluates the potential for high loads using an index referred to by Con Edison as temperature variable (TV),[8] which incorporates considerations of both temperature and humidity. Looking forward, TV thresholds that have historically occurred only once per year (e.g., 86°F), are projected to become common occurrences within a generation, occurring between 4 and 19 times per year by 2050 and 5 and 52 times per year by 2080, under the RCP 4.5 10th percentile and RCP 8.5 90th percentile, respectively, at LaGuardia (Figure 8). Smaller increases are expected at White Plains.

Figure 8 ■ Distributions showing historical (black line) and 2050 projected (blue and red lines) summer (June–August) daily electric TV at LaGuardia Airport. The 2050 projections show both the RCP 8.5 90th percentile and the RCP 4.5 10th percentile distributions.



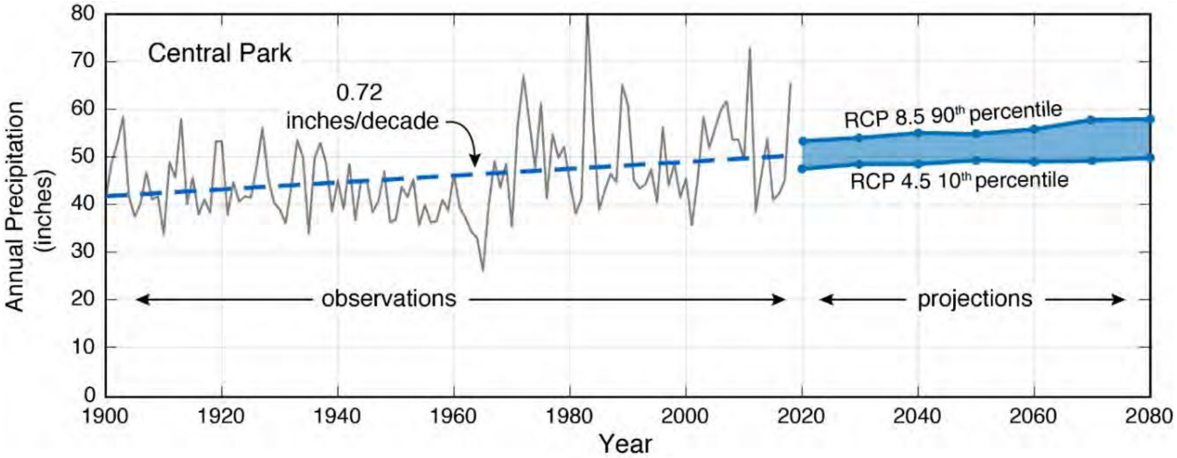
The heat index is a typical indicator of "how hot it feels," which considers the combined effect of air temperature and relative humidity. The index assesses health risks associated with overheating, including for Con Edison employees working under hot conditions. Looking forward, the frequency of occurrence for very high heat index thresholds is projected to increase dramatically through the century. Projections reveal that the number of days per year when the heat index equals or exceeds 103°F at LaGuardia could increase to between 7 and 26 days by 2050 under the RCP 4.5 10th percentile and the RCP 8.5 90th percentile, respectively, compared to only 2 days historically.

[8] Temperature variable is calculated using the weighted time integration of the highest daily recorded 3-hour temperature and humidity over a 3-day period. The reference TV for Con Edison is 86°F, which approximates a heat index of 105°F.

Precipitation

Con Edison's service territory experiences a range of precipitation events over a range of timescales, including rainfall, downpours, snowfall, and ice. Climate change is projected to drive heavier precipitation across these event types because a warmer atmosphere holds more water vapor and provides more energy for strong storms. Looking forward, average annual precipitation is projected to increase by 0% to 15% relative to the historical baseline in Central Park through 2050 (Figure 9).

Figure 9 ■ Observed and projected annual precipitation at Central Park. Projections show potential annual precipitation under both the RCP 8.5 90th percentile and the RCP 4.5 10th percentile. Projections represent 30-year time averages (shown as blue circles), which reveal the long-term trend, but underrepresent year-to-year variability. The dashed line represents the linear trend though the observational record, with observed increases given in inches per decade.



Projections of heavy rainfall reveal similar increases. For example, the heaviest 5-day precipitation amount could be 11.8 inches at Central Park by 2050, which represents a 17% increase over the historical reference period. Data from the Northeast Regional Climate Center[9] show that 25-year, 24-hour precipitation amounts at Central Park, LaGuardia, and White Plains could increase by 7% to 14% and 10% to 21% by mid- and late-century, respectively. Ultimately, projections point to a future defined by more frequent heavy precipitation and downpours, likely accompanied by smaller increases in the frequency of dry or light precipitation days (GCRP, 2017).

Projections for changes in snow and ice are more uncertain than those for rainfall. Overall, models project a decrease in snowstorm frequency corresponding to a warming climate (Zarzycki, 2018). However, while the likelihood of a given storm producing snow instead of rain will decrease in the future, if atmospheric conditions are cold enough to support frozen precipitation, then storms are expected to produce more snow (or ice) than during the present day (Zarzycki, 2018).

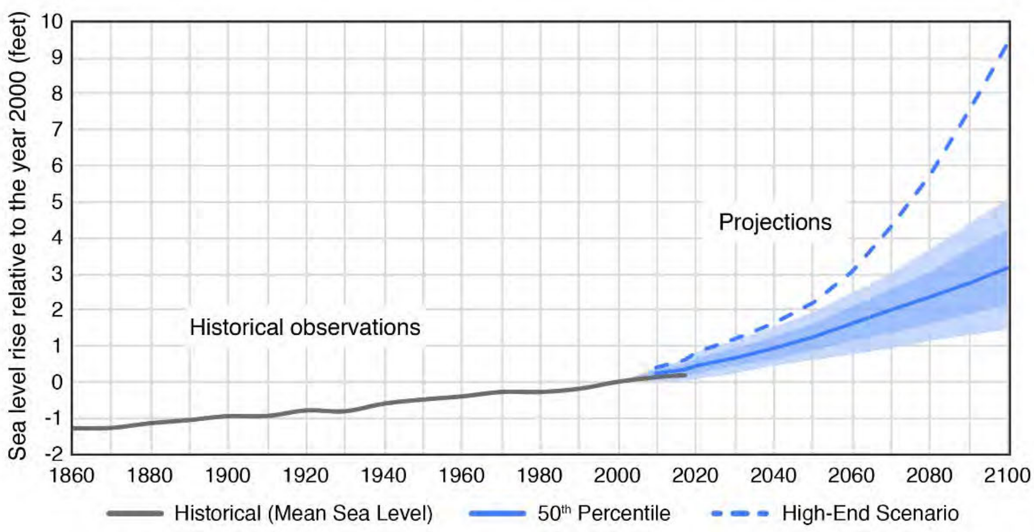
Sea Level Rise

A range of underlying factors, including thermal expansion of the ocean, the rate of ice loss from glaciers and ice sheets, atmosphere and ocean dynamics, and vertical coastline adjustments determine local sea level rise within Con Edison's service territory. State-of-the-art probabilistic

[9] http://ny-idf-projections.nrcc.cornell.edu/

projections (Kopp et al., 2014; 2017) determined these contributions and characterized the rate of future sea level rise in the region under both RCPs 4.5 and 8.5 (e.g., Figure 10). These sea level rise projections include a unique high-end scenario driven by rapid West Antarctic ice sheet mass loss in the later 21st century (DeConto & Pollard, 2016; Kopp et al., 2017). Con Edison has always implemented anti-flooding measures. Following Superstorm Sandy in 2012, the company implemented a minimum protection design standard of "FEMA plus three feet,"[10] allowing for 1 foot of sea level rise. In turn, forward-looking projections determine when sea level rise may exceed Con Edison's established risk tolerance of 1 foot of sea level rise.

Figure 10 ■ Historical and projected sea level rise in New York City under RCP 8.5 relative to the year 2000. The grey line shows historical mean sea level at the Battery tide gage. Projections are relative to the 2000 baseline year. The solid blue line shows the 50th percentile of projected sea level rise. The darker shaded area shows the likely range (17th–83rd percentiles), while the lighter shaded area shows the very likely range (5th–95th percentiles). The blue dashed line depicts a high-end projection scenario driven by rapid West Antarctic ice sheet mass loss in the later 21st century (DeConto & Pollard, 2016; Kopp et al., 2017).



Sea level rise will very likely be between 0.62 and 1.74 feet and 0.62 and 1.94 feet at the Battery tide gauge in lower Manhattan by 2050 under RCPs 4.5 and 8.5, respectively. Projections suggest that Con Edison's 1-foot sea level rise risk tolerance threshold may be exceeded as early as 2030 and as late as 2080.

In turn, rising sea levels will have profound effects on coastal flooding, as sea level rise is expected to increase both the frequency and height of future floods (Figure 11). For example, the flood height associated with the 1% annual chance (100-year) flood in New York City is projected to increase from 10.9 feet to as much as 15.9 feet under RCP 8.5 by 2100, representing an increase of close to 50%.[11] Similarly, today's 0.2% annual chance (500-year) flood could look like a 10% annual

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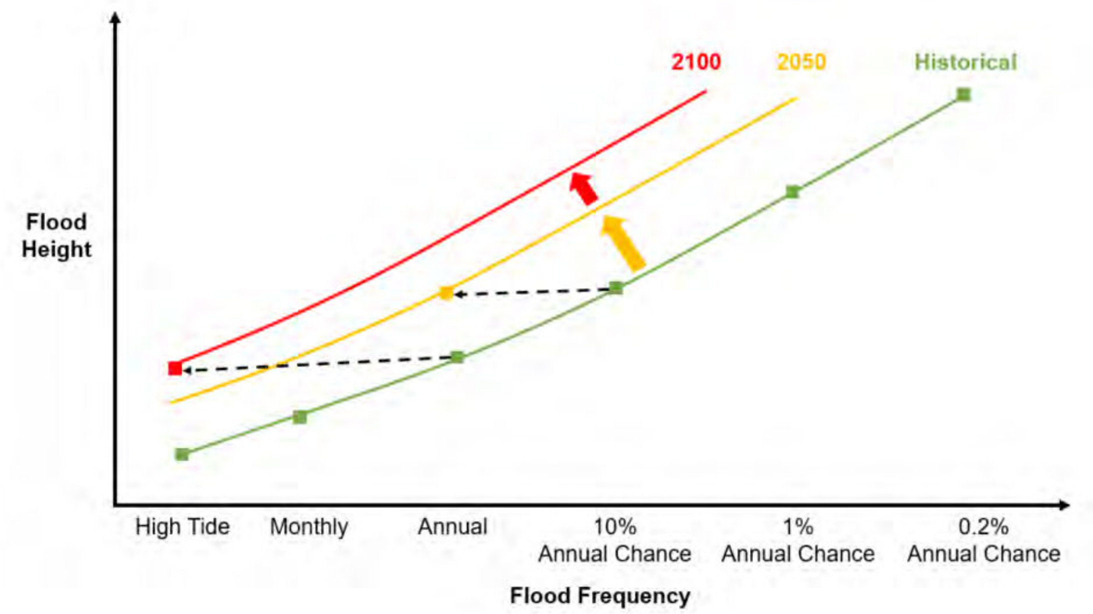
[10] This includes the FEMA 1% annual flood hazard elevation, 1 foot of sea level rise and 2 feet of freeboard (to align with 2019 Climate Resiliency Design Guidelines published by the New York City Mayor's Office of Recovery and Resiliency).
[11] Flood values are above the mean lower low water (MLLW) datum at the Battery tide gauge. MLLW is measured as 2.57 feet below mean sea level at the Battery.

chance (10-year) flood in 2100, making it 50 times more likely. At the end of the century, today's annual chance flood could occur at every high tide.

Figure 11 ■ Projected changes in the frequencies of historical flood heights as a result of sea level rise. Dashed lines represent projected changes in frequency; solid lines represent illustrative changes in flood frequency coinciding with flood heights



Extreme Events

Rare extreme events, such as strong hurricanes and long-duration heat waves, are low-probability and high-impact phenomena that pose outsized risks to infrastructure and services across Con Edison's service territory. While modeling rare extreme events remains challenging and at the forefront of scientific research, a growing body of evidence suggests that many types of extreme events will likely increase in frequency and intensity as a result of long-term climate warming.

To address these challenges, the Study team used feedback from Con Edison SMEs to prioritize a suite of extreme event narratives that combine plausible worst-case events from both climatological and impact perspectives. In turn, the narratives represent future worst-case scenarios designed to stress-test Con Edison and the local and regional systems with which it connects. The chosen narratives considered a prolonged heat wave, a Category 4 hurricane, and an unprecedented nor'easter striking the region.

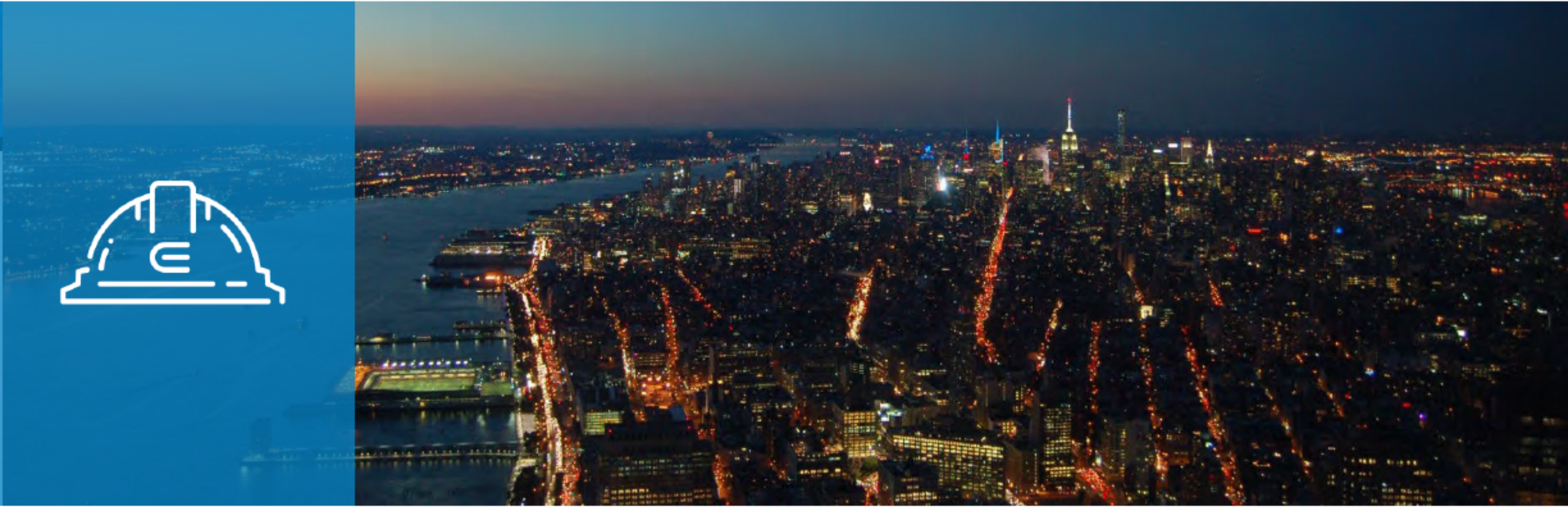
Best available climate science reveals that climate change will likely amplify these extremes over the coming century. For example, the mean heat wave duration in New York City is expected to increase to 13 and 27 days by 2050 and 2080, respectively, based on RCP 8.5 90th percentile projections (NPCC, 2019). At the same time, broadscale atmospheric and ocean surface temperature changes may drive stronger hurricanes and extratropical cyclones. Looking forward, while the total number of hurricanes occurring in the North Atlantic may not change significantly over the next century, the percentage of very strong and destructive (i.e., Categories 4 and 5) hurricanes is projected to increase in the North Atlantic basin (IPCC, 2013). It can therefore be argued that climate change could make it more likely for one of these storms to impact the New York Metropolitan Region, although the most dominant factor will remain unpredictable climate and weather variability (Horton & Liu, 2014). Finally, some recent studies project a 20% to 40% increase in nor'easter strengthening (i.e., producing the types of storms with destructive winds) immediately inland of the Atlantic coast by late-century, suggesting stronger storms may more frequently impact the New York Metropolitan Region with heavy precipitation, wind, and storm surge (Colle et al., 2013)

Signposts: Monitoring and Climate Science Updates

Understanding Con Edison's vulnerabilities to climate change and adapting to those changes over time require a robust monitoring strategy. Climate change evolves through time, meaning that the current spread of potential future climate outcomes produced by models will eventually converge on a smaller set of climate realizations. To keep up with this evolution, a range of signposts are required to sufficiently gauge relevant rates of change and best prepare Con Edison for the most likely climate future.

An awareness of past and present climate conditions in Con Edison's service territory is critical for understanding the trajectory of climate change. Con Edison currently operates a number of stations that monitor climate variables and is finalizing plans to expand the number of monitoring locations. Increasing observations from monitoring stations will help measure both local climate variations and climate change through time, informing Con Edison's climate resilience planning. Citywide observations of variables, such as hourly temperatures, precipitation, humidity, wind speed, and sea level, are paramount to building a broad and usable set of guiding measurements. With accurate and up-to-date data on these variables, Con Edison can better monitor both changing conditions and potential points of vulnerability.

Con Edison can supplement monitoring through a regularly updated understanding of the best available projections as models and expert knowledge evolve over time. Climate projections continually improve as the scientific community better understands the physical, chemical, and biological processes governing Earth's climate and incorporates them into predictive models. Ultimately, Con Edison wants to draw on the best available data and projections that are driven by scientific consensus, but also are accessible and applicable to company needs. Signposts for updating climate science used to inform potential Con Edison vulnerabilities include major science advancements, such as the release of the new Coupled Model Intercomparison Project (CMIP) projections and their integration and validation in new IPCC, NPCC, and National Climate Assessment (NCA) reports. These assessments include updated probabilistic climate projections representing model advancements, the best available science regarding difficult-to-model extreme events, and literature reviews reflecting the current state of science as guided by leading experts. Such signposts could justify Con Edison updating their climate projections of record to reflect the best available science or projections that represent a significant departure from previous understanding. Historically, major scientific reports, such as the IPCC, have been released about every 6 to 7 years, which provide a potential constraint on how frequently Con Edison's understanding of climate change within the service territory might be revisited.



Existing Efforts and Practices to Manage Risks Under a Changing Climate

Although this Study is Con Edison's first comprehensive assessment of climate change vulnerabilities, Con Edison has already undertaken a range of measures to increase the resiliency of its system. Lessons learned and vulnerabilities exposed during past events, most recently Superstorm Sandy (2012) and the back-to-back nor'easters (winter storms Riley and Quinn, 2018), resulted in significant capital investments to harden the system.

In addition, as Con Edison invests in the system of the future—one with greater monitoring capabilities, flexibility, and reliability—it is simultaneously building a system that is more resilient to extreme weather events and climate change. For example, grid modernization will both increase efficiency and enhance monitoring capabilities by employing new technology and modes of data acquisition. Con Edison is planning to support numerous grid modernization initiatives that target energy storage technologies, communications systems, distributed energy resources infrastructure and management, complex data processing, and advanced grid-edge sensors (Con Edison, 2019). Con Edison additionally plans to modernize its Control Center to assume more proactive and centralized management of its complex distribution grid. Throughout these modernization initiatives, the company remains in close collaboration with the City of New York.

Con Edison also conducts targeted annual updates to its system to ensure capacity and reliability. These annual updates help the company keep pace in real time with changes in some key hazards. For example, when conducting electric load relief planning, Con Edison incorporates load forecasts that use an annually updated set of TV data. Although these forecasts are not grounded in future projections that consider climate change, they do account for the most recent climate trends and, as such, allow the company to stay in stride with the most current data.

Con Edison's previous adaptation measures have made targeted improvements in (1) physical infrastructure, (2) data collection and monitoring, and (3) emergency preparedness. The following measures are illustrative of these targeted improvements, but are not meant to be exhaustive of the efforts that Con Edison has undertaken:

Physical Infrastructure

- Adopting the Dutch approach of "defense in depth" after Superstorm Sandy to protect all critical and vulnerable system components from coastal flooding risks, including the following:

- Upgrading and increasing the number of flood barriers and other protective structures
- Reinforcing tunnels
- Replacing equipment with submersible equivalents in flood zones (e.g., targeted main replacement program, gas system)
- Installing pumps and elevating infrastructure behind flood walls

- Protecting or elevating critical electrical infrastructure to the Federal Emergency Management Agency (FEMA) 100-year flood elevation plus 3 feet to account for sea level rise and freeboard during coastal storms
- Undertaking a targeted main replacement program that addresses low-pressure gas mains in low-lying areas, as well as other potentially vulnerable gas mains
- Installing isolation devices to limit the impact of damaged infrastructure on customers by de-energizing more granular sections of the system, when necessary
- Engaging innovative technologies to reduce the impact of extreme weather on electric distribution systems and quicken the recovery, including the following:
  - Demand response technologies that more efficiently regulate load
  - Automated splicing systems that reduce feeder processing times

Data Collection and Monitoring

- Developing programs that employ machine learning and remote monitoring to identify areas of heightened vulnerability in Con Edison's systems, including the following:
  - Leak-prone areas of the gas distribution system
  - Gas system drip pots that require draining
- Initiating a more diligent inspection system that effectively assesses the functionality of assets, as well as their exposure to potential hazards (e.g., nearby vegetation), including the following:
  - Underground network transformers and protectors
  - Underground structures
  - Flushing of flood zone vaults
  - Rapid assessments of overhead feeders
  - Overhead system pole-by-pole inspection for specification compliance
- Future deployment of advanced metering infrastructure (AMI) throughout the service territory has the potential to both improve information flow to customers and help absorb the impacts of extreme events. Specifically, AMI might be able to rapidly shed load on a targeted network to help ensure demand does not exceed supply, which reduces potential damages and likelihood of network-wide outages in the event of an extreme event.

Emergency Preparedness

- Improving contractor and material bases for post-storm repair crews and equipment, including the following:
  - Expanding and diversifying spare material inventories
  - Ensuring that all spare materials are housed in safe locations
- Conducting post-event debriefings to understand the impact of weather conditions on system performance
- Engaging with major telecommunications providers and enhancing communications systems among customer networks
- Facilitating equipment-sharing programs across New York State to ensure access to supplies during emergency response

Con Edison recognizes that the drivers behind future planning operations are inherently uncertain and is committed to both closely monitoring key signposts and continuously updating company investment plans and priorities.

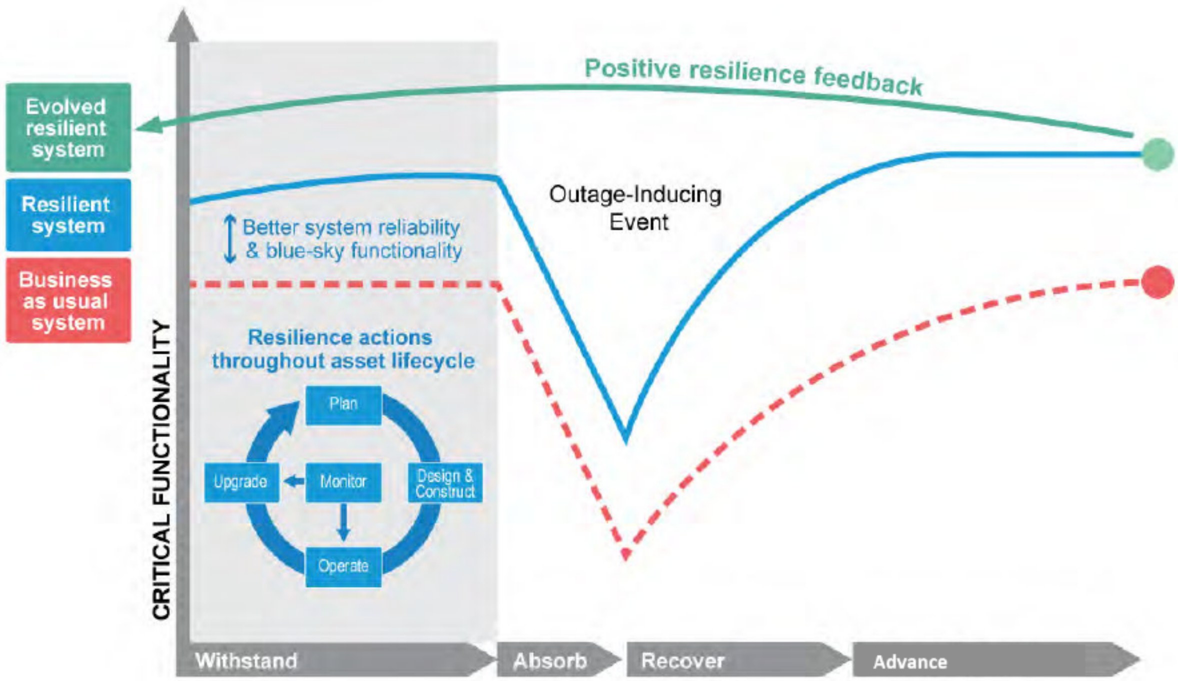
Vulnerabilities, a Resilience Management Framework, and Adaptation Options

Con Edison may face greater vulnerabilities due to future changes in temperature, humidity, precipitation, sea level rise, and extreme weather events. To understand this, the Study team evaluated key vulnerabilities of Con Edison's present-day electric, gas, and steam systems under a changing climate. The physical assets, operations, and planning of each system are uniquely vulnerable. In turn, building a detailed understanding of key vulnerabilities is an important step toward identifying priority adaptation measures.

Resilience Management Framework

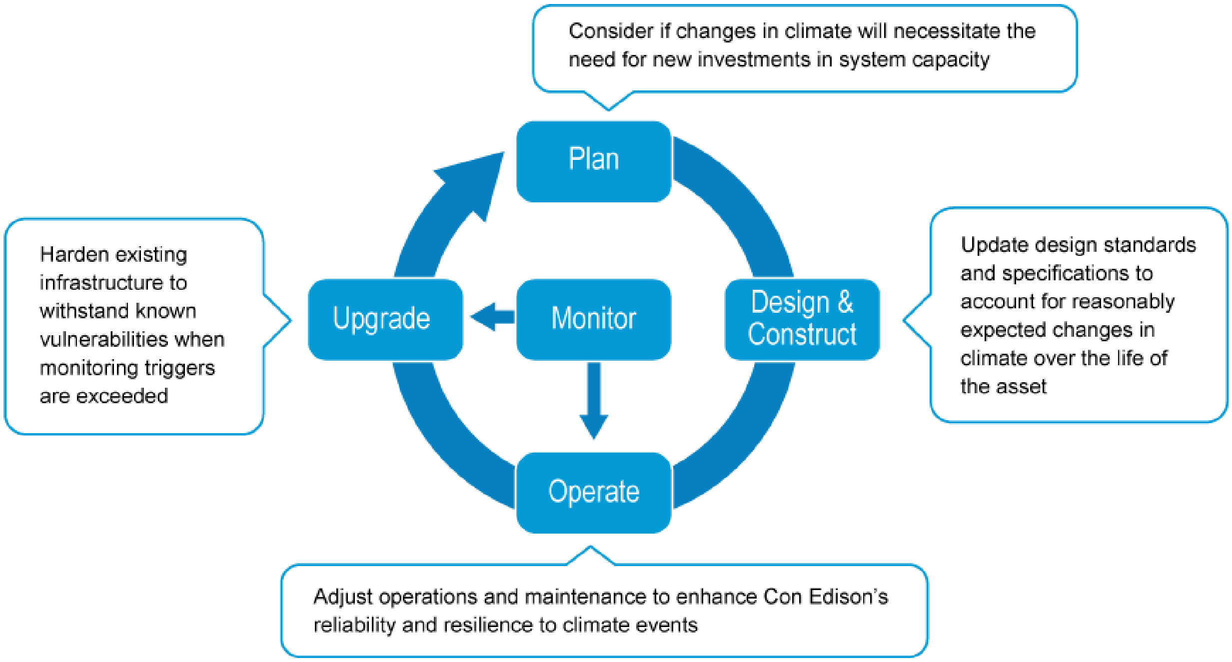
Under a changing climate, Con Edison will likely experience the increasing frequency and intensity of both gradual climate changes and extreme events. In response, the Study team developed a resilience management framework (Figure 12) to outline how a comprehensive set of adaptation strategies would mitigate future climate risks. The framework encompasses investments to better withstand changes in climate, absorb impacts from outage-inducing events, recover quickly, and advance to a better state. The "withstand" component of this framework prepares for both gradual (chronic) and extreme climate risks through resilience actions throughout the life cycle of assets. As such, many of the adaptation strategies identified in the following sections fall under the category of systematically bolstering Con Edison's ability to withstand future climate risks. Investments to increase the capacity to withstand also provide critical co-benefits, such as enhanced blue-sky functionality and the reliability of Con Edison's system. The resilience management framework facilitates long-term adaptation and creates positive resilience feedback so that Con Edison's system achieves better functionality through time. To succeed, each component of a resilient system requires proactive planning and investments.

Figure 12 ■ Conceptual figure representing a resilience management framework designed to withstand changes in climate, absorb and recover from outage-inducing events, and advance to a better state. Investing in a more resilient system (blue line) provides benefits relative to a less resilient, or business-as-usual, system (red dashed line) before, during, and after an outage-inducing event. Most resilience actions should occur systematically throughout the asset life cycle to enhance the ability to withstand changes in climate, while also enhancing system reliability and blue-sky functionality. Resilient systems also adapt so that the functionality of the system improves through time (green line). Each component of a resilient system requires proactive planning and investments.



"Withstand" entails proactively strengthening the system to mitigate and avoid climate change risks and increase the reliability of Con Edison's system. "Withstand" investments are not necessarily a one-time event. Rather, the ability to withstand climate change must be integrated and revisited throughout the life cycle of Con Edison's assets. Doing so requires changes in the planning, design, and construction of new infrastructure; ongoing data collection and monitoring; and eventually investing in the upgrade of existing infrastructure, using forward-looking climate information. This life cycle approach to considering climate change is captured in Figure 13. Across Con Edison's electric, gas, and steam systems, planning for new investments in system capacity serves as a critical and strategic opportunity to integrate climate considerations. In addition, an important aspect of increasing the capacity of new investments to withstand changes in climate is maintaining strong design standards that account for gradual changes in chronic stressors and more frequent extreme events. However, since design standards do not apply to existing infrastructure, a strong monitoring program and signposts for additional adaptation investments could help ensure that Con Edison's existing infrastructure remains resilient to climate change by informing adjustments to operations and potential needs for upgrades.

Figure 13 ■ "Withstand" actions and investments must be revisited throughout the life cycle of Con Edison's assets.



"Absorb" includes strategies to reduce the consequences of outage-inducing events, since Con Edison cannot and should not harden its energy systems to try to withstand every possible future low-probability, high-impact extreme weather event. These actions, many of which Con Edison is already implementing, include operational changes to reduce damage during outage-inducing events and to protect exposed systems from further damage.

"Recover" aims to increase the rate of recovery and increase customers' ability to cope with impacts after an outage-inducing event. Such strategies build on Con Edison's Emergency Response Plans and Coastal Storm Plans. In addition, there is a role that Con Edison can play to increase customer coping and prioritize the continued functioning of critical services. Resilient customers are those who are prepared for outages and are better able to cope with reduced energy service—through measures such as having on-site energy storage, access to locations in their community with power, the ability to shelter in place without power, and/or prioritized service restoration for vulnerable customers.

"Advance" refers to building back stronger after climate-related outages and updating standards and procedures based on lessons learned. Even with proactive resilience investments, outage-inducing climate events can reveal system or asset vulnerabilities. Adjusting Con Edison's planning, infrastructure, and operations to new and future risks after an outage-inducing event, while incorporating learning, will allow for a more effective and efficient transition to greater resiliency. Con Edison has taken this approach in the past, including investing a billion dollars in storm hardening measures after Superstorm Sandy. Moving forward, restoring service following an outage-inducing climate event to a better adapted, more resilient state begins with effective pre-planning for post-event reconstruction. Where assets need to be replaced during recovery, having a plan already in place for selection and procurement of assets designed to be more resilient in the future can help to ensure that Con Edison is adapting to future extremes in a continuously changing risk environment.

Implementation of adaptation strategies throughout all of these phases will need to be adjusted over time to manage for acceptable levels of risk despite uncertainties about future conditions. The flexible adaptation pathways approach, described in further detail in the subsequent section, ensures the adaptability of adaptation strategies over time as more information about climate change and external conditions becomes available.

All Commodities (Electricity, Gas, and Steam)

Vulnerabilities

The Study team identified priority hazards for each of Con Edison's commodity systems (electric, gas, and steam) and found that several hazards were priorities across all three systems, although these hazards present unique vulnerabilities to the various assets within each system. The hazards common to all three systems are heat index, precipitation, sea level rise and storm surge, and extreme and multi-hazard events. These are discussed below. System-specific vulnerabilities are subsequently discussed in separate sections.

Heat Index

Worker safety may be a point of vulnerability if heat index values rise as projected. The Occupational Safety and Health Administration has set a threshold of 103°F for high heat index risk for people working under hot conditions. During the base period (1998–2017), there were 2 days per year with maximum heat greater than or equal to 103°F (but below 115°F). Under a lower emissions climate scenario (RCP 4.5 10th percentile), the 103°F threshold may be met 5 to 7 days per year by 2050; under a higher emissions scenario (RCP 8.5 90th percentile), this may occur 14 to 20 days per year by 2050. This poses a potential health threat to all Con Edison workers whose duties require outdoor labor.

Projected increases in heat index may also affect cooling equipment across Con Edison's systems, including the HVAC units for Con Edison buildings, air cooling towers for the electric system, and a water cooling tower for Con Edison's East River Steam Generating Plant. In order to supply sufficient cooling to its systems in 2080, Con Edison's HVAC systems will have to increase their capacity by 11% due to projected increases in dry bulb temperature. These systems have a roughly 15-year life span and therefore can be upgraded during routine replacements at an incremental cost of $1.3 million for 157 units. Similarly, Con Edison's cooling towers will have to increase their capacity by 30% by 2050. Cooling towers have a 20- to 35-year life span, allowing them to be upgraded during routine replacements at an incremental cost of $1.1 million for 19 cooling towers at 13 sites.

Precipitation

The Study team conducted an analysis of the physical and operational vulnerabilities of Con Edison's steam system, gas system, and transmission and substation components of the electric system. Findings indicated that all underground assets are vulnerable to flooding damage (i.e., water pooling, intrusion, or inundation) from heavy precipitation occurring over a short period of time. Specific vulnerabilities and their relevant thresholds vary significantly by commodity and, as such, are outlined in their respective sections.

Sea Level Rise and Storm Surge

The Study team broke down evaluation of priority vulnerabilities related to sea level rise into two components.

The first component focuses on design standards for new infrastructure. The Study team assessed Con Edison's coastal flood protection standards for robustness to projected sea level rise. Con Edison's current design standard for coastal flood protections includes the FEMA 1% annual flood hazard elevation, 1 foot for sea level rise, and 2 feet of freeboard, which aligns with New York City's Climate Resilience Design Guidelines for critical infrastructure and water elevations that Con Edison experienced during Superstorm Sandy. Under high-end sea level rise (e.g., due to either rapid ice loss from the West Antarctic Ice Sheet corresponding to Kopp et al., 2017, or RCP 8.5 95th percentile projections corresponding to Kopp et al., 2014), the existing 1 foot sea level rise risk tolerance threshold could be exceeded by 2030; however, under more likely scenarios, the current threshold could be exceeded between 2040 and 2080.[12] The probability that sea level rise will exceed the 1-foot sea level rise risk tolerance by 2020 is under 10%; that increases to 65% to 70% by 2050, and to 100% by the 2080s.

The second evaluation component identified specific physical vulnerabilities of Con Edison's existing assets to impacts related to sea level rise, which are described by commodity below.

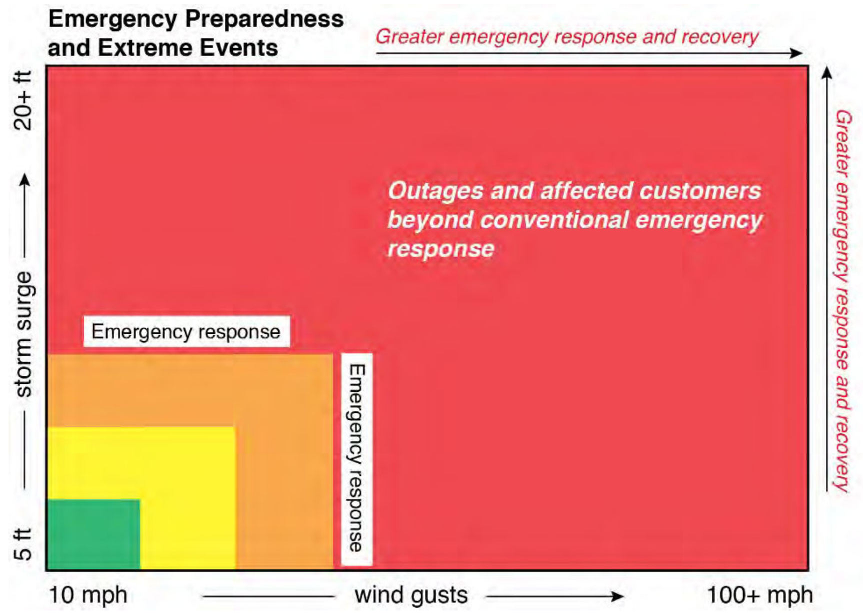
Extreme and Multi-Hazard Events

Assets across all systems are vulnerable to possible damage from extreme event flooding. Storm surge driven by an extreme hurricane event (i.e., a Category 4 hurricane) has the potential to flood both aboveground and belowground assets. Specific asset damage varies by commodity and is outlined in the commodity-specific sections. In addition, flooding from ice-melt and snowmelt may cause significant damage to assets across all commodities, especially if the melt contains corrosive road salts.

On an operational level, increasing frequency and intensity of extreme weather events may exceed Con Edison's currently robust emergency preparedness efforts. Con Edison's extreme weather response protocols are specified in the company's hazard-specific Emergency Response Plans and Coastal Storm Plans for electric, steam, and gas systems. Con Edison's current "full-scale" response, which calls for all Con Edison resources and extensive mutual assistance, is initiated when the number of customers out of service reaches approximately 100,000. However, low-probability extreme events can increase customer outages and outage durations by an order of magnitude, outpacing current levels of emergency planning and preparedness, as shown in Figure 14.

[12] The sea level rise projections use a baseline year of 2000. For more details on these projections and how they relate to Con Edison's design standards, see Appendix 4.

Figure 14 ■ Schematic diagram illustrating the increasing impacts during an extreme event (e.g., hurricane with extreme wind gusts and storm surge) that demands correspondingly large emergency response efforts that may exceed those experienced historically.



Adaptation Measures to Address Vulnerabilities

Several adaptation measures help address vulnerabilities across Con Edison's electric, gas, and steam systems: improved monitoring systems and capabilities to support planning and decision making, emergency preparedness and full system recovery, and improved customer coping.

Improved Monitoring Systems and Capabilities to Support Planning and Decision Making

Con Edison can collect updated and comprehensive data to further strengthen the resilience of its long-term plans and decision-making processes to climate change. Signposts guide planning and decision making, especially through informing the timing of implementation and the adjustment of adaptation measures, described in greater detail in the section below on Moving Towards Implementation.

As previously mentioned, it is important to have the latest information on climate variables and projections as the climate changes and the science improves. Monitoring local climate rates of change across the service territory can help Con Edison better track both changing conditions and potential points of vulnerability across its systems. Specific adaptation measures per commodity that are dependent on the monitoring of climate variable information are detailed in the respective commodity sections. In addition to information on climate variables, Con Edison will need to stay abreast of the latest climate science projections generated by expert organizations such as IPCC, NCA, and NPCC. The Study team suggests that Con Edison could revise its planning and decision-making processes at least every 5 years to incorporate updated climate science information.

Emergency Preparedness and Full System Recovery

Con Edison should consider a range of adaptation strategies to increase capacity for an efficient preparedness and recovery process, as defined in Table 3.

Table 3 ■ Emergency preparedness and system recovery adaptation strategies

Adaptation Strategy	Measures
Strengthen staff skills for streamlined emergency response.	• Use technology to increase the efficiency of emergency response work crews. • Review the Learning Center courses to ensure that crews are developing the skills required for emergency response. • Incorporate supply shortages into emergency planning exercises.
Plan for resilient and efficient supply chains.	• Develop a resilience checklist for resilient sourcing. • Have a plan already in place for selection and procurement of assets designed to be more resilient in the future. • Ensure that parts inventories are housed out of harm's way and in structures that can survive extreme weather events. • Standardize equipment parts, where possible.
Coordinate extreme event preparedness plans with external stakeholders.	• Continue coordination with telecommunication providers, including through joint emergency response drills. • Continue and strengthen collaboration with the city to improve citywide design, maintenance, and hardening of the stormwater system. For example, improved drainage could alleviate the potential impacts of flooding and increase the effectiveness of adaptation measures in which Con Edison invests (e.g., drain hardening at manholes).
Incorporate low probability events into long-term plans.	• Continue expanding the Enterprise Risk Management framework to include lower probability extreme weather events and long-term issues (e.g., 20+ years). • Conduct additional extreme weather tabletop exercises informed by the future narratives outlined in this report, and consecutive extreme weather events. • Consider expanding the definition of critical facilities and sensitive customers.
Track weather-related expenditures.	• Con Edison's Work Expenditures Group could track expenditures, such as the cost of outages and repairs or customer service calls. Concurrently tracking climate and cost data will enable Con Edison to perform correlation analysis over time.
Update extreme event planning tools.	• Con Edison currently uses an internal Storm Surge Calculator (an Excel workbook that determines the flood measures to be employed for coastal assets based on a given storm tide level) to help plan for coastal flooding impacts. Con Edison could adjust inputs to this program to reflect the following: – Updated storm surge projection information, using high-end forecasted surge – Information from coastal monitoring, such as sea level rise and coastal flooding • In addition, Con Edison could regularly revisit the definition of critical equipment so that the Storm Surge Calculator can best inform prioritization of equipment upgrades.
Expand extreme heat worker safety protocols.	• Implement safety protocols (e.g., shift modifications and hydration breaks) practiced in mutual aid work in hotter locations such as Florida and Puerto Rico. • Examine and report on the levels of workers necessary to prepare for and recover from extreme climate events.
Improve recovery times through system and technology upgrades.	• Consider the use of drones and other technology (satellite subscription) or social media apps for damage assessment. • Use GIS system to facilitate locating and documenting damage. • Expand the use of breakaway hardware and detachable service cable and equipment.

Improved Customer Coping

Extreme events can present outsized risks compared to chronic events—risks that, in some cases, also extend to larger geographic areas. For example, impacts from hurricanes can overwhelm multiple facets of Con Edison's system and surrounding communities. Con Edison is positioned at the center of increasingly interconnected societal, technological, and financial systems, making it difficult and inefficient to evaluate risks solely on a component-by-component basis (Linkov, Anklam, Collier, DiMase, & Renn, 2014). Together, these factors necessitate different approaches to considering adaptation compared with climate changes for which probabilities are more easily assigned.

While the City of New York has primary responsibility for coordinating resident emergency response efforts, Con Edison can play a role in increased customer coping and resilience. This includes helping customers cope with reduced energy service if an extreme event leads to prolonged outages (e.g., supporting on-site energy storage, access to locations in the community with power, prioritized service restoration for vulnerable areas). Table 4 provides more specific adaptation strategies. Overall, Con Edison could consider expanding the definition of critical facilities and sensitive customers.

Table 4 ■ Improved customer coping adaptation strategies

Adaptation Strategy	Measures
Create resilience hubs (see below for more information).	• Use solutions such as distr buted generation, hardened and dedicated distribution infrastructure, and energy storage so that resilience hubs can function akin to microgrids to provide a range of basic support services for citizens during extreme events. • Continue to promote the pilot resilience hub at the Marcus Garvey Apartments in Brooklyn, using a lithium ion battery system, fuel cell, and rooftop solar to provide back-up power to a building with a community room that has refrigerators and phone charging. • Support additional deployment of hybrid energy generation and storage systems at critical community locations and resilience hubs. • Use AMI capabilities to preserve service for vulnerable populations, if possible.
Invest in energy storage.	• Continue to enhance customer resilience through continued installation of energy storage strategies, including on-site generation at substations or mobile storage on demand/transportable energy storage system (TESS) units, and compressed natural gas tank stations. • Continue to explore ways to help customers install, maintain, and make use of distributed energy resource assets for power back-up, self-sufficiency, and resilience purposes.
On-site generation	• Con Edison currently supports on-site generation for customers through programs such as rebate and performance incentives for on-site residential and commercial photovoltaic solar generation, incentives for behind-the-meter wind turbines, and incentives for combined heat and power projects that Con Edison currently facilitates in collaboration with the New York State Energy Research and Development Authority. • On-site generation is a recommended approach for locations where resilience hubs may not be affordable or necessary. • Con Edison could continue to encourage on-site generation for individual businesses and residential buildings.
Energy efficiency	• Support improved passive survivability, or the ability to shelter in place for longer periods of time, through enhanced energy efficiency programs. • Continue to support energy efficiency programs and further expand its energy efficiency program portfolio to include additional incentives for energy-efficient building envelope upgrades.

Resilience hubs are an emerging idea in resilience planning, which focus on building community resilience by creating a space (or spaces) to support residents and coordinate resources before, during, and after extreme weather events (Baja, 2018). A key requirement for a resilience hub is continued access to energy services. The objective of a resilience hub is to be able to provide a range of basic support services for citizens during extreme events. To accomplish this, resilience hubs may require a hybrid energy solution that includes multiple generation sources (e.g., solar and natural gas generation) and energy storage (i.e., batteries), plus dispatching controls, similar to the functionality of a microgrid. Figure 15 and Figure 16 demonstrate how a fuel cell-based microgrid can be used to power key community locations during normal operating conditions and during emergency events.

Figure 15 ■ Fuel cell-based microgrid supplying energy to key community locations (Constellation Energy)

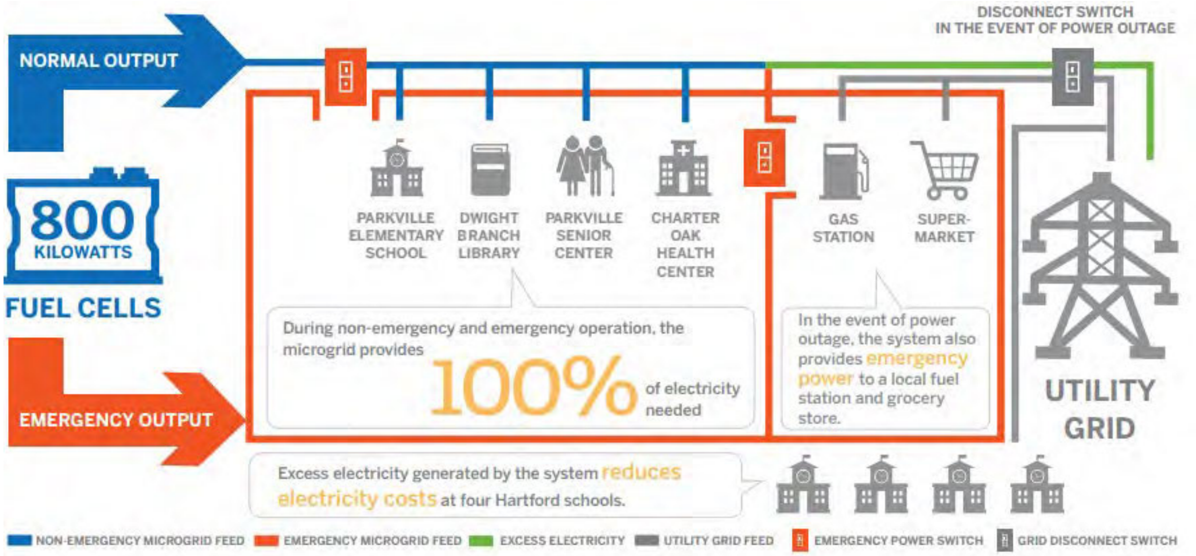


Figure 16 ■ Diagram of microgrid operations during normal and emergency operations (Constellation Energy)

Electric System

Electric System Overview

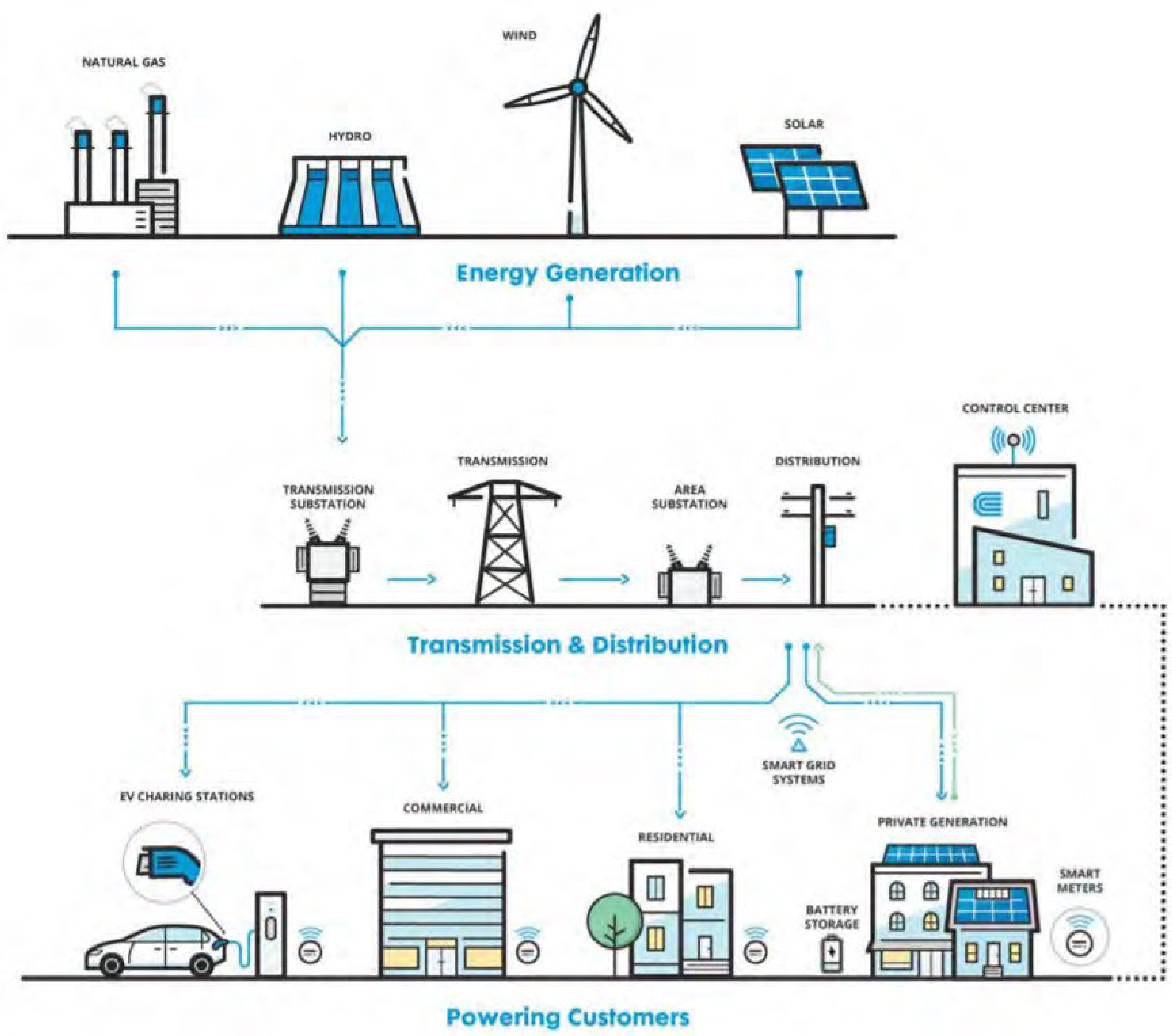
Con Edison's electric service territory includes both New York City and Westchester County, covering an area of 660 square miles and serving 3.3 million customers. Figure 17 depicts a schematic of the Con Edison electric system.

Con Edison's grid is a delivery system that connects energy sources to customers. While most electricity delivered is produced by large third-party generating stations, distributed energy resources also supply energy to the grid.

Energy produced by generating sources is delivered via the Con Edison transmission system, which includes 430 circuit-miles of overhead transmission lines and the largest underground transmission system in the United States, with 749 circuit-miles of underground cable. The system also includes 39 transmission substations. The high-voltage transmission lines bring power from generating facilities to transmission substations, which supply area substations, where the voltage is stepped down to distribution levels.

Con Edison has two different electric distribution systems—the non-network (primarily overhead) system and the network (primarily underground) system. The network system is segmented into independent geographical and electrical grids supplied by primary feeders at 13 kilovolts (kV) or 27 kV. The non-network system is designed using either overhead autoloops with redundant sources of supply, or 4-kV overhead grids arranged in a network configuration or as underground residential distribution systems designed in loop configurations.

Figure 17 ■ Diagram of the Con Edison Electric System



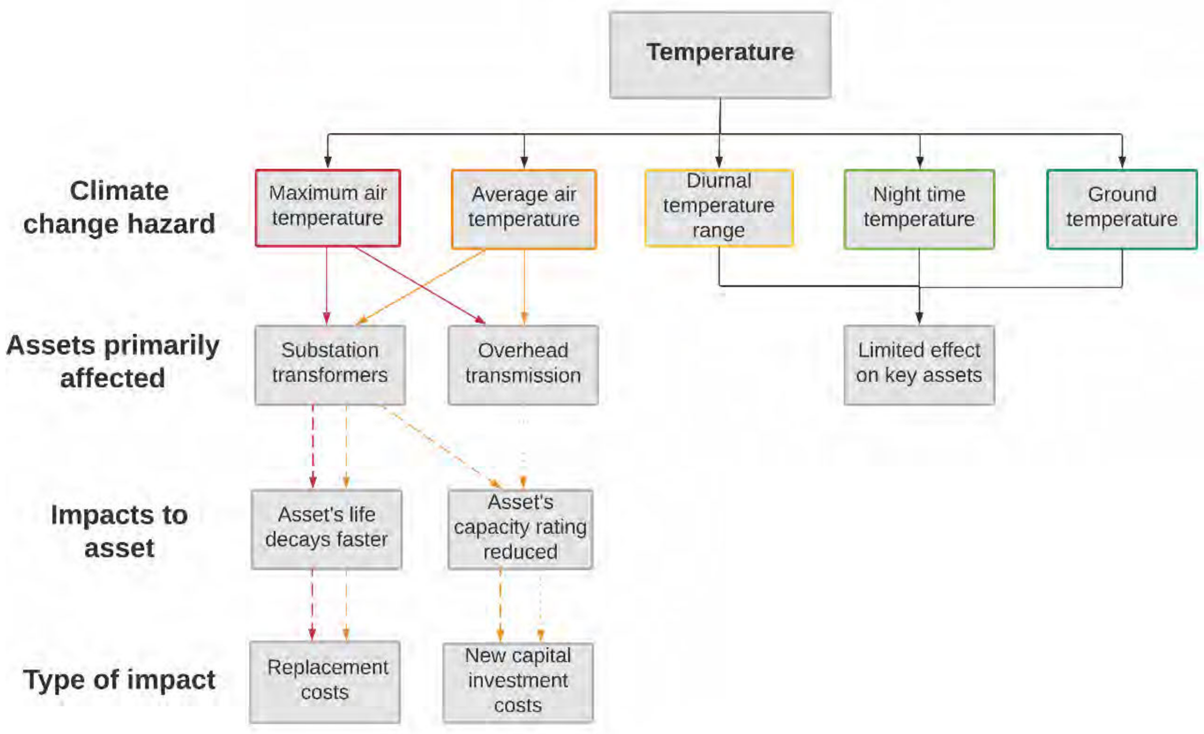
Electric Vulnerabilities

Assets in the electric segment of Con Edison's business are most vulnerable to climate-induced changes in temperature/humidity and sea level rise. Both climate hazards have already shown their ability to bring about outages or damage assets and interrupt operations and carry the potential for future impacts. More information on specific vulnerabilities for these and other climate stressors is discussed below.

Heat and Temperature Variable (TV)

The core electric vulnerabilities for increasing temperature and TV include increased asset deterioration, decreased asset capacity, decreased system reliability, and increased load. Figure 18 illustrates how temperature-related stressors, such as maximum and average air temperature, lead to impacts on the electric system.

Figure 18 ■ Temperature-related impacts on Con Edison's electric system



Increased Asset Deterioration

Increased average temperatures pose a threat to substation transformers. Within a substation, transformers are the asset most likely to be affected by projected higher temperatures since their ambient temperature design reference temperature is lower (i.e., 86°F) than that of most other assets.[13] Higher average and maximum ambient temperatures increase the aging rate of the insulation in transformers, resulting in decreased asset life.[14]

Decreased Asset Capacity

Because an asset's internal temperature is the result of the ambient temperature in which it operates, as well as the amount of power it delivers, operating in an ambient temperature above the design reference temperature decreases the operational rating of the asset. However, derating the system due to increasing temperatures would effectively decrease the capacity of the system. When the capacity of the system is decreased, Con Edison must make investments to replace that capacity. The Con Edison system is currently designed with the capacity to meet a peak summer demand of more than 13,300 megawatts (MW). Based on projected temperature increases, capacity reductions in 2050 could range from 285 MW

[13] Buses, disconnect switches, circuit breakers, and cables all have a design reference temperature of 104°F or higher.
[14] Not every excursion above the designed-for temperature will result in decreased service life. Two conditions must be met for the useful life of the transformer insulation to experience an increased rate of decay: (1) the ambient reference temperature rating must be exceeded, and (2) the transformer must be operating at the rated load, typically as a result of the network experiencing a single or double contingency.

to 693 MW for overhead transmission, switching stations, area station and sub-transmission, and network transformers.[15] This could potentially result in a capital cost of $237 million to $510 million by 2050.

The primary impact of increases in ambient temperatures on overhead transmission lines (assuming peak load) is increased line sag. Insufficient line clearance presents a safety risk should standard measures such as vegetation management not alleviate the risk. If standard measures cannot be applied, the lines would have to be derated and investments would be needed to replace the diminished capabilities of the line.

Decreased System Reliability

Increases in TV-related events are expected to affect the electric network and non-network systems by decreasing reliability. Con Edison uses a Network Reliability Index (NRI) model to determine the reliability of the underground distribution networks.[16] Con Edison has set an NRI value of 1 per unit (p.u.) as the threshold over which reliability is considered unacceptable. Currently, there are no networks that exceed this standard.

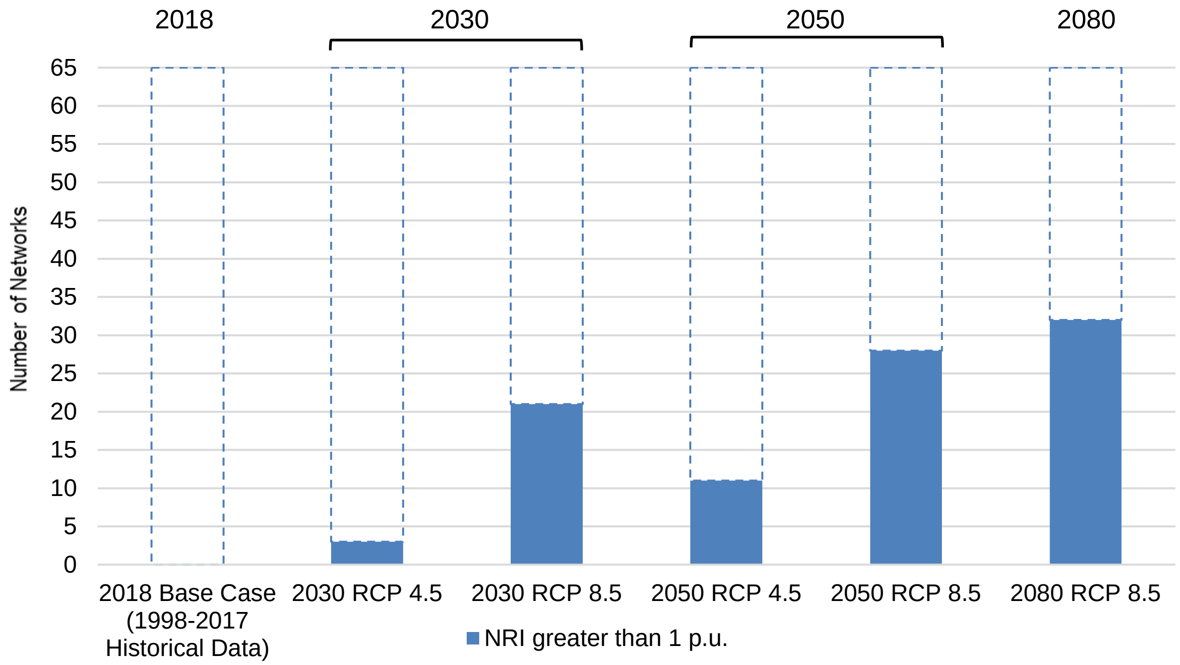
The Study team modeled how the NRI value of each network would change without continued investments in the system. The forward-looking NRI analysis found that with an increase in the frequency and duration of heat waves by mid-century, between 11 and 28 of the networks may not be able to maintain Con Edison's 1 p.u. standard of reliability by 2050, absent adaptation. Under the higher emissions scenario (RCP 8.5 90th percentile), projected impacts are relatively severe, even by 2030, with up to 21 total networks projected to exceed the NRI threshold by that year, absent adaptation (Figure 19). These deficiencies can be reduced by continuing to make investments to better withstand climate events, which Con Edison has done in the past through measures such as infrastructure hardening and added redundancy, diversity, and flexibility in power delivery. Such measures carry the co-benefit of improving blue-sky functionality and reliability.

Currently, Con Edison replaces paper-insulated, lead-covered (PILC) cables as an effective first line of defense against NRI increases. Con Edison is committed to continued investment in this measure, which will help reduce this heat-related vulnerability in the near term. The Study team also quantified the value of other measures to maintain network reliability, including innovative distribution designs and the use of distributed resources, which can be part of microgrids.

[15] The assumed decrease in capacity is 0.7% per °C (0.38% per °F) for substation power transformers, and 1.5% per °C (0.8% per °F) for overhead transmission conductors (Sathaye, 2013).

[16] NRI is a Monte Carlo simulation used to predict the performance of a network during a heat wave. The program uses the historical failure rates of the various components/equipment that are in the network, and through probability analysis determines which networks are more likely to experience a shutdown.

Figure 19 The number of networks above the NRI threshold of 1 p.u. under both climate scenarios for 2030, 2050, and 2080



The Study team also analyzed the impact of climate change on non-network reliability, which is measured in terms of the System Average Interruption Frequency Index (SAIFI).[17] The results indicate that the reliability of the non-network system is somewhat vulnerable to heat events; however, climate impacts would be negligible out to 2080. The average contribution to reliability from non-network autoloop feeder failures and 4-kV grid supply feeder failures due to increased temperatures would only contribute up to 8% of the maximum threshold SAIFI of 0.45 (i.e., a 0.035 increase in SAIFI in 2080) (New York Department of Public Service, 2018).

Increased System Load

When temperature and humidity increase, demand for electricity for cooling also increases. Therefore, higher TV in the summer can cause higher peak loads. The Study team found an increase in peak load in 2050 of 6.9% to 19.2%, as compared to historical conditions. These projected changes in load are due only to the impact of changing TV, and do not take into consideration changes in other factors (e.g., population, increased air conditioning penetration). The Study team found a decrease in winter peak electric load.

Increases in load may require investments in system capacity to meet the higher demand. This cost could be between $1.1 billion and $3.1 billion by 2050. The 10- and 20-year load relief investment plans use asset ratings and load forecasts as key inputs, both of which include temperature as a factor. This combination of a greater demand and a decreased capacity to fill that need will likely warrant a revision to the load relief planning process in the future (Table 5).

[17] SAIFI is a measure of customer reliability. It is the average number of times that a customer is interrupted for 5 minutes or more over the course of 1 year.

Table 5 The combined impacts of increased load and asset capacity reduction in 2050

Scenario	Total capacity under base and future temperature conditions (MW)	Incremental capacity reduction due to temperature	Peak load during current and future 1-in-3 events (MW)	Incremental load increase due to changes in TV	Total additional capacity needed under climate scenarios (MW)
Base Case 2050	13,300	0	13,525	–	0
RCP 4.5 10th percentile 2050	13,015	285	14,949	1,424	1,709
RCP 8.5 90th percentile 2050	12,607	693	16,491	2,966	3,659

Secondary Vulnerabilities

The Study team identified additional heat and humidity-related vulnerabilities in Con Edison's system that were not flagged as priority vulnerabilities but nonetheless present risks.

- **Transmission system:** Con Edison's current transmission system is designed for the highest anticipated loads based on historical values. The Study team found that while load exceeded 90% of the peak load (presenting the possibility for thermal overload) on 1.5% of summer days historically, by 2050, this may increase to 5.2% of days under the RCP 8.5 90th percentile scenario. This shift in TV distribution may result in a small increase in the frequency of load drop from the transmission system.
- **Summer operations and voltage reductions:** When summer temperatures soar, Con Edison implements a set of procedures to avoid voltage and thermal stresses on the system. These procedures are triggered by a threshold (e.g., TV 86, which is the 1-in-3 peak load-producing TV). The Study team found that there could be a significant increase in the number of days with voltage reductions and summer work restrictions. However, if Con Edison continues to invest in the system to ensure operational capacity during the 2050 1-in-3 TV event, then there will be a drop in the frequency of voltage reductions and summer work restrictions, relative to today.
- **Corporate Emergency Response Plan:** Con Edison also uses TV thresholds to trigger elevated threat levels under its Corporate Emergency Response Plan (CERP). The Study team conducted an analysis to understand how the projected changes in TV will affect the exceedance of current CERP threat levels. The analysis indicates that TV conditions exceeding current thresholds will increase in both the lower (RCP 4.5 10th percentile) and higher (RCP 8.5 90th percentile) climate change scenario. The conditions for reaching a "Serious" threat level based on the current thresholds, for example, would increase from 0.4 days per summer, on average, to 1.8 days under RCP 4.5, and 12.8 days under RCP 8.5.
- **Volume forecasting:** Con Edison conducts volume forecasting to estimate the volume of energy the company needs to purchase, a portion of which is weather-sensitive. The calculation for this portion relies primarily on heating degree-days (HDDs) for the winter and cooling degree-days (CDDs) for the summer. The Study team estimated that Con Edison could experience an increase in summertime CDDs, which could result in the energy delivery increasing from 43,077 gigawatt-hours (GWh) in 2050 under the base case to 43,685 GWh under the RCP 4.5 scenario (a 1.4% increase), and to 45,394 GWh under the RCP 8.5 scenario (a 5.4% increase). The Study team found a less significant decrease in HDDs due to climate change.

Sea Level Rise

RCP 4.5 and RCP 8.5 projections indicate that sea level rise may exceed Con Edison's current design standard for coastal flood protection (i.e., a 100-year storm with 1 foot of sea level rise and 2 feet of freeboard) between 2030 and 2080. The Study team analyzed the exposure of Con Edison's assets to 3 feet of sea level rise (i.e., the 2080 RCP 8.5 83rd percentile sea level rise projection), keeping the other elements of Con Edison's existing risk tolerance constant (i.e., a 100-year storm with 2 feet of freeboard). By summing the freeboard and sea level rise values, this equates to FEMA's 100-year floodplain elevation plus 5 additional feet.

Of the 324 electric substations (encompassing generating stations, area substations, transmission stations, unit substations, and Public Utility Regulating Stations [PURS]), 75 would be vulnerable to flooding during a 100-year storm if sea level rose 3 feet. Three of these potentially exposed substations would only require minimal modifications to protect them, 16 would require an extension of existing protections, eight would require a new protection approach (i.e., the existing protections cannot be extended), and 48 do not have existing protections because they are outside of the floodplain. Hardening all these substations is estimated to cost $636 million.

Precipitation

The Study team found that substations, overhead distribution, underground distribution, and the transmission system are most at risk for precipitation-based hazards.

Substations may experience an overflow of water from transformer spill moats, which could release oil-contaminated water within the substation. However, the risk of such an event is low, as transformer spill moats are built at a level that is robust to all but a severe and highly improbably conjunction of events.[18]

The transmission and overhead distribution systems are both vulnerable to the accumulation of radial ice, which can build up on lines and towers during winter precipitation events. In extreme scenarios, accumulation of radial ice can result in unbalanced structural loading and subsequent transmission line failure, especially when accompanied by heavy winds (Nasim Rezaei, Chouinard, Legeron, & Langlois, 2015). Con Edison's current system meets the National Electrical Safety Code standard for radial ice and is robust to ice accumulation. It is uncertain whether climate change will increase or decrease the intensity of future icing events.

The underground distribution system is vulnerable to flooding and salt runoff from snowfall and ice events. Flooding can damage non-submersible electrical equipment. This risk is mitigated through Con Edison's designs: All underground cables and splices operate while submerged in water, and all underground distribution equipment installed in current flood zones (and all new installations) are submersible. Snowfall and ice require municipalities to spread salt on roads, which eventually seeps into the ground with runoff water. Road salt can degrade wire insulation and lead to insulation burning and arcing, potentially causing safety concerns and customer outages. It is currently unclear how salting frequency will change over time.

Extreme Events

Hurricanes and nor'easters present physical risks associated with heavy winds, precipitation, and flooding, which can lead to widespread system outages and, at worst, physical destruction. During hurricanes, wind stress and windblown debris can lead to tower and/or line failure of the overhead transmission system

[18] In accordance with New York State code and federal Spill Prevention, Control, and Countermeasure recommendations, Con Edison's transformers are protected by moats designed to hold water from a 6-inch, 1-day storm event, in addition to the gallons of oil that may be released during a spill event and a further 50,000–60,000 gallons of fire suppression fluid. Based on this standard, Con Edison's substation transformer moats are robust to 6 inches of rain during a catastrophic emergency, and significantly more than that at all other times.

and damage overhead distribution infrastructure, which could cause widespread customer outages. Intense rain during hurricanes can also flood substations, which may cause an overflow of oil-contaminated water from transformer spill moats. A Category 4 hurricane could very likely lead to outages for more than 600,000 non-network customers and more than 1.6 million network customers.

During nor'easters, accumulation of radial ice can cause tower or line failure of the overhead transmission system. Similarly, snow, ice, and wind can damage the overhead distribution system. Indirectly, salt put down by the city to contend with snow and ice accumulation on roads could infiltrate the underground distribution system, causing arcing and failure of underground components.

Extreme heat waves present a range of effects that can contribute to failures, including a lower ampacity rating while increasing load demand, causing cables and splices to overheat, transformers to overheat, and transmission and distribution line sag. Distribution network component failures can cause Con Edison to exceed the network reliability design standard. Greater line sag can lead to flashovers and line trips.

Adaptation Options for the Electric System

Withstand

In the short term, Con Edison can work to address the vulnerabilities of the electric system by integrating climate hazard considerations into planning, collecting data on priority hazards, and updating design strategies.

There are several opportunities to integrate climate change data into planning processes. For example, Con Edison could integrate climate change projections into long-term load forecasts, consult utilities in cities with higher temperatures to refine the load forecast equation for high TV numbers, and develop a load relief plan that integrates future changes in temperature and TV into asset capacity and load projections. During load relief planning, Con Edison could also consider whether extreme events may shift the preferred load relief option—frequent extreme heat could reduce the effectiveness of demand response programs. For the transmission system, Con Edison could integrate considerations of climate change into the long-range transmission plan. For the distribution system, Con Edison could integrate climate projections into NRI modeling and install high-reliability components,[19] as needed.

Given the potential risks that temperature and heat waves pose to the electric system, the Study team suggests that Con Edison could collect data on these hazards to build greater awareness of their impacts to the system, as well as to monitor for signposts that would trigger additional action. Specifically, Con Edison could:

[19] System components vary in their reliability. For example, PILC cable performs more poorly than solid dielectric cable.

- Install equipment capable of collecting, tracking, and organizing temperature data at substations to allow for location-specific ratings and operations.
- Make ground temperature data more accessible and track increases over time.
- Expand monitoring and targeting of high-risk vegetation areas.
- Continue to track line sag and areas of vegetation change via light detection and ranging (LiDAR) flyovers to identify new segments that may require adaptation.

These data could be used to routinely review asset ratings in light of observed temperatures. Con Edison could also incorporate heat wave projections into reliability planning for the network system.

Hurricanes are another priority hazard for the electric system and therefore warrant robust planning tools that capture potential changes in climate. Con Edison could complement their existing model used to predict work crews required to service weather-driven outages with an updated model that better resolves extreme weather events and extreme weather impacts on customers in the service territory.

Design standards are a way to help standardize resilience by ensuring that new assets are built to withstand the impacts of climate change hazards. The Study team suggests a variety of design standards:

- **Temperature:** Standardize ambient reference temperatures across all assets for development ratings.
- **Precipitation:** Update precipitation design standards to reference National Oceanic and Atmospheric Administration (NOAA) Atlas 14 for up-to-date precipitation data. Consider updating the design storm from the 25-year precipitation event to the 50-year event to account for future increases in heavy rain events.
- **Sea Level Rise:** Revise design guidelines to consider sea level rise projections and facility useful life. Continue to build to the higher of the FEMA + 3′ level and the Category 2 storm surge levels at new-build sites, as is current practice. Add sea level rise to the Category 2 maps to account for future changes and a greater flood height/frequency.

In addition to these systematic approaches, Con Edison can also help the electric system better withstand climate hazards through asset-specific physical adaptation measures, when needed. Table 6 illustrates these physical options.

Table 6 Potential physical adaptation options for electric assets

Main Hazard(s)	Vulnerable Assets or Plan	Adaptation Option	Implementation Timeframe	Signpost or Threshold
Temperature	Grid modernization	Continue to invest in grid modernization to increase resilience to climate change through new technology and increased data acquisition. Efforts include distribution automation, grid-edge sensing (environmental, AMI), asset health monitoring, conservation voltage optimization, and targeted system upgrades.	Continuous	Change in ambient operating temperatures, including changes in science-based projections
Heat Waves	Network system, which may experience reduced reliability (and therefore increased NRI) due to heat waves	Complete PILC cable replacements.	2030	Increased frequency or duration of heatwaves
		Continue implementing load relief strategies to keep NRI ratings below 1. Options include: • Split the network into two smaller networks. • Create primary feeder loops within and between networks. • Install a distribution substation. • Incorporate distributed energy resources and non-wire solutions. • Design complex networks that consider combinations of adaptation measures.	Continuous	NRI value over 1 p.u.
	Non-network distribution system	Maintain non-network reliability in higher temperatures by implementing the following: • Autoloop sectionalizing • Increased feeder diversity	2080	Forecasted System Average Interruption Frequency Index (SAIFI) ratings (incorporating climate change projections) above established thresholds
	Overhead transmission	Replace limiting wire sections with higher rated wire to reduce overhead transmission line sag during extreme heat wave events. Alternatively, remove obstacles or raise towers to reduce line sag issues.	Continuous	Increased incidence of line sag; higher operating temperatures
		Explore incorporating higher temperature-rated conductors.	2050	Existing asset replacement
	Area and transmission substation transformers	Undertake measures that contribute to load relief, such as energy efficiency, demand response, adding capacitor banks, or upgrading limiting components, such as circuit breakers, or disconnect switches and buses.	2030/2050	Ambient temperatures exceeding asset specifications
		Gradually install transformer cooling, or replace existing limiting transformers within substations.	2050/2080	Ambient temperatures exceeding asset specifications
Precipitation	Substations	Harden electric substations from an increased incidence of heavy rain events by doing the following: • Raising the height of transformer moats • Installing additional oil-water separator capacity • Increasing "trash pumps" behind flood walls to pump water out of substations	2080	Changes in the 25-year return period storm
	Transmission and overhead distribution	Underground critical transmission and distribution lines.	2080	Increased incidence of icing

Main Hazard(s)	Vulnerable Assets or Plan	Adaptation Option	Implementation Timeframe	Signpost or Threshold
	Underground distribution	Retrofit ventilated equipment with submersible equipment to eliminate the risk of damage from water intrusion.	2050	Expanded area of precipitation-based flooding; better maps of areas at risk for current and future precipitation-based flooding
		Reduce the incidence of manhole events due to increased precipitation and salting by doing the following: • Expanding Con Edison's underground secondary reliability program • Accelerated deployment of vented manhole covers • Replacement of underground cable with dual-layered and insulated cable, which is more resistant to damage • Installation of sensors in manholes to detect conditions indicating a potential manhole event	2050	Increase in the City's use of salt over the winter period; increased rate of winter precipitation
Hurricanes	Overhead transmission	Continue to expand existing programs to reinforce transmission structures; address problems with known components.	Continuous	Increased frequency/severity of heavy winds; existing asset replacement
	Overhead distribution	Invest in retrofits for open wire design with aerial cable and stronger poles.	2080	Increased frequency/severity of heavy winds; existing asset replacement
		Underground critical sections of the overhead distribution system to ensure resilience against hurricane force winds and storm surge.	2080	Increased frequency/severity of heavy winds
Nor'easters	Overhead transmission and distribution	Continue to expand programs to reinforce transmission and distribution structures and expand the number of compression fittings used to address weak points in transmission lines.	Continuous	Increased incidence of icing; existing asset replacement
	Underground distribution	Upgrade high failure rate components.	Continuous	Increased frequency/severity of nor'easter events

Of course, it is neither practical nor feasible for Con Edison to build resilience to the point that its electric system can fully withstand the impacts of all climate hazards. The Study team thus suggests that Con Edison consider the following strategies to help the electric system better absorb and recover from impacts:

Absorb

- **Temperature:** Increase capabilities to provide flexible, dynamic, and real-time line ratings.
- **TV:** Routinely update voltage reduction thresholds and hands-off thresholds to account for changes in climate and the changing design of the system.
- **Hurricanes:** Continue to explore and expand operational measures to increase the resiliency of the overhead distribution system by increasing spare pole inventories to replace critical lines that are compromised during extreme weather events.
- **Heat waves:** Stagger demand response consecutive event days across different customer groups to increase participation; ensure that demand response program participants understand the purpose/cause of the event; use technology to more efficiently regulate load/use AMI to rapidly shed

load on a targeted network to help ensure that demand does not exceed supply; and continue installation of energy storage strategies, including on-site generation at substations or mobile storage on demand/transportable energy storage system (TESS) units, and compressed natural gas tank stations.

Recover

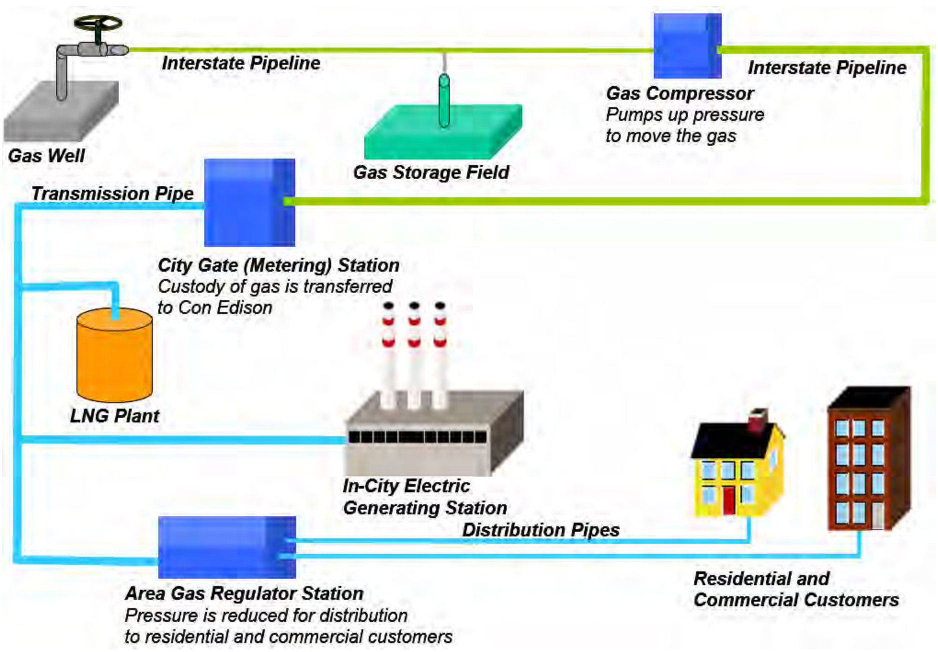
- **Heat waves:** Continue to actively engage forward-looking technologies to improve extreme recovery time for distribution systems, such as automated splicing systems to reduce feeder processing times.
- **Extreme events:** Support additional deployment of hybrid energy generation and storage systems at critical community locations and resilience hubs; support increasing the percentage of solar/other distributed generation projects to allow for islanding; encourage on-site generation for individual businesses and residential buildings; and increase the use of LiDAR and drones to assess damage and reduce manual labor.

Gas System

Gas System Overview

Con Edison's gas service territory covers Manhattan, Bronx, Westchester, and parts of Queens. Con Edison serves approximately 1.1 million firm customers and 900 large-volume interruptible customers who can alternate fuel sources. The natural gas system consists of more than 4,359 miles of pipe transporting approximately 300 million dekatherms (MMdt) of natural gas annually. About 56% of the system operates at low pressure, 11% operates at medium pressure, and 33% operates at high pressure. Figure 20 depicts the Con Edison natural gas delivery chain.

Figure 20 ■ Con Edison natural gas delivery chain



Gas Vulnerabilities

Most of Con Edison's gas assets are underground, and gas load peaks in the winter rather than in the summer, which means that gas assets are less likely to be damaged by subaerial extreme events, such as heat waves, lightning, and strong winds. As discussed in Con Edison's Post Sandy Enhancement Plan, Con Edison's gas assets are most vulnerable to underground water intrusion caused by flooding, and thus projected increases in the frequency of heavy precipitation and downpours, sea level rise and storm surge, and hurricanes and nor'easters pose a significant risk (Con Edison, 2013).

Water intrusion can occur if underground water enters gas pipes or mains and may result in a drop in pressure and lead to scattered service interruptions; low-pressure segments of the system and cast iron pipes are particularly vulnerable to this risk. In addition, pipe sections near open-pit construction projects may also be more vulnerable, because open excavation work can create opportunities for water intrusion if flood protection measures are not consistently used. Con Edison has already developed operational protocols that require crews working on open excavation sites to secure them to minimize water intrusion risk.

Water intrusion into gas regulators through aboveground vents may also cause damage. This intrusion could lead to water sitting on top of the diaphragm that allows each regulator to function and exerting additional pressure on the diaphragm that could, in turn, over-pressurize the regulator. Over-pressurized gas flowing through a system designed for lower pressure gas increases the possibility of tearing leaks in distribution piping, and in the worst-case scenario, could blow out pilot lights.

For the gas distribution system to function at full capacity and to be able to provide customers with desired gas supply, Con Edison must keep gas moving through the system at the intended flow rate, or pressure level, of each system segment. Once water enters the gas system, it is difficult to pinpoint the location and remove the water, which can increase the durations of resulting service interruptions.

Con Edison is currently undertaking several measures to manage underground water intrusion:

- Using drip pots to collect water at low points in the system (approximately 8,000 are currently in place)
- Developing a program to better prioritize gas infrastructure replacements. Remote sensors and machine learning could identify leak-prone areas to prioritize for upgrades intended to mitigate increasing precipitation risks in the face of climate change
- Developing a drip pot remote monitoring program using sensors, which would increase the efficiency of periodic emptying of drip pots and reduce the effort needed to monitor drip pots during the period of planned pipe replacement
- Shifting toward constructing and repairing infrastructure with more leak-resistant equipment, when possible

A climate change-driven increase in the frequency and intensity of flood events, such as heavy rain events or snow events followed by rapid snow melt, or coastal storm surge, may elevate the risk of water infiltration into the low-pressure gas system. The precipitation threshold currently used as a benchmark for monitoring and emptying drip pots is ½ inch of rain in 24 hours. Under the RCP 8.5 scenario, this threshold is projected to be exceeded 37 days per year in Central Park by the latter part of the century, which is nearly 20% more than the 31 days observed over the baseline period.

Low-probability, high-impact extreme events may also include heavy rainfall and storm surge that could increase the risk of water entering the distribution system. An increase in the frequency and intensity of extreme events may make water infiltration into the gas distribution system more likely. Con Edison's gas system has established criteria to ensure that new equipment, such as gas regulator line vents, is resilient against a 100-year storm and 1 foot of sea level rise. After Superstorm Sandy, Con Edison upgraded two regulator stations to meet this standard. The Study team determined that to protect regulator stations against 3 feet of sea level rise, Con Edison would need to update 32 regulator stations, at a cost of $13.8 million.

The gas transmission system is vulnerable to cold snaps associated with nor'easters, when temperatures can drop below 0°F for multiple days. Transmission system capacity is designed to meet demand projected for weather conditions at or above 0°F. Temperatures below that threshold may increase demand to a level that exceeds system capacity; in such an event, system pressure may decrease, resulting in customer service loss.

In a generally warmer climate, the gas sector could experience significant decreases in winter energy sales for heating. There could be up to a 33% decrease by 2050 and a 49% decrease by 2080. Similarly, under the RCP 8.5 scenario, winter gas peak load is projected to decrease by 144 MMdt in 2050, compared to the base case.

Adaptation Options for the Gas System

In addition to Con Edison's existing efforts, the Study team identified several additional adaptation options that the company could consider. Some measures proposed, such as remote information monitoring and analysis, address vulnerabilities in operations and planning processes. Most measures proposed address physical vulnerabilities (see Table 7), which fall within the "withstand" adaptation category.

In the short term, Con Edison could focus on expanding its monitoring capabilities, particularly through programs that use machine learning and remote monitoring to identify vulnerable areas of the distribution system, and remote drip pot monitoring sensors.

To account for changing temperatures, Con Edison could integrate climate change data on changes in the winter gas TV into gas volume and peak load forecasting so that the company is continuously planning for future changes in climate.

To address physical risks to existing infrastructure, Con Edison may need to invest in the system at strategic points in time, as described in Table 7.

Distribution system measures focus on minimizing the risk of flood water entering and depressurizing gas mains and pipes, and measures to more easily re-elevate pressure if water does enter the system.

Adaptation measures identified to address transmission system vulnerabilities primarily focus on diversifying the system and strengthening load management when capacity is constrained.

Table 7 ■ Physical adaptation options for gas commodities

Hazard	Asset	Adaptation Option	Implementation Timeframe	Signpost or Threshold
Extreme Hurricane (Category 4)	Transmission System	Procure additional compressed natural gas tank stations.	Designing for a future Category 4 hurricane	Increased frequency and severity of storms that could cut supply, including from science-based projections
	Gas Regulators	Install vent line protectors, extend vent lines and posts, seal all penetrations, and/or elevate key electric and communications equipment to protect vent lines.	2050	When sea level rise exceeds 1 foot, or if flooding is reported and the regulators do not have vent line protectors
	Distribution System	Continue targeted Main Replacement Program (planned completion by 2036) to harden gas mains against depressurization by water intrusion or other concerns.	~2030 (goal to complete program by 2036)	Increase in flooding events
Extreme Nor'easter	Transmission System	Construct additional gate stations.	Designing for a future worst-case nor'easter	More frequent or intense cold spells that drop temperatures below the design threshold for consecutive days and threaten supply
		Build larger and/or additional transmission mains.		
		Create ties between mains to diversify the transmission system.		
		Install remote operated valves to more efficiently isolate load for load management (temporarily disconnecting gas customers) during peak events.		

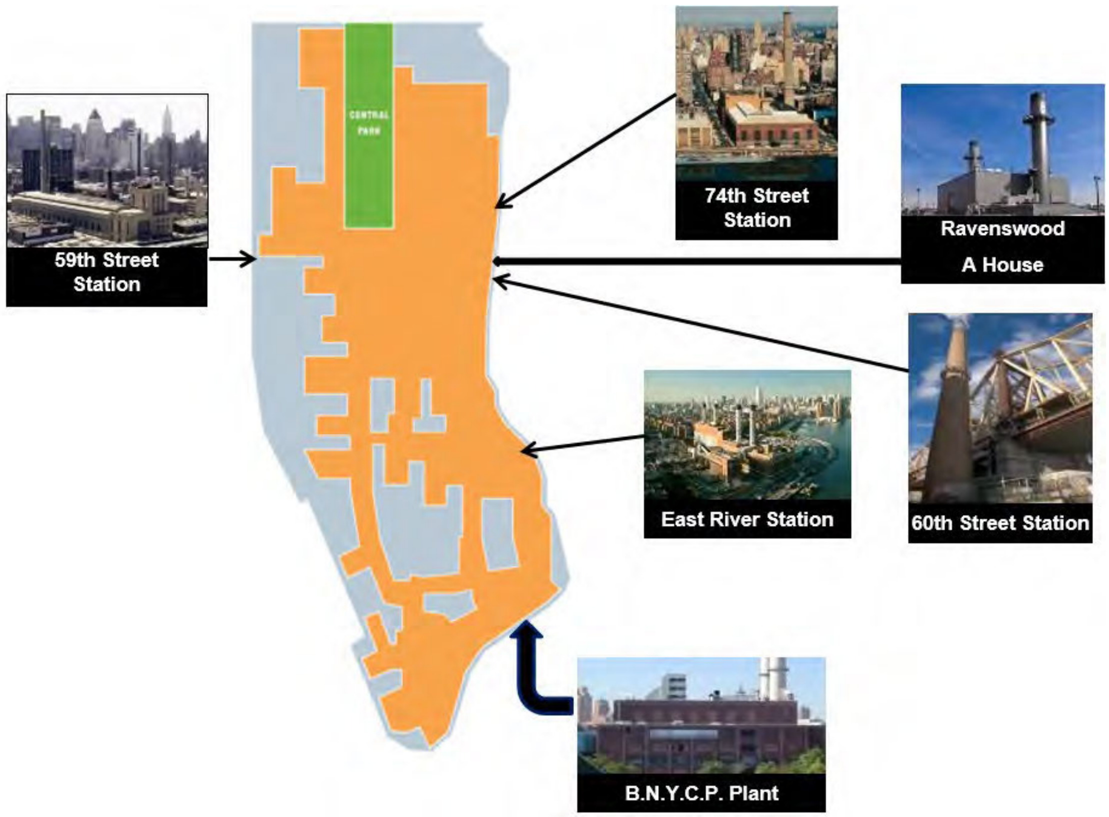
In addition, given the increasing potential for extreme events, Con Edison could consider distribution system resilience options such as exploring and implementing ways to elevate system pressure in low-flow conditions.

Steam System

Steam System Overview

Con Edison's steam system provides service to more than 3 million Manhattan residents (including approximately 1,720 metered customers) south of 96th Street. Total system capacity is about 11,676 thousand pounds per hour (Mlb/hr). The distribution system is comprised of a continuous network of pipes (steel main pipes and steel and brass service and condensate piping)—in aggregate, about 105 miles of piping. The pipes' physical location is directly correlated with the locations of generation sources and regional customer demand. Figure 21 shows the locations of several steam system assets.

Figure 21 ■ Key assets included in the Con Edison steam system



Steam Vulnerabilities

Like the gas system, much of Con Edison's steam system is underground, and steam is also a winter-peaking rather than a summer-peaking commodity. As such, steam generation and distribution assets are generally less prone to damage by shifts and extremes in temperature, humidity, and wind, and more vulnerable to flooding, which may be caused by increased precipitation, coastal inundation, snow melt, or storm surge in extreme events. Severe flooding impacts, such as broken distribution pipes and damaged steam generation stations, can take significant time to repair, further increasing the duration of customer impacts.

Increased frequency and intensity of precipitation events may increase the vulnerability of steam system manholes to "water hammer" events. When a high volume of water collects around a manhole, steam in the pipes underneath may cool and condense. Interaction between steam and the built-up condensate may cause a rupture in a steam pipe. One such water hammer event occurred in 2007 when a steam pipe at Lexington Avenue and 41st Street exploded during a period of heavy rainfall (Figure 22). Con Edison responded to that event by implementing a precautionary rain event threshold. If more than ¾ inch of rain is forecasted to fall within 3 hours, Con Edison will begin to proactively monitor and address flooding before it can cause a water hammer event. The key measure used to address flooding to prevent water hammer events is pumping water out of manholes and into the city sewer. In turn, Con Edison's capacity to manage flooding events that threaten steam generation and distribution assets depends on the capacity of the city's stormwater system to handle high volumes of water that Con Edison may need to pump away from assets under a changing climate.

Steam generation and distribution system assets are also vulnerable to projected increases in sea level and coastal inundation. Five out of six steam generating plants would be exposed to a 100-year storm if sea level rose by 3 feet. If water enters the steam generation system, it can degrade plant capacity or force unit or plant outages. Significant damage to steam generation systems would likely require long repair times, which could increase the duration of customer impacts. Hardening several of the generating stations to a higher level of protection would be difficult and costly. For example, at the East River Generating Station, raising mechanical equipment would require significant and costly alterations to the hydraulics of the steam system. Similarly, at East 13th Street, flood waters associated with a 100-year storm and 3 feet of sea level rise would reach the tertiary bushings on some 345-kV transformers, resulting in arcing and critical failure of the unit. The total estimated cost to harden the five steam generation plants against a 100-year storm and 3 feet of sea level rise is $30 million.

Figure 22 ■ 2007 steam pipe explosion

Con Edison has adopted storm hardening measures to protect the steam system in response to recent storms such as Superstorm Sandy. Those measures include developing location-specific plans and drills in preparation for storms, implementing physical hardening measures at steam generating stations, protecting critical equipment by waterproofing or relocating it, installing a new steam main to ensure that hospitals receive continued service, and introducing isolation valves in strategic locations to reduce the number of customers impacted by flooding in future extreme events. Because isolating steam lines is key to managing flooding impacts, Con Edison considers several potential flood sources (e.g., rainfall deluges, storm tides, water main breaks) when evaluating hardening options, and periodically reviews and updates both operational and physical risk mitigation strategies. The company is also investing in steam system resilience through measures such as waterproofing system components in the normal course of upgrades, prioritizing hardening steam mains by prior flooding issues (fewer than 10 of the original 86 locations identified are still vulnerable), and using remote monitoring to monitor manhole water level and steam trap operation (a system is currently under design and expected to be operational by 2021).

Extreme and multi-hazard events could also increase the vulnerability of the steam distribution system to salt damage and flood damage. During nor'easters and extreme ice storms, the City of New York and jurisdictions in Westchester County conduct widespread street-salting operations to mitigate ice build-up on roads and sidewalks. Rapid melt after nor'easters and extreme ice storms can lead to an influx of salt-saturated runoff into manholes, in turn causing equipment degradation and, in some cases, manhole fires or explosions.

In a generally warmer climate, the steam system could experience significant decreases in winter energy sales for heating. There could be up to a 33% decrease by 2050 and a 49% decrease by

2080. Similarly, under the RCP 8.5 scenario, winter gas peak load is projected to decrease by 891 Mlb/hr in the winter of 2050 compared to the base case.

Adaptation Options for the Steam System

To determine when to implement various adaptation strategies, Con Edison could track climate trends, including TV, precipitation, sea level rise and storm surge, and extreme events, as described in prior vulnerability and adaptation sections.

The Study team suggests that Con Edison could continue to work collaboratively with other city actors on initiatives that could help strengthen the resilience of the steam system. Specifically, the company could take measures, including the following:

- Strengthen collaboration with the city to improve citywide stormwater design to alleviate flooding impacts and make adaptation measures implemented by Con Edison, such as drain pumps at manholes, more effective.
- Discuss ways to minimize salt use during the winter.
- Incorporate considerations of New York City initiatives in coastal resiliency plans for lower Manhattan to re-evaluate Con Edison's storm response plans and stages of pre-emptive main shutoffs.

In addition to engaging in these monitoring and coordination efforts, the company could also consider taking measures to address physical vulnerabilities in existing infrastructure by strategically investing in the system. Physical measures developed by the Study team are listed in Table 8.

Table 8 ■ Physical adaptation options for steam commodities

Hazard	Asset	Adaptation Option	Implementation Timeframe	Signpost or Threshold
Extreme Hurricane (e.g., Category 4)	Generation System	Invest in additional storm hardening investment measures to protect generation sites against extreme hurricane-driven storm surge. Leverage new innovations and advancements in flood protection over time and raise moated walls around current generation sites.	2050	When sea level rise exceeds 1 foot
	Distribution System	Continue to segment the steam system to limit customer outages in flood-prone areas.	In preparation for a Category 4 hurricane	Increased frequency and severity of storms, including from science-based projections
	Distribution System	Expand programs to harden steam mains (waterproofing pipes and raising mains).	In preparation for a Category 4 hurricane	Increased frequency and severity of storms, including from science-based projections
		Pre-stage a greater number of drain pumps at critical or flood-prone manholes.		

As it is neither practical nor feasible for Con Edison to build resilience to the point that its steam system can fully withstand the impacts of extreme events, Con Edison could also consider implementing additional strategies to better absorb and recover from impacts, such as improving systems for crowd-sourcing steam system leak detection.

Moving Towards Implementation

Initial Climate Projection Design Pathway

Implementation of adaptation options to mitigate vulnerabilities requires clear climate design guidelines that incorporate forward-looking regional climate change projections. To this end, the Study team suggests that Con Edison could establish an "initial climate projection design pathway" that considers appropriate risk tolerance levels within the range of climate change projections. The initial climate projection design pathway is meant to guide preliminary planning and investments until and if Con Edison can refine the pathway to reflect new climate projections with reduced uncertainties, changes to Con Edison's operating environment, and changes in city guidance. The following section outlines an adaptive management approach that allows Con Edison to monitor, manage, and design to acceptable levels of climate risk through time.

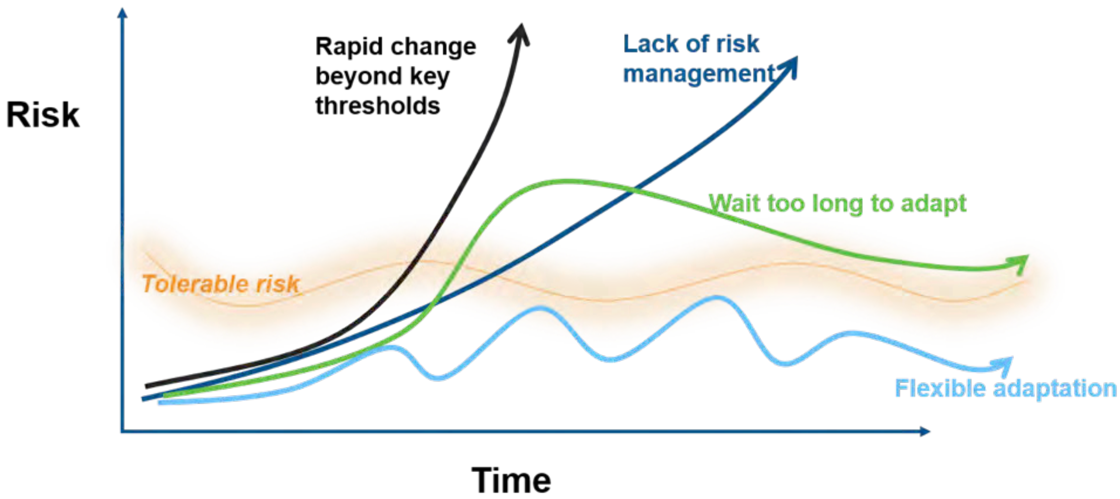
As an initial climate projection design pathway for decisions that require it, Con Edison will follow the conservative precedent set by the city's climate resiliency design standards (e.g., Mayor's Office of Recovery and Resiliency, 2019), combined with the state-of-the-art climate projections produced for this Study. Corresponding to city guidance, the same pathway may not apply uniformly across different climate change projections and hazards. More specifically, multiple climate projection design pathways may be required to address differences in the risk tolerance and projection uncertainty associated with different climate hazards. Under this framework, initial pathways could use the 50th percentile merged RCP 4.5 and 8.5 projections for sea level rise and high-end 90th percentile merged RCP 4.5 and 8.5 projections for heat and precipitation. Climate projection design pathways will be finalized for Con Edison's Climate Change Implementation Plan.

Alternative considerations are necessary to inform pathways for rare and difficult-to-model extreme events without probabilistic projections, such as 1-in-100-year heat waves and strong, multi-faceted hurricanes. Rather than prescribing statements of probability, these types of extremes require the blending of plausible worst-case scenarios from a climate perspective with stakeholder-driven worst-case scenarios from an impact perspective. Until climate modeling can better resolve and simulate these types of rare extreme events, the union of these two perspectives is critical for determining acceptable risk tolerance levels and setting initial pathways.

Flexible Adaptation Pathways Approach

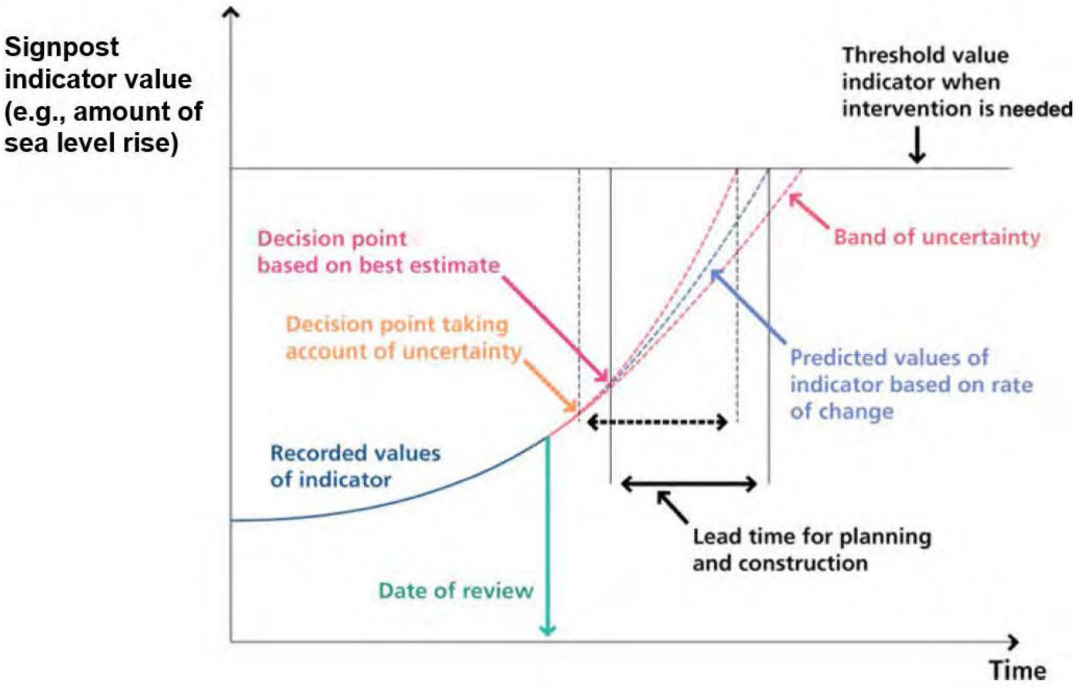
While the initial climate design pathway can inform asset design, a complementary approach is needed to ensure resilience over the lifetime of that asset. A flexible and adaptive approach will allow Con Edison to manage risks from climate change at acceptable levels, despite uncertainties about future conditions. The flexible adaptation pathways approach ensures continued adaptability over time as more information about climate change and external conditions is learned. Figure 23 depicts how flexible adaptation pathways are used to maintain tolerable levels of risk.

Figure 23 ■ Flexible adaptation pathways in the context of tolerable risk and risk management challenges to non-flexible adaptation. Adapted from Rosenzweig & Solecki, 2014.



Con Edison will need to consistently track changing conditions over time to identify when additional adaptation strategies are required. This approach relies on (1) monitoring indicators ("signposts") related to climate conditions, climate impacts, and external conditions that affect system resilience, and (2) pre-determined thresholds to signal the need for a change in risk management approaches ("transformation points"). This approach can support decisions on when, where, and how Con Edison can take action to continue to manage its climate risks at an acceptable level. Figure 24 depicts how a signpost indicator and a predefined threshold can be applied in the adaptation pathways approach to inform the timing of action given uncertainty.

Figure 24 ■ Schematic diagram of how an indicator of change for a particular signpost (e.g., amount of sea level rise) informs decision lead times that take into account uncertainty (Ranger et al., 2012).



Con Edison is already familiar with monitoring signposts to manage planning uncertainties and guide adjustments to its Electric, Gas, and Steam Long Range Plans.[20] Con Edison currently monitors signposts related to the pace of technology innovation (e.g., energy management technologies), the nature of regulation and legislation (e.g., new or revised greenhouse gas reduction policy targets), and the future of the economy (e.g., higher economic growth and impacts on demand), among others. In addition, the flexible adaptation pathways approach to manage climate change risks has been applied more widely by New York City and New York State (New York City Mayor's Office of Resiliency, 2019; Rosenzweig & Solecki, 2014) and utilities and infrastructure agencies across the United States, including San Diego Gas & Electric (Bruzgul et al., 2018; SDG&E, 2019) and Los Angeles Metro (Metro ECSD, 2019).

This flexible adaptation pathways approach allows Con Edison to develop an adaptation implementation plan in the near term, while adjusting adaptation strategies based on the actual climate conditions that emerge, thus reducing the cost of managing uncertainty. Under this adaptive approach, resilience measures can be sequenced over time to respond to changing conditions. For example, Con Edison may identify actions to implement now that protect against near-term climate changes and actions that are low and no regret, while leaving options open to protect against the wide range of plausible changes emerging later in the century. This implementation approach is preferred to implementing actions now that are optimized for present-day conditions or a single future outcome that ignores uncertainty.

[20] Long Range Plans are available at: https://www.coned.com/en/our-energy-future/our-energy-vision/long-range-plans

Illustrative Adaptation Pathway: Sea Level Rise Adaptation for Substation in FEMA + 3' Floodplain

Flexible adaptation pathways could be developed for guiding the management and protection of specific assets or types of assets. Here, we consider a hypothetical electric substation that is potentially vulnerable to sea level rise, as it is located within the FEMA + 3' floodplain (and, as such, is protected up to FEMA + 3' flood heights based on Con Edison's current design standards). This adaptation pathway is presented as *illustrative*; while it is grounded in the types of strategies that Con Edison would use for substation flood defense, a ready-to-implement pathway for implementation would require site-specific analysis and may differ from this configuration.

Figure 25 ■ Illustrative flexible adaptation pathway for a hypothetical Con Edison substation in a current FEMA + 3' floodplain

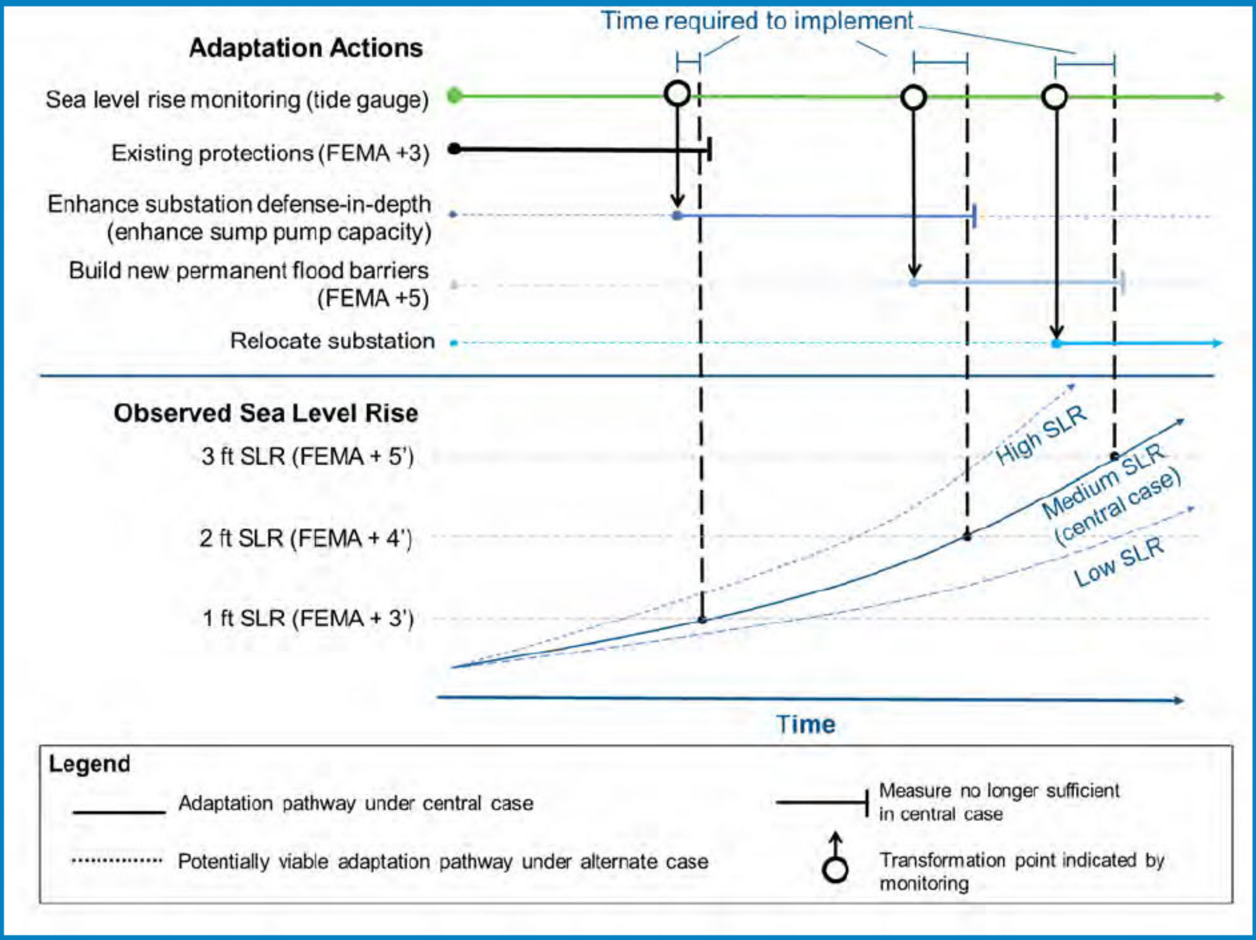


Figure 25 illustrates how the implementation of adaptation actions can be phased over time, with the implementation of new measures being triggered by observed sea level rise in excess of certain thresholds (transformation points). The timing of these transformation points is indicated by monitoring the rate of sea level rise at a local tide gauge (green line). Transformation points are set based on the point at which Con Edison needs to take action in order to implement a higher standard of protection before existing protections become insufficient.

In this adaptation pathway diagram, the implementation schedule of adaptation measures is illustrated based on a "central" sea level rise case. Measures based on this central scenario are illustrated with solid lines. If the actual pace of sea level rise deviates from the central case, monitoring of sea level rise may necessitate an accelerated or delayed implementation schedule

In this example, it is assumed that the substation already has existing protections to FEMA + 3' based on Con Edison's post-Superstorm Sandy hardening measures (black line). However, these protections will no longer be sufficient to provide the requisite 2 feet of freeboard under a 100-year flood scenario once sea level rise surpasses 1 foot.

- A trigger slightly under 1 foot leads to the first adaptation option, which is to supplement the substation's defense-in-depth strategy with additional sump pump capacity.
- The second adaptation option is triggered when sea level rise approaches 2 feet, and includes building new permanent flood barriers to a FEMA + 5' level.
- The final adaptation option, relocating the substation entirely, is triggered when sea level rise approaches 3 feet.

Each trigger is far enough in advance of the critical risk threshold (each foot of sea level rise, in this case) to have time for full implementation of the adaptation option.

Such a flexible adaptation pathway can allow Con Edison to better manage the costs of adaptation in the face of uncertainty, facilitating a prudent approach that avoids adapting too early or too late.

Signposts provide information that is critical for adaptive management decisions. Broad categories of signposts that Con Edison could consider monitoring include:

- **Climate variable observations and best available climate projections:** An awareness of recent and present climate conditions and their rates of change are key when determining potential asset exposure and risk. As described above, Con Edison currently operates a number of stations that monitor climate variables and is finalizing plans to expand the number of monitoring locations. Furthermore, access to the most recent and best available climate projections and expert knowledge is critical when updating plans for potential future scenarios as the science advances. In some cases, thresholds for action under climate variable and projection signposts may be determined by how quickly changes in climate conditions are approaching existing design or operational specifications.
- **Climate impacts:** Con Edison is already experiencing extreme weather and climate impacts to assets, operations and internal processes, and customers. Recognizing the risks, Con Edison is already conducting monitoring to identify areas of heightened vulnerability in its systems. Continued monitoring and evaluation of highest risk assets for impacts or near impacts can provide information about when and where additional adaptation options may be required.
- **Policy, societal, and economic conditions:** Evolving external conditions may affect climate-related decision making and areas of need throughout the service territory. Con Edison is already monitoring signposts for external conditions related to policies, society, and economies as part of its long-range plans. Additional external conditions may shift with a changing climate, such as adaptation strategies and investments led by the city.

The Study team identified a set of example signposts within each category, summarized in Table 9. Con Edison could consider coordinating with the city on NPCC's proposed New York City Climate Change Resilience Indicators and Monitoring System (Blake et al., 2019), where overlap and efficiencies in monitoring signposts may exist.

Table 9 ■ Example signposts for a flexible adaptation pathways approach

Category	Example Signposts
Climate variable observations and best available climate projections	• *Chronic variables:* Rate of change in TV, cooling degree-days, heating degree-days, sea levels, etc. relative to historical • *Extreme weather variables:* Number of days overheat index thresholds, storm surge levels, frequency of various storm types in the greater region, wind speeds, heat wave intensity and duration, intense precipitation levels, etc. • Updates to the best available climate projections: NPCC, IPCC, National Climate Assessment, etc.
Climate impacts	• *Assets:* Extent and magnitude of the costs of keystone asset damages (e.g., substations or power lines downed), damages incurred by events with different combinations of extreme weather, etc. • *Operations and internal processes:* Frequency of heat-related contingencies in the network and non-network systems, etc. • *Customers:* Number, spatial extent, and duration of outages caused by extreme weather, especially noting outages experienced by critical infrastructure and interdependent systems, etc.
Policy, societal, and economic conditions	• *Policy:* Updates to New York City design guidelines, etc. • *Societal:* Community-scale flood protection strategies led by New York City (e.g., East Side Coastal Resiliency Project), population shifts (e.g., retreat), etc. • *Economic:* Insurance prices and availability, etc.

Selecting Cost-Effective Solutions

As outlined in this Study, adapting to climate change will require investments in infrastructure and processes. Although some adaptation will be achieved through co-benefits from investments that Con Edison makes under existing processes, such as using distributed energy resources to meet growing electricity demand, other adaptation will require investments over and above those previously planned. The costs of those investments will ultimately be reflected in customers' bills. In order to minimize the financial impact of adapting to climate change, a cost-effective resilience planning process should identify a target level of resilience along with associated metrics, strike a balance between proactive and reactive spending, consider both the costs and benefits to customers, and select adaptation strategies that provide optimal benefit at the lowest cost.

As the energy industry grapples with how best to build resilience to the changing climate, the issue of how to quantify the resilience of energy systems is front and center. There is currently no standard *set of metrics* for the resilience of energy systems. A 2017 report from the National Academies of Sciences, Engineering, and Medicine found that "there are no generally agreed-upon resilience metrics [for the electricity sector] that are widely used today," also noting a contrast with the well-established set of electricity reliability metrics (NAS, 2017).

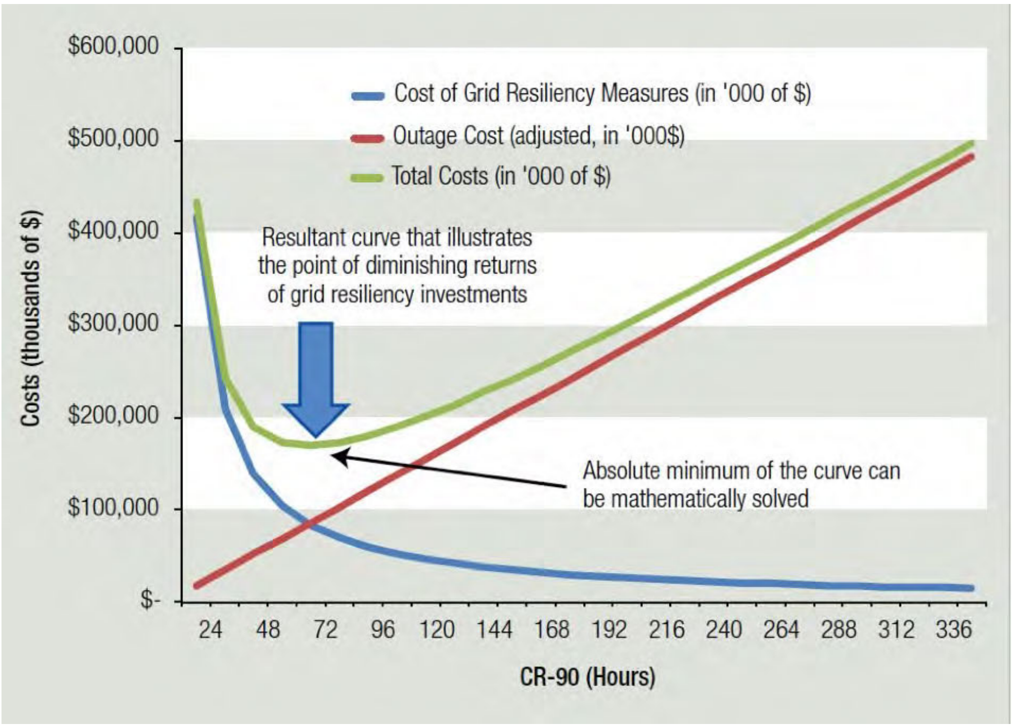
While there are a wide variety of energy resilience metrics that have been proposed or piloted in various contexts, most of these metrics fit within one of two broad categories. *Performance-based* metrics seek to quantify the resilience of the system through measurement of infrastructure performance during actual or modeled disruptive events. *Attribute-based* metrics, on the other hand, measure the presence of characteristics or features that are known or predicted to increase resilience performance in the event of a disruption. (Vugrin, Castillo, & Silva-Monroy, 2017).

Con Edison's storm hardening investments after Superstorm Sandy were guided by a combination of performance-based metrics, such as "past performance" in the selective undergrounding of feeders, and attribute-based metrics, such as "reducing the number of customers served by a single circuit to fewer than 500 customers," and adding "isolation devices to spurs and sub-spurs with open wire that are more than 2 spans in length" (Con Edison, 2013). Since the development of metrics is an active area of research and discussion, Con Edison could keep abreast of industry advances in resilience metrics for energy systems and incorporate those advances, where applicable, into its planning framework.

Even after a resilience metric(s) is selected, the question of exactly *how much* to spend on resilience or what the *right* level of resilience is, remains. One approach is to compare the societal cost of an outage against the cost of resiliency measures to shorten that outage. The total cost curve developed by ICF's Mihlmester and Kumaraswamy (Figure 26) is one example of such an approach (Mihlmester & Kumaraswamy, 2013). It shows for a hypothetical utility the post-outage time needed to restore service to 90% of customers, known in the industry as "CR-90." In this case, the lowest total costs, combining customer outage and grid-hardening costs, would be about $169 million for a 65-hour CR-90 restoration time. The graph also shows that getting the CR-90 time to less than a day would cost more than twice that amount.

For Con Edison, the "right" level of resiliency investment will be strongly linked to the climate projection design pathway selected for each of the climate stressors identified for resiliency planning.

Figure 26 ■ Total cost of resiliency (Mihlmester & Kumaraswamy, 2013)



Utilities have historically *reacted* to events, primarily because they lacked relevant climate projections and clear guidance or best practices for a methodology necessary to inform *proactive* adaptation and resiliency investments in infrastructure (California Energy Commission, 2018). Similarly, prior to conducting this study, Con Edison had limited information to guide proactive investments. The U.S. Department of Energy's North American Energy Resilience Model (U.S. DOE, 2019) highlights the need to "transition from the current reactive state-of-practice to a new energy planning and operations paradigm in which we proactively anticipate damage to energy system equipment, predict associated outages and lack of service, and recommend optimal mitigation strategies."

The Study team has described an overarching resilience management framework in Figure 12, designed to minimize the impacts of extreme events throughout asset life cycles. The framework considers how the system can withstand, absorb, recover, and adapt to risks posed by extreme events. To succeed, each measure of a resilient system requires *proactive planning and investments*.

Consideration of the *costs and benefits to customers* is a key component in the selection of adaptation options. Con Edison's capital budget cycle currently considers costs and benefits through an investment optimization and management process that compares the wide array of capital investments the company makes across its various business units. The process calculates a "strategic value" for each project to compare the benefit of investing in one capital project or program over another and to ensure that spend is in alignment with the company's corporate strategy. The strategic value is conveyed by a set of strategic drivers, each with relative weights, based on the company's long-term objectives. The strategic value of each capital project is assessed against that of other projects, and an optimized portfolio of capital projects is generated. While the strategic drivers include *reliability* and customer satisfaction components, the drivers do not include or consider the *resiliency* benefit of a project.

Con Edison developed and used a cost-benefit calculation model to prioritize storm hardening investments after Superstorm Sandy. The model estimated "the vulnerability of individual electric system assets based on the impact of electric system damage to customers and supporting critical infrastructure, the duration of an electric service outage, the likelihood of those assets being affected by either flooding or wind damage, and the reduction in vulnerability of those assets because of storm hardening initiatives." (Con Edison, 2014)

Con Edison's current distribution system planning process includes an evaluation of customer benefits resulting from investments. Con Edison's Distributed System Implementation Plan (DSIP) (Con Edison, 2016) includes the consideration of distributed energy resources as one option to meeting growing demand. As part of Con Edison's DSIP, the company has developed a Benefit Cost Analysis (BCA) Handbook that describes how to calculate individual benefits and costs. The BCA includes consideration of the unit cost of a particular option, per megawatt of delivery capacity, as well as an option's "social cost." Social cost accounts for the monetization of air pollution and carbon dioxide, using 20-year forecasts of marginal energy prices, the cost of complying with regulatory programs for constraining these pollutants, and the price paid for renewable energy credits. The social cost metric also qualitatively accounts for avoided water and land impacts. Beyond these environmental aspects, social cost accounts for net avoided restoration and outage costs to Con Edison, as well as net non-energy benefits (such as avoided service terminations, avoided uncollectable bills, and avoided noise and odor impacts).

This Study illustrates the use of multi-criteria analysis to compare criteria that may be difficult to quantify or monetize, or that may not be effectively highlighted in the financial analysis. This process identified additional complementary metrics that could be included in Con Edison's planning and budget prioritization process to account for uncertainty in climate outcomes. These metrics fall into two categories: co-benefits and adaptation benefits. Under a non-stationary climate, co-benefits (environmental, reputational, safety, and customer financial benefits) can help planners more comprehensively evaluate response options considering the additional challenges that climate change can pose on the system. In addition, consideration of adaptation benefits (flexibility, reversibility, robustness, proven technology, and customer's resilience) support long-term planning under climate uncertainty. These metrics allow for effective implementation of adaptation measures over time to achieve resilience. Con Edison's current processes include some of the metrics identified in the multi-criteria analysis (environmental and safety) but not others (customer's resilience and reversibility). Con Edison could work to incorporate this wider set of metrics as it incorporates resiliency planning into its broader capital budgeting process.

Key Issues to Be Addressed for Effective Implementation

Changes in the Policy/Regulatory and Operating Environment

Changes in the policy/regulatory and operating environment other than climate change were not accounted for in this Study but will be an important consideration when moving toward implementation. For example, the prioritization of adaptation strategies, and even the understanding of vulnerabilities, will need to consider these other drivers of change. Likewise, as Con Edison undertakes studies on how these factors will impact its business, climate change impacts could be factored into those studies. Some examples of possible changes in Con Edison's operating environment include:

- **Climate change and clean energy targets:** New York State and New York City have both adopted ambitious greenhouse gas emissions reduction targets (State of New York, 2019; City of New York, 2014), which will drive changes in the adoption of renewables, transportation electrification, energy storage, and so forth. It will also impact relative demand across the commodities (e.g., decreasing gas demand and increasing electricity demand).

- **Technological advances:** Advances in solar photovoltaics, energy storage, electric vehicles, and electrification of space heating are changing how and where electricity is generated and used.
- **Customer response to climate change impacts:** Customers will also have to respond to climate change impacts. This may include shifting away from flooded coastlines (depending on city-scale investments in coastal protection) and, with it, shifting demand away from portions of Con Edison's system.

Coordination with External Entities

Another critical need for effective implementation is coordination with external entities, including the City of New York and Westchester County, industry groups, equipment manufacturers, and others. Con Edison has limited authority to address certain vulnerabilities, such as the capacity of the city's stormwater system, so coordination is necessary for developing a more resilient system. In addition, coordination is needed to ensure that Con Edison is not over-investing in locations that the city plans to protect or retreat from. This project seeded the necessary relationships; however, the continuation of the interactions will need to be specified in the governance section of the upcoming implementation plan.

Establishing a Reporting and Governance Structure

Con Edison will need a continuing approach to updating stakeholders on climate risk management progress. Of the various reporting options, many companies are opting to follow the relatively new framework outlined by the Task Force on Climate-Related Financial Disclosures (TCFD).[21] This framework emphasizes the need to assess both the physical risks of climate change, which is covered in this study, as well as the risks and opportunities presented by transition to a low-carbon economy. It requires consideration of the financial implications of the risks and opportunities, as well as a measurable risk management plan that is integrated with a strong governance structure.

Two risks that were not explored in this study, but would fit well in the TCFD framework, include:

- **Costs and penalizations from service failure and outages:** Costs associated with an outage event include restoration; collateral damage; customer claims; penalties, fines, audits, remediation, and reporting; and the financial impact of lost confidence. For example, in 2007, Con Edison was penalized $18 million for its 2006 service disruptions, which included a 9-day blackout in western Queens.
- **Credit rating:** Increasingly frequent and intense extreme weather events could also impact credit rating risks and insurance liabilities. Credit rating agencies like Standard & Poor's and Moody's have added "resiliency" as a component of their rating criteria, indicating the relevance of climate risk for creditworthiness (Shafroth, 2016). Similarly, utilities may be increasingly choosing to retain a higher level of insurance to cope with more frequent and destructive weather-related events. However, a higher level of insurance protection leads to higher costs that may ultimately be reflected on customers' bills. Thus, while not as visible as physical asset or planning vulnerabilities, climate risks related to credit and insurance can have an impact on the utility.

Establishing a governance structure will be crucial for the successful continuation of Con Edison's climate change adaptation work. The governance structure can be used to encourage and track progress on the implementation of adaptation strategies (i.e., performance against set metrics and targets), ensure specific

[21] For more information on the Task Force on Climate-Related Financial Disclosures, see https://www.fsb-tcfd.org/

people are on point for monitoring and implementing various strategies, and establish a frequency and process for reporting on risks and adaptation actions from individual employees to senior managers to Con Edison's board of directors.

Next Steps

As a next step from this Study, Con Edison will develop a detailed Climate Change Implementation Plan to operationalize the suggestions from this Climate Change Vulnerability Study. The implementation plan will:

- Review the Study and investigate whether recent progress in climate science may warrant inclusion.
- Select climate change pathway(s) to incorporate into design standards and procedures.
- Establish life cycle tables that provide timeframes of reference climate variables through 2080.
- Aggregate input from subject matter experts on changes required for specifications/procedures and choices for risk mitigation measures.
- Develop a timeline and written plan for the implementation of risk mitigation measures.
- Identify the scope and cost within the 5-year capital plan and 10- and 20-year long-range plans.
- Establish signposts for the re-evaluation of measure installation schedules.
- Conduct periodic progress meetings for external stakeholders.
- Recommend a governance structure for climate change monitoring and updating.

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APPENDICES

Appendices

To inform the conclusions of this Study, the Study team undertook a series of in-depth vulnerability assessments corresponding to the climate hazards representing outsized risks to Con Edison: temperature, humidity, precipitation, sea level rise, and extreme events. These are included as appendices. Each appendix includes detailed historical and projected climate conditions; corresponding climate-driven vulnerabilities to operations, planning, and infrastructure across the company's electric, gas, and steam systems; and potential adaptation strategies to mitigate vulnerabilities.

For each hazard, the Study team collaborated with Con Edison subject matter experts to conduct a rapid screen of the sensitivity of operations, planning, and infrastructure to support a risk-first approach. Vulnerabilities were then selected for more detailed analyses, which focused on understanding asset vulnerabilities to climate change and, in turn, relevant adaptation options and evaluation of their costs and co-benefits. These analyses informed the development of flexible solutions and signposts to guide implementation of potential adaptation options through time.

Ultimately, the five appendices provide key context for the climate science, vulnerabilities, and adaptation strategies discussed in this report, and as such, can be referenced for more comprehensive information in each subject area.

- **Appendix 1 – Temperature:** Identifies how projected gradual trends in increasing temperature may affect operations, planning, and infrastructure across the electric, gas, and steam segments of Con Edison's business.
- **Appendix 2 – Humidity, Temperature Variable, and Load:** Addresses climate variables—humidity (expressed through wet bulb temperature), heat waves, cooling degree-days, heating degree-days, and the combination of projected changes in wet and dry bulb temperatures—that have a direct effect on system loads and reliability. These variables are also specifically addressed in specifications and procedures associated with upgrading system capacity and maintaining system reliability.
- **Appendix 3 – Changes in Precipitation Patterns:** Discusses the potential for climate-driven changes in rainfall and frozen precipitation in Con Edison's service territory, and the potential impacts of those changes on Con Edison's assets and operations.
- **Appendix 4 – Sea Level Rise and Changes in Coastal Storm Surge Potential:** Examines the ways in which changes in sea level may affect operations, planning, and infrastructure across the electric, gas, and steam segments of Con Edison's business.
- **Appendix 5 – Extreme Events:** Describes how extreme weather events (hurricanes, nor'easters, and heat waves), as well as concurrent or consecutive extreme events, may become more frequent and severe due to climate change, and considers their potential impact on operations, planning, and infrastructure across the electric, gas, and steam segments of Con Edison's business over the coming century.

RECLAMATION
Managing Water in the West

Continued Implementation of the 2008 Operating Agreement for the Rio Grande Project, New Mexico and Texas

Final Environmental Impact Statement

U.S. Department of the Interior
Bureau of Reclamation
Upper Colorado Region
Albuquerque Area Office, Albuquerque

September 30, 2016

MISSION STATEMENTS

Protecting America's Great Outdoors and Powering Our Future

The Department of the Interior protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Cover photo – Elephant Butte Dam, Powerplant and Reservoir, New Mexico, (Kevin Doyle, EMPSi)

Continued Implementation of the 2008 Operating Agreement for the Rio Grande Project, New Mexico and Texas, Final Environmental Impact Statement

Lead Agency:	Bureau of Reclamation, Upper Colorado Region
Responsible Official:	Brent Rhees, Regional Director
Cooperating Agencies:	Federal: U.S. Section, International Boundary and Water Commission State: Colorado Division of Water Resources Elephant Butte Irrigation District of New Mexico El Paso County Water Improvement District No.1 Texas Rio Grande Compact Commissioner
Abstract:	The proposed Federal action analyzed in this final environmental impact statement is to continue to implement the 2008 Operating Agreement for the Rio Grande Project and to implement long-term contracts for storage of San Juan-Chama Project water in Elephant Butte Reservoir. The Operating Agreement is a written agreement describing how Reclamation allocates, releases from storage, and delivers Rio Grande Project water to the Elephant Butte Irrigation District in New Mexico, the El Paso County Water Improvement District No. 1 in Texas, and to Mexico.
Release Date:	September 30, 2016
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Summary

The Bureau of Reclamation (Reclamation) has prepared this final environmental impact statement (FEIS) to analyze the environmental impacts of continuing to implement the Rio Grande Project Operating Agreement (OA) through 2050. The OA is a written agreement describing how Reclamation allocates, releases from storage, and delivers Rio Grande Project (RGP) water to diversion points (headings) of the Elephant Butte Irrigation District (EBID) in New Mexico, the El Paso County Water Improvement District No. 1 (EPCWID) in Texas, and the Republic of Mexico (herinafter Mexico). In addition, Reclamation will use this FEIS to evaluate the environmental effects of a proposal to renew a contract to store San Juan–Chama Project water in Elephant Butte Reservoir.

Purpose and Need for Action

Operating Agreement

The purpose for action is to meet contractual obligations to EBID and EPCWID and comply with applicable law governing water allocation, delivery, and accounting. These obligations are currently fulfilled under the 2008 OA (Appendix A). The need for action is to resolve the long and litigious history of the RGP and enter into mutually agreeable, operational criteria that comply with applicable law, court decrees, settlement agreements, and contracts. These include the 2008 Compromise and Settlement Agreement among Reclamation, EBID, and EPCWID and contracts between the U.S. and EBID and EPCWID.

San Juan–Chama Project Storage

The purpose and need for a similar action is to respond to a request to renew a multiyear storage contract of San Juan–Chama Project water in Elephant Butte Reservoir in accordance with Public Laws 97-140 and 87-483.

The Rio Grande Project and Geographic Scope

The study area for this FEIS is the RGP in southern New Mexico and far western Texas in the Rincon, Mesilla, and El Paso Valleys (Figure 1). The study area begins in the north with Elephant Butte Reservoir and extends southward and downstream along the Rio Grande to the El Paso-Hudspeth County line in Texas. The study area includes the service areas of the two irrigation districts and also includes deliveries to Mexico at the Acequia Madre at El Paso, Texas.

Cooperating Agencies

Reclamation is the lead Federal agency in the preparation of this FEIS. Cooperating agencies include the U.S. Section of the International Boundary and Water Commission (USIBWC), the Colorado Division of Water Resources, EBID, EPCWID, and the Texas Rio Grande Compact Commissioner.

Changes since the Draft EIS

Reclamation published a notice of availability of the draft EIS (DEIS) in the *Federal Register* (81 Fed. Reg. 14886) on March 18, 2016. Notice of the availability of the DEIS was published in newspapers, on Reclamation's internet web page, social media, and e-mail. Reclamation held two public hearings during the comment period to give the public an opportunity to learn more about the alternatives and impacts and to comment on the DEIS. After receiving multiple requests to extend the public comment period, the period was extended to June 8, 2016.

During this draft public comment period, Reclamation received 148 comments in 24 comment documents from Federal, state, and local agencies, and the public. Appendix E of this FEIS includes the comments received and responses. In assessing and considering these comments, Reclamation revised this FEIS. One of the comments pointed out an error in the hydrology model, so the FEIS includes some revised water resources data in Chapter 4 and Appendix C. Chapter 4 was reorganized by resource rather than by alternative to clarify the differences due to the alternatives versus climate change. Information for most resources was edited to better define and explain potential impacts, and cumulative actions and impacts were placed in a separate chapter. In response to comments, the No Action Alternative was changed from Alternative 1 to Alternative 5, as described below and in Chapter 2 and Appendix E. Alternative 1 has been selected as the agency's preferred alternative.

Alternatives

The Council on Environmental Quality's (CEQ) regulations for implementing the National Environmental Policy Act (NEPA) require that all EISs include the alternative of no action. CEQ (1981; 46 Fed. Reg. 18026) says there are two distinct interpretations of no action. The first interpretation is "no change from current management direction" and is typically applied to management plans. CEQ explains that this interpretiation of no action involves continuing with the present course of action or management until the action is changed. The second interpretation of no action is where a proposed activity would not take place and the resulting environmental effects from taking no action would be compared with the effects of permitting the proposed activity or an alternative activity to go forward. This is typically applied to construction actions.

Following CEQ's first interpretation of no action, the DEIS identfied Alternative 1 as the No Action Alternative because it involves continuation of the OA and San Juan-Chama storage contracts. The DEIS considered four other alternatives that vary in inclusion or exclusion of the allocation and accounting procedures established by the OA, the diversion ratio adjustment and carryover accounting , and storing San Juan-Chama Project water in Elephant Butte Reservoir. In the DEIS and this FEIS, Alternative 5 is consistent with past management practices prior to the OA, but based on comments received on the DEIS (see Appendix E, "Alternatives, No Action Alternative"), for this FEIS, Reclamation relabeled Alternative 5 as the No Action Alternative, applying CEQ's second interpretation of no action. The alternatives are summarized here and presented in detail in Chapter 2.

Alternative 1: Continuation of OA and San Juan-Chama Storage Contract, Preferred Alternative

Alternative 1 is Reclamation's preferred alternative. Alternative 1 includes continued implementation through the year 2050 of the operating procedures defined in the OA and corresponding Rio Grande Project Water Operations and Accounting Manual (Operations

Manual). Under Alternative 1, RGP allocation and accounting procedures would continue to include the diversion ratio adjustment and carryover accounting established by the OA and Reclamation would renew a contract to store up to 50,000 acre-feet of San Juan–Chama Project water in Elephant Butte Reservoir.

Alternative 2: No San Juan–Chama Project Storage

Alternative 2 is the same as Alternative 1 except that Reclamation would not store San Juan–Chama Project water in Elephant Butte Reservoir.

Alternative 3: No Carryover Provision

Alternative 3 is the same as Alternative 1 except that carryover accounting established by the OA would be excluded from RGP allocation and accounting procedures.

Alternative 4: No Diversion Ratio Adjustment

Alternative 4 is the same as Alternative 1 except that the diversion ratio adjustment established by the OA would be excluded from RGP allocation and accounting procedures.

Alternative 5: Prior Operating Practices, No Action Alternative

Alternative 5 (No Action) would eliminate both carryover accounting and the diversion ratio adjustment from RGP allocation and accounting procedures.

Selection of the Preferred Alternative

Based upon the analysis presented in this FEIS and after reviewing the comments and concerns of agencies, organizations and individuals (Appendix E), Reclamation's responsible official, the Regional Director of the Upper Colorado Region, selected Alternative 1 as the preferred alternative. At least 30 days after publishing a notice of availability of this FEIS, the Regional Director will sign a Record of Decision selecting an alternative and allowing implementation to proceed.

Major Conclusions

Based on the analysis of impacts of these alternatives in Chapters 4 and 5, major conclusions of the FEIS are as follows:

- **EBID's Annual Allocated Water**. Alternatives 1 and 2 would provide an average of 213,110 acre-feet under the central tendency climatic scenario. Alternative 3 would provide an average of 264,752 acre-feet; Alternative 4 would provide 272,269 acre-feet. Alternative 5 (No Action) would provide 314,327 acre-feet to EBID.
- **EPCWID's Annual Allocated Water**. Alternatives 1 and 2 would provide an average of 224,049 acre-feet under the central tendency climatic scenario. Alternative 3 would provide an average of 267,973 acre-feet; Alternative 4 would provide 207,296 acre-feet. Alternative 5 (No Action) would provide 239,317 acre-feet to EPCWID.
- **Total Storage**. Alternative 1 would provide an average of 483,445 acre-feet of total storage under the central tendency climatic scenario. Alternative 2 would provide an average of 455,233 acre-feet; Alternative 3 would provide 493,743 acre-feet; Alternative 4 would provide 465,907 acre-feet; and Alternative 5 (No Action) would provide 483,425 acre-feet.
- **Elephant Butte Reservoir Elevation**. Under the central tendency climate scenario, the average Elephant Butte Reservoir elevations would be 4,326 to 4,327 feet under all alternatives except that Alternative 2 would average 4,319 feet due to not storing San Juan-Chama Project water. As shown in Section 4.3, the differences in elevation would be greater

(10 to 12 feet) due to the projected effects of future climate change than due to implementation of the alternatives.

- **Special Status Species**. Reclamation concluded that implementation of Alterantive 1 “may affect, and is likely to adversely affect” the Southwestern willow flycatcher (*Empidonax traillii extimus*) and Western yellow-billed cuckoo (*Coccyzus americanus occidentalis*). A “may affect, and is likely to adversely modify**”** determination for flycatcher critical habitat and cuckoo proposed critical habitat is based on water resources modeling presented in Sections 4.13-4.14 that shows that reservoir filling would inundate this habitat. The U.S. Fish and Wildlife Service (Service) concurred with these findings in a biological opinion issued on May 25, 2016.
- **Regional Economic Impacts**. Under the central tendency climate scenario, the regional economic impacts in Doña Ana and Sierra Counties, New Mexico, where EBID is located, would decrease compared to Alternative 5 for all action alternatives. The regional economic impacts estimated for El Paso and Hudspeth Counties, Texas, where EPCWID is located, would increase for all action alternatives compared to Alternative 5. Changes (positive and negative) would be small compared to the entire regional economies of the New Mexico and Texas and there would be no high or disproportionate adverse impacts on environmental justice communities.

Environmental Commitments

The EIS process will end with completion of a Record of Decision (ROD). The ROD shall explain the agency’s decision and discuss plans for mitigating potential environmental effects and monitoring those commitments. Should Alternative 1 become the selected alternative, the following future commitments would be implemented.

- Under Alternative 1, Reclamation would continue to work with the USIBWC, EBID, and EPCWID to assess and determine the available supply, the release from storage, and delivery of RGP water.
- Under unforeseen or adverse conditions, Reclamation would continue to work with the USIBWC, EBID, and EPCWID under the parameters of the OA to resolve issues in an adaptive management framework.
- Reclamation has accepted the Service’s biological opinion dated May 25, 2016 and would continue to monitor vegetation and listed species in coordination with the USIBWC.

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Acronyms and Abbreviations

Acronym	Full Phrase
ABCWUA	Albuquerque Bernalillo County Water Utility Authority
AFY	acre-feet per year
CEQ	Council on Environmental Quality
CFR	Code of Federal Regulations
CFS	cubic feet per second
Convention of 1906	Convention between the United States and Mexico
CWA	Clean Water Act
DEIS	draft environmental impact statement
EA	environmental assessment
EBID	Elephant Butte Irrigation District
EIS	environmental impact statement
EPA	U.S. Environmental Protection Agency
EPCWID	El Paso County Water Improvement District Number 1
ESA	Endangered Species Act
ET_0	Evapotranspiration
FEIS	final environmental impact statement
Flycatcher	Southwestern willow flycatcher
Gwh	gigawatt-hour
HCCRD	Hudspeth County Conservation and Reclamation District No. 1
IMPLAN	IMpact analysis for PLANning
ITA	Indian trust assets
MF-OWHM	MODFLOW (modular finite-difference flow model); One Water Hydrologic Model
M&I	Municipal and industrial water
NEPA	National Environmental Policy Act
NHPA	National Historic Preservation Act
NMDA	New Mexico Department of Agriculture
NMDGF	New Mexico Department of Game and Fish
NMED	New Mexico Environment Department
NMEMNRD	New Mexico Energy, Minerals, and Natural Resources Department
NMOSE	New Mexico Office of the State Engineer
NMRPTC	New Mexico Rare Plant Technical Council
NMSP	New Mexico State Parks

Acronym	Full Phrase
OA	Operating Agreement for the Rio Grande Project
Reclamation	United States Department of the Interior, Bureau of Reclamation
RGP	Rio Grande Project, New Mexico and Texas
RMBHM	Rincon and Mesilla Basin Hydrologic Model
SEA	supplemental environmental assessment
Service	United States Department of the Interior, Fish and Wildlife Service
TCEQ	Texas Commission on Environmental Quality
U.S.	United States
URGIA	Upper Rio Grande Impact Assessment
URGSim	Upper Rio Grande Simulation Model
URGWOM	Upper Rio Grande Water Operations Model
USC	United States Code
USDA	United States Department of Agriculture
USGS	United States Geological Survey
USIBWC	United States Section of the International Boundary and Water Commission
VIC	Variable Infiltration Capacity Hydrology Model
WWCRA	West Wide Climate Risk Assessment

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1 Purpose of and Need for Action

1.1 Introduction

The Bureau of Reclamation (Reclamation) has prepared this FEIS to analyze the environmental effects of continuing to implement the OA for the RGP through the year 2050. The OA is a written agreement describing how Reclamation allocates, releases from storage, and delivers RGP water to two irrigation districts, the EBID and EPCWID, and to Mexico. In addition, Reclamation will use this FEIS to evaluate the environmental effects of a request to renew a multiyear contract for storing San Juan–Chama Project water in Elephant Butte Reservoir.

This FEIS has been prepared in compliance with NEPA, CEQ's NEPA implementing regulations (40 CFR 1500-1508), the U.S. Department of the Interior's NEPA regulations (43 CFR 46), and other relevant Federal and state laws, regulations, and policies.

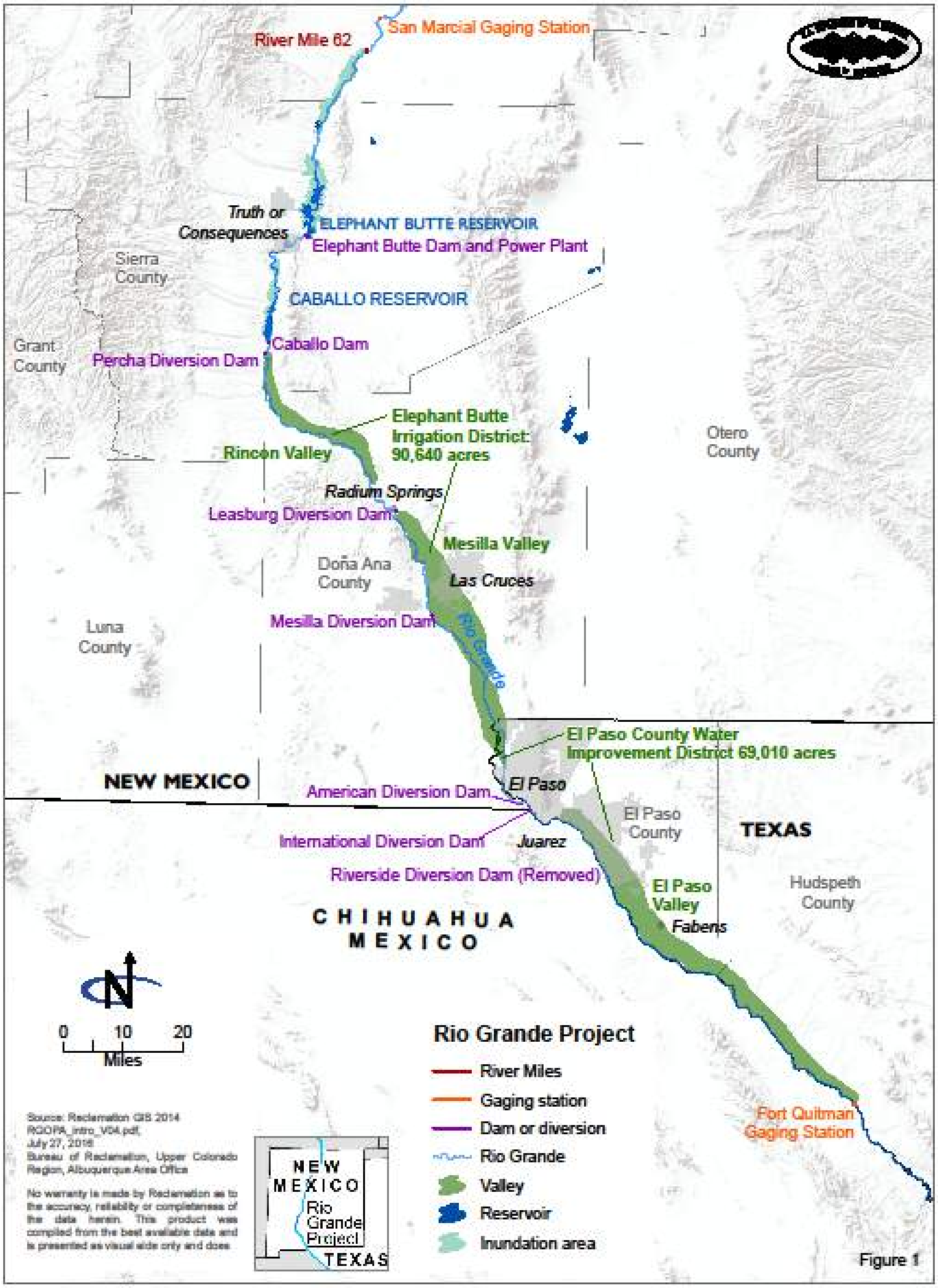
1.2 Rio Grande Project Operating Agreement

The OA is a written agreement describing how Reclamation allocates, releases from storage, and delivers RGP water to irrigation district diversion points (headings) of the EBID in New Mexico, EPCWID in Texas, and Mexico. The OA is Appendix A of this FEIS. It is described in Section 1.4.2.3 and in Chapter 2. The proposed action analyzed in this FEIS is continuing to implement the OA for the RGP for its remaining term, through 2050.

1.3 Rio Grande Project

The RGP is located in southern New Mexico and western Texas in the Rincon, Mesilla, and El Paso Valleys. Its facilities include the Elephant Butte and Caballo Dams and Reservoirs, a power generating plant, the Percha, Leasburg, Mesilla, American, and International Diversion Dams; 141 miles of canals, 462 miles of lateral ditches, and 457 miles of drains (Fig. 1). A sixth diversion dam, Riverside, was damaged by flood flows and was removed in 2003 to reduce flood hazards associated with further breaching.

Figure 1. Rio Grande Project in New Mexico and Texas.



Congress authorized the RGP under the authority of the Reclamation Act of 1902 and the Rio Grande Project Act of February 25, 1905, to serve lands in New Mexico and Texas. RGP water is made available to irrigate a variety of crops and for municipal and industrial (M&I) water uses. RGP water is also diverted to Mexico under the Convention between the United States and Mexico: Equitable Distribution of the Waters of the Rio Grande (Convention of 1906).

In 1907, Congress appropriated $1,000,000 to pay for the portion of the RGP necessary to provide storage of water for fulfillment of the Convention of 1906. As for funding the rest of the RGP, under the Reclamation Act of 1902, Congress intended that water projects would be self-supporting: each would generate sufficient revenue to cover the costs of construction, operation and maintenance, and the total estimated costs would be equitably borne by project beneficiaries. Therefore, EBID and EPCWID were required to enter into contracts with Reclamation under which they would cover these costs. The Reclamation Act of 1902 further states that the right to use RGP water "shall be appurtenant to the land irrigated and beneficial use shall be the basis, the measure, and the limit of the right" (32 Stat. 390; 43 USC Sections 372 and 383). The contracts among Reclamation, EBID and EPCWID establish the allocation of water between the two districts based on the irrigable acreage within each district.

A history of the RGP may be found in the *Rio Grande Project* (Autobee 1994) and Appendix C of Reclamation (2013a).

1.4 Background

1.4.1 Operations Overview

The RGP provides surface water for irrigation in southern New Mexico and for irrigation and M&I use in western Texas. It also provides for the delivery of surface water to Mexico under the Convention of 1906. The RGP also provides hydropower generation as a secondary function. Operation of the RGP involves four primary functions:

- Capture and storage of Rio Grande streamflow in Elephant Butte and Caballo Reservoirs
- Allocation of RGP water to EBID, EPCWID, and Mexico
- Release of RGP water to satisfy delivery orders from EBID, EPCWID, and the USIBWC on behalf of Mexico
- Diversion of RGP water from the Rio Grande and delivery of RGP water to headings and municipal water treatment facilities for beneficial use

The Rio Grande Compact contains a schedule for water that must be delivered to Elephant Butte Reservoir every year. In addition, Reclamation allows storage of San Juan–Chama Project water in Elephant Butte Reservoir currently under annual contracts with the Albuquerque-Bernalillo County Water Utility Authority (ABCWUA).

1.4.1.1 Surface Water Supply

At the beginning of the calendar year and prior to the onset of the irrigation season, Reclamation determines the total water in RGP storage. Total storage includes Rio Grande Compact deliveries, which are comprised of any accumulated inflows, less evaporative losses in Elephant Butte and Caballo Reservoirs. Reclamation then calculates the total usable RGP water by subtracting all non-RGP storage, including San Juan–Chama Project water and Rio Grande Compact credit water, from the total water in storage.

In years when the total usable RGP water at the beginning of the calendar year is not sufficient to provide a full allocation, Reclamation reevaluates RGP storage each month during the irrigation season until a final allocation is reached.

1.4.1.2 Allocation of Rio Grande Project Water

Reclamation allocates RGP water supplies such that the diversion allocations to EBID and EPCWID are proportionate to each district's respective acreages. EBID includes 90,640 acres authorized to receive RGP water in the Rincon and Mesilla Valleys of New Mexico. EPCWID includes 69,010 acres authorized to receive RGP water in the Mesilla and El Paso Valleys of Texas. Of the 159,650 acres, 57 percent of the acreage is in EBID and 43 percent is in EPCWID.

The annual diversion allocation is the quantity of RGP water that is allocated each year for delivery to EBID, EPCWID, and Mexico at their respective diversion headings. The annual diversion allocation is calculated based on the amount of RGP water in storage available for release and the estimated amount of water available for diversion at river headings accounting for canal bypass, drainage return flows, and other inflows or losses to the Rio Grande between Caballo Dam and International Dam.

In addition to their allocations of surface water from the RGP, irrigators within EBID and EPCWID have historically relied on groundwater pumping for supplemental irrigation. It is recognized that groundwater pumping in the Rincon and Mesilla Valleys depletes RGP surface water supplies by increasing seepage losses from the Rio Grande and decreasing groundwater discharge to the Rio Grande and to the network of drains that extends throughout the RGP. The magnitude of surface water depletions due to groundwater pumping is currently being studied. While groundwater is used for supplemental irrigation in both EBID and EPCWID, estimates of pumping for irrigation within EBID are an order of magnitude larger than corresponding estimates for EPCWID.

To determine how to provide each district with its annual diversion allocation, EBID and EPCWID do most of the water monitoring in the river and of water coming into the river from drains and other sources. These data are shared between parties and are used to schedule RGP orders, releases, and deliveries. Reclamation then executes the releases determined by the districts. Under the Convention of 1906, the U.S. is obligated to deliver 60,000 acre-feet of water annually in a full allocation year. In drought years when the full allocation is not available, the allocation to Mexico is reduced in the same proportion as water delivered to the districts.

1.4.1.3 Release and Diversion of Rio Grande Project Water

Reclamation delivers water to each district's diversion headings based on their water orders. Each district then distributes water through its conveyance system to its water users for irrigation or M&I use. The two districts use RGP water to irrigate a variety of crops, including lettuce, chilies, onions, cotton, sorghum, and pecans. Through contracts with EPCWID, El Paso Water[1] also receives RGP water. These contracts allow irrigation water to be converted to M&I uses. El Paso Water owns or leases farmland with first class water rights by which it is able to convert the associated irrigation water to M&I uses (Texas Water Development Board 2016).

Drainage and tailwater from RGP lands at the terminus of the RGP (the El Paso-Hudspeth County line) provides supplemental water to 18,000 acres in the Hudspeth County Conservation and

[1] El Paso Water is the new official name for what used to known as El Paso Water Utilities. See http://www.epwu.org/public_information/news_releases/nr_160630-01.html. They are a utility that delivers water to residents of the City of El Paso.

Reclamation District No. 1 (HCCRD) in Texas. Because HCCRD only receives seepage and drainage water through a contract with Reclamation by way of the EPCWID irrigation system and does not receive a direct allocation of RGP water, deliveries to HCCRD do not affect primary RGP operations.

The USIBWC carries out and schedules the deliveries at the request of Mexico. RGP water allocated to Mexico under the Convention of 1906 is officially delivered in the bed of the Rio Grande at the point adjacent to the head works of the Acequia Madre in Ciudad Juárez, about two miles downstream of the point where the river becomes the international border.

1.4.2 Historic Operations

1.4.2.1 Project Initiation to 1979-1980

From 1908 through 1979, Reclamation operated the RGP. Reclamation determined the annual allotment of RGP water per acre of authorized land and delivered the annual allotment to farm headgates and to the Acequia Madre for Mexico.

In 1937, Congress authorized the execution of amended repayment contracts with EBID and EPCWID. These contracts reduced the repayment obligations and established a corresponding right of use to a proportion of the annual water supply, based on an established irrigated acreage in each district: 57 percent to EBID and 43 percent to EPCWID, as explained in Section 1.4.1.2.

The districts' amended repayment contracts also required three changes to occur to historical operations. First, once the two districts paid the total reimbursable costs for the RGP, they were required to take over the day-to-day responsibility for operating and maintaining the irrigation delivery and drainage system. Second, once this transfer of operation and maintenance occurred, Reclamation and the two districts agreed to formalize a set of operating procedures that would govern the operations of transferred project works. Third, on transfer, Reclamation would no longer calculate, allocate, and deliver water to project land; instead, it would deliver an annual diversion allocation to each district's headings.

In 1979-1980, the two districts paid off their construction obligations to the U.S. In 1979, Reclamation contracted with EBID to assume responsibility for operating and maintaining the Percha, Leasburg, and Mesilla Diversion Dams in New Mexico. In 1980, Reclamation contracted with EPCWID to transfer operation and maintenance for the Riverside Diversion Dam (removed in 2003) and the distribution and downstream drainage system in Texas, which delivers tailwater to the HCCRD. Both contracts required Reclamation and the districts to create a mutually agreeable, "detailed operational plan…setting forth procedures for water delivery and accounting."

1.4.2.2 Operations from 1980 to 2007

Beginning in 1980, Reclamation determined annual diversion allocations to each district and delivered water to the authorized points of diversion. The districts were then responsible for conveying water from the point of diversion to individual farm gates. Until a mutually agreeable operations plan was in place, Reclamation imposed ad hoc operating procedures to govern operations. It modified these procedures as needed between 1980 and 2007. During that time, Reclamation calculated, allocated, and delivered each district's annual diversion allocation; however, it modified and optimized the methods, equations, and procedures according to real-time water conditions. The lack of an operations plan led to conflicts and litigation during this period.

1.4.2.3 Operations from 2008 to Present

In 2008, EBID, EPCWID, and Reclamation agreed to execute and implement the OA as a settlement of the litigation then pending and filed by both districts. The three parties are the signatories of the OA. The term of the resulting 2008 OA is from January 1, 2008, until December 31, 2050 (Appendix A).

As a part of the OA, the three parties prepared the RGP Water Accounting and Operations Manual (Reclamation 2012d) that contains more detailed information regarding the methods, equations, and procedures used to implement the OA. The Operations Manual is an addendum to the OA and is found in Appendix B. It is consistent with the OA and does not modify the provisions in the OA. The parties to OA consult with each other to review the Operations Manual. The most recent revision was in 2012.

1.4.2.3.1 The OA, Operations Manual, and Diversion Ratio

The OA largely reflects historical operation of the RGP, with two key changes. First, the OA provides carryover accounting for any unused portion of the annual diversion allocations to EBID and EPCWID. Under historical operations prior to the OA, the unused portion of a district's annual allocation balance contributed to the total amount of usable water available for allocation to both districts during the following year. As a result, a portion of one district's unused allocation became part of the other district's annual allocation the following year. Under the OA, any unused portion of the annual diversion allocations to EBID and EPCWID, based on a regression line reflecting past delivery performance, referred to as the D-2 Curve, is carried over to that district's allocation balance the following year. The carryover provision of the OA is designed to encourage water conservation in the RGP by allowing each district to retain its unused allocation up to a specified limit.

Second, the OA adjusts the annual allocations to EBID and EPCWID to account for changes in RGP performance[2], as characterized by the diversion ratio. The diversion ratio is calculated as the sum of net allocation charges (i.e., sum of allocation charges minus allocation credits) to EBID, EPCWID, and Mexico divided by the total (cumulative) Project release from Caballo Dam over a specified period. The diversion ratio provision of the OA was developed to adjust the annual RGP allocations to the districts so as to provide RGP deliveries to EPCWID consistent with historical operations, prior to substantial increases in groundwater pumping within EBID and corresponding decreases in RGP performance. The annual RGP allocation to EBID is then adjusted to reflect current-year RGP performance as represented by the diversion ratio. When the diversion ratio is high, greater than one (>1.0), EBID generally receives an increase in allocation compared to historical RGP operations. When the diversion ratio is low, less than one (<1.0), EBID generally receives a decrease in RGP allocation compared to historical RGP operations.

While numerous factors affect RGP performance, recent changes in performance are predominantly driven by the actions of individual landowners within the EBID service area. These changes are:

- Crop selection and related effects on crop irrigation requirement
- Irrigation practices and related effects on farm irrigation efficiency

[2] By "performance", we mean historical performance of the RGP. While this may not have been called "diversion ratio" in the past, historically Reclamation calculated the amount of water that was delivered to lands in relation to the amount that was released from storage to determine if there was enough water to increase the allocation to lands and Mexico.

- Widespread use of groundwater for supplemental irrigation, as permitted and regulated by the State of New Mexico

The diversion ratio provision of the OA ensures that annual allocations and deliveries to EPCWID are consistent with historical performance. Moreover, it ensures that deviations in performance relative to historical conditions would be accounted for by adjusting the annual allocation to EBID.

Under the diversion ratio provision, the annual project allocation to EPCWID is equal to the district's historical diversion allocation, based on a regression line reflecting past delivery performance, as defined by the D-2 Curve (Appendix A, Section 2.5). The annual allocation to EBID is adjusted to reflect current year (actual) project performance, as reflected by the project diversion ratio. Again, when the diversion ratio is high relative to the baseline delivery performance defined by the D-2 Curve, EBID generally receives an increase in annual allocation compared to its diversion allocation under prior operating practices. When the diversion ratio is low relative to the D-2 Curve baseline, EBID generally receives a decrease in project allocation compared to prior operating practices.

1.4.2.3.2 Principles Underlying the Operating Agreement

The provisions adopted in the OA for the RGP reflect Reclamation and the two districts' interest in equitable distribution of RGP water. These include Rio Grande surface waters and hydraulically connected groundwater in New Mexico and the portion of the Mesilla Valley in Texas. Implementing the OA fulfills contractual obligations among Reclamation and the two irrigation districts and resolves litigation in compliance with the legal settlement (Reclamation 2013a).

<u>Surface Water/Groundwater Interaction</u>

The interaction between the surface water and groundwater is a critical factor in understanding the OA. Previous studies (Conover 1954, Hanson et al. 2013, Haywood and Yager 2003, S.S. Papadopoulos & Associates, Inc. 2007 [henceforth SSPA 2007], Stringham et al. 2016) indicate a strong hydraulic connection between the Rio Grande and underlying groundwater aquifers in the areas served by the RGP, particularly in the Rincon and Mesilla Basins. Groundwater recharge via seepage and deep percolation of RGP water would continue under any alternative. In years when there is an increase in RGP allocation and delivery to EBID, there is a corresponding increase in recharge via seepage and deep percolation within EBID, as well as a decrease in demand for supplemental irrigation by groundwater pumping within EBID. Conversely, when there is a decrease in allocation, recharge and deep percolation decrease, demand for supplemental irrigation water increases, which may result in increased groundwater pumping within the district under permits issued by the State of New Mexico (Reclamation 2013a).

When groundwater elevations adjacent to the Rio Grande or a given drain segment are above the surface water elevation in the channel, the hydraulic gradient drives groundwater flows toward the channel (Fig. 2a). In this situation, groundwater discharge to the channel increases the available surface water supply. When groundwater elevations adjacent to the Rio Grande or a given drain segment are below the water elevation in the channel, the hydraulic gradient drives groundwater flow away from the river (Fig. 2b). In this situation, seepage from the channel into the underlying aquifer decreases the available surface water supply. In the event that groundwater elevations adjacent to a given channel segment fall substantially below the channel elevation, the channel may become hydraulically disconnected from the underlying aquifer (Fig. 2c). In this situation, seepage from the channel reaches a maximum rate and is no longer affected by fluctuations in groundwater elevation (Winter et al. 1998).

While numerous factors affect groundwater in the Rincon and Mesilla Valleys, groundwater pumping for supplemental irrigation is a primary driver of groundwater declines. In addition, irrigators within both the New Mexico and Texas portions of the RGP often supplement RGP surface water deliveries with groundwater from privately owned wells. Supplemental groundwater pumping is authorized and managed by the states, independently of the RGP and is currently the subject of litigation.

D-1 and D-2 Curves

The RGP serves irrigated lands in the Rincon, Mesilla and El Paso Valleys, as well as providing water to the City of El Paso for M&I uses. EBID provides water to 90,640 acres in the Rincon and Mesilla Valleys of New Mexico. EPCWID provides water to 69,010 acres in the Mesilla and El Paso Valleys of Texas (Fig. 1). Groundwater pumping in the El Paso Valley portion of EPCWID does not affect RGP deliveries (Reclamation 2015c). This is because the effects of pumping occur downstream of RGP diversion points for the El Paso Valley portion of EPCWID.

The OA represents mutually agreeable procedures for water delivery and accounting by Reclamation to satisfy objections by both districts in how deliveries were provided starting in 1980. The D-1 and D-2 Curves used by Reclamation to determine annual RGP allocations represent the effects of inflows and losses within the RGP on historical RGP performance.

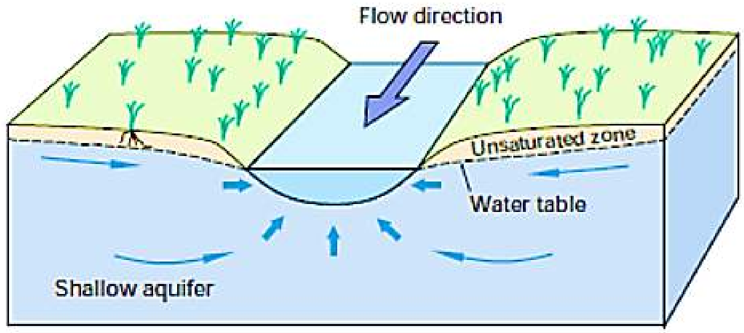
The D-1 and D-2 Curves were developed from operations data from 1951 to 1978. They reflect historical project performance during those years, including the effects of losses and inflows on project deliveries. The climatic and hydraulic conditions during these years ranged from low-flow drought conditions to high-flow full water supply. The D-1 Curve, used for making the allocation to Mexico, is a linear regression equation that represents the historical relationship between the total annual release from RGP storage and the total project delivery to lands within the U.S., plus delivery in the bed of the river at the point adjacent to the head works of the Acequia Madre. The D-2 Curve, used for making the water allocation to the districts, is a linear regression equation that represents the historical relationship between the total annual release from project storage and the total project delivery to canal headings on the Rio Grande. It includes delivery to all authorized points of diversion for EBID, EPCWID, and Mexico.

Adaptive Management

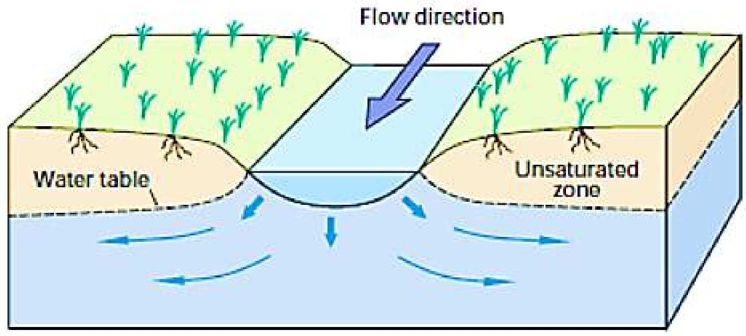
The OA and Operations Manual are intended to establish the overarching approach for management of the RGP, but it is recognized that they do not cover every possible contingency and may require adjustment. Under the principle of adaptive management (Holling 1978, Walters 1986), when unforeseen conditions or events occur in the future, the parties to the OA, consisting of Reclamation, EBID, and EPCWID, would consult and use their professional judgement and experience to adaptively manage the operations of the project.

Figure 2. Surface water and groundwater interaction; a gaining stream; b losing stream; c disconnected stream.

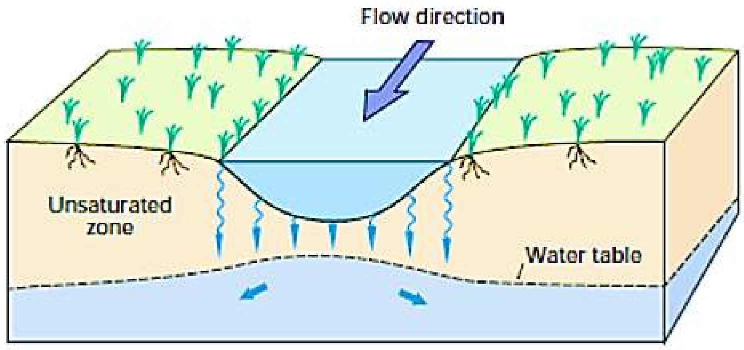
a. Gaining stream



b. Losing stream



c. Disconnected stream



Source: Winter et al. (1998).

1.4.3 San Juan-Chama Storage Contract

This FEIS evaluates the environmental effects of renewing multiyear contracts for storing San Juan–Chama Project water in Elephant Butte Reservoir, under the authority of Public Law 97-140 (95 Stat. 1718). The San Juan–Chama Project was authorized as a participating project of the Colorado River Storage Project Act in 1956. It consists of a system of diversion structures, trans-basin tunnels, and a storage reservoir to transfer water from the San Juan River in the Colorado River Basin to the Rio Chama in the Rio Grande Basin. San Juan–Chama Project repayment contractors receive their annual water allocations with no provisions for carryover; therefore, these contractors may benefit by storing unused annual allocations in Elephant Butte Reservoir for future use.

1.5 NEPA Analyses History

1.5.1 Operating Agreement

Two NEPA documents were prepared for the OA before this FEIS. In 2007, Reclamation prepared an environmental assessment (EA) to evaluate the effects of the OA through 2012. This EA committed Reclamation to gather data over the first five years of implementation to evaluate effects on the environment (Reclamation 2007).

In 2013, Reclamation supplemented the 2007 EA (SEA). This SEA was initially intended to analyze the potential impacts of implementing the OA through 2050. However, given the uncertainties of persisting drought and the need to improve analytical tools, Reclamation determined that analysis of a longer period would have been of limited use (Reclamation 2013a, b). In 2013, Reclamation began developing and refining modeling tools to thoroughly analyze the effects of implementing the OA through 2050, as documented in this FEIS.

1.5.2 San Juan–Chama Storage Contract

In 2010, Reclamation prepared an EA for a 40-year contract for storing ABCWUA's San Juan–Chama Project water in Elephant Butte Reservoir. The long-term contract was never implemented because information became available that rendered the associated Finding of No Significant Impact obsolete. Since 2010, Reclamation has been executing an annual contract with ABCWUA to store up to 50,000 acre-feet of San Juan–Chama Project water in Elephant Butte Reservoir, covered by categorical exclusions. Once stored, San Juan–Chama Project water is not included in the total RGP storage for purposes of allocations, but is maintained as a separate pool until exchanged upstream. The ABCWUA has proposed extending the contract to store San Juan-Chama Project water in Elephant Butte Reservoir through 2050.

1.6 Proposed Action

Reclamation is proposing to continue implementing the 2008 OA for the RGP for its remaining term, through 2050. In addition, it is proposing a similar action (as defined at 40 CFR 1508.25(a)(3)) of implementing long-term contracts for storing San Juan–Chama Project water in Elephant Butte Reservoir. The proposed action and alternatives are described in Chapter 2.

1.7 Purpose and Need for Action

1.7.1 Operating Agreement

The purpose for action is to meet contractual obligations to EBID and EPCWID and comply with applicable law governing RGP water allocation, delivery, and accounting. The purpose is also to provide a method to mitigate for the effects on the RGP of groundwater interaction in the Rincon and Mesilla Valleys. The need for action is to resolve the long and litigious history of the RGP by having mutually agreeable, detailed operational criteria.

1.7.2 San Juan–Chama Project Storage

The purpose and need for a similar action is to respond to a request to renew a multiyear storage contract of San Juan–Chama Project water in Elephant Butte Reservoir in accordance with the Act of December 29, 1981, Public Law 97-140. A similar action is defined by CEQ's regulations (40 CFR 1508.25(a)(3)) as actions that, when viewed with a proposal, have similarities such as common timing or geography that provide a basis for evaluation together. The analysis of a long-term contract for storing San Juan–Chama Project water in Elephant Butte Reservoir is a potentially similar action sharing common timing and geography with the OA. It is considered along with the proposed action of continuing to implement the 2008 OA.

1.8 Compliance with Other Authorities

In addition to meeting the requirements of NEPA, this FEIS documents compliance with other environmental laws and policies such as:

- Endangered Species Act (ESA)
- National Historic Preservation Act (NHPA)
- Executive Order 12898, Federal Actions to Address Environmental Justice in Minority Populations
- Executive Order 13007, Indian Sacred Sites
- Executive Order 13112, Invasive Species
- Executive Order 13175, Tribal Consultation

1.9 Public Scoping

Public scoping began with publication of a notice of intent to prepare an EIS in the *Federal Register* (79 FR 2691) on January 15, 2014. The public was notified of the start of the NEPA review and scoping by:

- Placing newspaper advertisements in the *Santa Fe New Mexican* on January 27 and 28, 2014, the *Albuquerque Journal* on January 26, 2014, the *Las Cruces Sun News* on January 26, 2014, and the *El Paso Times* on January 26, 2014
- Announcing the public scoping meetings via Reclamation's social media sites and the project website (http://www.usbr.gov/uc/albuq/rm/RGP/)

Scoping meetings were held on both weekday and weekend dates and during both daytime and evening. Reclamation held three public scoping meetings at each of the following locations:

- Thursday, January 30, 2014, 3:00 p.m. to 5:00 p.m.—Reclamation, Albuquerque Area Office, 555 Broadway NE, Suite 100, Albuquerque, New Mexico
- Friday, January 31, 2014, 6:00 p.m. to 8:00 p.m.—Elephant Butte Irrigation District, 530 South Melendres Street, Las Cruces, New Mexico
- Saturday, February 1, 2014, 9:00 a.m. to 11:00 a.m.—Reclamation, El Paso Field Division, 10737 Gateway West, Suite 350, El Paso, Texas

Reclamation staff conducted the meetings, prepared the handouts, and answered questions. Persons attending the Albuquerque and Las Cruces meetings were primarily representatives of government agencies, but only Reclamation staff attended the meeting in El Paso. (Therefore, a hearing on the DEIS was not held in El Paso.)

Two comment letters were received during the scoping process, one from the New Mexico Interstate Stream Commission and the other from the City of Las Cruces. More information on the scoping process, including comments received, may be found in the NEPA Scoping Summary Report (Reclamation 2014c), which is also available on the project website (http://www.usbr.gov/uc/albuq/rm/RGP/). Reclamation took these comments into consideration in preparing this FEIS. In addition, comments received on the DEIS were considered in finalizing the FEIS.

1.10 Key Issues

Key issues or resources relevant to the analysis were identified based on the SEA (Reclamation 2013a), public comments and concerns raised during scoping, from internal scoping, and outreach to Federal, state, and local agencies and tribal governments; and legal, regulatory or policy requirements. The following issues or resources are analyzed in detail in this FEIS.

- Water Resources: total storage, Elephant Butte Reservoir elevations, allocation, releases, net diversion, farm surface water deliveries, farm groundwater deliveries, groundwater elevations, water quality
- Biological Resources: vegetation communities including wetlands, wildlife, aquatic species, and special status species and critical habitat
- Cultural Resources: historic properties, Indian sacred sites, and resources of tribal concern
- Socioeconomic Resources: Indian trust assets, recreation, hydropower, regional economic impacts and economic benefits, and environmental justice.

2 Alternatives

This chapter describes five alternatives analyzed in detail in this FEIS. This chapter also explains the criteria for selecting the preferred alternative and discusses alternatives that were considered, but not analyzed in detail.

2.1 Alternatives Development Process

Formulation of alternatives began in the fall of 2014 and continued through early 2015. Reclamation received suggestions for alternatives during scoping and these were considered during the alternatives development process. Additional alternatives were proposed during the public comment period for the FEIS in 2016.

A key step in the alternatives development process was a workshop held on November 4, 2014, at Reclamation's office in El Paso, Texas. Reclamation staff, contractors, and representatives of the cooperating agencies at that time: EBID, EPCWID, USIBWC, the City of Santa Fe, and the Rio Grande Compact Commission's Texas Commissioner—participated in the workshop in person or remotely. Workshop participants reviewed and discussed the purpose and need statement to assess where there was discretion for considering alternatives to current practices. The workshop included facilitated discussions of the alternatives. It also clarified the difference between annual implementation of the Operations Manual and the overall water supply allocation process described in the OA.

Reclamation reviewed the output of the screening exercise and outlined the elements of the alternatives to be carried forward for further review. Reclamation determined that the carryover provision and the diversion ratio adjustment were the basis of the settlement agreement and represented variables or elements for creating a reasonable range of alternatives. Reclamation also determined that due to similar geography and timing, the environmental effects of storing San Juan–Chama Project water in Elephant Butte Reservoir should be analyzed in the EIS.

2.2 Description of Alternatives

The alternatives were derived from the methods, equations, and procedures that Reclamation, EBID, and EPCWID use in determining the annual diversion allocation and water accounting for the RGP. As shown in Table 2-1, the alternatives vary in inclusion of the diversion ratio adjustment, carryover accounting, and the San Juan-Chama storage contract.

2.2.1 Operational Elements Common to All Alternatives

Some elements of project operations are common to all alternatives and would not vary. Reclamation would continue to store, allocate, release, and deliver RGP water for authorized uses in the U.S. and for delivery to Mexico under all alternatives. Reclamation would continue to determine annual allocations based on the usable water in RGP storage available for release during the current year. This includes usable water in storage at the start of the year. Added to this is any usable water that becomes available during the year as inflow to RGP storage or as relinquishment of Rio Grande Compact credit waters.

Under all alternatives, annual diversion allocations to EBID, EPCWID, and Mexico would continue to be based on two linear regression relationships between RGP releases and RGP deliveries, referred to as the D-1 and D-2 Curves, as described in Section 1.4.2.3.2 of Chapter 1. Reclamation and the USIBWC developed the D-1 Curve in 1980 to calculate the annual allocation to Mexico when less than a full supply is available. In accordance with the Convention of 1906, the annual RGP allocation to Mexico is 60,000 acre feet per year (AFY), except in years of extraordinary drought or serious accident to the U.S. irrigation system. The water for Mexico is officially delivered in the bed of the Rio Grande at the point adjacent to the head works of the Acequia Madre, in cooperation with the USIBWC.

The D-2 Curve represents the total (gross) amount of water available for diversion from the Rio Grande by EBID, EPCWID, and Mexico during the year under historical RGP performance conditions. The amount of water available for diversion in the U.S. by EBID and EPCWID would be determined by subtracting the annual allocation to Mexico from the total volume of water available for diversion during the year, as calculated by the D-2 Curve. EBID would then be allocated 88/155$^{\text{ths}}$ (57 percent) of the volume of water available for diversion and EPCWID would be allocated 67/155$^{\text{ths}}$ (43 percent).

The annual diversion allocations to EBID, EPCWID, and Mexico would continue to be based on the D-1 and D-2 Curves. RGP releases would continue to be scheduled and managed to meet delivery orders submitted by EBID, EPCWID, and USIBWC on behalf of Mexico.

2.2.2 Alternatives

Five alternatives are carried through detailed analysis in this FEIS. Table 0-1 highlights the differences among alternatives.

Alternative 1—Continuation of OA and San Juan-Chama Storage Contract, Preferred Alternative

- Continue to implement the diversion ratio adjustment provision of the OA in computing annual diversion allocations
- Continue to implement the carryover accounting provisions of the OA, which allows carryover of unused allotment balance from one year to the next
- Continue to store up to 50,000 acre-feet of San Juan–Chama Project water in Elephant Butte Reservoir

Alternative 1 is the continued implementation through 2050 of the operating procedures defined in the OA and Operations Manual, as amended for any given year. Under these operating procedures, the carryover accounting and diversion ratio provisions would continue. Reclamation would continue to implement a contract through 2050 with the ABCWUA to store up to 50,000 acre-feet of San Juan–Chama Project water in Elephant Butte Reservoir. Details of data, inputs, and calculations used in the allocation procedure are described in Table 4 of the OA (Appendix A). Additional details on allocation calculations are provided in the Operations Manual (Appendix B).

Under the OA, representatives of EBID, EPCWID, and Reclamation consult to establish the monthly and final water allocations for the year for each district and Mexico and review the Operations Manual. The manual was last updated in 2012 to clarify calculations used in the allocation procedure and to optimize operations (Reclamation 2012e).

Alternative 2—No San Juan–Chama Project Storage

- Continue to implement the diversion ratio adjustment provision of the OA in computing annual diversion allocations
- Continue to implement the carryover accounting provisions of the OA, which allows carryover of unused allotment balance from one year to the next
- Do not store any San Juan–Chama Project water in Elephant Butte Reservoir

Alternative 2 is the same as Alternative 1, except Reclamation would not continue with contracts to store San Juan–Chama Project water in Elephant Butte Reservoir. Alternative 2 allows Reclamation to model and determine the effects of storing San Juan-Chama Project water in the RGP.

Alternative 3—No Carryover Provision

- Continue to implement the diversion ratio adjustment provision of the OA in computing annual diversion allocations
- Do not implement the carryover accounting provisions of the OA
- Eliminate the carryover allocations and relinquish the unused allotment balance at the end of each calendar year
- Continue to store up to 50,000 acre-feet of San Juan–Chama Project water in Elephant Butte Reservoir

Alternative 3 is the same as Alternative 1, except Reclamation would not implement the carryover accounting provisions of the OA. Alternative 3 allows Reclamation to model and determine the effects of the carryover provision.

Alternative 4—No Diversion Ratio Adjustment

- Do not implement the diversion ratio adjustment provision of the OA
- Compute annual diversion allocations based only on the D-1 and D-2 regression equations without adjusting for variations in RGP performance
- Continue to implement the carryover accounting provisions of the OA, which allows carryover of unused allotment balance from one year to the next
- Continue to store up to 50,000 acre-feet of San Juan–Chama Project water in Elephant Butte Reservoir

Alternative 4 is the same as Alternative 1, except Reclamation would not implement the diversion ratio adjustment provision of the OA. Alternative 4 allows Reclamation to model and determine the effects of the diversion ratio adjustment provision.

Alternative 5—Prior Operating Practices, No Action Alternative

- Do not implement the diversion ratio adjustment provision of the OA
- Compute annual diversion allocations based only on D-1 and D-2 Curves regression equations that reflect historical conditions
- Do not implement the carryover accounting provisions of the OA
- Eliminate the provision for carryover allocations for each district
- Continue to store up to 50,000 acre-feet of San Juan–Chama Project water in Elephant Butte Reservoir

For this FEIS, Alternative 5 is the No Action Alternative. It allows a comparison through 2050 of operations under the OA and a simulation of procedures prior to the OA which did not apply the carryover allocation accounting for each district and diversion ratio adjustment provisions in the calculation of the allocation to EBID. Alternative 5 is the best possible representation of prior operating practices in a modeling context and is based on strict application of the D-1 and D-2 Curves.

Table 2-1 Key elements of alternatives

Alternative	Continue Diversion Ratio Adjustment	Continue Carryover Accounting	Continue Storage of San Juan–Chama Project Water
1	●	●	●
2	●	●	
3	●		●
4		●	●
5			●

Because they are not part of the OA, the alternatives do not include the following:

- Changes to the dams, storage facilities, the power generating plant, diversion facilities, and delivery points
- Negate obligations under the Convention of 1906 and the Rio Grande Compact or compliance with various court decrees, settlement agreements, and contracts
- Construction of new facilities or other actions that are physically different from or that exceed the bounds of historic operations within the RGP
- Changes to the basic operation of the dams and other RGP facilities
- Changes to the channel capacity

The alternatives analyzed in this FEIS vary in including or excluding the carryover provision, diversion ratio adjustment, and the San Juan-Chama storage contract. The range of alternatives is designed to determine whether these elements would result in environmental impacts when simulated using a hydrology model described in Section 4.1 of Chapter 4.

Continuing to implement the OA is part of the settlement of litigation between Reclamation and the two districts. Since 1979 and 1980, Reclamation, EBID, and EPCWID have had contractual obligations resulting from the transfer of the irrigation and drainage facilities from Reclamation to each district to agree on a detailed operational plan, setting forth procedures for allocation, delivery, and accounting of RGP water. This need was finally satisfied in 2008 when the three parties entered into the 2008 settlement agreement, which required implementing the OA and the Operations Manual (Reclamation 2014c). Alternative 1 represents the operational procedures in place since 2008 and an existing agreement among Reclamation and the districts to continue implementing the OA through 2050. Alternative 5 represents the No Action Alternative.

2.2.2.1 Carryover Provision

The carryover provision of the OA provides for carryover accounting for the unused allocation balances remaining on EBID's and EPCWID's respective RGP water accounts at the end of each year. If either district does not use all of its total diversion allocation during a given year, for purposes of modeling for this FEIS, the corresponding quantity of water that would have been released from RGP storage to satisfy the unused portion of the district's allocation instead would remain in storage at the end of the year.

Each district may accrue and maintain carryover balance for any period of years up to 60 percent of its respective full annual allocation under the OA. EBID, therefore, may accrue carryover balance up to a limit of 305,918 acre-feet and EPCWID may accrue carryover balance up to 232,915 acre-feet. In the event that either district accrues carryover balance in excess of their respective limit, the excess balance would be transferred to the other district's RGP water account.

The carryover provision of the OA does not affect the procedure used to determine the annual RGP allocation to Mexico. In accordance with the Convention of 1906, the allocation to Mexico would be 60,000 AFY, except in years of extraordinary drought or serious accident to the U.S. irrigation system. During extraordinary droughts, the annual allocation to Mexico would be determined based on the total release from storage and annual delivery to lands within EBID and EPCWID, plus total deliveries to the heading of the Acequia Madre, as calculated using the D-1 Curve. (See Section 1.4.2.3.2.)

2.2.2.2 Diversion Ratio Adjustment

As described in Section 1.4.2.3, the diversion ratio represents the amount of diversion allocation that is used per unit release of RGP water from Caballo Dam. It is a measure of RGP performance in meeting delivery obligations to EBID, EPCWID, and Mexico. The OA provides the method for determining the initial annual diversion allocations to EBID and EPCWID. It also includes the methods for adjusting these allocations based on RGP performance, as measured by the diversion ratio, which is affected by groundwater levels, and return flows to the Rio Grande.

As described in Section 1.4.2.3.1, Reclamation uses the diversion ratio to adjust allocations to EBID and EPCWID to account for changes in RGP performance. This is done to account for the effects of groundwater and surface water conjunctive use by irrigators in the Rincon and Mesilla Basins, on current year RGP performance. The diversion ratio adjustment ensures that the annual RGP allocation to EPCWID is consistent with historical RGP performance, as characterized by the D-2 Curve. It also ensures that deviations in RGP performance are accounted for by adjusting the annual RGP allocation to EBID.

Calculating annual allocations to EBID and EPCWID under the OA involves additional adjustments under some conditions. A positive adjustment (increase) is applied to both districts' allocations when the usable water available for current-year allocation is greater than 600,000 acre-feet and current (actual) RGP performance exceeds the historical D-2 baseline. A negative adjustment (decrease) is applied to both districts' allocations during extreme droughts. These are defined as consecutive years where RGP releases are below 400,000 AFY.

The OA implemented a minor modification to the application of the D-2 Curve. The 763,842 acre-feet for a full allocation release was increased to 790,000 AFY as specified as the normal release in the Rio Grande Compact.

2.2.2.3 San Juan–Chama Storage

Alternatives 1, 3, 4, and 5 include storing San Juan–Chama Project water in Elephant Butte Reservoir. The ABCWUA is seeking to renew a multiyear contract for storage of up to 50,000 acre-feet of San Juan–Chama Project water in Elephant Butte Reservoir through 2050.

2.3 Alternatives Eliminated from Detailed Study

This section discusses alternatives that were considered but eliminated from detailed study and explains the reasons for their elimination.

2.3.1 Removing Credits and Charges and Using Actual Deliveries of Water in Accounting

The New Mexico Interstate Stream Commission submitted an alternative during scoping and again during the DEIS comment period requesting analysis of an alternative to remove credits and charges in water accounting for the RGP. Allocation charges reflect the volume of surface water diverted from the Rio Grande; allocation credits reflect the volume of water bypassed or returned to the Rio Grande and available for diversion at a downstream diversion point. In general, allocation charges are computed as the greater of the volume of water ordered for diversion at a specified diversion point and the volume of water actually diverted; alternatively, allocation credits are computed as the lesser of the volume of water ordered or bypassed at specified bypass points and the actual volume of water bypassed or returned to the Rio Grande. Depending on the allocation charges and credits on corresponding RGP water orders promotes efficient operation of the RGP by creating an incentive to divert all water ordered or available. This was not carried forward for several reasons. First, because it would remove the incentives for efficient operations which would increase water use throughout the project area and reduce the amount of allocation for EBID due to a reduction to the diversion ratio. Second, charges are a method of tracking allocation use. If charges were removed, then there would be no way to track the allocation used by each district. This would be contrary to contracts among Reclamation and the two districts. Largely because of the second reason, i.e., being contrary to contracts, it means this alternative would not meet the purpose and need for action.

2.3.2 Change the Rio Grande Compact Accounting Point to San Marcial

During scoping, a request was made to change the Rio Grande Compact accounting point back to San Marcial. This alternative was not carried forward because it does not meet the purpose of and need for the proposed action. Specifically, changing the Compact accounting point is beyond Reclamation’s authority. Such a change would require a resolution of the Rio Grande Compact Commission, such as the change that was made in 1948 which changed the accounting point from San Marcial Station to storage in Elephant Butte Reservoir.

2.3.2 Add Point of Diversion for La Mancha Wetlands

During the comment period, the Southwest Environmental Center request a new diversion point on the river to divert surface water to the La Mancha wetlands. This alternative was not carried forward because it does not meet the purpose of and need for action. It is also beyond Reclamation's authority to grant this request. New diversions on the river would require coordination with the USIBWC, EBID, and others.

2.3.3 Change Carryover Accounting to Reflect Actual Conservation

Reclamation considered a suggestion to analyze changing carryover accounting to reflect conservation. Conservation is not how carryover is determined. Accumulation of carryover in each district’s account is not only dependent on conservation, but it is a summation of the water allotted at the point of diversion against the water diverted and charged against their account.

2.3.4 Changes in Drought Factor and Evaporation Calculations

Reclamation considered alternative elements to address how evaporation losses are calculated and potentially adjusting the drought factor. These elements were not carried forward as part of the final alternatives because they are potential adjustments that could be made by revising the Operations Manual.

2.3.5 Climate Change and Compact Modeling and Analysis Assumptions

Reclamation received requests for new alternatives to account for changes in RGP efficiency caused by climate change and alternatives looking at Rio Grande Compact credit water accounting. These requests are not true alternatives, but are modeling and analysis assumptions or parameters contributing to the effects analysis in Chapters 4 and 5.

2.3.6 Impairment from Groundwater Pumping

A proposal was submitted to consider taking action if impairment from groundwater pumping depletes the RGP water supply. Actions which Reclamation may take outside the OA are outside the scope of the proposed action and are too speculative to attempt to analyze in this FEIS.

2.3.7 Mimic Natural Hydrograph

During the public comment period on the DEIS, two comments were made requesting new alternatives of modifying releases to mimic the natural flow regime, with higher water released in spring and lower water released in summer and fall to benefit native plants and wildlife. The alternative to release water for such purposes is beyond Reclamation’s authority and does not meet the purpose and need for action for this FEIS.

2.3.8 Mitigation Measure to Revegetate

A request was made during the public comment period on the DEIS to add a mitigation measure of planting cottonwoods and willows in the reservoir pool following reservoir drawdowns. Reclamation considered this request, but given the cycles of filling and drawdown of the reservoirs, there would be natural regeneration occurring and such proposed revegetation would not be required. However, Reclamation has committed to monitor vegetation changes and meet with the Service to assess the habitat (cottonwoods, willows, and tamarisk) available for the Southwestern willow flycatcher and the Yellow-billed cuckoo. Revegetation would be considered in the future as needed to comply with the ESA.

2.3.9 San Juan–Chama Storage Alternative Contract Options

During scoping, Reclamation considered various alternatives for differing amounts or durations of storage of San Juan–Chama Project water in Elephant Butte Reservoir. While working on the DEIS, the ABCWUA requested renewal of a long-term contract for storing up to 50,000 acre-feet. Analysis under Alternative 2 allows comparison of the effects of this proposed San Juan–Chama Project storage.

During the public comment period on the DEIS, Reclamation received several comments suggesting expansion of the geographic scope of analysis to analyze the effect of future exchanges of San Juan-Chama Project water upstream. The modelling approach used to evaluate the San Juan-Chama Project storage provides a reasonable analysis of environmental effects within the scope of this FEIS. Any environmental effects related to San Juan-Chama Project water above Elephant Butte Reservoir or exchanges are out-of-scope for this FEIS. Any environmental effects related to San Juan-Chama water flowing downstream or exchanges upstream are out-of-scope for this FEIS, but will be analyzed when such actions are ripe for analysis. This FEIS analyzes the effects of storage of San Juan-Chama water and the resulting higher water elevations in Elephant Butte Reservoir as a result of ABCWUA’s proposed contract.

2.3.10 Store Project Water in Higher Elevation Reservoirs Upstream

An environmental organization requested evaluation of an alternative of storing water in upstream reservoirs that have lower evaporation rates and could offer benefits to riparian and riverine habitats. The Rio Grande Compact (Article IV) requires New Mexico to deliver water to Elephant Butte Reservoir. The Compact contemplates storage of water in upstream reservoirs and actually requires such storage of water in upstream reservoirs to the extent of any accumulated debit in Compact deliveries, consistent with the physical limitations of such reservoirs. Article VII, however, generally prohibits increases in storage in upstream reservoirs constructed after 1929 when there is less than 400,000 acre feet of water stored in Elephant Butte Reservoir. Upstream storage does not meet the purpose and need for action and this would require a Compact amendment. Therefore, this is not analyzed in this FEIS.

2.4 Comparison of Alternatives and Selection of Preferred Alternative

Table 2-1 illustrates the differences among alternatives. The preferred alternative is Alternative 1. It incorporates carryover accounting, the diversion ratio provision, and the storage of San Juan-Chama water in Elephant Butte Reservoir. The preferred alternative is the alternative Reclamation believes would fulfill its statutory mission and responsibilities, considering environmental, technical, economic, and other factors described in Chapters 4 and 5, and best meets the purpose and need for action. See Chapters 4 and 5 for comparisons of effects of the alternatives.

3 Affected Environment

This chapter describes the water resources, biological, cultural, and socioeconomic resources that would be affected by implementation of the alternatives presented in Chapter 2 or whose review is required by law, regulation, or policy.

3.1 Resources Considered

Resources or resource topics analyzed and not analyzed in this FEIS are presented in Table 3-1. The resources considered but not analyzed may not be present in the study area or they may not be relevant to the scope of the Federal action. In other cases, any potential to affect the resource may be negligible or speculative. This determination is based on scoping, input from cooperating agencies, prior NEPA review (Section 1.5), and the experience of interdisciplinary team members.

Table 3-1 Resources and issues analyzed in the FEIS

Resource	Relevance	Agency Determination
Aesthetics	Not included	This resource issue is not relevant to the scope of the action.
Agriculture, Farmlands	Included	Socioeconomic analysis includes economic benefits and impacts related to agriculture, but Farmland Protection Policy Act compliance is not required because of the assumption of a constant cropping pattern and no change in farm numbers or acreage. Contract freeze RGP acreage at 159,650 acres. Furthermore, RGP delivers water to the headings and not individual farms.
Air quality	Not included	There would be no effects to air quality related to the alternatives and no compliance with the Federal Clean Air Act is required.
Biological resources	Included	Aquatic species, vegetation and wetlands, and wildlife and special status species, and invasive species are relevant to the scope of the action and are included in the FEIS.
Climate change	Included	The alternatives would not affect climate change, but climate change would affect other resources and is included in the water resources modelling presented in Chapter 4.
Cultural resources	Included	Historic properties, Indian sacred sites, and resources of tribal concern are relevant to the scope of the action.
Environ-mental justice	Included	This is relevant to the scope of the Federal action based on the presence of minority and low-income communities in the study area per Executive Order 12898.
Geology, soils, paleontology	Not included	There would be no effects on geology and soils related to the alternatives. Although paleontological resources have been found within Elephant Butte Reservoir, there is negligible potential to affect paleontological resources based on the scope of the action.
Indian trust assets	Included	There are no Indian trust assets in the project area; however, Secretarial Order 3335 and Reclamation policy require description of this resource.

Noise	Not included	There are no effects on noise related to the action.
Hydro-power, Energy	Included	CEQ regulations at 40 CFR 1502.16 require consideration of energy requirements of alternatives. Hydropower is relevant due to generation at the Elephant Butte Powerplant.
Recreation	Included	Relevant due to public recreational opportunities provided by RGP reservoirs, state parks, and the river.
Socio-economics	Included	Relevant to the scope of the Federal action due to potential economic benefits and regional economic indicators.
Solid and hazardous waste	Not included	There would be no generation of solid or hazardous wastes related to the action.
Traffic	Not included	There would be no effects on traffic or transportation related to the action.
Water resources	Included	Surface water and groundwater are relevant to the scope of the action.
Water quality	Included	Water quality is relevant to the scope of the action.

3.2 Geographic Scope

Geographic areas of analysis vary by resource or resource issue. For all resources, the geographic area of analysis begins with Elephant Butte Reservoir in the north and extends downstream along the Rio Grande to the El Paso-Hudspeth County line. Reservoirs located upstream of Elephant Butte Reservoir are operated independently of the RGP and any environmental effects related to operations of these reservoirs or the effects of San Juan-Chama water flowing downstream to Elephant Butte Reservoir have either been analyzed in prior NEPA reviews or would be analyzed in the future depending on the alternative selected and when such actions would be ripe for analysis.

The El Paso-Hudspeth County line forms the southern boundary for the analysis because it marks the downstream end of RGP facilities and effects of the alternatives are not measurable beyond this line.

Implementation of the alternatives would not involve constructing new facilities or other actions that are physically different from or that exceed the bounds of historical operations of the RGP. The alternatives would not change the structure of the storage or diversion dams nor change obligations under the Convention of 1906, the Rio Grande Compact, or compliance with various court decrees, settlement agreements, and contracts.

3.2.1 Rio Grande Project

As shown in Fig. 1, the RGP is located in southern New Mexico and western Texas. The constructed features of the RGP are the Elephant Butte and Caballo Dams and Reservoirs, six diversion dams, 139 miles of canals, 457 miles of laterals, 465 miles of drains, and a hydroelectric powerplant. Reclamation and multiple entities own and operate the facilities and distribution infrastructure of the RGP.

As described in Section 1.4.1.2, Reclamation allocates RGP water proportionate to the districts' respective acreages. EBID includes 90,640 acres authorized to receive RGP water in the Rincon and Mesilla Valleys of New Mexico. EPCWID includes 69,010 acres authorized to receive RGP water in the Mesilla and El Paso Valleys of Texas. RGP water allocated to Mexico under the

Convention of 1906 is delivered in the bed of the Rio Grande at the point adjacent to the head works of the Acequia Madre in Cuidad Juárez, Mexico.

The HCCRD, below the RGP boundary in Texas, uses excess flows from the RGP. Under a Warren Act contract between HCCRD and Reclamation, HCCRD has used drainage and wastewater from the RGP since 1925. The contract extends only to the return water; it does not obligate the RGP or Reclamation to deliver specific amounts of water.

3.3 Water Resources

This section summarizes existing water resources, including surface water, groundwater, and water quality. The study area includes Elephant Butte and Caballo Reservoirs, the Rio Grande between the reservoirs, and the Rio Grande below Caballo Reservoir to diversion points to EBID and EPCWID lands, and Mexico.

3.3.1 Regulatory Framework

The legal and regulatory framework governing surface water in the study area is complex. Important authorities and agreements are:

- Reclamation Act of 1902 and the Rio Grande Project Act of 1905
- 1906 Convention between the U.S. and Mexico.
- Rio Grande Compact of 1939
- Public Law 97-140, 95 Stat. 1717, Section 5(c) (authority for storage of San Juan-Chama water in Elephant Butte Reservoir)
- Public Law 102-575, Title XXXIII—Elephant Butte Irrigation District, New Mexico, Section 3301 Transfer (authority for transfer to the two districts title to easements, ditches, laterals, canals, drains, and other rights-of-way)
- Court Order No. CIV-90-95-HB/WWD of 1996 (Court order to keep Caballo Reservoir storage level below 50,000 acre-feet from October 1 to January 21 annually under most conditions)

3.3.2 Data Sources

Water resources data were compiled primarily from Reclamation sources (e.g. Reclamation 2013a; Appendix F).

3.3.3 Elephant Butte and Caballo Reservoirs Storage

Reclamation stores RGP water in Elephant Butte and Caballo Reservoirs. Elephant Butte Reservoir has a capacity of 2,024,586 acre-feet, all of which is conservation storage for later release for authorized project purposes (Reclamation 2008b). Caballo Reservoir has a total capacity of 324,934 acre-feet, which includes 224,934 acre-feet of conservation storage and 100,000 acre-feet of flood control space (Reclamation 2008b). Total conservation storage within the RGP is 2,249,520 acre-feet.

In a typical year, storage in Elephant Butte Reservoir increases in the spring due to snowmelt and decreases during the irrigation season (generally March to October), although its contents can swing dramatically due to variations in runoff from summer monsoons. Storage in Caballo Reservoir generally increases from January through March, decreases from March through April, increases from May through June, decreases from June through October, and increases from October through December (Reclamation 2013a).

3.3.4 Releases and Rio Grande below Caballo Dam

The study area for releases from the dams includes the Rio Grande below Elephant Butte Dam and the Rio Grande below Caballo Dam to the El Paso-Hudspeth County line in Texas. This marks the geographic end of the RGP facilities.

EBID, EPCWID, and USIBWC on behalf of Mexico, place orders with Reclamation for releases from storage to meet their delivery requirements at authorized points of diversion. Orders are placed daily during the irrigation season. If the districts cannot agree on the volume or timing of releases, Reclamation makes the final determination. Reclamation releases water from RGP storage for diversion by Mexico. Reclamation determines the amount and schedule of release for Mexico to meet the delivery schedule set by Mexico at its point of delivery.

Historically, the Rio Grande between the reservoirs and below Caballo Dam dries during the non-irrigation season when no surface water is released. Portions may remain wet due to rain and snowfall, groundwater, or municipal discharges. The annual flow below Caballo Dam was constant from 1960 to 2013 with the exception of a few wet and dry periods. The most significant dry period occurred during the mid-1960s, while the two wettest periods occurred during the mid-1980s and mid-1990s. In a typical year, flow below Caballo Dam is low in January, gradually increases until March, decreases during April and May, peaks in July, and decreases until December.

3.4 Groundwater

In addition to the background information in Chapter 1, this section summarizes existing conditions for groundwater in the Rincon Valley of New Mexico, the Mesilla Valley of New Mexico and Texas, and the El Paso Valley of Texas. The Mesilla Valley extends from Radium Springs, New Mexico, to the El Paso Narrows in El Paso, Texas, near the New Mexico-Texas-Mexico border. El Paso Valley is the low-lying area containing the Rio Grande channel, from south of the El Paso Narrows to near Fabens, Texas.

3.4.1 Regulatory Framework

Groundwater in New Mexico is regulated by the New Mexico Office of the State Engineer (NMOSE). In 1980, NMOSE recognized the Lower Rio Grande Underground Basin and imposed a permit system on well drilling. Before this declaration, there were no restrictions on well drilling in this area. The volume of groundwater that may be pumped under pre-basin groundwater rights[3] is currently being determined through a basin adjudication process by the State of New Mexico.

Groundwater within Texas is managed and regulated by local or regional groundwater conservation districts, if present.[4] The portion of the study area in Texas is governed by the rule of capture and a landowner needs no authorization or permit to pump.

[3] That is, under water rights established by groundwater use prior to the basin being declared.
[4] No Texas groundwater conservation districts currently exist in the RGP study area (Texas Water Development Board 2016).

3.4.2 Data Sources

Groundwater information was reviewed from Conover (1954), Frenzel (1992), Frenzel and Kaehler (1992), Reclamation (2013a, 2015c), and Stringham et al. (2016). Groundwater data also came from the following sources:

- Groundwater elevation data by the USGS using records extracted for individual groundwater measurement sites from a geo-database compendium (Burley 2010).
- Groundwater recharge data estimated by assessing deep percolation of irrigation water, channel seepage from the Rio Grande and RGP conveyance facilities, and mountain-front and slope-front recharge from surrounding areas. Values have been extracted from the final model input files for the NMOSE and collaborators' groundwater model of the Rincon and Mesilla Basins (SSPA 2007).
- Groundwater pumping for irrigation in the Rincon and Mesilla Basins has been estimated based on the Lower Rio Grande Groundwater Flow Model. While metering of groundwater pumping has occurred since the 1980s and has been required since 2009, comprehensive metering records of groundwater pumping for irrigation in the Rincon and Mesilla Basins are unavailable.

3.4.3 Existing Groundwater Conditions

As described in Chapter 1, adapting to and managing for the impact on the RGP supply caused by groundwater pumping by irrigators in the RGP service area was a purpose of the OA.

3.4.3.1 Aquifers

As described in Section 1.4.2.3.2, the shallow unconfined aquifer systems in the Rincon and Mesilla Valleys are hydraulically connected to the Rio Grande; therefore, groundwater pumping from these aquifers in New Mexico and Texas has the potential to affect RGP supply and deliveries. The unconfined aquifer system in the El Paso Valley is also hydraulically connected to the Rio Grande. However, most of the RGP diversions and return flows occur upstream of the portion of this aquifer system that is affected by groundwater pumping and are not substantially affected by fluctuations in groundwater conditions in the El Paso Valley (Reclamation 2013a; Appendix F).

3.4.3.2 Groundwater Recharge and Demand

Groundwater use and recharge are currently affected by factors including drought, increasing demands, and changing farm irrigation efficiencies (Stringham et al. 2016). In the Lower Rio Grande Underground Water Basin (NMOSE 2015), including the Rincon and Mesilla Valleys of New Mexico, groundwater use has recently been estimated to range from 50,000 to 100,000 AFY in years of full RGP surface water supply and from 200,000 to 300,000 AFY in years of low RGP supply. Groundwater use for supplemental irrigation depends on irrigated acreage, crop distribution, and weather conditions during the growing season in addition to RGP supply (Barroll 2005, Reclamation 2013a). Average seasonal groundwater pumping is greater from March through October than from November to February, which reflects the use of the groundwater for supplemental irrigation. Pumping has varied over time with the volume in years of extremely heavy pumping up to six times that of years with the lowest pumping. Accurate estimates of historical and current groundwater pumping for supplemental irrigation of RGP lands in the Texas portion of the Mesilla Valley and in the El Paso Valley of Texas are not available at this time. Water quality considerations and other factors limit the groundwater use on RGP lands in the El Paso Valley of Texas, which overlies the Hueco Bolson groundwater aquifer.

In general, an increase in RGP allocation and surface water diversions to either district is expected to increase groundwater recharge from canal seepage and deep percolation of irrigation water in that district, along with a corresponding decrease in groundwater demand for supplemental irrigation. Conversely, a decrease in RGP allocation and diversions to either district is expected to decrease groundwater recharge in the district and increase groundwater demand for supplemental irrigation.

Previous analysis in the SEA determined that it was not possible to quantify the total change in groundwater recharge and demand from 2008 to 2012 nor the portion of that total change that would be attributable to the OA. An order of magnitude estimate suggests that incremental changes in groundwater recharge and groundwater demand for supplemental irrigation in the Rincon and Mesilla Valleys during this period were small compared to the total recharge and pumping in the region (Reclamation 2013a; Appendix F).

Groundwater pumping is not an authorized function of the RGP and is not directly a part of RGP operations. However, it is worth noting that groundwater pumping from aquifers hydraulically connected to the Rio Grande, or to the network of canals, laterals, ditches, drains, and wasteways used to convey RGP deliveries and return flows, is likely to affect RGP supplies and deliveries through the interaction of the groundwater and surface water systems. In addition, groundwater demand for supplemental irrigation depends in part on the availability of surface water from the RGP. Previous studies have indicated that seepage from the Rio Grande and deep percolation of irrigation water from RGP lands to the underlying aquifer system are a primary source of groundwater recharge to the shallow unconfined aquifers of the Lower Rio Grande Underground Water Basin (Hanson et al. 2013, Haywood and Yager 2003, SSPA 2007, Stringham et al. 2016).

3.4.3.3 Groundwater Trends

Analysis based on historical measurements of groundwater elevations from monitoring wells in the RGP and surrounding areas of the Rincon and Mesilla Valleys demonstrates widespread and statistically significant negative trends in groundwater elevation from 1980 to the present. Analysis of previous decades suggest that this trend is confined to the past decade, indicating that sustained groundwater pumping in excess of recharge (i.e., groundwater mining) was not prevalent in the RGP or adjacent lands before the current drought (Reclamation 2013a; Appendix F).

Other groundwater trends are:

- Trends in groundwater elevation are predominantly negative, although some wells exhibit neither negative nor positive trends over the same period. Trends in groundwater elevation at each measurement site reflect conditions near that site.
- Full allocations each year in the early 1990s to early 2000s lessened concerns about allocations and no substantial changes in RGP operations, district operations, or groundwater use for supplemental irrigation in the RGP or adjacent areas of the Rincon or Mesilla Valleys occurred between the late 1990s and early 2000s.
- Efforts to increase irrigation efficiency and to reduce distribution losses, including lining and piping portions of the distribution system, may have contributed to recent groundwater declines in some portion of the Mesilla Valley by reducing recharge from deep percolation of irrigation and canal seepage. It is likely that recent groundwater declines are associated with the severe and sustained drought conditions that have affected the RGP since 2003 (Reclamation 2013a, Appendix F).

The analysis presented in the SEA (Reclamation 2013a, Appendix F) indicates a statistically significant positive correlation between groundwater elevation and annual flow below Caballo Dam, as well as the total annual RGP diversions under both wet and dry conditions. These results are intuitively consistent with conjunctive use of surface water and groundwater in the RGP. During periods of high surface water availability, streambed recharge from the Rio Grande to the underlying aquifer increases and groundwater pumping decreases, resulting in higher groundwater elevations. Conversely, during periods of low surface water availability, streambed recharge decreases and pumping increases, resulting in declining groundwater levels. Results suggest a strong connection between surface water and groundwater resources in areas served by the RGP, particularly in the Rincon and Mesilla Basins, as indicated by numerous previous studies (Deb et al. 2012, Reclamation 2013a; Appendix F, Stringham et al. 2016).

3.5 Water Quality

This section summarizes existing water quality between Elephant Butte Reservoir and the Rio Grande at the El Paso-Hudspeth County line.

3.5.1 Regulatory Framework

The legal and regulatory framework for water quality includes:

- Federal Water Pollution Control Act or Clean Water Act (CWA; 33 USC Section 1251 et seq.)
- Public Health Service Act, Safe Drinking Water Act (Title XIV of the Public Health Service Act; Public Law 107-377)
- New Mexico Administrative Code 20.6.4
- Texas Administrative Code Title 30, Chapter 307

Under the CWA, water quality is managed by the New Mexico Environment Department (NMED) and Texas Commission on Environmental Quality (TCEQ). These state agencies have developed water quality standards based on designated uses for which the body of water is suitable. Both state agencies divide the Rio Grande into water quality segments for which standards must be met.

3.5.2 Data Sources

Water quality data are from Hogan (2013), New Mexico Environment Department (NMED 2016), Reclamation (2013a; SEA Appendix H), Texas Commission on Environmental Quality (TCEQ 2016), and the U.S. Environmental Protection Agency (EPA 2015a, b).

3.5.3 Existing Reservoir Water Quality Conditions

The NMED Surface Water Quality Bureau (2016:175-176) reports that water quality in Elephant Butte Reservoir (HUC 13020211) has improved recently and the reservoir has been taken off the state's impaired list, but there is still a fish consumption advisory due to mercury in fish tissue. Caballo Reservoir (HUC: 13030101) is impaired due to mercury in fish tissue and high levels of nutrients. Fish consumption advisories are in place (NMED 2016:176).

3.5.4 Existing Rio Grande Water Quality

The Rio Grande between Elephant Butte and Caballo Reservoirs has historically been impaired by low dissolved oxygen levels and excessive nutrients, but in 2016, no impairments were found (NMED 2016:177-178). However, the state plans to reassess the dissolved oxygen levels. The

NMED (2016:178) has listed the Rio Grande in the HUC: 13030102, El Paso-Las Cruces reach, as impaired due to exceedances of the *E. coli* criterion.

The TCEQ (2016) lists the Rio Grande River (Basin 23; AUID 2312-2) as impaired for aquatic life from the Texas-New Mexico border to International Dam due to depressed dissolved oxygen levels and a toxic substance (methylene chloride) in sediment. For general uses, total dissolved solids and nutrients exceed standards. In addition, groundwater quality may be a concern within the districts' service areas.

The Rio Grande is impaired for primary contact recreational use from Percha Dam to the Texas boundary due to exceedance of the *E. coli* bacteria standard. The Rio Grande downstream of the New Mexico border is impaired due to excessive *E. coli* and high salinity or total dissolved solids. At El Paso, the average total dissolved solids is about 750 mg/L, and at Fort Quitman it commonly is in excess of 2,000 mg/L and up to an average of 3,200 mg/L during the irrigation season (Hogan 2013, Phillips et al. 2003, Stringham et al. 2016). Total dissolved solids are typically elevated in the winter when flows are lower and are reduced in the summer when higher flows dilute concentrations (Michelsen et al. 2009).

3.6 Vegetation Communities, Wetlands and Special Status Plant Species

This section describes vegetation communities including wetlands and special status plant species within the Elephant Butte and Caballo Reservoir pools and along riverbanks between the reservoirs and down to the El Paso-Hudspeth County line. "Special-status species" includes species given varying levels of protection with the highest level of protection given to species listed or proposed for listing as endangered or threatened under the ESA.

3.6.1 Regulatory Framework

A number of laws, regulations, and policies apply to vegetation communities and plant species. These include:

- ESA
- CWA Section 404
- Executive Order 11990, Protection of Wetlands
- New Mexico Energy, Minerals, and Natural Resources Department (NMEMNRD) Forestry Division (NMEMNRD 2015) Section 75-6-1 NMSA 1978
- Texas Parks and Wildlife Department Code Chapter 88 and Sections 69.01 through 69.9 of the Texas Administrative Code

3.6.2 Data Sources

Data sources for vegetation in the study area include the U.S. Geological Survey's (USGS) Southwest Regional Gap Analysis (USGS 2011), the New Mexico Rare Plant Technical Council (NMRPTC 2015), New Mexico State Parks' (NMSP) management plans (NMSP 2000, 2006), endangered plant information from the New Mexico Energy, Minerals, and Natural Resources Forestry Division (NMEMNRD 2015), and the Service's National Wetland Inventory, and publications such as Muldavin et al. (2000).

Field surveys and aerial photography conducted by Reclamation (2003a, 2012b), USIBWC (various), and others (e.g. Sogge et al. 1997) to document habitat for the endangered Southwestern willow flycatcher (*Empidonax traillii extimus*, flycatcher) also provide data about vegetation communities in the five county biological resources study area.

3.6.3 Existing Vegetation Conditions

The study area is in the Chihauhuan Desert on the ecotone[5] between Desert Scrub and Desert Grassland (Brown 1982, Dick-Peddie 1993). Riparian-wetland vegetation borders the study area along the shoreline of the reservoirs and the floodplain of the Rio Grande. Within the study area, the location and distribution of individual plant species depends on the soil, elevation, degree of slope, and proximity to water, etc.

The Southwest Regional Gap Analysis Project (USGS 2011) provides land cover data for the study area, classified according to the National Vegetation Classification System. Following this system, vegetation within the full-pool footprint of Elephant Butte Reservoir and its delta include the following:

- Western Great Plains Riparian Woodland and Shrubland
- North American Arid West Emergent Marsh
- North American Warm Desert Playa
- North American Warm Desert Wash
- North American Warm Desert Riparian Woodland and Shrubland

Since 1995, Elephant Butte Reservoir has receded more than 24 miles downstream, exposing thousands of acres of bare soil (Fig. 3). This area is dominated by Goodding's willow (*Salix gooddingii*), interspersed with broadleaf cattails (*Typha latifolia* L.), and marsh grasses (Muldavin et al. 2000). To the east, opposite the Low Flow Conveyance Channel outfall, dense monotypic stands of nonnative tamarisk or saltcedar (*Tamarix* spp.) are dominant (Reclamation 2012a).

Scant riparian development exists along the floodplain of the Rio Grande between Elephant Butte and Caballo Reservoirs. Vegetation in this reach is typically limited to a narrow band of tamarisk with a few overstory cottonwoods (*Populus fremontii*) (Reclamation 2012a).

Where the Rio Grande broadens into the upper delta of Caballo Reservoir, several patches of tamarisk and overstory cottonwoods and a variety of herbaceous and grass species persist (Reclamation 2012a). The broadening of the floodplain and Caballo Reservoir account for the relatively high water table that supports this vegetation.

Little vegetation is found in and around Caballo Reservoir due to annual mowing and management (Reclamation 2012a). However, a 40-acre parcel has been fenced to exclude livestock. This parcel, known as the Las Palomas site, supports a mosaic of native riparian and wetland vegetation that provides wildlife habitat. Downstream of the Las Palomas site, several large patches of native willows (*Salix* spp.) have developed in the bottom of the reservoir pool. Several of these patches are comparable to the high-quality wildlife habitat in the Elephant Butte Reservoir and consist of young to middle-aged coyote willow (*Salix exigua*) and Goodding's willow. These patches are classified as North American Arid West Emergent Marsh, North American Warm Desert Playa, and North American Warm Desert Riparian Woodland and Shrubland.

[5] A transitional area between two biological communities

Downstream of Percha Dam (2.0 miles below Caballo Dam) to the American Dam at El Paso, the affected environment is the floodway managed by the USIBWC. The floodway ranges in width from approximately 50 to 2,100 feet for over 100 miles. In most of the floodway there is little to no vegetation, but portions of it are described by USIBWC (2003, 2009b) as a combination of farmland and North American Arid West Emergent Marsh and North American Warm Desert Riparian Woodland and Shrubland.

Through the years, the USIBWC has managed vegetation to reduce erosion potential, remove potential obstructions that could reduce flood containment capacity, help stabilize stream banks, control weeds and brush including saltcedar, and provide wildlife habitat at suitable locations. The USIBWC's Record of Decision for River Management Alternatives for the Rio Grande Canalization Project (USIBWC 2009a) calls for enhancing native vegetation within the floodway by reducing mowing and revegetation.

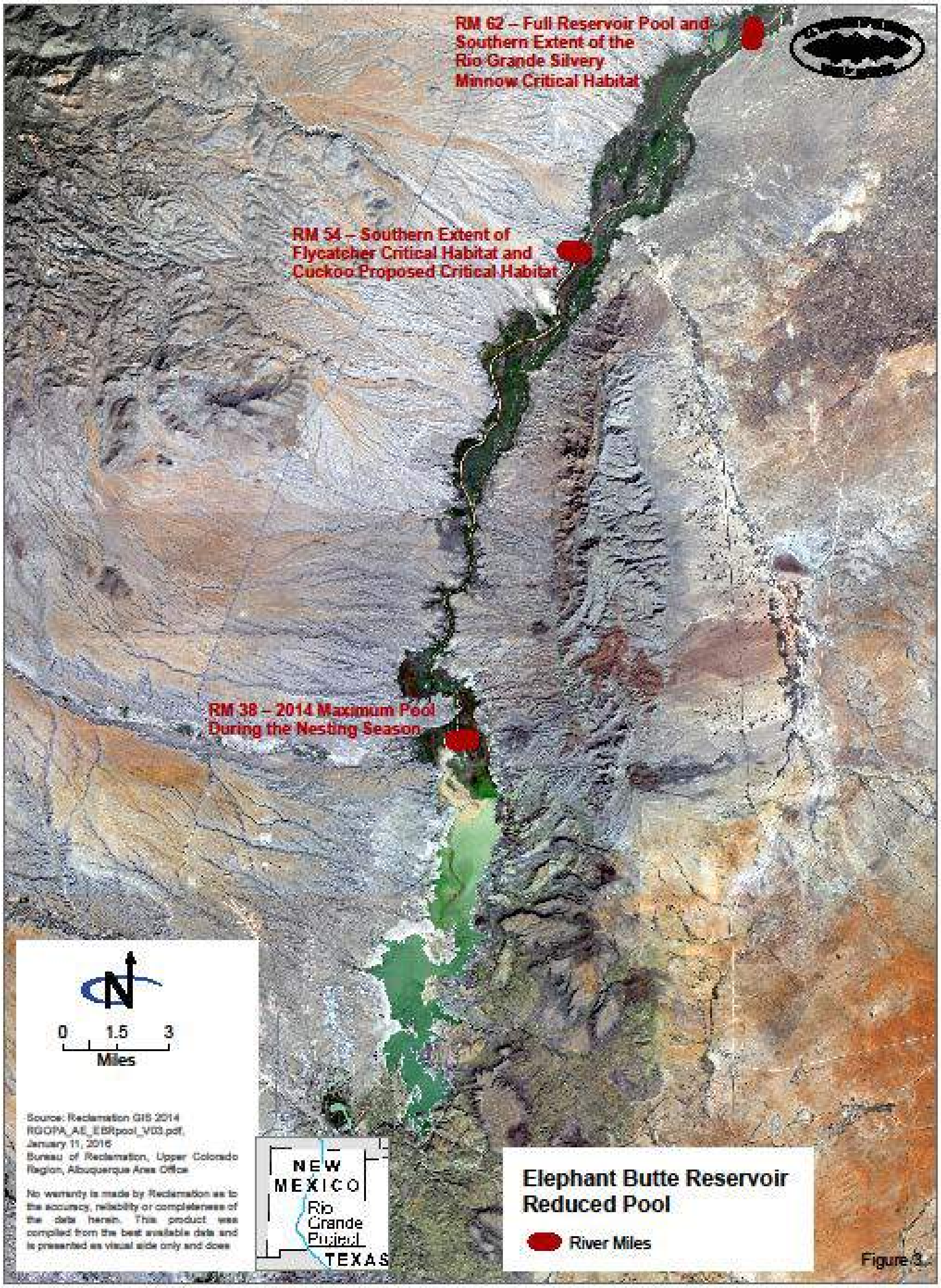
3.6.4 Vegetation Trends

The recession of Elephant Butte Reservoir over the last decade has allowed the development of a mosaic of native and nonnative vegetation (Fig. 3, Reclamation 2012a). Downstream, at the sediment delta of Caballo Reservoir, several patches of tamarisk and overstory cottonwoods and a variety of herbaceous and grass species have grown, including the densely vegetated Las Palomas site referenced in Section 3.6.3 (Reclamation 2012a). These vegetated patches within the full pool footprint of both reservoirs are dynamic due to both natural succession and to changes brought about by fluctuating reservoir levels.

While defoliation of tamarisk due to the tamarisk leaf beetle (*Diorhadba* spp.), has yet to occur in the study area, it is likely that individual trees and patches of dense, monotypic tamarisk will become defoliated as the beetle expands over time.

Below Caballo Reservoir, there is minimal native vegetation along the Rio Grande. The river is channelized to accommodate agricultural and urban land uses, but additional acres adjacent to the river has recently been allocated for riparian restoration and managed grasslands. Approximately 350 additional acres may be designated as no-mow zones in future years to accommodate new conditions, such as increased flycatcher habitat buffer areas or new restoration sites (USIBWC 2014b).

Figure 3. Elephant Butte Reservoir reduced pool, 2014



3.6.5 Special Status Plant Species

There are 13 Federal- or state-listed special status plant species in the five counties in the biological resources study area, but based on habitat requirements and soil associations, only the Pecos sunflower (*Helianthus paradoxus*) and Wright's marsh thistle (*Cirsium wrightii*) have any potential to occur in the study area. To date, no occurrences of either species have been reported. These species are discussed in more detail below.

3.6.5.1 Pecos sunflower (Helianthus paradoxus)

The Pecos sunflower is a wetland species that requires saturated saline soils of desert wetlands. It is usually associated with desert springs (cienegas) or the wetlands created from modifying desert springs at 3,300 to 6,600 feet of elevation. Some activities that degrade or destroy wetlands and therefore threaten Pecos sunflower are channel incision that reduces water tables, groundwater depletion, water diversions, filling, and saltcedar invasion. Livestock will eat Pecos sunflower, especially the flower heads, when other green forage is scarce. Disturbance may facilitate hybridization (NMRPTC 2015).

3.6.5.2 Wright's marsh thistle (Cirsium wrightii)

Wright's marsh thistle grows in wet, alkaline soils in spring seeps and marshy edges of streams and ponds at elevations of 3,450 to 8,500 feet. Desert springs (cienegas) are susceptible to drying up or being diverted. Populations in the City of Roswell, Chavez County, at Lake Valley, Sierra County, and at the San Bernardino Cienega in Arizona appear to be extirpated. Introducing insects as biological control for weedy thistles may pose a grave hazard for non-weedy thistle species. The effects of fire and livestock grazing on this species have not been studied (NMRPTC 2015).

3.7 Wildlife and Special Status Wildlife Species

This section summarizes existing conditions for terrestrial wildlife and special status wildlife species, including consideration of birds, mammals, reptiles, amphibians, arthropods, and gastropods. For this FEIS, special status species are those protected by the laws listed below.

3.7.1 Regulatory Framework

The primary laws protecting wildlife are:

- ESA
- Bald and Golden Eagle Protection Act (16 USC, Sections 668-668d)
- Migratory Bird Treaty Act of 1918 (16 USC, Sections 703-712), as amended
- New Mexico Wildlife Conservation Act (17-2-40.1 NMSA 1978)
- Texas Parks and Wildlife Department Code, Chapters 67 and 68, and Texas Administrative Code, Sections 65.171-65.176, of Title 31

3.7.2 Data Sources

Data sources for wildlife in the study area are based on descriptions of the vegetation communities in Section 3.6, plus data provided by the Service on special status species in the five counties: Doña Ana, Sierra, and Socorro Counties, New Mexico, and El Paso and Hudspeth Counties, Texas. Wildlife data from New Mexico State Parks' (NMSP) management plans (2000, 2006) are incorporated by reference. Reclamation also reviewed the Service's online Critical Habitat Portal (Service 2014a) and *Federal Register* notices for designated critical habitat for special status species. The New Mexico Department of Game and Fish's (NMDGF) online database, the Biota Information System of New Mexico, was reviewed for Federal and state threatened, endangered, and species of concern (NMDGF 2015a). Also, reviewed were data from the New Mexico natural heritage program sensitive species by county database (NMDGF 2015a) and the Texas natural diversity database and rare, threatened, and endangered species of Texas by county database maintained by Texas Parks and Wildlife Division (TPW 2016).

The New Mexico Ornithological Society has an online database of bird sightings throughout the state (New Mexico Ornithological Society 2015), and there are several available lists showing documented bird species for these counties that were reviewed. Publications of the Service listing species, designating critical habitat, recovery or management plans, and biological opinions were reviewed and data from these publications are incorporated by reference (e.g. Service various).

3.7.3 Existing Wildlife Conditions

This section provides a general overview of the wildlife and bird species and their habitats that could be in the study area, with an emphasis on special status species. As with vegetation, the potentially affected habitat focused on potential inundation areas associated with reservoir pools and the effects of the frequency, timing, and extremes in reservoir elevation changes over the long term.

The vegetation in and around the two reservoirs and along the floodplain of the Rio Grande provides habitat for a diversity of wildlife species (USIBWC 2001; Reclamation 2002, 2003b). Common wildlife at both Elephant Butte and Caballo Reservoirs are mule deer, coyote, rabbits, pocket gopher, ground squirrel, chipmunk, raccoon (NMSP 2000, 2006). NMSP (2000, 2006) has documented more than 250 species of birds in and around the reservoirs, with common species including woodpecker, egret, killdeer, quail, great blue heron, and shorebirds.

The reservoirs and shorelines support many species of reptiles, amphibians, and invertebrates. Among the invertebrates, currently no tamarisk leaf beetles (*Diorhadba* spp.) have been documented in the study area, but the beetle has been dispersing in Texas and New Mexico since at least 2010. *Diorhabda* has been known to defoliate over 90 percent of tamarisk at some sites, with possible tamarisk mortality after 3-5 years of repeated defoliation. The defoliation of tamarisk could affect the use of the study area by birds including the endangered flycatcher, as described below.

Downstream of Caballo Reservoir, typical wildlife includes the black-tailed jackrabbit, desert cottontail, cotton rat, ground squirrel, mourning dove, meadowlark, kestrel, red-tail hawk, skunk, burrowing owl, several species of waterfowl, other migratory birds, and non-game animals (USIBWC 2007, 2014a).

Riparian areas constitute less than one percent of the land area in the arid Southwest, yet provide habitat to a greater number of wildlife species than any other ecological community in the region. These areas are also critical corridors for migratory species, especially migratory birds. When analyzing the river portion of the study area from Caballo Reservoir to El Paso, USIBWC assessed the quality of wildlife habitat in the area as below average to poor (USIBWC 2003).

Some riverine wetlands in the river channel offer high-quality habitat, but these are small and far apart. Wildlife habitat along the river, from the Elephant Butte Dam to El Paso, has been impacted by agricultural and urban development. In general, the remaining high-value wildlife habitat is associated with the Elephant Butte and Caballo Reservoirs and a riparian strip next to the Rio Grande. The dynamic nature of flooding and drying at the upper portions of the Elephant Butte Reservoir has allowed large areas of riparian vegetation to establish itself, which provides important wildlife habitat. Smaller patches of similar vegetation have developed on the drought-exposed bed of Caballo Reservoir.

3.7.4 Special Status Wildlife Species

The endangered flycatcher and the threatened Western yellow-billed cuckoo (*Coccyzus americanus occidentalis*; cuckoo) are seasonally present within the study area/action area. Reclamation also considered potential for the endangered New Mexico meadow jumping mouse (*Zapus hudsonius luteus*; mouse), the endangered Interior least tern (*Sterna antillarum*), and the threatened piping plover (*Charadruis melodus*; plover) in the action area. For the mouse (see Section 3.7.4.3), the Service (2014c, 2013c) indicates it could be present in Socorro County, New Mexico, but surveys for the species, as well as examination of its potential habitat based on vegetation communities, indicate this species is not present in the action area. While migrating individual Interior least tern and plover could occur during transitory stopover periods, no habitat for these species has been found along the riverine portion of the action area.

3.7.4.1 Southwestern Willow Flycatcher

The flycatcher is a small perching bird (order Passeriformes), about six inches long, with a life span of generally one to three years; some live four to seven years (Langridge and Sogge 1997, Netter et al. 1998, Paxton et al. 1997). They winter in neotropical areas of southern Mexico and Central America and begin to arrive at New Mexico breeding sites in early May. Flycatcher habitat along the Rio Grande has two primary functions: habitat for breeding and feeding during the breeding season and stopover habitat while migrating.

The flycatcher was originally listed as endangered due to loss of habitat, brood parasitism, and lack of adequate protective regulations (Service 1995). The greatest ongoing threats to flycatchers in the Rio Grande are the decline in the quality of critical nesting habitat related to drought and loss of dense riparian vegetation, invasion of the saltcedar leaf beetle (*Diorhabda* spp.), and nest predation by brown-headed cowbird (*Molothrus ater*).

The Service published the final rule designating critical habitat for the flycatcher in 2013 and included about 14.4 kilometers (9.0 miles) of the upper part of Elephant Butte Reservoir in the Middle Rio Grande Management Unit (Service 2013a:380).

Regarding the sediment delta at the north of Elephant Butte Reservoir, the Service reported that:

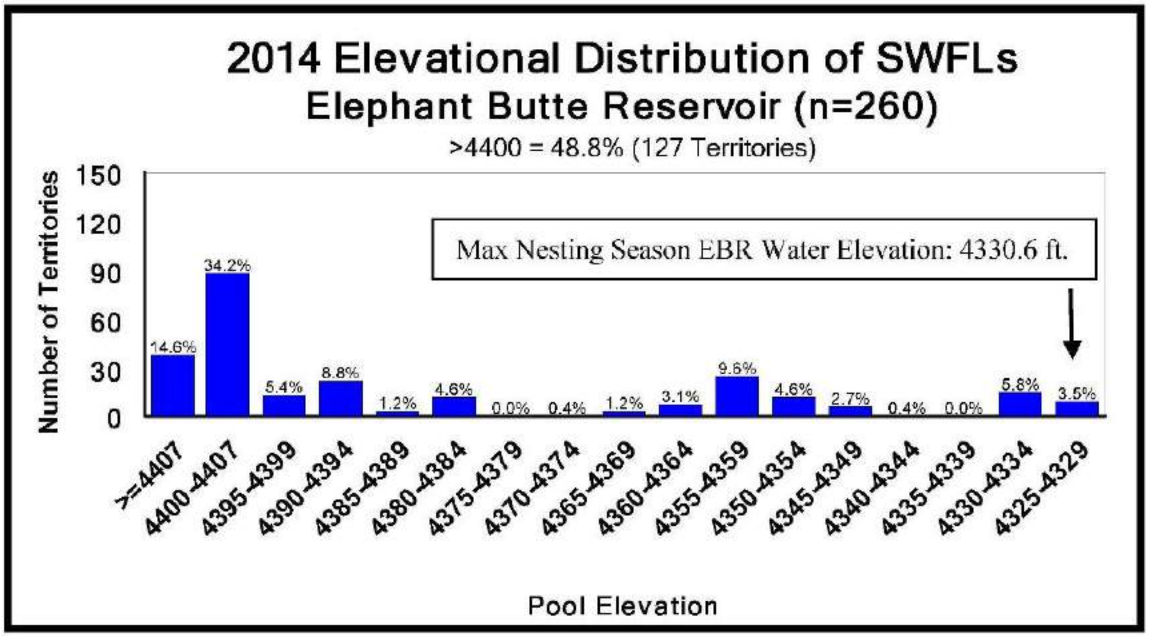
> "Over time, as the lake at Elephant Butte has declined, there has been an increase of willows and other trees in the delta of Elephant Butte Reservoir, and also an increase in flycatcher territories within the reservoir pool and north of the reservoir pool where the habitat is supported by the low-flow conveyance channel. The area within and north of Elephant Butte Reservoir supports the largest known population of flycatchers in the range of the subspecies." [Service 2013a:365]

The final rule also found that the southerly margin of Elephant Butte Reservoir contains some elements of flycatcher habitat (Service 2013a:380). However, the Service determined that this southern segment in the active conservation pool of the Elephant Butte Reservoir is not necessary for the conservation of flycatcher and it was not designated as critical habitat (Service 2013a:349).

3.7.4.1.1 Presence

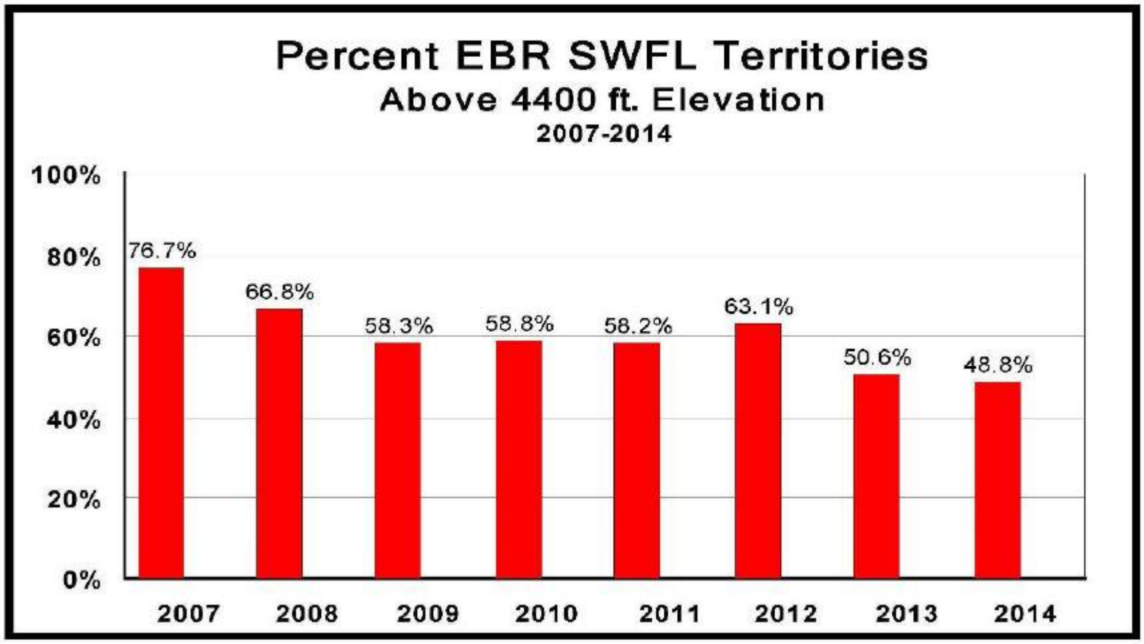
The upper or northern part of Elephant Butte Reservoir is located in the Service's Middle Rio Grande Management Unit. Patches of vegetation at the northernmost extent within the historic reservoir (considered south of River Mile 62) became suitable for flycatchers in the mid-1990s. Flycatcher habitat is dynamic system, with the birds requiring dense patches of vegetation with tall trees. High-quality flycatcher habitat within the reservoir that has developed is a result of more recent reservoir recession that continues to improve and is providing new habitat for nesting and migrant flycatchers (Reclamation 2015a).

Figure 4. Elevational distribution of Southwestern Willow Flycatcher territories within Elephant Butte Reservoir, 2014, with maximum water levels.



Source: Reclamation (2015d).

Figure 5. Percentage of Southwestern Willow Flycatcher territories above the high pool of Elephant Butte Reservoir, 2007-2014.



Source: Reclamation (2015d).

During the 2014 surveys, 598 resident flycatchers were documented throughout the Middle Rio Grande Management Unit, which included resident birds forming 234 pairs and establishing 364 territories (Reclamation 2015a). Consistent with previous years, the San Marcial reach was the most productive, with 307 territories and 205 pairs. The 2014 surveys showed a second consecutive year of increased territory numbers after a large drop in 2012. The 2014 monitoring included nesting success rates, productivity, and brown-headed cowbird (*Molothrus ater*) parasitism. The San Marcial reach was again most productive, with 255 nests and 151 flycatcher fledglings. Overall, nesting success for all of the Middle Rio Grande Management Unit was the lowest observed in the past 16 years of monitoring, with most failures due to depredation (Reclamation 2015a).

Figure 4 presents the distribution of flycatchers by elevation in Elephant Butte Reservoir during 2014. Because the elevation of the full reservoir is approximately 4,400 feet, the reservoir is important in providing flycatcher habitat**.** Figure 5 shows the percent of flycatcher territories above the high reservoir pool from 2007 to 2014.

3.7.4.2 Yellow-Billed Cuckoo

Cuckoos are insect specialists but also prey on small vertebrates, such as tree frogs and lizards; they are also known to be nest parasites of other bird species, including flycatchers. In the arid west, cuckoos are usually found in cottonwood-willow riparian associations along watercourses. The cuckoo requires large tracts of willow-cottonwood or mesquite (*Prosopis* spp.) forest or woodland for its nesting season habitat. Hydrologic conditions at cuckoo breeding sites can vary between years. This year-to-year change in hydrology can affect food availability and habitat suitability for cuckoos. Extended inundation reduces habitat suitability because the larvae of sphinx moths pupate, and the eggs of katydids are laid underground; prolonged flooding kills the larvae and eggs (Service 2014b), thus removing important food sources.

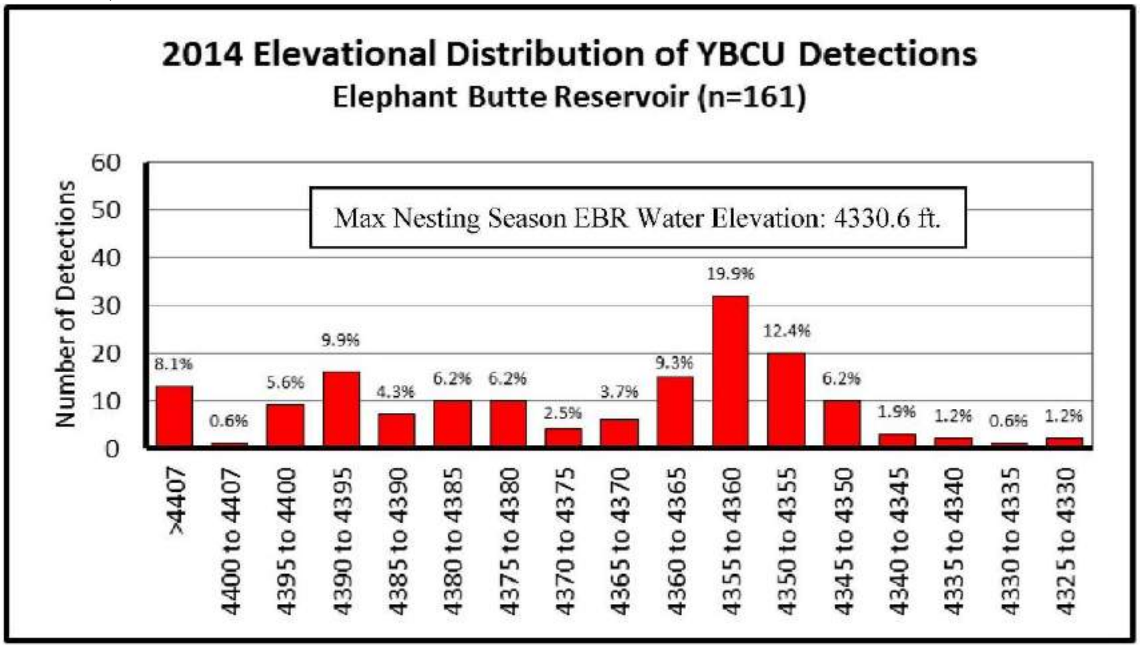
The cuckoo was listed as threatened due to the “habitat loss associated with [man-made] features that alter watercourse hydrology so that the natural processes that sustained riparian habitat in western North America are greatly diminished” (Service 2013b:59992). In addition to habitat loss, reduction of prey insect abundance due to the use of pesticides has been identified as a major threat to the cuckoo (Service 2014e).

In 2014, the Service proposed designating critical habitat for the cuckoo, which included the Middle Rio Grande Unit NM-8 (Service 2014b). It is 61,959 acres in extent and is an approximately 170-mile-long continuous segment of the Rio Grande, from the Elephant Butte Reservoir in Sierra County at approximately River Mile 54, upstream through Socorro, Valencia, and Bernalillo Counties to below Cochiti Dam in Cochiti Pueblo in Sandoval County, New Mexico. This unit is consistently occupied by a large number of breeding cuckoos and currently is the largest breeding group of the species north of Mexico. The site also provides a movement corridor for cuckoos moving farther north. Tamarisk, a nonnative species that reduces habitat quality for cuckoos, is a major component of habitat in this unit. The Service has not yet finalized critical habitat designation for the species, including identifying actual boundaries at Elephant Butte Reservoir.

3.7.4.2.1 Presence

In Reclamation’s 2013 survey of cuckoos from State Highway 60 downstream to the Elephant Butte Reservoir, the San Marcial Reach (River Mile 68.5 to 38.5) had the most cuckoo habitat of any of surveyed reaches (Reclamation 2014b). In 2013, the exposed pool of the Elephant Butte Reservoir constituted 86 percent of all cuckoo detections and 86 percent of all territories found within the San Marcial Reach. This subset of San Marcial also contained 48 percent of all cuckoo detections and 50 percent of all territories found in the entire Middle Rio Grande study area. The biological assessment (Reclamation 2015d) includes more information on the cuckoo and its distribution in the study area. The distribution of cuckoos by elevation in Elephant Butte Reservoir during the 2014 surveys is provided in Fig. 6.

Figure 6. Elevational distribution of Yellow-billed Cuckoo detections within Elephant Butte Reservoir, 2014.



Source: Reclamation (2015d).

3.7.4.3 New Mexico Meadow Jumping Mouse

There have been relatively few studies of this endangered mouse and its natural life history. The mouse is unique in that it hibernates about eight to nine months out of the year, longer than most mammals, and it is active for only three to four months during the summer. Within this short time frame, it must breed, give birth, raise young, and store up sufficient fat reserves to survive the next year's hibernation period. As a result, if resources are not available in a single season, populations may be greatly impacted. In addition, New Mexico meadow jumping mice live three years or less and have one small litter annually, with seven or fewer young, so the species has limited capacity for high population growth rates due to this low fecundity.

According to the Service (2013c), the New Mexico meadow jumping mouse has specialized habitat requirements in that it appears to only utilize two riparian community types: 1) persistent emergent herbaceous wetlands (beaked sedge and reed canarygrass); and 2) scrub-shrub wetlands found in riparian areas along perennial streams that are composed of willows and alders. It especially uses microhabitats or patches or stringers of tall dense sedges on moist soil along the edge of permanent water. Habitat requirements are characterized by tall (averaging at least 24 inches) dense herbaceous riparian vegetation, composed primarily of sedges and forbs. This suitable habitat is found only when wetland vegetation achieves full growth potential associated with perennial flowing water

The mouse was originally listed as endangered due to the "present or threatened destruction, modification, or curtailment of its habitat or range; the inadequacy of existing regulatory mechanisms; and the natural and manmade factors affecting its continued existence" (Service 2014c:33120). In addition, isolated populations make natural recolonization of impacted areas highly unlikely or impossible in most areas (Service 2014c). Because the species occurs only in areas that are water saturated, populations have a high potential for extirpation when habitat dries due to ground and surface water depletion, draining of wetlands, or drought.

In April 2014, the Service reopened comment on proposed designated critical habitat for the mouse along the Rio Grande Valley (Service 2014d). Areas proposed for critical habitat for the mouse in this unit incorporate the Bosque del Apache National Wildlife Refuge, which is the only habitat believed to be occupied by the subspecies in the Middle Rio Grande with the capability to support its breeding and reproduction. Final designation of critical habitat has not yet occurred.

3.7.4.3.1 Presence

Based on work conducted in support of delta channel maintenance (Reclamation 2013c), the New Mexico meadow jumping mouse is not expected to occur in the study area. Frey and Kopp (2014) completed a preliminary assessment of mouse habitat down to River Mile 38 using GIS-based vegetation mapping and field evaluations of irrigation drains and the Low Flow Conveyance Channel. Mapping did identify potentially suitable habitat (herbaceous and regenerating willow) next to the Low Flow Conveyance Channel. Because of the quality of available data, this was a conservative effort that overestimated the amount of habitat. Further assessment and surveys have not found potentially suitable mouse habitat (Frey and Kopp 2014).

3.8 Aquatic Resources and Special Status Fish Species

This section summarizes existing conditions for aquatic habitats, the fish community, and special status fish species in this potentially affected environment. The area of analysis includes the full-pool of Elephant Butte and Caballo Reservoirs, the Rio Grande between the reservoirs, and the Rio Grande downstream of Caballo Dam to diversion facilities for the irrigation districts and the American Diversion Dam. Hydrological modeling simulates reservoir filling and drying affecting aquatic habitats along the Elephant Butte Reservoir delta reach, from River Mile 62 to River Miles 38 to 36, and the Elephant Butte and Caballo Reservoirs. Such habitat changes can affect the numbers and life stage of fish.

3.8.1 Regulatory Framework

The same laws applicable to wildlife apply to aquatic species.

3.8.2 Data Sources

No original aquatic resource or fish data were collected for the FEIS. Data used to describe existing conditions for aquatic resources and special status fish species in the study/action area include Reclamation sampling surveys for the endangered Rio Grande silvery minnow and habitat, including maps. Additional data were derived from NMDGF reports on sport and game fish species (NMDGF 2015b). Aquatic resource conditions are described through 2014, which marked the baseline for consultation with the Service.

3.8.3 Existing Fisheries Conditions

Beyond the irrigation season, except for relatively limited durations of stormflow input from the watershed, the Rio Grande channel between the reservoirs and downstream of Caballo Dam has long periods of low to no flows. The reaches of the Rio Grande below the reservoirs do not develop a sustainable or transient fishery or aquatic community, precluding needs for aquatic life assessment. Consequently, fisheries and other aquatic life resources of concern included in this assessment are limited to those in the delta reach inflows through the full-pool footprints and within the changing wetted perimeters of the two reservoirs.

3.8.3.1 Elephant Butte Reservoir Headwaters

With the drawdown of the water surface elevation since 1995, more than 24 miles of channel formed through the delta reach at Elephant Butte Reservoir, from River Mile 62 to River Miles 38 to 36. Reclamation surveyed fish populations in this channel from 2010 through 2012 (Table 3-2). In 2010, minnows were the most abundant fish collected from this temporary delta channel. They were captured in a variety of habitat types at the four survey sites selected, based on accessibility between River Miles 45.8 and 51.3.

Table 3-2 Fish species collected during September sampling in the temporary channel in Elephant Butte Reservoir, 2010-2012

Species	2010		2011		2012	
	No.	Number per 100 m^2	No.	Number per 100 m^2	No.	Number per 100 m^2
Rio Grande silvery minnow	233	24.07	65	2.83	0	0
Red shiner	78	6.68	219	9.53	1044	29.74
Western mosquitofish	41	3.70	26	1.13	1287	36.66
Channel catfish	24	1.93	55	2.39	11	0.31
Flathead chub	2	0.30	3	0.13	2	0.06
Threadfin shad	1	0.09	0	0	0	0
Yellow bullhead	1	0.08	0	0	0	0
River carpsucker	0	0	7	0.30	0	0
Common carp	0	0	0	0	2	0.06
Logperch	0	0	0	0	2	0.06
Fathead minnow	0	0	0	0	1	0.03

Source: Reclamation 2013a; Key m^2 = square meters

In 2011, silvery minnow was the second most abundant fish collected; however, overall fish densities were much lower than those observed in 2010. In October 2012, Reclamation sampled four sites from River Miles 46 to 52 and captured seven fish species. No silvery minnows were captured during any of the 2012 field season. Sampling at two sites produced no fish and there were no dry sites. Western mosquitofish were the most abundant, followed by red shiners. Red shiners were distributed evenly across the sites and mosquitofish were slightly more abundant at the downstream sites.

3.8.3.2 Elephant Butte Reservoir

Elephant Butte Reservoir is New Mexico’s largest lake and most popular state park for recreation. The fish community is monitored annually, in the spring and fall. The most recent available spring fish electroshocking survey reports provide information for the years 2007 through 2010 and fall experimental gill net surveys for 2007 to 2011 (NNDGF 2012). Ten fish species were reported in these surveys, as follows:

- Smallmouth bass (*Micropterus dolomieu*)
- Largemouth bass (*M. salmoides*)
- Bluegill (*Lepomis macrochirus*)
- Longear sunfish (*Lepomis megalotis*)
- Green sunfish (*L. cyanellus*)
- White crappie (*Pomoxis annularis*)

- Black crappie (*P. nigromaculatus*)
- White bass (*Morone chrysops*)
- Striped bass (*M. saxatilis*)
- Walleye (*Sander vitreus*)

Although based on a relatively small sample size, the collection data for smallmouth bass indicated a relative imbalance, dominated by older, larger fish (NNDGF 2012). The condition was most likely the result of "poor habitat, due to fluctuating water levels during the spring spawn, poor spawning substrate, water clarity, and inadequate forage fish" (NMDGF 2012). In contrast, collection data for largemouth bass indicated that their population had shifted to larger, healthier fish until 2010, when this trend reversed. It appeared that natural recruitment was very low (NMDGF 2012).

Capture rates for other centrarchids (white bass, crappie, sunfish, striped bass, and walleye) were low. Catch data for populations for these fish was inconsistent between years, most likely due to sample bias, inappropriate habitat in the survey sites, and relatively low densities of many of these fish. Overall, Reclamation concluded that habitat quality undoubtedly restricted the abundance of centrarchids at Elephant Butte Reservoir, with the lack of suitable spawning habitat and escape cover attributable to the age of the lake and water use practices (NMDGF 2012).

The fall gill net surveys, conducted during November from 2007 to 2011, found the number of fish captured remained stable (NMDGF 2012). However, gizzard shad, normally the most commonly captured and abundant forage fish, showed a substantial population decrease through the survey period, and with an increase in size, makes the population potentially less available as forage. Blue catfish became the most abundant fish in the reservoir based on percent captured data, with their abundance more than doubling from 2009 to 2011. The relative abundance of both striped bass and white bass declined appreciably throughout the survey period.

Table 3-3 Fish in Elephant Butte Reservoir, 2014

Name	Number	% Caught	% Biomass
Blue catfish	597	52.09	27.08
Gizzard shad	207	18.06	9.38
Smallmouth buffalo	98	8.55	42.05
Channel catfish	48	4.19	1.26
Common carp	29	2.53	6.01
Walleye	23	2.01	4.95
White bass	18	12.04	7.34
Striped bass	1	0.09	1.71
Largemouth bass	1	0.09	0.18
Freshwater drum	1	0.09	0.03
Longear sunfish	1	0.09	0.01
Bluegill	1	0.09	0.01
Threadfin shad	1	0.09	0.01

Source: Mammoser (2015).

Table 3-3 provides data from the 2014 fall fish community gill net survey in Elephant Butte Reservoir. Blue catfish, gizzard shad, white bass, smallmouth buffalo, channel catfish, common carp, and walleye comprised most of the surveyed fish community; all other species accounted for less than 2 percent of the fish caught (Mammoser 2015).

From a fish community perspective, Elephant Butte Reservoir suffers from age and management practices that have been, and will continue to be, detrimental to some species while benefitting others" (New Mexico Department of Game and Fish [NMDGF] 2012). Present day management of the fishery populations is viewed to be affected by yearly fluctuating water levels due to irrigation demands and poor habitat created by severe drought conditions; centrarchid populations (e.g., bass and sunfish) are much below state management objectives (NMDGF 2011).

The lack of submerged vegetation in the reservoir has limited the recruitment and survivorship of bass. The absence of vegetation to help filter suspended particulates, reduce the water's turbidity, and stabilize the lake's banks negatively affects many fish species, including white, largemouth, and smallmouth bass, which tend to avoid turbid areas. In contrast, other fish species, like blue catfish, can tolerate increased turbidity, with populations quadrupling in Elephant Butte Reservoir in recent years, while channel catfish populations have markedly declined.

3.8.3.3 Caballo Reservoir

Caballo Reservoir fishery data come from experimental gill net surveys in mid-November 2008 (NMDGF 2012). At that time due to very low water levels in the reservoir, only three randomly selected sites were sampled. Catfish and walleye were the main game species captured, representing most of the community in percent captured and percent of biomass. Walleye, catfish, and white bass are the primary species targeted by anglers in the reservoir.

Gizzard shad represented 17.5 percent of the fish captured in 2008, a percent similar to those captured in 2006. The capture data indicate a well-balanced population with moderate recruitment (NMDGF 2012). Walleye represented 27 percent of the 2008 fish captured. Walleye fry have been stocked in Caballo Reservoir every year since 2007. While their capture number was lower than in 2004 and 2006, their population remained abundant. Their population size reduction was attributed to the decrease in lake levels and the increase in the percent catch of blue catfish. Blue catfish capture numbers increased in 2008 from previous surveys in 2004 and 2006, and they had become the dominant game fish in 2008. The report suggested that water level effects on habitat conditions likely dictate which species are more prevalent each year.

3.8.4 Special Status Species, Rio Grande Silvery Minnow

The Rio Grande silvery minnow is the only ESA-listed fish species present in the study area. The Rio Grande silvery minnow was listed as endangered in 1994 (Service 1994, 59 Fed. Reg. 36988). Silvery minnows are pelagic spawners,[6] producing numerous semi-buoyant, non-adhesive eggs. Most spawning typically has been observed in the spring, from late April through June, accompanying the period of snowmelt runoff (Reclamation 2012c). Spawning also has been observed during runoff following summer monsoons. Both juvenile and adult minnows primarily use meso-habitats with moderate depths (15 to 40 centimeters), low water velocities (4 to 9 centimeters per second), and silt/sand substrates. During the winter, these minnows become less active and seek habitats with cover, such as debris piles and other areas with low water velocities.

During spring sampling, large concentrations of reproductively mature silvery minnows are often collected on inundated lateral overbank habitats (Hatch and Gonzales 2008). Further study is

[6] They lay their eggs in open water

needed to determine whether minnows exhibit preferential use of lateral habitat (including overbank) for spawning. Surveys of inundated overbank habitats often have captured large numbers of gravid females and ripe male minnows (Gonzales and Hatch 2009).

3.8.4.1 Threats

According to the Service (2010, 75 Fed. Reg. 7625 and 1994:36988), decline of the fish is due to destruction and modification of its habitat due to dewatering and diversion of water, water impoundment (including Elephant Butte and Caballo Dams), and modification of the river (channelization). Competition and predation by non-native species, water quality degradation, and other factors have contributed to its status as endangered.

Silvery minnow populations remain at risk in the Rio Grande due to:

- Channel drying and the lack of suitable perennial refugia habitat during the irrigation season and periods of drought, leading to complete desiccation of potential habitat for minnows
- The lack of abundant feeding habitat consisting of channel flows less than a half a foot per second, and high flow velocities suspending and scouring away potential benthic and other attached food supplies for minnows, decreasing survival
- Floodplain habitats that fail to connect and inundate during spawn-stimulating flows, stranding minnow eggs and developing fry in high-velocity channel flows that have long been known to produce very high to total mortality of eggs and developing fry in small-bodied fish species (Harvey 1987)

3.8.4.2 Critical Habitat

The Service (2003, 68 Fed. Reg. 8087) designated critical habitat for the Rio Grande silvery minnow from the San Acacia Diversion Dam to the headwaters of Elephant Butte Reservoir at River Mile 62. The lateral extent of critical habitat was defined as areas bounded by levees, or in areas without levees, 300 feet of riparian zone adjacent to each side of the river (Service 2003:8119). Areas other than the Rio Grande, including the study area, were excluded from the designation of critical habitat for silvery minnow under Section 4(b)(2) of the ESA.

3.8.4.3 Presence

Historically, silvery minnows were distributed throughout most of the Rio Grande, from near the Gulf of Mexico to the upper reaches of both the Pecos River and the Rio Grande, reaching into the Rio Chama. The only reach in the FEIS study area where silvery minnows currently occur is in the channel through the Elephant Butte delta reach from River Mile 62, extending south to the active pool at approximately River Miles 38 to 36; i.e., at the headwaters of Elephant Butte Reservoir.

3.9 Invasive Species

An invasive species as defined by Executive Order 13112 is a species that is non-native or alien to the ecosystem and whose introduction is likely to cause economic or environmental harm or harm to human health.

3.9.1 Regulatory Framework

Authorities for combating the introduction or spread of invasive species are:

- Executive Order 13112
- New Mexico Noxious Weed Control Act

- New Mexico Aquatic Invasive Species Control Act
- Texas Agricultural Code Chapter 71, Subchapters D and T

3.9.2 Existing Invasive Species Conditions

According to the NMDA (2009) and U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (2015), invasive species within the project area are mostly noxious weeds, or plants that are not native, that are targeted for management and control, and that have a negative impact on the economy or the environment. The New Mexico State Noxious Weed List suggests the potential presence of the following noxious weeds:

- Five Class A species—camelthorn (*Alhagi maurorum*), hoary cress/whitetop (*Cardaria* spp.), parrot feather watermilfoil (*Myriophyllum aquaticum*), ravennagrass (*Saccharum ravennae*), and Scotch cottonthistle (*Onopordum acanthium*)
- Five Class B species—African rue (*Peganum harmala*), Malta starthistle (*Centaurea melitensis*), perennial pepperweed (*Lepidium latifolium*), Russian knapweed (*Acroptilon repens*), and tree of heaven (*Ailanthus altissima*)
- Six Class C species—cheatgrass (*Bromus tectorum*), field bindweed (*Convolvulus arvensis*), jointed goatgrass (*Aegilops cylindrical*), Russian olive (*Elaeagnus angustifolia*), saltcedar (*Tamarix* spp.), and Siberian elm (*Ulmus pumila*)
- Four watch list species—crimson fountaingrass (*Pennisetum setaceum*), giant cane (*Arundo donax*), Sahara mustard (*Brassica tournefortii*), and spiny cocklebur (*Xanthium spinosum*)

In Texas, noxious weeds identified as particularly worrisome invasive species in the Trans-Pecos ecoregion and study area are camelthorn (*Alhagi maurorum*), field bindweed (*Convolvulus arvensis*), giant reed (*Arundo donax*), Japanese dodder (*Cuscuta japonica*), and tamarisk or saltcedar (*Tamarix ramosissima*).

As mentioned in Section 3.6.4, the release of tamarisk leaf beetle (*Diorhadba* spp.) at locations along the Rio Grande in Texas is expected to result in the defoliation of saltcedar as the beetles arrive in Elephant Butte and Caballo Reservoirs.

Quagga mussels (*Dreissena bugensis)* were discovered in Nevada in 2007 and have subsequently spread throughout the west. Zebra mussels (*Dreissena polymorpha*) were documented in California in 2008 and they have also been spreading throughout Western waters. NMDGF has recently adopted new rules to combat the spread of invasive mussels and other aquatic invasive species. In Texas, six lakes are infested with zebra mussels. At this time, Elephant Butte and Caballo Reservoirs are mussel-free.

3.10 Cultural Resources

Cultural resources refer to historic and prehistoric buildings, structures, sites, objects, districts, Indian sacred sites, and resources of tribal concern. Historic properties are the subset of cultural resources listed on or eligible for listing on the National Register of Historic Places. The study area or area of potential effects for cultural resources includes Elephant Butte and Caballo Dams and Reservoirs, the Rio Grande floodplain between the two reservoirs, and the Rio Grande below Caballo Dam to the El Paso-Hudspeth County line.

3.10.1 Regulatory Framework

The principal Federal law addressing cultural resources is the NHPA (54 USC 306108), formerly known as Section 106. Its implementing regulations are found at 36 CFR 800. These require Federal agencies to take into account the effects of their actions on historic properties and to allow the Advisory Council on Historic Preservation an opportunity to comment. Executive Order 13007 requires consultation with Indian tribes regarding Indian sacred sites. The executive memorandum from the White House of April 29, 1994, requires government-to-government consultation on issues of tribal concern that may include cultural resources.

3.10.2 Existing Conditions

Listed historic properties in the area of potential effects of this undertaking include Elephant Butte Dam, the diversion dams, and the Franklin Canal. Other historic properties are the Garfield Lateral (LA-111726), Pittsburg Placer Mine (LA-13557), a Mogollon pithouse site (LA-2806), and an Apache battle site (LA-132559). Class III surveys of the Elephant Butte and Caballo Reservoirs were conducted in 1998 and 1999 and there are archaeological resources in the reservoir pools (Reclamation 2013a).

As part of the tribal consultation supporting the SEA, the Mescalero Apache Tribe expressed concerns with native plants growing along the irrigation canals in the service areas of EBID and EPCWID. The Mescalero Tribe collects plant material for cultural purposes.

For this undertaking, Reclamation consulted with the New Mexico State Historic Preservation Officer and they concurred with Reclamation's determination of "no historic properties affected" (Appendix D). In addition, Reclamation consulted with the Mescalero Apache Tribe and Ysleta del Sur, but they did not identify any resources or issues of concern.

3.11 Indian Trust Assets

Indian trust assets (ITAs) are legal interests in property held in trust by the U.S. for Federally-recognized Indian tribes or individual Indians.

3.11.1 Regulatory Framework

Management of ITAs is based on the several policies:

- Secretarial Order No. 3175, Departmental Responsibilities for Indian Trust Resources
- Secretarial Order No. 3206, American Indian Tribal Rights, Federal-Tribal Trust Responsibilities, and the ESA
- Secretarial Order No. 3215, Principles for the Discharge of the Secretary's Trust Responsibility
- Departmental Manual 512 DM Chapter 2, Departmental Responsibilities for Indian Trust Resources
- Indian Policy of Reclamation

3.11.2 Data Sources

No ITAs have been identified in the project area through consultation with Indian tribes or the Bureau of Indian Affairs.

3.12 Socioeconomics

The study area for socioeconomics includes Doña Ana and Sierra Counties, New Mexico, and El Paso and Hudspeth Counties, Texas. A small portion of Elephant Butte Reservoir is in Socorro County; however, no RGP-irrigated lands are in this county so it is not included in the socioeconomic study area. Recreation facilities associated with Elephant Butte Reservoir are in Sierra County.

3.12.1 Regulatory Framework

The NEPA and its implementing regulations are the authorities requiring analysis of socioeconomics.

3.12.2 Data Sources

Data sources include the U.S. Department of Commerce, Bureau of Economic Analysis (2014, 2015)), U.S. Department of Labor (2015), Census of Agriculture (USDA 2014), U.S. Department of Commerce Bureau of Economic Analysis (2015), and IMPLAN (2013).

3.12.3 Existing Conditions, Farm Employment and Income

Indicators include employment, labor income, and output. According to the U.S. Department of Commerce, Bureau of Economic Analysis, Regional Economic Accounts (2014), during the years from 1970 to 2014, farm employment in the four counties shrank from 5,230 to 4,792 jobs, an 8.4 percent decrease, while non-farm employment grew from 174,608 to 510,948 jobs, a 192.6 percent increase. In 2014, Hudspeth County, Texas had the largest percent of total farm employment (11.9 percent), and El Paso County, Texas had the smallest (0.23 percent).

From 1970 to 2014, farm earnings grew from $141.0 million to $171.6 million, a 21.6 percent increase, while non-farm earnings grew from $7,114.2 million to $22,993.0 million, a 223.2 percent increase. In 2014, Hudspeth County, Texas had the largest percent of total earnings from farm earnings (11.52 percent), and El Paso County had the smallest (0.04 percent).

From 1970 to 2014, net income, including corporate farms, grew from $77.6 million to $84.2 million, an 8.5 percent increase. During this period, cash receipts from crops grew from $214.3 million to $301.7 million, a 40.8 percent increase.

3.12.4 Existing Conditions, Industry Output

Industry output or sales represent the value of goods and services produced by businesses within a sector of the economy. The New Mexico study area (Doña Ana and Sierra Counties) had $12.1 billion in industry output. The Texas study area (El Paso and Hudspeth Counties) had $2.866.6 billion in industry output. The service sectors make up the largest percentage of industry sales in both study areas. Non-service-related industries make up the second largest portion of total output. Agriculture makes up 4.4 percent and 0.9 percent of total output in the New Mexico and Texas study areas, respectively. Table 3-4 summarizes the percent of output by industry.

Table 3-4 Percent of total output by industry

	Doña Ana and Sierra Counties, New Mexico	El Paso and Hudspeth Counties, Texas
Non-Service Industries	**28.8%**	**44.2%**
Agriculture, Forestry, Fishing, and Hunting	4.4%	0.9%
Mining	0.3%	5.8%
Utilities	2.9%	2.3%
Construction	7.4%	6.1%
Manufacturing	13.8%	29.1%
Service Industries	**54.1%**	**49.6%**
Wholesale trade	2.4%	5.4%
Retail trade	5.3%	4.2%
Transportation and warehousing	2.7%	3.5%
Information	2.9%	3.6%
Finance and insurance	3.7%	5.6%
Real estate and rental	10.6%	7.7%
Professional, scientific, and technical services	7.1%	5.8%
Management of companies	0.1%	0.9%
Administrative and waste services	2.4%	2.4%
Educational services	0.4%	0.5%
Health and social services	9.3%	4.8%
Arts, entertainment, and recreation	0.9%	0.5%
Accommodation and food services	3.8%	2.5%
Other services	2.6%	2.2%
Government	**17.1%**	**6.2%**
Government and other	17.1%	6.2%

Source: IMPLAN (2013).

Table 3-5 Farmland by type by county, 2012

Farmland	Doña Ana	Sierra	El Paso	Hudspeth
Number of farms	2,184	256	657	167
Land in farms (acres)	659,970	1,250,136	209,393	2,251,109
Average farm size (acres)	302	4,883	319	13,480
Approximate land area (acres)	2,437,000	2,674,533	648,206	2,925,329
Approximate percent of land area in farms	27.1	46.7	32.3	77

Source: U.S. Department of Agriculture, National Agricultural Statistics Service, Census of Agriculture (2014b).

Table 3-6 Number of farms by type and county, 2012

Farms by type	Doña Ana	Sierra	El Paso	Hudspeth
All Farms	2184	256	657	167
Oilseed & grain	14	0	1	0
Vegetable & melon	64	9	0	4
Fruit & nut tree	1310	24	193	0
Greenhouse, nursery	29	0	2	3
Other crop	356	67	225	52
Beef cattle ranch, farm	123	110	57	74
Animal, all types	288	46	179	34
Percent of Total				
Oilseed & grain	0.6%	0.0%	0.2%	0.0%
Vegetable & melon	2.9%	3.5%	0.0%	2.4%
Fruit & nut tree	60.0%	9.4%	29.4%	0.0%
Greenhouse, nursery	1.3%	0.0%	0.3%	1.8%
Other crop	16.3%	26.2%	34.2%	31.1%
Beef cattle ranch, farm	5.6%	43.0%	8.7%	44.3%
Animal, all types	13.2%	18.0%	27.2%	20.4%

Source: U.S. Department of Agriculture, National Agricultural Statistics Service, Census of Agriculture (2014b).

3.12.6 Agricultural Conditions, Farmland and Type

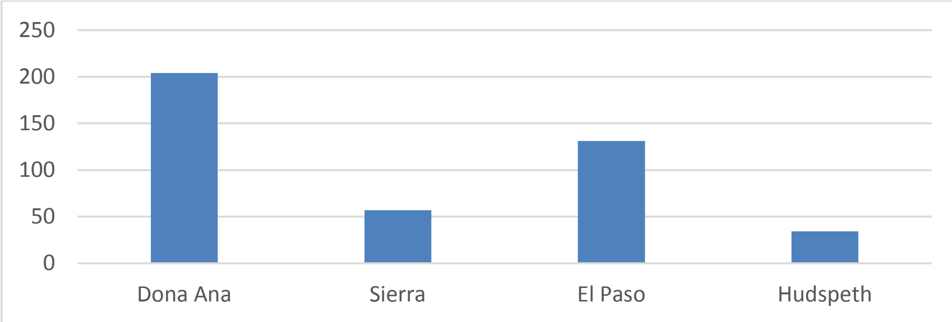
Table 3-5 presents statistics for agricultural conditions in the four-county study area in 2012. As shown, Hudspeth County had the largest percent of land area in farms (77 percent) while Doña Ana County had the smallest (27.1 percent). In the four-county study area, some 50.3 percent of the land was in farms in 2012. Table 3-6 presents the number and percentage of farms by type. As shown, in 2012, Hudspeth County has the smallest number or percent of oilseed and grain farming and the largest percent of beef cattle ranching and farming (44.3 percent) and Dona Ana County had the smallest percent in beef cattle ranching and farming (5.6 percent).

3.12.7 Population Growth and Income

According to the U.S. Department of Commerce, Bureau of Economic Analysis (2015) and as shown in Fig. 7, between 1970 and 2014, Doña Ana County, New Mexico had the largest percent change in population (204 percent) and Hudspeth County, Texas has the smallest (34 percent). During this period, the population of the four county study area increased by 141 percent and the population of the U.S. increased by 56 percent.

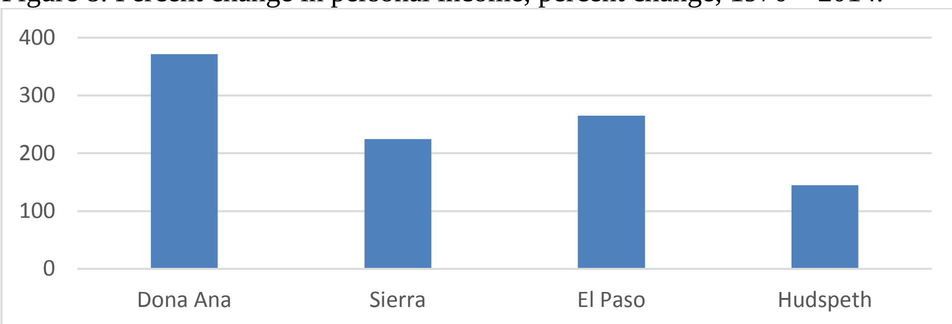
As shown in Fig. 8, between 1970 and 2014, Doña Ana County, New Mexico had the largest percent change in personal income (372 percent) and Hudspeth County, Texas had the smallest (145 percent). During this period, the change in personal income in the four county study area was 281 percent and the change in the U.S. was 182 percent.

Figure 7. Percent change in population by county, 1970 – 2014.



Source: U.S. Department of Commerce, Bureau of Economic Analysis (2015)

Figure 8. Percent change in personal income, percent change, 1970 – 2014.



Source: U.S. Department of Commerce, Bureau of Economic Analysis (2015)

3.13 Hydropower

3.13.1 Regulatory Framework

Energy requirements and conservation potential are required analyses under the CEQ's regulations at 40 CFR 1502.16.

3.13.2 Data Sources and Existing Conditions

The hydroelectric plant at Elephant Butte Dam generates power that is dependent on flow volume and head. Power production does not occur during the winter when RGP releases do not occur; hydropower calculations are based on the calculated average elevation from March to October only.

The Elephant Butte Powerplant has a rated head of 140 feet and is assumed to operate with 90 percent efficiency. Energy generation is calculated from reservoir elevation, with the rated head achieved at the maximum elevation over the study period and the potential energy conversion of 1.024 kilowatt-hours per acre-foot per foot of head. Calculated production based on the average March to October monthly elevation and release data for 2014 is 3 percent below the actual powerplant production of 13.4 gigawatts per hour (Gwh) reported by Reclamation (2015b).

3.14 Recreation

3.14.1 Regulatory Framework

The NEPA and its implementing regulations are the primary authorities requiring analysis of economic resources, including contributions of the travel and tourism sector to the regional economy.

3.14.2 Data Sources

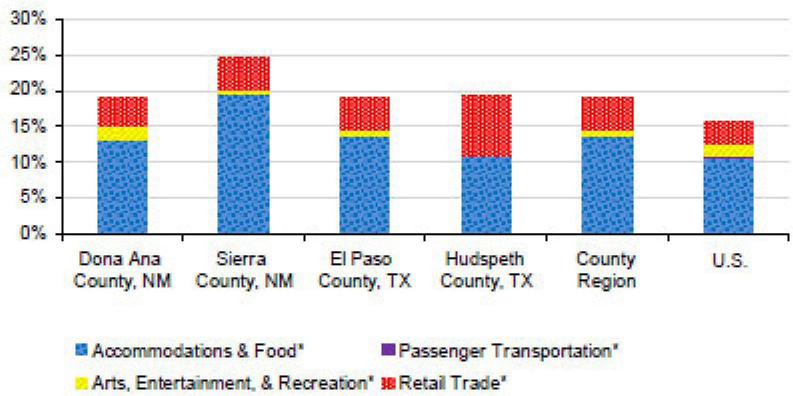
Data on recreation, or travel and tourism, are from the U.S. Department of Commerce, Census Bureau (2015b).

3.14.3 Existing Conditions

In 1998, travel and tourism represented 16 percent of total employment in the four counties. By 2013, travel and tourism represented 19 percent of total employment. From 1998 to 2013, travel and tourism employment grew from 36,584 to 51,346 jobs, a 40.4 percent increase (U.S. Department of Commerce, Census Bureau 2015b).

In 2014, Fig. 9 shows that Sierra County, New Mexico had the largest percent of total jobs in industries that include travel and tourism. In 2014, accommodations and food was the largest component of travel and tourism-related employment (13.6 percent of total jobs) in the four county study area.

Figure 9. Travel and tourism industries by county (percent of total private employment), 2014.



Source: U.S. Department of Commerce, Census Bureau (2015b)

3.15 Environmental Justice

3.15.1 Regulatory Framework

Executive Order 12898, Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations, directs Federal agencies to identify and address disproportionately high and adverse effects of its programs and activities on minority and low-income populations.

3.15.2 Data Sources

Guidelines provided by the CEQ (1997) and the Federal Interagency Working Group (2016) indicate minority communities may be defined where minorities comprise more than 50 percent of the population. Minorities include people who self-identify as Hispanic, Black or African-American, American Indian, Asian, Native Hawaiian, or some other race alone or combined. In this FEIS, the study area is the four counties, Doña Ana, Sierra, El Paso, and Hudspeth. The CEQ and Federal Interagency Working Group (2016) guidelines indicate that low-income communities may be defined following the Office of Management and Budget's Directive 14 poverty thresholds which vary by family size.

3.15.3 Low-income Populations

Table 3-7 presents the number and percent of people living in poverty during the 2010-2014 period. While none of the counties had half of their population living below the poverty threshold, based on a comparison of the percent of individuals living below the poverty threshold to the total county percentage (24.3 percent), Doña Ana County had slightly more persons living in poverty (27.8 percent), while Hudspeth County had the highest estimated percent of persons living below the poverty threshold (43.2 percent).

For families, 20.6 percent of the County families were living below the poverty threshold. Doña Ana County had slightly more than that (21.8 percent) and Hudspeth County had the highest estimated percent of families living below the poverty threshold (33.8 percent). These statistics define Doña Ana and Hudspeth Counties as environmental justice communities based on their comparatively high percentages of low-income persons or families.

Table 3-7 Poverty by county, 2010-2014

	Doña Ana	Sierra	El Paso	Hudspeth
People	207701	11486	809165	3017
Families	51778	2467	194230	742
People below poverty	57837	2037	189586	1303
Families below poverty	11304	235	39622	251
Percent of Total				
People below poverty	27.8	17.7	23.4	4302
Families below poverty	21.8	9.6	20.4	33.8

Source: U.S. Department of Commerce, Census Bureau, American Community Survey Office. (2015a). Key: Calculated using average ACS annual surveys during 2010-2014.

3.15.4 Minority Populations

In the 2009-2014 period, Table 3-8 shows Doña Ana, El Paso, and Hudspeth Counties had more than 50 percent of the population self-identifying as Hispanic or Latino. Hispanic or Latino refers to a cultural identification, not a race. In the 2009-2014 period, El Paso County, Texas had the highest estimated percent of the population that self-identify as Hispanic or Latino of any race (81.4 percent). This makes these three counties environmental justice communities.

Table 3-8 Minority populations by county, 2009- 2014

	Doña Ana	Sierra	El Paso	Hudspeth
Total Population	212,942	11,774	823,862	3,344
Hispanic of any race	141,087	3,394	670,946	2,634
White alone	62,649	7,929	110,287	671
Black alone	3,223	26	24,393	23
American Indian alone	1,702	120	2,177	0
Asian alone	2,291	113	8,331	16
Pacific Islander alone	12	0	1,014	0
Some other race	154	366	697	0
Two or more races	1,824	192	6,017	0
Percent of Total				
Hispanic of any race	66.3	28.8	81.4	78.8
White alone	29.4	67.3	13.4	20.1
Black alone	1.5	0.2	3	0.7
American Indian alone	0.8	1	0.3	0
Asian alone	1.1	1	1	0.5
Pacific Islander alone	0	0	0.1	0
Some other race	0.1	0	0.1	0
Two or more races	0.9	1.6	0.7	0

Source: U.S. Department of Commerce, Census Bureau, American Community Survey Office (2015a.)

4 Environmental Consequences

This FEIS is not intended to review the existence of the RGP or its historical operations; the focus is on how the alternatives described in Chapter 2 might change the water resources, biological, cultural, and socioeconomic resources in the study area. The temporal scope of the analysis and the proposed action extends to 2050. As such, the analyses in this chapter are based on modeling of RGP operations under each alternative through 2050 using an integrated hydrologic and water operations model. Model results are subsequently used as inputs to the evaluation of potential changes to other resources. Modeling of future RGP operations incorporates assumptions regarding future climatic and hydrologic conditions, cropping and irrigation practices, and M&I water demands. This chapter begins with a summary of the hydrologic model developed to assess the effects of the alternatives on water resources.

4.1 Water Resource Modeling Methods and Assumptions

Analyses of potential environmental consequences presented in this chapter are based on simulations of future RGP operations through the year 2050, including the storage, release, and delivery of surface water for beneficial use to EBID, EPCWID, and to Mexico under the Convention of 1906. These simulations were carried out using the Rincon and Mesilla Basins Hydrologic Model (RMBHM), as described in this section and Appendix C.

As discussed in Chapter 1, previous studies indicate a strong interaction between the Rio Grande and underlying groundwater aquifers, particularly in the Rincon and Mesilla basins (Conover 1954, Hanson et al. 2013, Haywood and Yager 2003, SSPA 2007). Groundwater pumping in the Rincon and Mesilla Basins results in depletion (capture) of surface-water supplies, including increased seepage losses from the Rio Grande as well as decreased drainage and return flows from irrigated lands. Depletion of RGP surface-water supplies, in turn, increases the amount of water that must be released from storage to meet delivery orders from EBID, EPCWID, and Mexico, and ultimately reduce the amount of RGP surface water that can be delivered to project diversion points (headings). Conversely, RGP operations affect the timing, distribution, and volume of groundwater recharge that occurs as seepage from the Rio Grande and unlined canals and laterals and as deep percolation of applied irrigation water. Simulation of future RGP operations therefore requires an integrated modeling approach capable of representing RGP operations, groundwater demand and use, and groundwater/surface-water interactions between Caballo Dam and the RGP's downstream-most diversion point at International Dam.

The RMBHM was developed by Reclamation in collaboration with USGS to allow for simulation of RGP operations under the five alternatives described in Chapter 2, while accounting for the role of groundwater/surface-water interactions on RGP operations and surface-water and groundwater resources. The RMBHM builds on previous hydrologic models of the Rincon and Mesilla Basins (SSPA 2007) and the USGS (Hanson et al. 2013). The RMBHM uses the One-Water Hydrologic Flow Model (MF-OWHM; Hanson et al. 2013), an integrated hydrologic modeling software based on the USGS Modular Groundwater Model, MODFLOW. To simulate RGP operations under each alternative, the MF-OWHM was enhanced with additional software features. These features, developed and implemented by Reclamation in collaboration with the USGS (Ferguson et al. 2014), allow for dynamic simulation of storage, allocation, release, and diversion of RGP surface water supplies according to specified allocation and accounting procedures.

The RMBHM is used to simulate RGP operations and corresponding surface-water and groundwater resources under each alternative, including surface water storage in Elephant Butte and Caballo Reservoirs; allocations to EBID, EPCWID, and Mexico; releases from Caballo Dam; and diversions to EBID, EPCWID, and Mexico at their respective diversion points (headings). A spreadsheet post-processing tool was subsequently used to calculate the maximum volume of San Juan–Chama Project water in Elephant Butte Reservoir under each alternative on a monthly basis. All alternatives were simulated under a common set of future climatic and hydrologic conditions. Model results were post-processed and compiled to facilitate comparison of RGP operations and surface water and groundwater resources under the alternatives.

Details of the RMBHM are provided in Appendix C, Hydrology Technical Memo. Model configuration and inputs to RMBHM for the FEIS are summarized below, along with verification of RMBHM with respect to simulation of historical RGP operations. Assumptions regarding future climatic and hydrologic conditions, cropping and irrigation practices, and municipal and industrial water demands and uses are also summarized below.

4.1.1 Model Configuration

Model configuration refers to the extent and discretization of the simulated area (spatial domain) and simulation period (temporal domain), as well as the specified physical and hydraulic properties (constant parameters) of the Rincon and Mesilla Basins. The spatial domain of RMBHM extends from Caballo Dam at the northern end of the Rincon Valley to below American Dam at the southern end of the Mesilla Valley. The spatial domain is discretized using a uniform horizontal grid, with each grid cell encompassing 0.25 miles by 0.25 miles (1320 feet by 1320 feet, equal to 40 acres), and five vertical layers of varying thickness. The spatial domain and discretization used by RMBHM are identical to previous models (SSPA 2007) and USGS (Hanson et al. 2013).

For the FEIS, the temporal domain of RMBHM extends from the start of the 2007-2008 non-irrigation season (November 1, 2007) through the end of the 2050 irrigation season (October 31, 2050). There are 43 years in the simulation. Each simulated year is divided into a non-irrigation season from November through February (120.25 days) and an irrigation season from March through October (245 days). Each season is simulated using approximately monthly time step, with four time-steps of equal length during each non-irrigation season and eight time-steps of equal length during each irrigation season. Model results are output for 516 approximately monthly time steps. Representation of the simulation period based on irrigation and non-irrigation seasons is consistent with previous models (SSPA 2007) and USGS (Hanson et al. 2013); however, previous models used four time steps of varying length for each season rather than the monthly time steps used by RMBHM.

RMBHM requires constant parameters representing physical and hydraulic properties throughout its spatial domain, including subsurface properties (e.g., aquifer hydraulic conductivity, specific storage, and yield), channel properties (e.g., hydraulic conductivity of channel beds, channel slope and geometry, and channel roughness), and vegetation-related parameters (e.g., soil properties, root profiles). RMBHM also requires parameters related to irrigation practices, including on-farm irrigation efficiency. The majority of constant parameters used in RMBHM are identical to those used in the previous model by USGS (Hanson et al. 2013). Parameters related to subsurface and channel bed hydraulic conductivities, aquifer specific storage and specific yield, capillary fringe depth, and on-farm irrigation efficiency were adjusted on a trial-and-error basis during model evaluation to provide better agreement between simulated and observed reservoir storage, releases, and diversions as summarized in Appendix C.

4.1.2 Model Inputs

Model inputs refer to specified time-varying values representing hydrologic, climatic, and anthropogenic stressors to the surface-water and groundwater systems over the simulated area. Hydrologic stressors in RMBHM include surface water inflows to RGP storage. Climatic stressors include reservoir precipitation and evaporation rates and climate factors affecting irrigation demands (e.g., precipitation and temperature). Anthropogenic stressors include human factors affecting irrigation demands (e.g., cropping patterns and irrigated acreage), as well as on-farm irrigation efficiency of agricultural lands, M&I groundwater pumping rates and locations, and discharge of treated effluent from municipal wastewater treatment facilities.

In addition to hydrologic, climatic, and anthropogenic stressors, the storage and relinquishment of Rio Grande Compact credit water in Elephant Butte Reservoir is represented as a time-varying input. The amount of water available for allocation and release by the RGP is equal to the total RGP storage less any non-project water in storage, including Rio Grande Compact credit water. The amount of credit water in Elephant Butte Reservoir at any given time is determined according to Rio Grande Compact accounting procedures, which are not represented in RMBHM. The volume of compact credit water in Elephant Butte Reservoir must therefore be specified for each time step as an input to RMBHM. Certain provisions of the Rio Grande Compact may affect reservoir storage and releases upstream of Elephant Butte Reservoir—and thus inflows to Elephant Butte Reservoir—when RGP storage falls below a specified threshold. RMBHM does not consider the potential feedbacks under the Rio Grande Compact between RGP operations, storage in Elephant Butte Reservoir, and reservoir operations upstream of Elephant Butte Reservoir.

The simulation period for the FEIS extends through November 1, 2050. Model inputs are therefore based on projected future conditions, rather than observed historical conditions. It is not possible to reliably predict the year-to-year and month-to-month evolution of climate and hydrologic conditions through the end of the simulation period, such as the timing, duration, and severity of wet and dry periods. Similarly, it is not possible to reliably predict future cropping and irrigation practices or changes in future municipal, industrial and domestic (collectively referred to as M&I) water demands. Therefore, model inputs for the FEIS were based on a combination of recent historical conditions and projections of effects of future climate change.

Model inputs representing hydrologic and climate stressors over the simulation period were obtained from previous analyses carried out by Reclamation and others as part of the West Wide Climate Risk Assessment (WWCRA; Reclamation 2011a, 2011b) and Upper Rio Grande Impact Assessment (URGIA; Reclamation 2013d). Projections of monthly precipitation and temperature throughout the simulation area were obtained from downscaled projections of future climate developed as part of WWCRA (see Reclamation 2011a, 2011b). Projections of monthly inflows to Elephant Butte Reservoir and monthly reservoir precipitation and evaporation were obtained from simulations carried out for URGIA with the Upper Rio Grande Simulation Model (URGSim; Roach 2007). Analyses of future climate change and its impacts on surface water supplies and management in the upper Rio Grande Basin carried out by WWCRA and URGIA are based on a set of 112 projections of future climate conditions. Three sets of model inputs were developed to represent the range of projected climate and hydrologic conditions over the simulation period, including one representing the drier end of the projected range, one representing the wetter end, and one representing the central tendency (median). Climate projections consistently indicate drier conditions over the Rio Grande Basin over the simulation period; as a result, the average annual inflow to Elephant Butte Reservoir over the simulation period is less than the observed average annual inflow over the past several decades, even under the scenario representing the wetter end of the projected range of future conditions. Additional details regarding model inputs representing future climate and hydrologic conditions are provided in Appendix C and references therein.

Model inputs representing future M&I water uses were based on recent estimates of M&I groundwater pumping within the simulated area. All M&I demand within the simulated area is met by groundwater. Estimates of M&I groundwater pumping exist through 2004 (SSPA 2007) and were subsequently updated through 2009 by USGS (Hanson et al. 2013). For the FEIS, model inputs representing future M&I groundwater pumping were developed based on average annual M&I pumping over the period 2000-2009. See Section 4.1.4 for additional discussion of assumptions regarding future M&I water uses.

Lastly, model inputs representing future irrigation demands throughout the simulated area were developed based on recent estimates of consumptive irrigation requirements[7] for the water year 2000 irrigation season, adjusted based on projected changes in reference evapotranspiration (ET_0) and effective precipitation. Projected changes in ET_0 and effective precipitation were calculated from projected monthly precipitation and temperature from the three climate projections selected for the FEIS. Additional details regarding model inputs representing future irrigation demands are provided in Appendix C. See Section 4.1.4 for additional discussion of assumptions regarding future irrigation demands.

4.1.3 Model Evaluation

The suitability of RMBHM for simulating RGP operations and their interaction with surface-water and groundwater resources in the Rincon and Mesilla Valleys was evaluated by simulating RGP operations under historical hydrology, climate, and cropping conditions for the period 1960-2009 and comparing simulation results to observed historical operations during this period. Historical hydrology and climate conditions were represented through time-varying model inputs, including historical inflows to Elephant Butte Reservoir, historical reservoir precipitation and evaporation rates, and historical crop irrigation requirement computed based on historical meteorology, crop distribution, and irrigated acreage data. For evaluation purposes, historical project operations were represented by implementing a consistent set of project allocation and accounting procedures representative of historical operations for the period 1990-2006. It should be noted that RMBHM uses a fixed set of operating rules over the duration of the evaluation period (1960-2009), whereas actual operating procedures varied over this period. Simulated operations are therefore not expected to perfectly match historical operations.

Model results were compared to historical records of project storage, releases, diversions, and flow in the Rio Grande below Caballo Dam and at El Paso, and to previous estimates of project surface-water deliveries and groundwater deliveries for supplemental irrigation in the Rincon and Mesilla Valleys. Project operations simulated by RMBHM closely match historical operations. As illustrated in Fig. 10, simulated total project storage is well correlated with observed historical storage ($R^2 = 0.94$) and exhibits little systematic bias. Similarly, Fig. 11 shows that simulated annual releases from Caballo Dam also agree well with observed historical releases. The simulated average annual project release is within one percent of the historical average, and the simulated average annual total project diversion from the Rio Grande is within five percent of the historical average. Simulated surface-water and groundwater deliveries to irrigated lands in the Rincon and Mesilla valleys also agree well with previous estimates (SSPA 2007). Strong agreement of RMBHM with historical records and previous modeling studies suggests that RMBHM accurately represents the key operational and hydrologic factors that drive surface-

[7] The quantity of irrigation water, exclusive of precipitation, stored soil moisture, or groundwater that is required consumptively for crop production.

water and groundwater management and use in the Rincon and Mesilla Basins. See Appendix C for additional details.

Figure 10. Observed and simulated monthly total project storage in Elephant Butte and Caballo Reservoirs (acre-feet), 1960-2010.

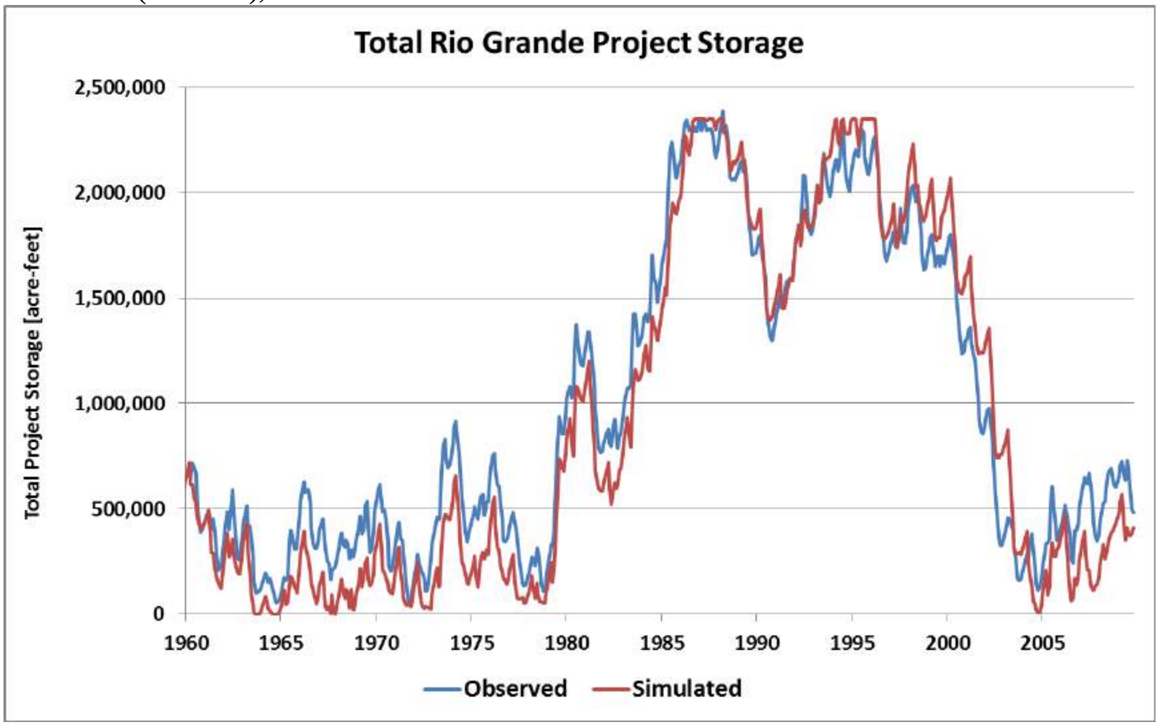
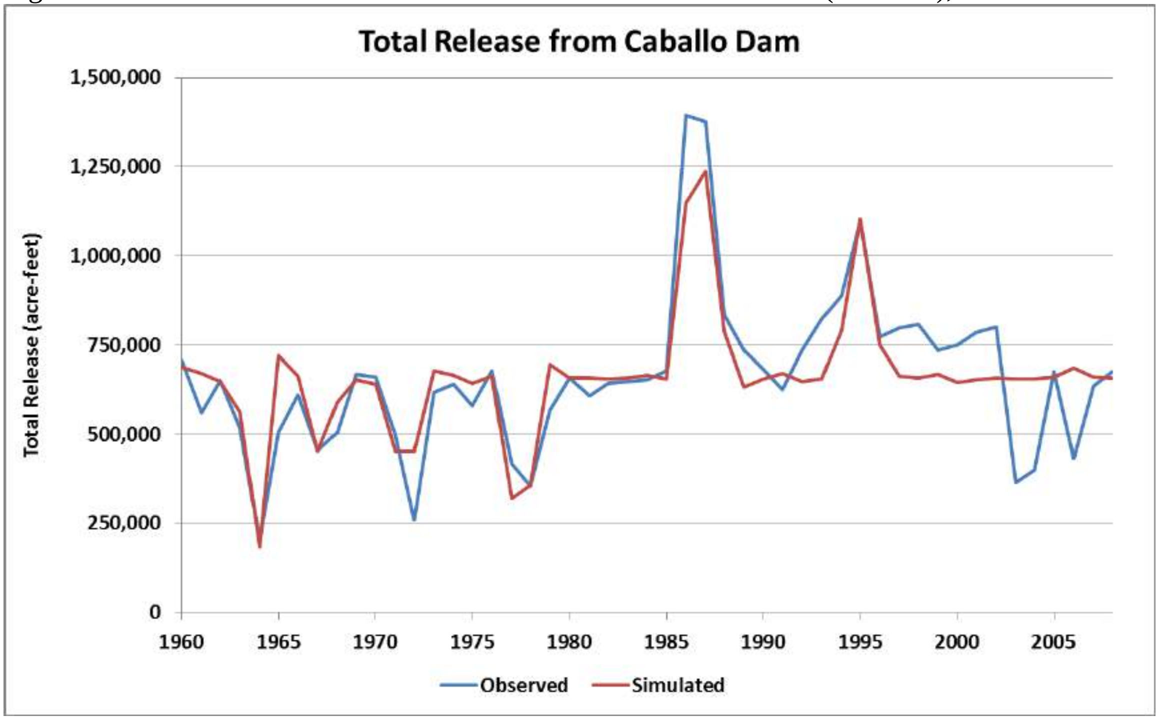


Figure 11. Observed and simulated annual release from Caballo Dam (acre-feet), 1960-2010.



4.1.4 Simulation of Alternatives

Each alternative evaluated in this FEIS was simulated by modifying the portion of the RMBHM source code that computes allocations to EBID, EPCWID, and Mexico, including calculation of annual allocations as well as carryover allocations where applicable. All other aspects of the RMBHM source code, configuration, and inputs are identical across all alternatives. Modifications implemented to simulate each alternative are summarized in Table 4-1. Additional discussion of modeling methods and assumptions is provided in Appendix C.

4.1.5 Modeling Assumptions

The simulation period for the FEIS extends through November 1, 2050. As discussed in Section 4.1.2, it is not possible to reliably predict the evolution of climate and hydrologic conditions, cropping and irrigation practices, M&I water uses, and other stressors through the end of the simulation period. Simulation of future RGP operations therefore requires reasonable assumptions regarding future conditions within the simulated area.

Modeling assumptions were consistent across all alternatives. Key assumptions used in developing model inputs representing future climate and hydrologic conditions, crop irrigation requirements, and M&I water use in Rincon and Mesilla Valleys are summarized below. Additional modeling assumptions are discussed in Appendix C.

Table 4-1 Simulation of FEIS alternatives using RMBHM

Alter-native	Alternative Name	Alternative Description	Summary of Modifications to RMBHM
1	Preferred Alternative, Continuation of OA and San Juan–Chama Project Storage	Continue to implement the OA and continue to store up to 50,000 acre-feet of San Juan–Chama Project (SJCP) water in Elephant Butte Reservoir.	Calculation of annual allocations to EBID and EPCWID incorporate diversion ratio adjustment. Calculation of total allocations to EBID and EPCWID incorporate carryover accounting. Calculation of maximum SJCP storage calculated via post-processing.
2	No San Juan–Chama Project Storage	Continue to implement the OA but do not store SJCP water in Elephant Butte Reservoir.	Same as Alternative 1, except that SJCP storage is equal to zero (eliminates SJCP storage).
3	No Carryover	Implement only 1 of the 2 components of the OA and continue to store up to 50,000 acre-feet of SJCP water in Elephant Butte Reservoir.	Same as Alternative 1, except that RMBHM source code modified to exclude carryover accounting from calculation of total allocations to EBID and EPCWID.
4	No Diversion Ratio Adjustment	Implement only 1 of the 2 components of the OA and continue to store up to 50,000	Same as Alternative 1, except that RMBHM source code modified to exclude the diversion ratio adjustment

Alter-native	Alternative Name	Alternative Description	Summary of Modifications to RMBHM
		acre-feet of SJCP water in Elephant Butte Reservoir.	from calculation of annual allocations to EBID and EPCWID.
5	No Action Alternative, Prior Operating Practices	Revert to operations before the OA (as summarized for the modeling) into the future.	Same as Alternative 1, except that RMBHM source code modified to exclude the diversion ratio adjustment from calculation of annual allocations to EBID and EPCWID and to exclude carryover accounting from calculation of total allocations to EBID and EPCWID.

4.1.5.1 Climate and Hydrology Inputs

As summarized in Section 4.1.2, model inputs representing future climate and hydrologic conditions were obtained from previous analyses of projected climate and hydrologic conditions (Reclamation 2011a, b; 2013c). Previous analyses consider the range of projected climate change over the Rio Grande basin from its headwaters to Elephant Butte Reservoir and corresponding changes in surface water supplies and management. Projected climate conditions were developed based on an ensemble of 112 statistically downscaled climate projections. Projected surface water supplies and management were then developed by using the Variable Infiltration Capacity (VIC) hydrology model to simulate changes in runoff and streamflow and the Upper Rio Grande Simulation Model (URGSim) to simulate corresponding changes in surface water management and use. In addition to reservoir operations, URGSim represents interstate water delivery obligations and accounting under the Rio Grande Compact. While there is considerable uncertainty regarding future climate and hydrologic conditions and water management in the simulated area, the projections developed by WWCRA and URGIA constitute the best available information on future inflows to Elephant Butte Reservoir and Compact credit water in Elephant Butte Reservoir over the simulation period.

It should be noted that under Article VII of the Rio Grande Compact, the volume of water in RGP storage could influence the operation of upstream reservoirs and thus the inflow to Elephant Butte Reservoir. RMBHM, which was developed for this FEIS, does not simulate this interaction between RGP storage and inflow to Elephant Butte Reservoir under the Compact. As discussed in Section 3.2, interactions between RGP operations and water management and use upstream of Elephant Butte Reservoir are beyond the scope of this analysis. Furthermore, despite the availability of existing models representing surface-water management and use upstream of Elephant Butte Reservoir (e.g., URGWOM and URGSim), modifying these models to interact with RMBHM would require very significant technical efforts, including substantial involvement from the agencies who lead development of these models. Reclamation, in consultation with the cooperating agencies, determined that such efforts are not necessary to accurately evaluate potential changes to resources resulting from implementation of the five alternatives.

4.1.5.2 Crop Irrigation Requirement Inputs

Model inputs representing future irrigation demands throughout the simulated area were developed based on estimates of crop irrigation requirement for the water year 2000 irrigation season. Crop irrigation requirements for each year of the simulation period were calculated by adjusting the year 2000 crop irrigation requirements to reflect projected changes in annual reference evapotranspiration (ET_0) and effective precipitation, where changes in ET_0 and effective precipitation were derived from projected monthly precipitation and temperature from the three climate projections selected for the FEIS. This approach implicitly assumes that irrigated acreage and cropping patterns over the duration of the simulation period remain consistent with water year 2000.

Previous studies have assumed that any shortage in RGP surface water supply relative to crop irrigation requirements in Rincon and Mesilla Valleys is made up for by the use of groundwater for supplemental irrigation (e.g., Appendix F of SSPA 2007). Under this assumption, widespread use of groundwater to supplement RGP surface water supplies precludes the need to fallow land or shift to lower water-use crop during periods of low surface water supply. Analysis of irrigated acreage in Rincon and Mesilla Valleys over the past several decades shows no relationship between irrigated acreage and RGP surface water supply. Similarly, year-to-year fluctuations in cropping patterns (percent of acreage in a given crop) exhibit no relationship with RGP surface water supply. Historical cropping and acreage data thus support the assumption that cropping decisions are primarily influenced by market drivers, rather than by RGP surface water supplies. As a result, it is not possible to reliably predict future changes in cropping patterns and irrigated acreage based on simulated changes in RGP supplies.

4.1.5.3 M&I Groundwater Pumping Inputs
While plans of the cities of Las Cruces and El Paso are discussed in Chapter 5 as cumulative actions with potential cumulative impacts, there is considerable uncertainty regarding future M&I water demands and use in the study area. As noted in Chapter 5 (Section 5.3.10), future M&I water demands or use will depend on population growth, economic development, and other factors or actions that are not reasonably foreseeable. Given the large uncertainties related to M&I water demands and use through the year 2050, model inputs representing groundwater pumping for M&I use were developed based on estimates of M&I groundwater pumping for the period 2000-2009. This assumption is consistent with the fact that despite significant population and economic growth over the past two decades, water conservation programs have reduced per capita water demands and resulted in little change in actual M&I water use over this period (Hanson et al. 2013, McCoy et al. 2007, SSPA 2007). This assumption is also supported by the possibility that any further increases in pumping could be offset by fallowing of agricultural land or other conservation measures.

4.1.6 Analysis and Presentation of Model Results in FEIS
Potential environmental consequences of each alternative are evaluated based on simulations of future RGP operations and corresponding surface-water and groundwater resources. RMBHM was used to simulate the effects of the alternatives over the 43-year simulation period (November 2007 to October 2050), including year-to-year fluctuations in hydrology and climate and resulting fluctuations in water supplies, demands, and operations. Detailed results are in Appendix C, Hydrology Technical Memorandum.

Sections 4.2 to 4.11 summarize data from Appendix C, presenting averages for each simulated water resource variable (RGP allocations, releases, diversions, deliveries, etc.). Tables 4-2 to 4-13 are organized such that each column presents a single alternative and each row presents a single climate scenario with three climate scenarios presented to characterize uncertainties in future RGP operations and surface water and groundwater resources. Differences between alternatives may be evaluated by comparing columns in these tables. Differences due to potential climate change may be evaluated by comparing row. In addition, effects of climate change may be evaluated as the difference in a given water resource variable or indicator between historical (observed) climate conditions and projected future climate conditions.

The three climate scenarios considered in the FEIS—the drier scenario (P25), central tendency or median scenario (P50), and wetter scenario (P75)—are all based on the best available projections of future climate and hydrologic conditions in the Rio Grande Basin and are each considered equally likely projections of future conditions. To assess impacts on special status species in Elephant Butte Reservoir, Reclamation used the wetter climate scenario. The wetter scenario represents a conservative worst case for the species and their habitat in the reservoir pool due to the impact of fluctuations of the water surface elevation and area, but the drier scenario would be the worst case for biological resources downstream of Caballo Dam.

4.2 Reservoir Storage

Total storage is the total volume of water (acre-feet) in Elephant Butte and Caballo Reservoirs at the end of each month. Project storage is the total volume of RGP water[8] in the reservoirs at the end of each month, excluding Rio Grande Compact credit water and San Juan–Chama Project water. Table 4-2 presents average monthly total storage by alternative and climate scenario. Table 4-3 presents average monthly storage in Elephant Butte Reservoir and Table 4-4 presents average monthly storage in Caballo Reservoir.

As shown, the FEIS alternatives are not likely to have a strong effect on reservoir storage. Differences in average monthly storage among the alternatives range from 38,421 to 44,360 acre-feet, while differences among future climate scenarios range from 175,224 to 193,452 feet. In other words, uncertainties in future climate conditions are significantly greater than the effect of implementing one or another alternative.

Table 4-2 Average monthly total storage (acre-feet) by alternative and climate scenario

	Alternative				
Climate	1	2	3	4	5
Drier	311,875	279,081	317,502	281,367	293,084
Central	483,445	455,233	493,743	465,907	483,425
Wetter	487,099	462,627	506,987	464,527	486,536

[8] Project storage is the combined capacity of Elephant Butte Reservoir and all other reservoirs actually available for the storage of usable water below Elephant Butte and above the first diversion to lands of the RGP, but not more than a total of 2,638,860 acre-feet (http://www.wrri nmsu.edu/wrdis/compacts/Rio-Grande-Compact.pdf).

Table 4-3 Average monthly Elephant Butte Reservoir storage (acre-feet) by alternative and climate scenario

	Alternative				
Climate	1	2	3	4	5
Drier	293,148	259,152	298,307	264,678	275,596
Central	449,822	419,547	458,839	433,580	449,601
Wetter	447,860	421,558	465,693	426,740	446,448

Table 4-4 Average monthly Caballo Reservoir storage (acre-feet) by alternative and climate scenario

	Alternative				
Climate	1	2	3	4	5
Drier	18,727	19,929	19,195	16,689	17,488
Central	33,624	35,686	34,904	32,327	33,825
Wetter	39,238	41,068	41,294	37,786	40,088

4.2.1 Alternative 1: Continued OA and San Juan–Chama Storage, Preferred Alternative

Under Alternative 1, Table 4-2 shows the average monthly total storage would be 483,445 acre-feet under the central tendency future climatic scenario. Alternative 1 would be almost identical to Alternative 5 (No Action) under central tendency or wetter conditions, but under drier conditions, the average monthly storage under Alternative 1 would be 18,791 acre-feet higher than Alternative 5 (No Action).

4.2.2 Alternative 2: No San Juan–Chama Project Storage

Under Alternative 2, the average monthly total storage would be 455,233 acre-feet under the central tendency climatic scenario. Alternative 2 would be 14,002 acre-feet, 28,192 acre-feet, or 23,909 acre-feet below Alternative 5 (No Action) under drier, central tendency, or wetter climatic conditions respectively.

4.2.3 Alternative 3: No Carryover Provision

Under Alternative 3, the average monthly total storage would be 493,743 acre-feet under the central tendency climate scenario. Alternative 3 would be 24,418 acre-feet, 10,318 acre-feet, or 20,451 acre-feet higher than Alternative 5 (No Action) under drier, central tendency, or wetter conditions respectively.

4.2.4 Alternative 4: No Diversion Ratio Adjustment

Under Alternative 4, the average monthly total storage would be 465,907 acre-feet under the central tendency climate scenario. Alternative 4 would be 11,716 acre-feet, 17,518 acre-feet, or 22,009 acre-feet below Alternative 5 (No Action) under drier, central tendency, or wetter conditions respectively.

4.2.5 Alternative 5: Prior Operating Practices, No Action Alternative

Under Alternative 5 (No Action), the average monthly total storage would be 483,425 acre-feet under the central tendency climate scenario. It would range from 311,875 to 447,099 acre-feet under drier to wetter climates.

4.3 Elephant Butte Reservoir Elevation

Because of the biological importance of the elevation of the water surface in Elephant Butte Reservoir, Table 4-5 provides the simulated average monthly water surface elevation in feet above sea level. As shown, the simulated maximum difference in average Elephant Butte Reservoir water surface elevation among the five alternatives is 7 to 9 feet, while the simulated maximum difference among the three future climate scenarios is 10 to 12 feet.

Table 4-5 Average monthly Elephant Butte Reservoir elevation (feet above sea level) by alternative and climate scenario

	Alternative				
Climate	1	2	3	4	5
Drier	4,316	4,307	4,316	4,313	4,315
Central	4,326	4,319	4,327	4,325	4,326
Wetter	4,325	4,319	4,327	4,324	4,325

4.3.1 Alternative 1: Continued OA and San Juan–Chama Storage, Preferred Alternative

Under Alternative 1, Table 4-5 shows the average monthly elevation of the water surface in Elephant Butte Reservoir would be 4,326 feet above sea level under the central tendency climatic scenario. Alternative 1 would be almost identical to Alternative 5 (No Action) under all climatic scenarios.

4.3.2 Alternative 2: No San Juan–Chama Project Storage

Under Alternative 2, the average monthly elevation would be 4,319 feet under the central tendency climatic scenario. Alternative 2 would be an average of 7 feet lower than Alternative 5 under central tendency climatic conditions or 8 feet under drier conditions. There would be no difference from Alternative 5 under wetter conditions.

4.3.3 Alternative 3: No Carryover Provision

Under Alternative 3, the average monthly elevation would be 4,327 feet under the central tendency climatic scenario. Alternative 3 would be 1 to 2 feet higher than Alternative 5 (No Action) under all climate scenarios.

4.3.4 Alternative 4: No Diversion Ratio Adjustment

Under Alternative 4, the average monthly elevation would be 4,325 feet under the central tendency climatic scenario. Alternative 4 would be 1 to 2 feet lower than Alternative 5 (No Action) under all climate scenarios.

4.3.5 Alternative 5: Prior Operating Practices, No Action Alternative

Under Alternative 5, the average monthly elevation would be 4,326 feet under the central tendency climatic scenario, 4,315 feet under the drier climate scenario and 4,325 under the wetter climate scenario.

4.4 Annual Allocation to EBID and EPCWID

Table 4-6 shows the simulated average annual allocations in acre-feet to the two districts by alternative and climate scenario. The maximum difference to EBID among the alternatives would be 91,665 acre-feet under drier conditions, 101,217 under central tendency conditions, and 90,915 acre-feet under wetter conditions. The maximum difference to EPCWID among the alternatives would be 64,668 acre-feet under drier conditions, 60,677 acre-feet under central tendency conditions, and 59,925 acre-feet under wetter conditions.

Table 4-6 Average annual allocation (acre-feet) to districts by alternative and climate scenario

District &			Alternative		
Climate	1	2	3	4	5
EBID					
Drier	176,988	176,988	207,180	230,319	268,652
Central	213,110	213,110	264,752	272,269	314,327
Wetter	271,315	271,315	298,875	320,104	362,229
EPCWID					
Drier	196,833	196,833	240,025	175,357	204,542
Central	224,049	224,049	267,973	207,296	239,317
Wetter	258,768	258,768	303,640	243,716	275,788

4.4.1 Alternative 1: Continued OA and San Juan–Chama Storage, Preferred Alternative

Under Alternative 1, the mean annual allocation to EBID would be 213,110 acre-feet under the central tendency climatic scenario. The mean annual allocation to EPCWID would be 224,049 acre-feet under the central tendency climatic scenario.

4.4.2 Alternative 2: No San Juan–Chama Project Storage

As shown in Table 4-6, Alternative 2 would be the same as Alternative 1.

4.4.3 Alternative 3: No Carryover Provision

Under Alternative 3, the mean annual allocation to EBID would be 264,752 acre-feet under the central tendency climatic scenario and 267,973 acre-feet to EPCWID.

4.4.4 Alternative 4: No Diversion Ratio Adjustment

Under Alternative 4, the mean annual allocation to EBID would be 272,269 acre-feet under the central tendency climatic scenario and 207,296 acre-feet to EPCWID .

4.4.5 Alternative 5: Prior Operating Practices, No Action Alternative

Under Alternative 5 (No Action), the mean annual allocation to EBID would be 314,327 acre-feet under the central tendency climatic scenario. The mean annual allocation to EPCWID would be 239,317 acre-feet under the central tendency climatic scenario.

4.5 Total Allocation to EBID and EPCWID

Table 4-7 shows the simulated average total allocation in acre-feet to the two districts by alternative and climate scenario. The total allocation to each district is calculated as the sum of its annual allocation and carryover allocation. The maximum difference to EBID among the alternatives would be 63,354 acre-feet under wetter conditions, 59,177 acre-feet under central tendency conditions, and 61,472 acre-feet under wetter conditions. The maximum difference to EPCWID among the alternatives would be 97,650 acre-feet under central tendency conditions, 97,352 acre-feet under wetter conditions, and 80,013 acre-feet under drier conditions.

Table 4-7 Average total allocation (acre-feet) to districts by alternative and climate scenario

District &	Alternative				
Climate	1	2	3	4	5
EBID					
Drier	222,539	222,539	207,180	278,015	268,652
Central	255,150	255,150	264,752	321,955	314,327
Wetter	335,499	335,499	298,875	410,996	362,229
EPCWID					
Drier	284,556	284,556	240,025	260,666	204,542
Central	336,967	336,967	267,973	310,152	239,317
Wetter	373,140	373,140	303,640	356,520	275,788

4.5.1 Alternative 1: Continued OA and San Juan–Chama Storage, Preferred Alternative

Under Alternative 1, the mean total allocation to EBID would be 255,150 acre-feet under the central tendency climatic scenario. The mean total allocation to EPCWID would be 336,967 acre-feet under the central tendency climatic scenario. The mean total allocation to EBID would range from 222,539 acre-feet under the drier climate scenario to 335,499 acre-feet under the wetter scenario. The mean total allocation to EPCWID would range from 204,542 acre-feet under the drier scenario to 275,788 acre-feet under the wetter climate scenario.

4.5.2 Alternative 2: No San Juan–Chama Project Storage

As shown in Table 4-7, Alternative 2 would be the same as Alternative 1.

4.5.3 Alternative 3: No Carryover Provision

Under Alternative 3, the mean total allocation to EBID would be 264,752 acre-feet under the central tendency climatic scenario. The mean total allocation to EPCWID would be 310,152 acre-feet under the central tendency climatic scenario.

4.5.4 Alternative 4: No Diversion Ratio Adjustment

Under Alternative 4, the mean total allocation to EBID would be 321,955 acre-feet under the central tendency climatic scenario. The mean total allocation to EPCWID would be 310,152 acre-feet under the central tendency climatic scenario.

4.5.5 Alternative 5: Prior Operating Practices, No Action Alternative

Under Alternative 5 (No Action), the mean total allocation to EBID would be 314,327 acre-feet under the central tendency climatic scenario with a range from 268,652 to 362,229 acre-feet under the drier to wetter climate scenarios respectively. The mean total allocation to EPCWID would be 239,317 acre-feet under the central tendency climatic scenario with a range from 204,542 to 275,788 acre-feet under the drier to wetter climate scenarios respectively.

4.6 Rio Grande Project Releases

Figure 11 shows that simulated releases from Caballo Dam agree well with observed historical releases. Table 4-8 shows the simulated average annual project release in acre-feet by alternative and climate scenario. The maximum difference to EBID among the alternatives would be 91,665 acre-feet under drier conditions, 101,217 acre-feet under central tendency climatic conditions, and 90,915 acre-feet under wetter conditions. The maximum difference to EPCWID among the alternatives would be 64,668 acre-feet under drier conditions, 60,677 acre-feet under central tendency climatic conditions, and 59,925 acre-feet under wetter conditions.

Table 4-8 Average annual RGP release (acre-feet) by alternative and climate scenario

	Alternative				
Climate	1	2	3	4	5
Drier	479,601	479,601	478,320	482,903	480,759
Central	529,170	529,170	525,808	531,229	527,421
Wetter	585,623	585,623	578,858	587,718	527,421

4.6.1 Alternative 1: Continued OA and San Juan–Chama Storage, Preferred Alternative

Under Alternative 1, Table 4-8 shows the central tendency annual project release would be 529,170 acre-feet under the central tendency climatic scenario and the total release would average 541,019 acre-feet.

4.6.2 Alternative 2: No San Juan–Chama Project Storage

As shown in Table 4-8, Alternative 2 would be the same as Alternative 1.

4.6.3 Alternative 3: No Carryover Provision

Under Alternative 3, the average annual project release would be 525,808 acre-feet under the central tendency climatic scenario and the total release would average 539,140 acre-feet.

4.6.4 Alternative 4: No Diversion Ratio Adjustment

Under Alternative 4, the average annual project release would be 531,229 acre-feet under the central tendency climatic scenario and the total release would average 543,089 acre-feet.

4.6.5 Alternative 5: Prior Operating Practices, No Action Alternative

Under Alternative 5 (No Action), the average annual project release would be 527,421 acre-feet under the central tendency climatic scenario and the total release would average 539,807 acre-feet.

4.7 Net Diversions

Table 4-9 shows the simulated average annual net diversions in acre-feet to the two districts by alternative and climate scenario. The simulations for EPCWID are for Rincon and Mesilla Valleys only. The maximum difference to EBID among the alternatives would be 49,426 acre-feet under wetter conditions, 49,165 acre-feet under central tendency conditions, and 41,220 acre-feet under drier conditions. The maximum difference to EPCWID among the alternatives would be 14,720 acre-feet under central tendency conditions, 12,794 acre-feet under drier conditions, and 7,678 acre-feet under wetter conditions.

Table 4-9 Average annual net diversion (acre-feet) to districts by alternative and climate scenario

District &	Alternative				
Climate	1	2	3	4	5
EBID					
Drier	148,818	148,818	154,454	190,038	189,864
Central	179,198	179,198	198,287	227,069	228,363
Wetter	223,271	223,271	217,316	266,742	256,654
EPCWID					
Drier	34,155	34,155	30,554	24,968	21,361
Central	40,262	40,262	34,805	29,491	25,543
Wetter	37,075	37,075	36,805	30,701	29,397

4.7.1 Alternative 1: Continued OA and San Juan–Chama Storage, Preferred Alternative

Under Alternative 1, the mean annual net diversion to EBID would be 148,818 acre-feet under the central tendency climatic scenario. The mean annual net diversion to EPCWID would be 40,262 acre-feet under the central tendency climatic scenario.

4.7.2 Alternative 2: No San Juan–Chama Project Storage

As shown in Table 4-9, Alternative 2 would be the same as Alternative 1.

4.7.3 Alternative 3: No Carryover Provision

Under Alternative 3, the mean annual net diversion to EBID would be 198,287 acre-feet under the central tendency climatic scenario. The mean annual net diversion to EPCWID would be 34,805 acre-feet under the central tendency climatic scenario.

4.7.4 Alternative 4: No Diversion Ratio Adjustment

Under Alternative 4, the mean annual net diversion to EBID would be 227,069 acre-feet under the central tendency climatic scenario. The mean annual net diversion to EPCWID would be 29,491 acre-feet under the central tendency climatic scenario.

4.7.5 Alternative 5: Prior Operating Practices, No Action Alternative

Under Alternative 5 (No Action), the mean annual net diversion to EBID would be 228,363 acre-feet under the central tendency climatic scenario. The mean annual net diversion to EPCWID would be 25,543 acre-feet under the central tendency climatic scenario.

4.8 Farm Surface Water Deliveries

Table 4-10 shows the simulated average farm surface water deliveries in acre-feet to the two districts by alternative and climate scenario. The simulations for EPCWID are for Mesilla Valley only. The maximum difference to EBID among the alternatives would be 31,194 acre-feet under wetter conditions, 26,728 under central tendency conditions, and 23,908 acre-feet under drier conditions. The maximum difference to EPCWID among the alternatives would be 2,259 acre-feet under drier conditions, 2,058 acre-feet under central tendency conditions, and 1,699 acre-feet under wetter conditions.

Table 4-10 Average farm surface water deliveries (acre-feet) to districts by alternative and climate scenario

District &	Alternative				
Climate	1	2	3	4	5
EBID					
Drier	66,053	66,053	70,101	89,961	88,532
Central	84,054	84,054	94,477	110,782	110,314
Wetter	101,217	101,217	99,232	130,426	123,473
EPCWID					
Drier	13,259	13,259	12,416	11,949	10,999
Central	15,954	15,954	15,029	14,964	13,896
Wetter	17,156	17,156	16,553	15,935	15,456

4.8.1 Alternative 1: Continued OA and San Juan–Chama Storage, Preferred Alternative

Under Alternative 1, the mean annual farm surface water delivery to EBID would be 84,054 acre-feet under the central tendency climatic scenario. The mean annual farm surface water delivery to EPCWID would be 15,954 acre-feet under the central tendency climatic scenario.

4.8.2 Alternative 2: No San Juan–Chama Project Storage

As shown in Table 4-10, Alternative 2 would be the same as Alternative 1.

4.8.3 Alternative 3: No Carryover Provision

Under Alternative 3, the mean annual farm surface water delivery to EBID would be 94,477 acre-feet under the central tendency climatic scenario. The mean annual farm surface water delivery to EPCWID would be 15,029 acre-feet under the central tendency climatic scenario.

4.8.4 Alternative 4: No Diversion Ratio Adjustment

Under Alternative 4, the mean annual farm surface water delivery to EBID would be 110,782 acre-feet under the central tendency climatic scenario. The mean annual farm surface water delivery to EPCWID would be 14,964 acre-feet under the central tendency climatic scenario.

4.8.5 Alternative 5: Prior Operating Practices, No Action Alternative

Under Alternative 5 (No Action), the mean annual farm surface water delivery to EBID would be 110,314 acre-feet under the central tendency climatic scenario. The mean annual farm surface water delivery to EPCWID would be 13,896 acre-feet under the central tendency climatic scenario.

4.9 Groundwater

Based on the assumptions described in Section 4-1 and Appendix C, Table 4-11 shows the simulated change in total groundwater storage in Rincon and Mesilla Valleys in acre-feet over the 43-year simulation period by alternative and climate scenario. The change in total groundwater storage is calculated as the difference in the total groundwater storage, summed over the simulated area of RMBHM, at the end of the simulation period compared to the start of the simulation period. The maximum difference among alternatives in the simulated change in groundwater storage would be 9,875 acre-feet under the wetter climate scenario, 5,513 acre-feet under the central tendency scenario, and 3,444 acre-feet under the drier scenario.

Table 4-11 Change in total groundwater storage (acre-feet) by alternative and climate scenario

	Alternative				
Climate	1	2	3	4	5
Drier	-56,632	-56,632	-56,162	-44,472	-46,575
Average	-29,470	-29,470	-28,055	-25,657	-23,957
Wetter	-2,277	-2,277	-4,361	937	-2,508

4.9.1 Alternative 1: Continued OA and San Juan–Chama Storage, Preferred Alternative

Under Alternative 1, the total volume of groundwater storage in Rincon and Mesilla Valleys would decline by 29,470 acre-feet between 2007 and 2050 under the central tendency climatic scenario. The total volume of groundwater storage would decline by 56,632 acre-feet under the drier scenario and by 2,277 acre-feet under the wetter scenario.

4.9.2 Alternative 2: No San Juan–Chama Project Storage

As shown in Table 4-11, Alternative 2 would be the same as Alternative 1.

4.9.3 Alternative 3: No Carryover Provision

Under Alternative 3, the total volume of groundwater storage in Rincon and Mesilla Valleys would decline by 28,055 acre-feet between 2007 and 2050 under the central tendency climatic scenario. The total volume of groundwater storage would decline by 56,162 acre-feet under the drier scenario and by 4,361 acre-feet under the wetter scenario.

4.9.4 Alternative 4: No Diversion Ratio Adjustment

Under Alternative 4, the total volume of groundwater storage in Rincon and Mesilla Valleys would decline by 25,657 acre-feet between 2007 and 2050 under the central tendency climatic scenario. The total volume of groundwater storage would decline by 44,472 acre-feet under the drier scenario and increase by 937 acre-feet under the wetter scenario.

4.9.5 Alternative 5: Prior Operating Practices, No Action Alternative

Under Alternative 5, the total volume of groundwater storage in Rincon and Mesilla Valleys would decline by 23,957 acre-feet between 2007 and 2050 under the central tendency climatic scenario. The total volume of groundwater storage would decline by 46,757 acre-feet under the drier scenario and by 2,508 acre-feet under the wetter scenario.

4.10 Farm Groundwater Deliveries

Irrigation requirements that are not satisfied by RGP surface water deliveries are assumed to be met through supplemental groundwater pumping. As a result, combined total delivery of RGP surface water and supplemental groundwater to RGP lands in the Rincon and Mesilla Valleys would be nearly identical under all alternatives. Table 4-12 shows the simulated average annual farm groundwater deliveries in acre-feet to the two districts by alternative and climate scenario. The simulations for EPCWID are for Rincon and Mesilla Valleys only. The maximum difference to EBID among the alternatives would be 31,194 acre-feet under wetter conditions, 26,728 acre-feet under central tendency conditions, and 23,908 acre-feet under drier conditions. The maximum difference to EPCWID among the alternatives would be 2,259 acre-feet under drier conditions, 2,058 acre-feet under central tendency conditions, and 1,699 acre-feet under wetter conditions.

Table 4-12 Average annual farm groundwater deliveries (acre-feet) to districts by alternative and climate scenario

District & Climate	Alternative 1	2	3	4	5
EBID					
Drier	243,662	243,662	239,489	217,637	219,276
Central	214,370	214,370	202,791	184,273	185,061
Wetter	194,619	194,619	197,481	161,595	169,660
EPCWID					
Drier	15,563	15,563	15,951	16,406	17,357
Central	11,850	11,850	12,486	12,533	13,607
Wetter	10,593	10,593	10,859	11,454	11,939

4.10.1 Alternative 1: Continued OA and San Juan–Chama Storage, Preferred Alternative

Under Alternative 1, the mean annual farm groundwater delivery (pumping of groundwater) to EBID would be 214,370 acre-feet under the central tendency climatic scenario. The mean annual farm groundwater delivery to EPCWID would be 11,850 under the central tendency climatic scenario.

4.10.2 Alternative 2: No San Juan–Chama Project Storage

As shown in Table 4-12, Alternative 2 would be the same as Alternative 1.

4.10.3 Alternative 3: No Carryover Provision

Under Alternative 3, the mean annual farm groundwater delivery to EBID would be 202,791 acre-feet under the central tendency climatic scenario. The mean annual farm groundwater delivery to EPCWID would be 12,486 acre-feet under the central tendency climatic scenario.

4.10.4 Alternative 4: No Diversion Ratio Adjustment

Under Alternative 4, the mean annual farm groundwater delivery to EBID would be 184,273 acre-feet under the central tendency climatic scenario. The mean annual farm groundwater delivery to EPCWID would be 12,533 acre-feet under the central tendency climatic scenario.

4.10.5 Alternative 5: Prior Operating Practices, No Action Alternative

Under Alternative 5, the mean annual farm groundwater delivery to EBID would be 185,061 acre-feet under the central tendency climatic scenario. The mean annual farm groundwater delivery to EPCWID would be 13,607 acre-feet under the central tendency climatic scenario.

4.11 Groundwater Elevations at Selected Wells

Water elevation data for 15 wells in the Rincon and Mesilla Basins were used for simulation analysis (Appendix C). Simulated fluctuations in groundwater elevations are qualitatively similar among all wells within each basin, so data from only one well in each basin are presented here. The mean monthly groundwater elevation for the representative well in the Rincon Basin (Rin-2) is shown in Table 4-13, along with the data from the well in the Mesilla Basin (Mes-6). As shown, the maximum difference in well elevations among the alternatives would be 3 feet for the Rin-2 well under central tendency climatic conditions, and 1 foot for the Mes-6 well under all climate scenarios.

Table 4-13 Average annual farm groundwater elevations at selected wells (feet above sea level) by alternative and climate scenario

Well &	Alternative				
Climate	1	2	3	4	5
Rin-2					
Drier	4,059	4,059	4,060	4,062	4,062
Central	4,061	4,061	4,062	4,063	4,063
Wetter	4,063	4,063	4,063	4,065	4,065
Mes-6					
Drier	3,813	3,813	3,813	3,814	3,814
Central	3,814	3,814	3,815	3,816	3,815
Wetter	3,816	3,816	3,816	3,817	3,817

4.11.1 Alternative 1: Continued OA and San Juan–Chama Storage, Preferred Alternative

Under Alternative 1, the mean elevation in the Rincon-2 well would be 4,061 feet under the central tendency or central tendency climatic scenario with the mean under drier conditions of 4,059 feet to 4,063 feet under wetter climate conditions. The mean elevation in the Mesilla-6 well would be 3,814 feet under the central tendency climatic scenario with the mean under drier conditions of 3,813 feet to 3,816 feet under wetter conditions.

4.11.2 Alternative 2: No San Juan–Chama Project Storage

As shown in Table 4-13, Alternative 2 would be the same as Alternative 1.

4.11.3 Alternative 3: No Carryover Provision

Under Alternative 3, the mean elevation in the Rincon-2 well would be 4,062 feet under the central tendency or central tendency climatic scenario. The mean elevation in the Mesilla-6 well would be 3,815 feet under the central tendency climatic scenario.

4.11.4 Alternative 4: No Diversion Ratio Adjustment

Under Alternative 4, the mean elevation in the Rincon-2 well would be 4,063 feet under the central tendency or central tendency climatic scenario. The mean elevation in the Mesilla-6 well would be 3,816 feet under the central tendency climatic scenario.

4.11.5 Alternative 5: Prior Operating Practices, No Action Alternative

Under Alternative 5, the mean elevation in the Rincon-2 well would be 4,063 feet under the central tendency or central tendency climatic scenario. The mean elevation in the Mesilla-6 well would be 3,815 feet under the central tendency climatic scenario.

4.12 Water Quality

4.12.1 Analysis Methods and Assumptions

This FEIS incorporates by reference the water quality analysis from SEA (Reclamation 2013a). Assumptions are that increased reservoir storage or increased releases to the river would improve water quality. Other assumptions include:

- Water is generally not released from Caballo Reservoir in the non-irrigation season under any alternative. As such, water quality may fluctuate during this period but is not related to the alternatives.
- Water used by municipal users is treated, and the level of treatment would not change under the various alternatives.
- Changes in nonpoint source runoff would be the same under the various alternatives.

4.12.2 Effects Common to All Alternatives

Water quality effects are common to all alternatives. These are identified and described below.

4.12.2.1 Mercury and PCBs in Fish

Concentrations of methylmercury and other contaminants in fish would not be affected by the alternatives. Mercury and other contaminants in water bioaccumulate in fish due to complex ecological and biogeochemical processes and would not be affected by the volume of water in storage.

4.12.2.2 Dissolved Oxygen

Low dissolved oxygen below the two dams is a seasonal condition caused by upstream sources of deoxygenated water and nutrient levels, as well as release patterns. Given the common volumes and timing of released water among the alternatives, none of the alternatives would alter the existing seasonally low dissolved oxygen concentrations.

4.12.2.3 Total Dissolved Solids, Salinity and Nutrients

As shown in Section 4.6 and Table 4-8, across all alternatives, the differences in releases would be minor and insufficient to change the existing impairment of water quality due to high concentrations of dissolved oxygen, dissolved solids, nutrients, or salinity.

4.12.2.4 Groundwater Quality

As noted by the Texas Water Development Board (2016), groundwater quality issues in the study area are generally related to naturally high concentrations of total dissolved solids (TDS) or to the occurrence of elevated concentrations of individual dissolved constituents, and while there are local instances of groundwater quality degradation, there are no major trends suggesting a widespread water quality problem due to the downward percolation of surface contaminants. The groundwater well elevations may be suggestive of groundwater water quality. Results presented in Section 4.11 and Table 4-13 show the differences among alternatives in groundwater elevations are likely too small to result in any measurable differences in groundwater quality.

4.13 Vegetation and Wetlands

This section projects changes to vegetation communities and wetlands due to implementation of the alternatives. (No special status plants are present, as described in Chapter 3.) The study area for vegetation is the action area for special status aquatic and wildlife species and their designated or proposed critical habitats under the ESA. The action area is defined as all areas affected directly or indirectly by the Federal action (50 CFR 402.02) and is subdivided into the following reaches or segments:

- Elephant Butte Reservoir from full pool to dead pool
- The Rio Grande downstream from Elephant Butte Dam to Caballo Reservoir
- Caballo Reservoir from full pool to dead pool
- The Rio Grande from Caballo Dam downstream to International Dam

While vegetation in all these reaches was considered, the analysis focuses on vegetation in and around Elephant Butte Reservoir for three reasons. One, upland desert shrub communities further from the river would be unaffected by the alternatives because none of the alternatives would change the volume or pattern of releases from the dams to the extent that these vegetation communities would be affected.

Two, there is only a narrow band of riparian vegetation, including some wetlands, along the river banks between the reservoirs and downstream of Caballo Dam that could be affected by releases and this vegetation has been previously considered by Reclamation in the SEA (Reclamation 2013a) or by the USIBWC (various). Release data from Section 4.6 and Table 4-8 are provided below, but the vegetation communities and wetlands along the river would be unaffected by implementation of one or another alternative.

Three, Caballo Reservoir pool levels would be relatively stable under all alternatives. The vegetation in and around this reservoir is relatively constant: it is dense near the water's edge and gradually reduces in density away from the water line. For these reasons, the analysis focuses on Elephant Butte Reservoir vegetation.

4.13.1 Analysis Methods and Assumptions

The RMBHM hydrologic modeling of reservoir elevations (Appendix C, Section 4,3) and surface area (Table 4-14) is used to project changes in vegetation communities in and around Elephant Butte Reservoir because, as noted by Dick-Peddie et al. (1999:27-32), moisture availability is the primary factor influencing vegetation patterns in New Mexico, although climatic regime and disturbances such as fire, flood, grazing, plowing, etc. influence the distribution of individual plants and some vegetation communities. However, the moisture availability caused by fluctuating water levels of Elephant Butte, like all reservoirs (cf. Lesica and Miles 2004), creates habitats different from those associated with natural riparian systems due to the repeated cycles of inundation that tend to prevent vegetation from proceeding beyond the earliest stages of succession.

Section 4.3 and Table 4-5 describe the projected average Elephant Butte Reservoir elevations by alternative and Table 4-14 shows the surface area of the reservoir, but the indicator for change in vegetation is the duration of cycles of inundation or drawdown, shown by the time series simulations for reservoir elevations (Figs. 12, 13).

4.13.1.1 Drawdown and Low Reservoir

Presently most of the vegetation at Elephant Butte Reservoir occurs in the sediment delta, from full pool at River Mile 62 to where the Rio Grande enters into the current baseline pool at River Miles 38 to 36, and there is a gradient in density/quality from west to east and south to north. In the future, as simulated by the RMBHM and Section 4.3, reservoir levels will fluctuate and the assumption is that when the reservoir recedes, as it has over the last decade, it will expose moist, bare alluvium that is rapidly colonized by annuals, biennials, short-lived perennials, as well as woody species such as cottonwood, willow, and tamarisk. If the water level of the reservoir remains low, without periodic inundation, the vegetation upstream and adjacent to the reservoir pool would mature over time through natural succession and would eventually shift to longer-lived, more xeric, upland species.

Tamarisk appears to be better adapted to colonizing drawdown reservoir pools, but tamarisk greater than five years old rarely grow in most reservoirs because three months of inundation may kill them (Ellis et al. 2008, Lesica and Miles 2004).

4.13.2.2 Inundation and High Reservoir

Historically, Elephant Butte Reservoir has fluctuated and this is expected to occur under all alternatives and all climate scenarios. In the future when the reservoir water surface elevation rises, some plants (including mature cottonwoods) and patches of riparian vegetation would benefit from the rising water table. Habitat that is partially inundated could be enhanced through deposition of new sediments and nutrients, flushing of accumulated salts, and irrigation of the respective site.

However, prolonged or complete inundation could result in the total loss of particular plants and patches of riparian habitat, with the losses depending on the particular species and age class. Based on monitoring of Elephant Butte Reservoir vegetation, young Goodding's willows are more flood tolerant than saltcedars (Reclamation 2009). Following a period of six months of inundation with 18 to 24 inches of water over the terminal bud primarily during the dormant season, Goodding's willow densities and heights increase. Similar observations have been reported by Ellis et al. (2008), who reported a die-off of saltcedar understory and survival of Goodding's willow at Roosevelt Lake, and by Lesica and Miles (2004) who found that tamarisk in reservoir pools were destroyed after two summers (three months) of inundation.

Prolonged or complete inundation, which is expected to occur during the analysis period, could result in the loss of some riparian habitat, and survivability would depend on species composition and age class. Ellis and others (2008) also found that most species were not able to survive more than one year of complete inundation. Reclamation (2009) has also previously reported that partial (10 to 15 feet) and temporary (less than six months) flooding would likely cause a reduction in woody vegetation. The shrub layer, if present, could be slow to recover.

Figures 12 and 13 provide the time series outputs from the hydrological model, showing projected durations of time or cycles when Elephant Butte Reservoir would be rising or falling. These figures, combined with the data on surface area of the reservoir in Table 4-14, are used to project vegetation effects of the alternatives. As shown by Table 4-14, the maximum difference in average values among the alternatives would be about 1,000 acres.

Table 4-14 Elephant Butte Reservoir mean surface area (acres) by alternative and climate scenario

Area &	Alternative				
Climate	1	2	3	4	5
Drier	8,780	7,637	8,878	8,299	8,533
Average	11,425	10,493	11,570	11,127	11,404
Wetter	11,349	10,478	11,661	10,958	11,306

Figure 12. Time series of Elephant Butte Reservoir by alternatives under a drier climate scenario.

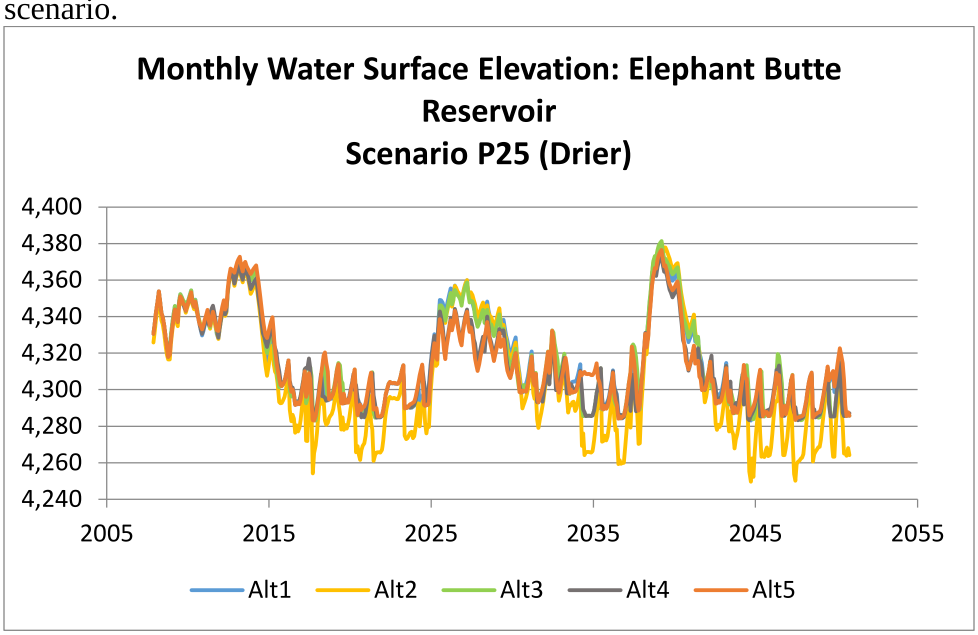
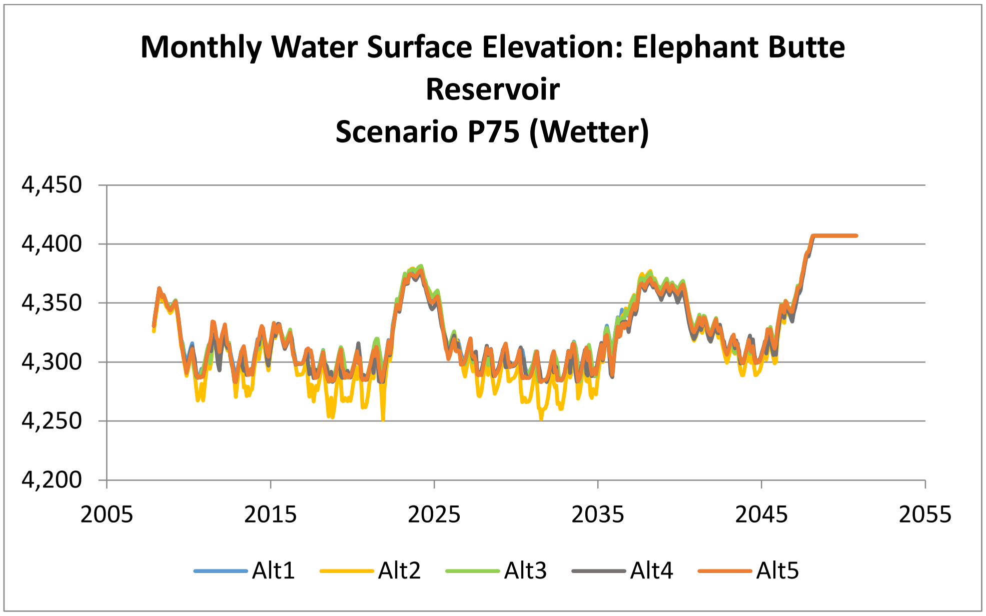


Figure 13. Time series of Elephant Butte Reservoir by alternatives under a wetter climate scenario.



4.13.3 Alternative 1: Continued OA and San Juan–Chama Storage, Preferred Alternative

Alternative 1 is projected to have three periods of reservoir drawdown that could affect vegetation under all climate scenarios. As shown in Table 4-14, under Alternative 1, the average surface area of Elephant Butte Reservoir under the central tendency climate scenario would potentially cover or inundate 11,425 acres. The difference from No Action is projected to be an average of only 21 acres under central tendency climate conditions. Under central tendency climate conditions, releases under Alternative 1 would tend to be slightly higher (1,212 acre-feet) than Alternative 5 (No Action), but for the reservoir and river, there would be no difference to vegetation between Alternative 1 (Preferred) and Alternative 5 (No Action).

4.13.4 Alternative 2: No San Juan–Chama Project Storage

Alternative 2 would also have the same three periods of reservoir drawdown, but would tend to remain at lower levels than the other alternatives. Under Alternative 2, average surface area of Elephant Butte Reservoir under the central tendency climate scenario would be 10,493 acres, a difference of 910 acres from Alternative 5 (No Action). Releases would be the same as Alternative 1.

4.13.5 Alternative 3: No Carryover Provision

Alternative 3 would have the same three periods of reservoir drawdown that could affect vegetation. Average surface area under central tendency climate would cover or inundate 11,570 acres. Under the wetter climate scenario, vegetation would be the most affected with a projected mean of 11,661 acres inundated. For vegetation, the releases would be virtually the same as Alternative 5; the average difference in total releases would be -667 acre-feet.

4.13.6 Alternative 4: No Diversion Ratio Adjustment

Alternative 4 would tend to be the same as Alternative 5, which exhibits the same three periods of reservoir drawdown periods as the other alternatives. Average surface area under the central tendency climate scenario would cover or inundate 11,127 acres; i.e., 298 acres less than Alternative 1 and 277 acres less than Alternative 5. Under Alternative 4, releases would vary the most from Alternative 5 (No Action), with the average total release under the central tendency climate condition 3,282 acre-feet higher than Alternative 5.

4.13.7 Alternative 5: Prior Operating Practices, No Action Alternative

Alternative 5 (No Action) is projected to have the same three periods of reservoir drawdown that could affect Elephant Butte Reservoir vegetation. Average surface area under the central tendency climate scenario would cover or inundate 11,404 acres, less vegetation (surface acres) than Alternatives 1, 2, or 3, but it would tend to cover more surface acres than Alternative 4. Releases would be most similar to Alternative 3, with slightly higher total releases under Alternatives 1, 2, and 4, but again, no differences in moisture availability to riverine plants or wetlands is expected under any of the alternatives.

4.14 Wildlife and Special Status Species

Effects on wildlife are mostly based on how the alternatives would affect vegetation that serves as wildlife habitat in and around Elephant Butte Reservoir, especially the delta reach. The analysis focuses on the potential effects to flycatcher and the cuckoo. The endangered mouse is not expected to occur in the study area because of the lack of suitable habitat. Further, there is no proposed critical habitat for the mouse in the study area; the nearest proposed critical habitat is approximately 16 river miles upstream, at Bosque del Apache National Wildlife Refuge.

4.14.1 Analysis Methods and Assumptions

The analysis method for special status species is to determine the potential for the alternatives, particularly Alternative 1, the Preferred Alternative, to affect listed species or their critical habitat. Reclamation prepared a biological assessment of the effects of Alternative 1 on listed species and their critical habitat and consulted with the Service. The Service's biological opinion is provided in Appendix F.

In addition to how the cycles of rising or falling reservoir levels affect vegetation or wildlife habitat, indicators specific to wildlife include:

- Decline in reservoir elevations, which degrades the riparian habitat along the outside edge of the reservoirs, but also enhances and creates riparian habitat within the reservoir area from River Mile 62 to River Miles 38 to 36
- Death or decreased reproductive success of wildlife species due to habitat alteration

Current and historical information from field surveys conducted by Reclamation or others, as well as a literature review, was used to document the status of the species and their habitat in 2014—the environmental baseline for consultation with the Service under the ESA. If the presence of a listed species or supporting habitat features were determined to be likely, then the alternatives' potential effects were analyzed to determine whether they would affect the species or associated habitat. The following considerations apply:

- Fluctuations in Elephant Butte Reservoir and Caballo Reservoir water levels up to the full pool have historically been a normal feature of the reservoirs.

- The habitat that currently supports the largest flycatcher population in the Southwest was created when the Elephant Butte Reservoir receded, allowing various age classes of vegetation to develop.
- Based on hydrologic data collected since 2004, a large part of the northern portion of the reservoir pool receives water throughout the year. The source of this water is agricultural return from the outfall of the low flow conveyance channel (Reclamation 2005) and not from the river channel into the Elephant Butte Reservoir. Though habitats are changing, suitable habitat in this portion of the reservoir pool remains relatively abundant.
- The revised designated critical habitat for the flycatcher and proposed critical habitat for the cuckoo includes a part of the Elephant Butte Reservoir delta reach, downstream to River Mile 54. Above River Mile 54, the reservoir inundates designated critical habitat.
- The flycatcher and cuckoo are presently restricted to elevations in Elephant Butte Reservoir above 4,325 feet, which was the baseline for consultation with the Service. Flycatcher designated critical habitat and cuckoo proposed critical habitat extends to River Mile 54, at approximately the 4,380-foot elevation. The action's primary determinant of effect on birds would be months when Elephant Butte Reservoir surface elevation rises and remains greater than 4,325 feet. Above this elevation, rising waters might inundate and potentially affect flycatcher.
- Based on the 2014 flycatcher surveys, approximately 31 percent of the flycatcher territories (260) and 65.1 percent (161) of cuckoo territories would be affected by the reservoir rising to 4,380 feet (Moore and Ahlers 2015, Reclamation 2015b). The reservoir elevations typically begin rising in November, after minimum storage occurs in October, continuing to maximum storage peaks for the year as the spring releases begin, following irrigation demands. Thus, reservoir levels typically increase in the fall after flycatchers and cuckoos have departed for over-wintering territories and higher reservoir levels due to runoff end in the spring when the birds begin to establish breeding territories.

4.14.2 Effects Common to All Alternatives

References such as Reitan and Thingstad (1999) and the simulated reservoir water surface elevations presented in Section 4.3 and Table 4-5, were used to extrapolate potential effects of the alternatives into the future, relative to the range in water surface elevations from full pool (4,407 feet) to the 4,325 foot elevation level where flycatcher and cuckoo territories are currently, and the 4,380 foot elevation at River Mile 54 where the flycatcher designated critical habitat and the proposed cuckoo critical habitat extend into Elephant Butte Reservoir. The modeling simulates recurring cycles during which Elephant Butte Reservoir elevation would rise above the 4,325-foot level for different lengths of time. As shown in Figs. 12, 13 and Table 4-14, there are times when the reservoir is projected to rise above 4,325 feet, but most of the time, the reservoir would be below this level. As such, implementing one or another of the alternatives through 2050 is projected to produce little, if any, differences in direct effects on flycatchers, cuckoo, or their habitat in these segments, beyond impacts associated with current operations and climate variability.

Effects on flycatcher and cuckoo habitat under all alternatives are projected to be as follows:

- Without inundation from rising pool elevations, nutrients would not be replenished and salts would not be flushed in areas of trees associated with flycatchers and cuckoos. This would reduce the vigor of vegetation, degrading its overall habitat suitability for flycatchers and cuckoos. Periods of lower water inflows and lower pool elevations in Elephant Butte Reservoir would lead to maturation of vegetation communities and changes in species composition that could eventually render flycatcher and cuckoo nesting habitat unsuitable. This would come about without other types of disturbance in the delta reach, such as fire or mechanical disturbance.
- Inundation could create short-term impacts on birds and shrubs through the physical loss of riparian vegetation (Service 2014a); however, over the long term, a rising reservoir would support riparian vegetation by increasing the water table in some areas, resulting in denser vegetation and taller trees favored by the birds. Inundation would also flush accumulated salts from the soils, replenish nutrients, and deposit new sediments.

4.14.3 Alternative 1: Continued OA and San Juan–Chama Storage, Preferred Alternative

Under Alternative 1, Table 4-14 and Figs. 12-13, and show there would be periods of both increasing and decreasing reservoir levels under all climate scenarios. To assess impacts on special status species, Reclamation consulted with the Service on the effects of the wetter climate scenario, which provided a conservative worst-case, based on the potential impacts to vegetation used by listed species. Reclamation's finding is that implementation of Alternative 1 "may affect, and is likely to adversely affect" flycatcher and cuckoo that could be present in Elephant Butte Reservoir. Compared to the 2014 baseline, individual birds may be displaced and some territories/nests may be inundated by a rising reservoir. Such a rising reservoir would result in only minor adverse effects because there is more suitable habitat available that is not being used, and vegetation regrowth could occur quickly under the right conditions.

Reclamation's finding for critical habitat is that Alternative 1 "may affect, and is likely to adversely modify" flycatcher designated critical habitat and cuckoo proposed critical habitat. Modeling presented in Section 4.3 and Table 4-5 shows that reservoir rising/filling would inundate existing critical habitat. This determination is also appropriate for indirect effects related to the habitat south of River Mile 54, which is projected to be regularly inundated due to water level increases in the reservoir.

Additionally, note that willow habitat, documented to be preferred for nesting in the delta reach of the Elephant Butte Reservoir, matures with time, becoming unsuitable for flycatcher nesting (Reclamation 2013a, Service 2002). Similarly, as described in the proposed critical habitat designation (Service 2014b), cuckoos require large tracts of willow-cottonwood forest or woodland for their nesting habitat. This habitat also matures with time, becoming unsuitable for cuckoo nesting. Prolonged flooding of the overly mature habitat would likely destroy the old vegetation. Quality nesting habitat would then be regenerated after the reservoir water level recedes.

4.14.4 Alternative 2: No San Juan–Chama Project Storage

Alternative 2 tends to reduce the reservoir water surface elevation relative to Alternative 5 (No Action). Under Alternative 2, Elephant Butte Reservoir would reach a lower elevation than under the other alternatives, and there would most likely be longer periods of lower elevations.

Therefore, the impacts on flycatchers and cuckoos associated with a rising reservoir and a greater number of acres of habitat inundated would occur.

When the reservoir recedes, reservoir bottomlands or nutrient-enriched exposed soils would quickly be revegetated with both desirable species, such as willow, and undesirable species, such as nonnative or invasive plants. This recession could create habitat for the flycatcher and cuckoo. If the reservoir were to remain at low water levels, habitat upstream to River Mile 62 and next to the reservoir pool would ultimately mature through natural succession past a point of suitability for the flycatcher and cuckoo. A low reservoir level equates to lower water in the Rio Grande system overall, so under drier conditions in the future degrading riparian vegetation would eventually be replaced by more upland species until the reservoir levels increase and this older vegetation is replaced.

Alternative 2 has the greatest potential for creating habitat, if the reservoir were to fill, depending on the timing and duration of filling. Alternative 2 also has the greatest amount of habitat that could be inundated and potentially destroyed. Therefore, under Alternative 2, riparian vegetation would expand, leading to more flycatcher and cuckoo habitat. Conversely, under Alternative 2, flycatcher and cuckoo habitat has the greatest potential for maturing beyond the point of suitability. It could also lead to increased drying and expansion of upland vegetation into formerly riparian areas.

4.14.5 Alternative 3: No Carryover Provision

Under Alternative 3, Elephant Butte Reservoir water surface elevations would fluctuate over time. The birds currently are above the 4,325-foot elevation level, so some impacts are expected when the reservoir rises above that elevation.

4.14.6 Alternative 4: No Diversion Ratio Adjustment

Under Alternative 4, Elephant Butte Reservoir water surface elevations would fluctuate over time. The birds are presently located above 4,325 feet, so under Alternative 4 some impacts are expected when the reservoir rises above that elevation.

4.14.7 Alternative 5: Prior Operating Practices, No Action Alternative

Under Alternative 5, the No Action Alternative, Elephant Butte Reservoir water surface elevations would fluctuate over time. Again, the birds are presently located above the 4,325-foot elevation level, so under Alternative 5 (No Action), some impacts would be expected when the reservoir rises above that elevation.

4.15 Aquatic Resources and Special Status Fish Species

This section projects effects of the alternatives on sport fish in the reservoirs and on the endangered Rio Grande silvery minnow, which is found in the riverine portion of Elephant Butte Reservoir.

4.15.1 Analysis Methods and Assumptions

Previous studies indicate the sport fishery benefits when the reservoirs rise or with full, stable reservoirs (Ozen 2002, Sammons and Bettoli 2000). The New Mexico Department of Game and Fish (NMDGF 2011, 2015b) reported that fluctuating water levels, both annual and inter-annual, plus resulting high turbidities and a general lack of emergent vegetation produce poor habitat conditions for centrarchid species,[9] white bass, gizzard shad, and channel catfish in the reservoirs. Fluctuating water levels apparently result in increased populations of other species, such as blue catfish.

The NMDGF reported that declining water levels during spawning, water turbidity, and inadequate forage seem to be the limiting factors for smallmouth bass and largemouth bass populations. Because Elephant Butte Reservoir is 100 years old, it tends to have very little aquatic emergent or sub-emergent vegetation to provide a viable seed bank in years when water levels rise. As such, the development of necessary emergent vegetation communities commonly associated with healthy bass populations is lacking. The NMDGF (2011) adds that it is important to have flooded vegetation every three to four years to produce strong year classes of largemouth bass, which is what occurs as the reservoir fills since the upper portion of the reservoir is flatter with more recurring vegetative growth.

The NMDGF (2015b) suggests that centrarchid habitat could be improved if the lake would refill to near capacity. However, multiple years of low lake levels have allowed natural revegetation in the upper lake and have depressed centrarchids and other fish populations.

The analysis method is considering the potential effects of the alternatives on water resources to determine whether these would affect aquatic wildlife and their habitats. Reclamation considered data and information related to hydrology modeling used to develop the baseline conditions for aquatic resources in the study area. It used these data to assess potential biological responses to habitat condition modifications, including reservoir inundation extremes, during the assessment period (relative to baseline conditions of 2014).

Fluctuations in reservoir water surface elevations are anticipated during the 43-year simulation period for all alternatives and climate scenarios. In general, the Rio Grande silvery minnow would be expected to benefit from lower water levels and a longer river channel into Elephant Butte Reservoir.

In addition, Elephant Butte Reservoir is projected to reach capacity or full pool during both the central tendency and wetter climate scenarios (Appendix C). In general, sport fish would benefit from an increasing reservoir shoreline and flooded vegetation; although riverine fish would have slightly less riverine habitat in the reservoir pool, they are expected to move upstream to suitable habitat as the reservoir fills.

4.15.2 Effects Common to All Alternatives

Under all alternatives, there would be cycles of rising and falling reservoirs. During wetter periods, when the RMBHM model simulates rising water levels in the reservoirs, the populations of sport fish may increase or improve, while periods of reservoir decline would benefit the endangered Rio Grande silvery minnow due to increased riverine conditions.

For sport fish, periods of low water elevations might result in the localized loss of some species and restocking would be necessary to maintain or enhance the public's recreational opportunities. Fish stocking by NMDGF is commonly practiced to augment various fish species populations in both reservoirs.

[9] e.g., largemouth and smallmouth bass, crappie, and bluegill

4.15.3 Alternative 1: Continued OA and San Juan–Chama Storage, Preferred Alternative

Under Alternative 1, Elephant Butte Reservoir is predicted to reach slightly higher maximums during modeled wet periods than predicted for the other alternatives (Fig. 13). Sport fish would benefit from an increasing reservoir shoreline and flooded vegetation; riverine fish would have slightly less habitat in the reservoir pool, but they are expected to move upstream to suitable habitat as the reservoir levels increase. Riverine fish species in Elephant Butte Reservoir headwaters would benefit from a lower reservoir and a longer river channel into the reservoir, while lake fish would have slightly less habitat in the reservoir pool.

4.15.3.1 Rio Grande Silvery Minnow

The model simulation indicates that Elephant Butte Reservoir would fill under both average and wetter climate scenarios (Fig. 13) and would displace minnows in the delta channel as the water elevation rises. The minnows would be displaced to more upstream reaches of the river in the delta reach until Elephant Butte Reservoir reaches its full storage volume. This gradual upstream movement of minnows could extend into their critical habitat reach of the Rio Grande, upstream of the full pool extent of Elephant Butte Reservoir (River Mile 62).

As the reservoir pool subsequently contracts, the minnows could and likely would again repopulate the river channel within the reservoir. Minnows could swim freely in the available delta channel habitat of the reservoir. Reclamation would continue to maintain the delta channel for efficient delivery of water to the reservoir; even without a maintained channel, a naturally formed river channel would develop as long as upstream river flows were sufficient to enter the Elephant Butte Reservoir pool. The minnow is not considered to live within the Elephant Butte Reservoir past the furthest south point of the river channel due to a lack of appropriate food and habitat. Minnows do not occur in the other downstream Rio Grande reaches of the OA study area below Elephant Butte Reservoir. The minnow has been extirpated from the river below Elephant Butte Reservoir, except for the pilot population of introduced minnows in Big Bend, Texas. Due to the absence of minnows in these reaches of the study area, continued implementation of the OA would not affect this species.

Reclamation consulted with the Service on the effects of implementing Alternative 1 on the Rio Grande silvery minnow and the Service's biological opinion is presented in Appendix F. The analysis was based on the wetter climate scenario, which constitutes a conservative, worst-case for the minnow and its habitat. Reclamation's finding was that given future fluctuations under Alternative 1, and based on the observations of biologists that in low water conditions, the minnow is able to move upstream/downstream, following the water, the action "may affect, is not likely to adversely affect" the minnow. With sufficient magnitude and duration of reservoir filling, critical habitat upstream of River Mile 62 may receive beneficial effects due to increased deposition of sediment north of the full pool of the reservoir.

4.15.4 Alternative 2: No San Juan–Chama Project Storage

The effects of Alternative 2 on the sport fish and the Rio Grande silvery minnow would be similar to those described under Alternative 1. The delta channel may extend farther into the reservoir for longer periods and would provide some additional riverine habitat due to fluctuations in reservoir levels.

4.15.5 Alternative 3: No Carryover Provision

The effects of Alternative 3 on sport fish and the Rio Grande silvery minnow would be almost identical to those described under Alternative 1 because of the fluctuations in reservoir levels over time.

4.15.6 Alternative 4: No Diversion Ratio Adjustment

The effects of Alternative 4 on sport fish and the Rio Grande silvery minnow would be almost identical to those under Alternative 1 because of the fluctuations in reservoir levels over time.

4.15.7 Alternative 5: Prior Operating Practices, No Action Alternative

Under the No Action Alternative (Alterantive 5) the effects on sport fish and the Rio Grande silvery minnow are projected to be the same as those under Alternative 1.

4.16 Invasive Species

4.16.1 Analysis Methods and Assumptions

As described in Section 4.13, the assumption is that lower reservoir levels may lead to the spread of noxious weeds and invasive plants including saltcedar, which competes with native, riparian vegetation. The spread of invasive animal species, including zebra and quagga mussels, is unrelated to reservoir elevations or releases from the dams. Therefore, these species are not relevant to the alternatives.

4.16.2 Effects Common to All Alternatives

The potential for spread and continued presence of invasive species, both plant and animal, would be the same under all alternatives. Invasive zebra and quagga mussels have been detected in upstream reservoirs. Under all alternatives, there is a potential for mussels to become established in Elephant Butte and Caballo Reservoirs; however, slight alterations in reservoir operations or flows in the river reaches do not affect the potential for the reservoirs' colonization or infestation by mussels. Preventative measures to clean boats entering and leaving reservoirs would continue under all alternatives.

4.17 Cultural Resources

4.17.1 Analysis Methods and Assumptions

Reclamation evaluated the effects of the alternatives on historic properties using the criteria defined in 36 CFR 800, which define adverse effects as "direct or indirect alteration of the characteristics that qualify a property for inclusion in the NRHP in a manner that diminishes integrity of location, design, setting, materials, workmanship, feeling, or association." The integrity of historic properties is assessed by the ability of the property to convey the important traditional, scientific, and public values for which it is determined to be historically significant.

4.17.2 Effects Common to All Alternatives

Under all alternatives, the effects would be the same: "no historic properties affected," in accordance with 36 CFR 800.4(d)(1). In November 2015, the New Mexico State Historic Preservation Officer concurred with this finding. (See Chapter 6 and Appendix D).

Because RGP water would continue to flow under all alternatives and allow the growth and harvesting of plants valued by the Mescalero Apache Tribe, there should be no effects to resources of tribal concern. No Indian sacred sites have been identified to date, and thus there would be no effect on these cultural resources.

4.18 Indian Trust Assets

4.18.1 Effects Common to All Alternatives

Government-to-government consultation to date with potentially affected tribes, including the Mescalero Apache Tribe and the Pueblo of Ysleta del Sur, has not identified any ITAs. Therefore, implementing any of the alternatives would have no impact on ITAs.

4.19 Socioeconomics

4.19.1 Impact Indicators

The socioeconomic analysis evaluated impacts of the alternatives on economic benefits and regional economic indicators, as listed below. The summary of the results is found in Section 4.19.5. Economic benefit (direct impact) indicators are:

1. Economic value of agricultural water use in EBID
2. Economic value of agricultural water use in EPCWID
3. Economic value of urban water use in EPCWID
4. Economic value of recreation at Elephant Butte Reservoir
5. Economic value of hydropower generation at Elephant Butte Powerplant

Regional economic indicators are:

1. Employment (full and part-time jobs)
2. Income (employee compensation and proprietors' income)
3. Output (sales)

4.19.2 Analysis Methods and Assumptions

The proposed alternatives are analyzed using two economic measures: 1) the economic benefits, or direct impacts; and 2) the regional economic impacts. The economic benefits or direct impacts measure the effects of each alternative from a societal standpoint (a gain or loss to society from a change in activities). The regional economic impacts measure the effects of each alternative on a region's economy (such as changes in employment and income).

For this FEIS, the net economic benefit and regional economic impact calculations rely on hydrologic outcomes of project alternatives as provided by the hydrology technical memorandum (Reclamation 2015c; Appendix C) and available economic data.

The economic benefits and regional economic impacts stemming from the use of RGP water under each alternative are calculated and presented along with the differences from Alternative 5, the No Action Alternative. The economic benefits or direct impacts and regional economic impacts are calculated for the following categories of water use or users:

1. EBID
2. EPCWID
3. Hydropower production at Elephant Butte Powerplant

4. Recreation benefits at Elephant Butte Reservoir

Note that the regional economic impacts are measured based on the same general water use categories except for hydropower production at Elephant Butte Powerplant.

4.19.2.1 Economic Benefits (Direct Impacts)

4.19.2.1.1 Elephant Butte Irrigation District

The estimation of net economic benefit value is limited to agricultural users and is based on the findings shown in the hydrology technical memorandum (Appendix C). The hydrologic simulation found that although depletion of shallow groundwater within the EBID service area occurs under all alternatives, the available supply to project irrigators was never exhausted, and therefore all crops received a full irrigation supply under all simulated conditions. The full impact of changes in project deliveries between alternatives is thus calculated as the differences in costs of pumping groundwater between alternatives.

The hydrologic modeling identified complete substitution of groundwater when surface water deliveries were not available. No changes in cropping or acreage resulted during the study period. Focusing solely on the Rincon and Mesilla Basins, the difference in the economic benefits between alternatives is limited to the differences in pumping costs incurred by project irrigators when surface water is not available.

Differences in costs of RGP surface water delivery between alternatives are not considered because costs are almost entirely fixed and are not volume dependent. While irrigators may experience differences in labor costs and other factors in using surface water instead of groundwater, there is no basis for quantifying these differences and so they are not considered.

Pumping costs are determined by the total volume pumped and the total head. Because both volume and head differ by alternative, each factor is used in calculating pumping costs. Capital costs are not considered, as all project irrigators are assumed by the hydrology technical memorandum (Appendix C) to have access to available supplemental groundwater as needed, and the relatively small volumes that differentiate alternatives are assumed to have no effect on pump lifetimes or maintenance costs.

Groundwater pumping cost calculation

The calculation of groundwater pumping costs was based on the energy costs of delivering the quantity of groundwater identified under each project alternative. The annual average groundwater delivery and the elevations and beginning of period well depths were taken from the hydrology technical memorandum (Appendix C), and the static head was taken from crop enterprise budgets for Sierra and Doña Ana Counties (New Mexico State University 2005). Energy (electric) costs and pump efficiency were likewise obtained from the crop enterprise budgets. The wells cover all cropping areas in EBID, and the simple average well elevation changes within each cropping area were used to calculate average pumping heads for each alternative.

Groundwater elevations for regions served by major canals were taken from the hydrology technical memorandum (Appendix C), which calculated groundwater elevations and initial groundwater depths. Groundwater elevations reported under each alternative for the 15 wells in the project area were averaged for the Rincon Valley and the Mesilla Valley Leasburg, Eastside, and Westside Canals. The total groundwater deliveries to EBID were allocated to each region based on the acreage reported in the hydrology technical memorandum (Appendix C). The starting well depth was also taken from the hydrology technical memorandum (Appendix C). The typical head across the region and study period was 70 to 80 feet with 50 feet of static head (New Mexico State University 2005) and a calculated 20 to 30 feet well depth to water.

A pump efficiency of 0.47 for electric pumps and an electricity cost of $0.1098/kilowatt-hour for electricity were taken from crop enterprise budgets (New Mexico State University 2005). The cost of electricity was adjusted to 2015 levels using the producer price index for North American Industry Classification System 2211, electric utilities. A resulting energy cost of $0.152/kilowatt-hour was used (price index 2015 = 144.3; 2005 index = 104.2). The potential energy conversion is 1.024 kilowatt-hour /acre-foot/foot, meaning that at 100 percent efficiency, 1.024 kilowatt-hour of energy is required to lift one acre-foot of water to a height of 1 foot.

4.19.2.1.2 El Paso County Water Improvement District Number 1

RGP deliveries to water users from the American Diversion Dam are not treated in the hydrologic modeling and there is no specific information on the disposition of RGP waters after delivery (Appendix C). The most recent financial report from El Paso Water (2015) gives an average year surface water delivery of 60,000 acre-feet for M&I uses, with these flows providing approximately half of the El Paso Water supply. The balance of the M&I water supplies is pumped from the Hueco and Mesilla Basins. All other surface water deliveries at the American Diversion Dam are then available for diversion for agricultural uses. (Deliveries to Mexico at the International Diversion Dam are included within the hydrologic modeling [Appendix C], and do not vary by alternative; therefore, they are not further considered in the economic analysis.) The historical full EPCWID allocation of 376,842 acre-feet then gives surface diversions of 316,842 acre-feet available for agricultural uses. Acreages of 6,494 and 62,516 in the Mesilla and El Paso Valleys, respectively, are used to calculate Mesilla and El Paso Valley full allocation diversions of 29,816 and 287,026 acre-feet, respectively. Any greater levels of urban surface water use would result in proportionally lower levels of Rio Grande agricultural diversions; this possibility is not considered here.

EPCWID El Paso Valley agricultural water users

Net benefits of RGP water use reported by Ward and Pulido-Velazquez (2012) are used to estimate the economic benefits associated with RGP surface water deliveries at the American Diversion Dam to El Paso Valley agricultural users. Their base scenario reports average deliveries to agricultural users of 237,000 acre-feet, with average net benefits of $112 per acre-foot. This is taken as the value of RGP surface water deliveries to El Paso Valley agricultural users when diversions fall below the full allocation level. According to Ward and Pulido-Velazquez (2012), agricultural users have not developed much groundwater pumping infrastructure and therefore are not reported to make significant use of groundwater to supplement their surface water use.

EPCWID El Paso Valley urban water users

El Paso urban uses rely heavily on groundwater, and sustainability of both the quantity and quality of groundwater supplies are a concern. To value the Rio Grande surface water delivered for urban use, the Ward and Pulido-Velazquez (2012) “sustaining” and “renewing” natural capital scenarios were used, which report a difference in urban water use of 6,000 acre-feet. The difference in the reported net benefits to urban water users is $574 per acre-foot and is taken here as the value of RGP water in El Paso urban uses when supply falls below 60,000 acre-feet.

Distribution between agricultural and urban users

The hydrology technical memorandum hydrologic studies provide no guidance on the distribution of RGP water to urban versus agricultural uses (Appendix C). Because values in urban and agricultural uses can be substantially different, economic valuation would be sensitive to this distribution. The economic analysis here assumes that RGP water is distributed proportionally to urban and agricultural uses throughout the study period, and that urban uses are held to 60/376.842 = 15.9 percent of total EPCWID diversions, and agricultural uses receive 84.1 percent of diversions.

EPCWID Mesilla Valley agricultural water users
Deliveries of RGP water to EPCWID agricultural water users in the Mesilla Valley are valued identically to EBID agricultural water users. The hydrologic studies show full availability of groundwater to substitute for surface water when diversions fall below allocations. Total benefits from the use of groundwater and RGP surface water are calculated identically to EBID project users.

4.19.2.1.3 Hydropower
The hydroelectric plant at Elephant Butte Dam generates power that is dependent on flow volume and head. Because both flows and reservoir elevation would differ between alternatives, expected power generation would also vary. There is currently no hydroelectric production at Caballo Dam, and thus no economic differences between alternatives exist, despite differing releases between alternatives.

Reservoir elevation and releases
The hydrology technical memorandum provides monthly elevations at Elephant Butte Reservoir for each alternative (Appendix C, Reclamation 2015c). Power production does not occur during winter months when RGP releases do not occur. Hydropower calculations are thus based on the calculated average elevation during the March to October period only. Annual releases from Elephant Butte Reservoir reported by the hydrology technical memorandum, reduced by the volume of spills, are used with the March to October average elevations (Appendix C) to calculate hydropower generation.

Power plant characteristics and valuation
The Elephant Butte Powerplant has a rated head of 140 feet and is assumed to operate with 90 percent efficiency. Energy generation is calculated from reservoir elevation, with the rated head achieved at the maximum elevation over the study period, and the potential energy conversion of 1.024 kilowatt-hour per acre-foot per foot of head. Calculated production based on the average March to October monthly elevation and release data for 2014 is 3 percent below the actual power plant production of 13.4 gigawatt-hours reported by Reclamation (2015d). Economic valuation of production is based on the economic opportunity cost concept and uses the same $0.152/ kilowatt-hour value as is assigned to the cost of groundwater pumping. This neglects distribution costs and losses (which would suggest a lower figure), but also does not consider use of the power plant for short-term peaking operations (which suggest an increased valuation). Reservoir elevation for purposes of hydropower calculations use only Alternative 1 reported values.

4.19.2.1.4 Recreation
Elephant Butte Reservoir provides a variety of recreational benefits that vary based on reservoir storage. Because storage varies between project alternatives, recreational benefits are calculated for Elephant Butte Reservoir. Similarly, Caballo Reservoir provides recreational benefits. These benefits are not addressed, however, because the differences in Caballo Reservoir storage among alternatives are small and would not result in significant differences in economic benefits from recreation at Caballo Reservoir under each alternative.

Annual recreation benefits reported by Ward and Pulido-Velazquez (2012) are based on:

$$\textit{Value of Elephant Butte Reservoir recreation} = 379.82 + 2.21\,X - 0.0005030852\,X^2$$

where X equals the average annual storage in thousand acre-feet and the economic value is in thousand dollars. Management costs of $0.31 per acre-foot of storage (due to increased visitation) are also identified (Ward 2014) and deducted from the economic benefit calculation reported here. The hydrology technical memorandum annual average reservoir storage is used with the above equation to estimate direct economic benefits of recreation (Reclamation 2015c, Appendix C).

4.19.2.2 Regional Economic Impacts

In addition to considering the net economic benefits or direct impacts of each alternative, the socioeconomic analysis estimates the potential regional economic impacts. The regional impacts may stem from changes in agricultural pumping costs, the costs of providing urban water, and recreation visitation expenditures. These direct economic impacts are input into the IMPLAN model to estimate total regional impacts. The direct economic impacts of hydropower are assumed to have no impacts on the regional economy.

IMPLAN is the modeling package used to assess the regional economic impacts stemming from the direct impacts associated with each alternative. IMPLAN is an economic input-output modeling system that estimates the effects of economic changes in a defined analysis area. IMPLAN is a static model that estimates impacts for a snapshot in time when the impacts are expected to occur, based on the makeup of the economy at the time of the underlying IMPLAN data. IMPLAN measures the initial impact on the economy but does not consider long-term adjustments as labor and capital move into alternative uses. Realistically, the structure of the economy would adapt and change; therefore, the IMPLAN results can only be used to compare relative changes between the No Action Alternative and the action alternatives and cannot be used to predict or forecast future employment, labor income, or output (sales).

Input-output models measure commodity flows from producers to intermediate and final consumers. Purchases for final use (final demand) drive the model. Industries produce goods and services for final demand and purchase goods and services from other producers. These other producers, in turn, purchase goods and services. This buying of goods and services (indirect purchases) continues until leakages from the analysis area (imports and value added) stop the cycle. These indirect and induced effects (the effects of household spending) can be mathematically derived using a set of multipliers. The multipliers describe the change in output for each regional industry caused by a $1.00 change in final demand.

This analysis used 2013 IMPLAN data for the counties encompassing the study areas. IMPLAN data files for the analysis area are compiled from a variety of sources, including the U.S. Bureau of Economic Analysis, the U.S. Bureau of Labor, and the U.S. Census Bureau.

4.19.3 Economic Benefits (Direct Impacts)

4.19.3.1 Elephant Butte Irrigation District

The hydrologic modeling assumes there are no changes in cropping or acreage during the study period. Focusing solely on the Rincon and Mesilla Basins, the difference in the economic benefits or direct impacts between alternatives is limited to differences in pumping costs incurred by project irrigators when surface water is not available. The hydrology modeling assumes that the cropping pattern for each service area within the model domain is based on cropping data available for the year 2000.

The average annual ground water supply available to EBID as estimated by the hydrology model (Appendix C) are shown above in Section 4.10 entitled Farm Groundwater Deliveries. These EBID deliveries are split between the Rincon (roughly 20 percent) and Mesilla (roughly 73 percent) Valleys based on the acreage distribution between the two valleys (including EPCWID land in the Mesilla Valley).

Table 4-15 EBID average annual pumping costs (millions of dollars) by alternative and climate scenario

Valley &	Alternative				
Climate	1	2	3	4	5
Rincon					
Drier	1.3	1.3	1.3	1.1	1.1
Central	1.1	1.1	1.1	0.9	0.9
Wetter	1.0	1.0	1.0	0.8	0.9
Mesilla					
Drier	4.7	4.7	4.6	4.1	4.2
Central	4.1	4.1	3.8	3.4	3.4
Wetter	3.6	3.6	3.7	2.9	3.1

Table 4-16 EBID Agricultural benefit values (millions of dollars) relative to a change between No Action and action alternatives and climate scenario

Valley &	Alternative				
Climate	1	2	3	4	5
Rincon					
Drier	-0.2	-0.2	-0.2	0.0	No Action
Central	-0.2	-0.2	-0.2	0.0	No Action
Wetter	-0.1	-0.1	-0.1	0.1	No Action
Mesilla					
Drier	-0.5	-0.5	-0.4	0.1	No Action
Central	-0.7	-0.7	-0.4	0.0	No Action
Wetter	-0.5	-0.5	-0.6	0.2	No Action
Total					
Drier	-0.7	-0.7	-0.6	0.1	No Action
Central	-0.9	-0.9	-0.6	0.0	No Action
Wetter	-0.6	-0.6	-0.7	0.3	No Action

4.19.3.1.1 Alternative 1: Continued OA and San Juan–Chama Storage, Preferred Alternative

Under Alternative 1, the estimated pumping costs equal $1.1 million in the Rincon Valley and $4.1 million in the Mesilla Valley based on the central climate scenario as shown in Table 4-15. The impact of this alternative is measured relative to Alternative 5 (No Action) as shown in Table 4-16. Under Alternative 1, pumping costs increase relative to Alternative 5, therefore under this alternative, economic benefits decrease, based on the central climate scenario, by $0.2 in the Rincon Valley and $0.7 in the Mesilla Valley.

4.19.3.1.2 Alternative 2: No San Juan–Chama Project Storage

As shown in Tables 4-15 and 4-16, Alternative 2 would be the same as Alternative 1.

4.19.3.1.3 Alternative 3: No Carryover Provision

Under Alternative 3, the estimated pumping costs equal $1.1 million in the Rincon Valley and $3.8 million in the Mesilla Valley based on the central climate scenario as shown in Table 4-15. The impact of this alterative is measured relative to Alternative 5 (No Action) as shown in Table 4-16. Under Alternative 3, pumping costs increase relative to Alternative 5, therefore under this alternative economic benefits decrease, based on the central climate scenario, by $0.2 and $0.4, in the Rincon Valley and Mesilla Valley, respectively.

4.19.3.1.4 Alternative 4: No Diversion Ratio Adjustment

Under Alternative 4, the estimated pumping costs equal $0.9 million in the Rincon Valley and $3.4 million in the Mesilla Valley based on the central climate scenario as shown in Table 4-15. The impact of this alterative is measured relative to Alternative 5 (No Action) as shown in Table 4-16. Under Alternative 4, pumping costs do not change relative to Alternative 5, therefore under this alternative economic benefits are unchanged, based on the central climate scenario, in both the Rincon and Mesilla Valleys.

4.19.3.1.5 Alternative 5: Prior Operating Practices, No Action Alternative

Under Alternative 5, the estimated pumping costs equal $0.9 million in the Rincon Valley and $3.4 million in the Mesilla Valley based on the central climate scenario as shown in Table 4-15. Alternative 5 is the No Action Alternative, therefore the impacts of the action alternatives are relative to this alternative.

4.19.3.2 El Paso County Water Improvement District No. 1

As discussed in Section 4.19.2, EPCWID supplies water to both agricultural water users and urban or M&I users. The economic benefits and regional economic impacts are analyzed separately for agricultural and M&I water uses. The average annual water supply available to EPCWID is estimated by the hydrology model (Appendix C). The economic analysis here assumes that RGP water is distributed proportionally to M&I (15.9 percent of diversions) and agricultural (84.1 percent of diversions) uses throughout the study period.

4.19.3.2.1 El Paso Valley agricultural use

EPCWID El Paso Valley agricultural water use value is based on the net benefits of RGP water use reported by Ward and Pulido-Velazquez (2012). Agricultural users in this area are not reported to make significant use of groundwater to supplement their surface water use. Therefore, the agricultural benefit value is based on the effects of surface water deliveries for each alternative as it relates to surface water deliveries.

Table 4-17 EPCWID El Paso Valley average annual agricultural benefits (millions of dollars) by alternative and climate scenario

Valley & Climate	Alternative 1	2	3	4	5
Drier	20.6	20.6	20.5	19.2	19.5
Central	23.4	23.4	22.8	22.0	21.7
Wetter	26.2	26.2	26.3	25.3	25.2

Table 4-18 EPCWID El Paso Valley average annual agricultural benefits changes (millions of dollars) between alternatives and climate scenario

Valley & Climate	Alternative 1	2	3	4	5
Drier	1.1	1.1	1.0	-0.3	No Action
Central	1.7	1.7	1.1	0.3	No Action
Wetter	1.0	1.0	1.1	0.1	No Action

4.19.3.2.1.1 Alternative 1: Continued OA and San Juan–Chama Storage, Preferred Alternative

Under Alternative 1, the estimated value of production is $23.4 million in the El Paso Valley based on the central climate scenario as shown in Table 4-17. The impact of this alterative is measured relative to Alternative 5 (No Action) as shown in Table 4-18. Under Alternative 1 based on the central climate scenario, the change in value of production is $1.7 million compared to Alternative 5.

4.19.3.2.1.2 Alternative 2: No San Juan–Chama Project Storage

As shown in Tables 4-17 and 4-18, Alternative 2 would be the same as Alternative 1. Under Alternative 2 based on the central climate scenario, the change in value of production is $1.7 million compared to Alternative 5 (No Action).

4.19.3.2.1.3 Alternative 3: No Carryover Provision

Under Alternative 3, the estimated value of production is $22.8 million in the El Paso Valley based on the central climate scenario as shown in Table 4-17. The impact of this alterative is measured relative to Alternative 5 (No Action) as shown in Table 4-18. Under Alternative 3 based on the central climate scenario the change in value of production is $1.1 million compared to Alternative 5.

4.19.3.2.1.4 Alternative 4: No Diversion Ratio Adjustment

Under Alternative 4, the estimated value of production is $22.0 million in the El Paso Valley based on the central climate scenario as shown in Table 4-17. The impact of this alterative is measured relative to Alternative 5 (No Action) as shown in Table 4-18. Under Alternative 4 based on the central climate scenario the change in value of production is $0.3 million compared to Alternative 5.

4.19.3.2.1.5 Alternative 5: Prior Operating Practices, No Action Alternative

Under Alternative 5, the estimated value of production is $21.7 million in the El Paso Valley based on the central climate scenario as shown in Table 4-17. Alternative 5 is the No Action Alternative, therefore the impacts of the action alternatives are relative to this alternative.

4.19.3.2.2 Mesilla Valley agricultural use

In the Mesilla Valley, the hydrologic studies show full availability of groundwater to substitute for surface water when diversions fall below allocations. The difference in the economic benefits or direct impacts between alternatives is limited to differences in pumping costs incurred by project irrigators when surface water is not available.

Table 4-19 EPCWID Mesilla Valley agricultural benefit values relative to a change ($ millions) between No Action and action alternatives and climate scenario

Mesilla Valley & Climate	Alternative 1	2	3	4	5
Drier	0.3	0.3	0.4	0.4	0.4
Central	0.3	0.3	0.3	0.3	0.3
Wetter	0.2	0.2	0.2	0.2	0.3

Table 4-20 EPCWID Mesilla Valley annual agricultural benefits changes ($ millions) between No Action and action alternatives by alternative and climate scenario

Mesilla Valley & Climate	Alternative 1	2	3	4	5
Drier	0.1	0.1	0.0	0.0	No Action
Central	0.0	0.0	0.0	0.0	No Action
Wetter	0.1	0.1	0.1	0.1	No Action

4.19.3.2.2.1 Alternative 1: Continued OA and San Juan–Chama Storage, Preferred Alternative

Under Alternative 1, the estimated pumping cost is $0.3 million in the Mesilla Valley based on the central climate scenario as shown in Table 4-19. The impact of this alterative is measured relative to the No-Action Alternative (Alternative 5) as shown in Table 4-20. There is no change in pumping costs under Alternative 1 compared to the No-Action Alternative; therefore, the economic benefit value is unchanged.

4.19.3.2.2.2 Alternative 2: No San Juan–Chama Project Storage

As shown in Tables 4-19 and 4-20, Alternative 2 would be the same as Alternative 1. There is no change in pumping costs under Alternative 2 compared to Alternative 5 (No Action); therefore, the economic benefit value is unchanged.

4.19.3.2.2.3 Alternative 3: No Carryover Provision

Under Alternative 3, the estimated pumping cost is $0.3 million in the Mesilla Valley based on the central climate scenario as shown in Table 4-19. The impact of this alterative is measured relative to Alternative 5 (No Action) as shown in Table 4-20. There is no change in pumping costs under Alternative 3 compared to Alternative 5; therefore, the economic benefit value is unchanged.

4.19.3.2.2.4 Alternative 4: No Diversion Ratio Adjustment

Under Alternative 4, the estimated pumping cost is $0.3 million in the Mesilla Valley based on the central climate scenario as shown in Table 4-19. The impact of this alterative is measured relative to Alternative 5 (No Action) as shown in Table 4-20. There is no change in pumping costs under Alternative 4 compared to Alternative 5; therefore, the economic benefit value is unchanged.

4.19.3.2.2.5 Alternative 5: Prior Operating Practices, No Action Alternative

Under Alternative 5, the estimated pumping cost is $0.3 million in the Mesilla Valley based on the central climate scenario as shown in Table 4-19. The impact of this alterative is measured relative to Alternative 5 (No Action) as shown in Table 4-20. Alternative 5 is the No Action Alternative; therefore, the impacts of the action alternatives are relative to this alternative.

4.19.3.2.3 EPCWID El Paso Valley urban use

The Ward and Pulido-Velazquez (2012) values were used to estimate the economic benefit values for urban water use in EPCWID as explained in Section 4.19.2. A value of $574 per acre-foot was applied to the estimated average annual urban deliveries to estimate the average annual benefits value for the alternative.

Table 4-21 EPCWID El Paso Valley urban use average annual economic benefits ($ millions) by alternative and climate scenario

El Paso Valley & Climate	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
Drier	19.9	19.9	19.6	18.3	18.3
Central	22.8	22.8	21.8	21.2	20.7
Wetter	25.3	25.3	25.1	23.8	23.7

Table 4-22 EPCWID El Paso Valley urban use average annual economic benefits ($ millions) changes between No Action and action alternatives by alternative and climate scenario

El Paso Valley & Climate	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
Drier	1.6	1.6	1.3	0.0	No Action
Central	2.1	2.1	1.1	0.5	No Action
Wetter	1.6	1.6	1.4	0.1	No Action

4.19.3.2.3.1 Alternative 1: Continued OA and San Juan–Chama Storage, Preferred Alternative

Under Alternative 1, the estimated value of urban water in EPCWID is $22.8 million based on the central climate scenario as shown in Table 4-21. The impact of this alterative is measured relative to Alternative 5 (No Action), as shown in Table 4-22. Under Alternative 1 based on the central climate scenario the change in value is $2.1 million compared to Alternative 5.

4.19.3.2.3.2 Alternative 2: No San Juan–Chama Project

As shown in Tables 4-21 and 4-22, Alternative 2 would be the same as Alternative 1. Under Alternative 2 based on the central climate scenario, the change in value is $2.1 million compared to Alternative 5 (No Action).

4.19.3.2.3.3 Alternative 3: No Carryover Provision

Under Alternative 3, the estimated value of urban water in EPCWID is $21.8 million based on the central climate scenario as shown in Table 4-21. The impact of this alterative is measured relative to Alternative 5 (No Action) as shown in Table 4-22. Under Alternative 3 based on the central climate scenario, the change in value is $1.1 million compared to Alternative 5.

4.19.3.2.3.4 Alternative 4: No Diversion Ratio Adjustment

Under Alternative 4, the estimated value of urban water in EPCWID is $21.2 million based on the central climate scenario as shown in Table 4-21. The impact of this alterative is measured relative to Alternative 5 (No Action) as shown in Table 4-22. Under Alternative 4 based on the central climate scenario the change in value is $0.5 million compared to Alternative 5.

4.19.3.2.3.5 Alternative 5: Prior Operating Practices, No Action Alternative

Under Alternative 5, the estimated value of urban water in EPCWID is $20.7 million based on the central climate scenario as shown in Table 4-21. Alternative 5 is the No Action Alternative; therefore, the impacts of Alternatives 1 to 4 are shown relative to this alternative.

4.19.3.3 Hydropower

Flows and reservoir elevations differ between alternatives; therefore, the expected power generation (gigawatt-hour) would also vary between alternatives. The estimated generation at Elephant Butte Dam by alternative is shown in Table 4-23. The estimated economic value of this generation is shown in Table 4-24 and the impacts by alternative are shown in Table 4-25.

Table 4-23 Elephant Butte hydropower (Gwh) average annual economic benefits by alternative and climate scenario

Benefit &	Alternative				
Climate	1	2	3	4	5
Drier	25.2	25.2	26.2	24.8	25.0
Central	34.8	34.8	34.3	33.5	33.7
Wetter	39.6	39.6	36.1	34.7	35.0

Table 4-24 Elephant Butte hydropower average annual economic benefits ($ millions) by alternative and climate scenario

	Alternative				
Climate	1	2	3	4	5
Drier	3.8	3.8	4.0	3.8	3.8
Central	5.3	5.3	5.2	5.1	5.1
Wetter	6.0	6.0	5.5	5.3	5.3

Table 4-25 Elephant Butte hydropower average annual economic benefits ($ millions) changes between No Action and action alternatives by alternative and climate scenario

	Alternative				
Climate	1	2	3	4	5
Drier	0.0	0.0	0.2	0.0	No Action
Central	0.2	0.2	0.1	0.0	No Action
Wetter	0.7	0.7	0.2	0.0	No Action

4.19.3.3.1 Alternative 1: Continued OA and San Juan–Chama Storage, Preferred Alternative

Under Alternative 1, the estimated value of hydropower is $5.3 million based on the central climate scenario as shown in Table 4-24. The impact of this alterative is measured relative to Alternative 5 (No Action) as shown in Table 4-25. Under Alternative 1 based on the central climate scenario the change in value is $0.2 million compared to Alternative 5.

4.19.3.3.2 Alternative 2: No San Juan–Chama Project Storage

As shown in Tables 4-24 and 4-25, Alternative 2 would be the same as Alternative 1. Under Alternative 2 based on the central climate scenario, the change in value is $0.2 million compared to Alternative 5 (No Action).

4.19.3.3.3 Alternative 3: No Carryover Provision

Under Alternative 3, the estimated value of hydropower is $5.2 million based on the central climate scenario as shown in Table 4-24. The impact of this alterative is measured relative to Alternative 5 (No Action) as shown in Table 4-25. Under Alternative 3 based on the central climate scenario the change in value is $0.1 million compared to Alternative 5.

4.19.3.3.4 Alternative 4: No Diversion Ratio Adjustment

Under Alternative 4, the estimated value of hydropower is $5.1 million based on the central climate scenario as shown in Table 4-24. The impact of this alterative is measured relative to Alternative 5 (No Action) as shown in Table 4-25. Under Alternative 4 based on the central climate scenario there is no change in value compared to Alternative 5.

4.19.3.3.5 Alternative 5: Prior Operating Practices, No Action Alternative

Under Alternative 5, the estimated value of hydropower is $5.1 million based on the central climate scenario as shown in Table 4-24. Alternative 5 is the No Action Alternative; therefore, the impacts of the action alternatives are relative to this alternative.

4.19.3.4 Recreation

Elephant Butte Reservoir provides a variety of recreational benefits that vary based on reservoir storage. Because storage varies between alternatives, recreational benefits are calculated for Elephant Butte Reservoir (Mesilla Valley). Recreational activities at Caballo Reservoir also provide recreational benefits. Because the differences in Caballo storage between project alternatives are small and would not result in significant differences in economic benefits from Caballo recreation, these benefits were not estimated.

Table 4-26 Elephant Butte recreation average annual economic benefits ($ millions) by alternative and climate scenario

	Alternative				
Climate	1	2	3	4	5
Drier	0.9	0.9	0.9	0.8	0.9
Central	1.1	1.1	1.1	1.1	1.1
Wetter	1.1	1.1	1.2	1.1	1.1

Table 4-27 Elephant Butte recreation average annual economic benefits changes ($ millions) between No Action and Action Alternatives by alternative and climate scenario

	Alternative				
Climate	1	2	3	4	5
Drier	0.0	0.0	0.0	-0.1	No Action
Central	0.0	0.0	0.0	0.0	No Action
Wetter	0.0	0.0	0.1	0.0	No Action

4.19.3.4.1 Alternative 1: Continued OA and San Juan–Chama Storage, Preferred Alternative

The estimated value of recreation is shown in Table 4-26. The impact of this alterative is measured relative to Alternative 5 (No Action) as shown in Table 4-27. The differences in Elephant Butte Reservoir storage compared to Alternative 5 are small and would not result in significant differences in economic benefits.

4.19.3.4.2 Alternative 2: No San Juan–Chama Project Storage

As shown in Tables 4-26 and 4-27, Alternative 2 would be the same as Alternative 1. The differences in Elephant Butte Reservoir storage compared to Alternative 5 (No Action) are small and would not result in significant differences in economic benefits.

4.19.3.4.3 Alternative 3: No Carryover Provision

The estimated value of recreation is shown in Table 4-26. The impact of this alterative is measured relative to Alternative 5 as shown in Table 4-27. The differences in Elephant Butte Reservoir storage compared to Alternative 5 (No Action) are small and would not result in significant differences in economic benefits.

4.19.3.4.4 Alternative 4: No Diversion Ratio Adjustment

The estimated value of recreation is shown in Table 4-26. The impact of this alterative is measured relative to Alternative 5 as shown in Table 4-27. The differences in Elephant Butte Reservoir storage compared to Alternative 5 are small and would not result in significant differences in economic benefits.

4.19.3.4.5 Alternative 5: Prior Operating Practices, No Action Alternative

Alternative 5 is the No Action Alternative; therefore, the impacts of the action alternatives are relative to this alternative.

4.19.4 Regional Economic Impacts

4.19.4.1 Elephant Butte Irrigation District

The regional economic impacts in EBID would result from a change in pumping costs. Pumping cost changes would result in higher or lower net farm income, which translates to farm households having more or less money to spend within the regional economy.

Table 4-28 EBID regional economic impacts by alternative under the central tendency climate change scenario (incremental to Alternative 5)

	Alternative				
EBID Ag.	1	2	3	4	5
Employment	-5	-5	-4	0	No Action
Labor Income	(185,947)	(185,947)	(123,965)	0	No Action
Output	(599,166)	(599,166)	(399,444)	0	No Action

4.19.4.1.1 Alternative 1: Continued OA and San Juan–Chama Storage, Preferred Alternative

Pumping costs in the Rincon and Mesilla Valleys are estimated to increase by $0.9 million compared to Alternative 5 (No Action) under the central tendency climate change, as discussed in Section 4.19.3. The regional impacts of this alternative stem from a decrease ($0.9) in farm household income, because of the pumping cost increase, relative to Alternative 5. The changes in employment, labor income, and output under Alternative 1 are shown in Table 4-28.

4.19.4.1.2 Alternative 2: No San Juan–Chama Project Storage

As shown in Table 4-28, Alternative 2 would be the same as Alternative 1. The regional impacts of this alternative stem from a decrease ($0.9) in farm household income because of the pumping cost increase relative to Alternative 5 (No Action).

4.19.4.1.3 Alternative 3: No Carryover Provision

Pumping costs in the Rincon and Mesilla Valleys are estimated to increase by $0.6 million compared to Alternative 5, under the central tendency climate change, as discussed in Section 4.19.3. The regional impacts of this alternative stem from a decrease ($0.6) in farm household income, because of the pumping cost increase, relative to Alternative 5 (No Action). The changes in employment, labor income, and output under the Alternative 3 are shown in Table 4-28.

4.19.4.1.4 Alternative 4: No Diversion Ratio Adjustment

Compared to Alternative 5, under the central tendency climate scenario there is no estimated change in pumping costs in the Rincon and Mesilla Valleys under Alternative 4 as discussed in Section 4.19.3. Therefore, there is no change in the estimated regional impacts under this alternative as shown in Table 4-28.

4.19.4.1.5 Alternative 5: Prior Operating Practices, No Action Alternative

The regional economic impacts are measured based on incremental changes from Alternative 5 conditions; therefore, the total regional impacts associated with Alternative 5 (No Action) were not measured.

4.19.4.2 El Paso County Water Improvement District No. 1

4.19.4.2.1 El Paso Valley agricultural use

The regional impacts stemming from El Paso Valley agricultural use are based a change in production value as shown in Table 4-18.

Table 4-29 EPCWID, El Paso Valley agriculture regional impacts under the central tendency climate change scenario by alternative (incremental to Alternative 5)

	Alternative				
EPCWID Ag. El Paso	1	2	3	4	5
Employment	45	45	29	8	No Action
Labor Income	1,107,627	1,107,627	716,700	195,463	No Action
Output	3,194,525	3,194,525	2,067,046	563,740	No Action

4.19.4.2.1.*1 Alternative 1: Continued OA and San Juan–Chama Storage, Preferred Alternative*

Under Alternative 1, the agricultural production value is estimated to increase by $1.7 million (shown in Table 4-18) compared to Alternative 5 (No Action). This increase in value has a positive impact on the regional economy in terms of job, labor income, and output as shown in Table 4-29.

4.19.4.2.1.2 Alternative 2: No San Juan–Chama Project

As shown in Table 4-29, Alternative 2 would be the same as Alternative 1 in terms of job, labor income, and output as shown in Table 4-29.

4.19.4.2.1.3 Alternative 3: No Carryover Provision

Under Alternative 3, the agricultural production value is estimated to increase by $1.1 million (shown in Table 4-18) compared to Alternative 5 (No Action). This increase in value has a positive impact on the regional economy in terms of job, labor income, and output as shown in Table 4-29.

4.19.4.2.1.4 Alternative 4: No Diversion Ratio Adjustment

Under Alternative 4, the agricultural production value is estimated to increase by $0.3 million (shown in Table 4-18) compared to Alternative 5 (No Action). This increase in value has a positive impact on the regional economy in terms of job, labor income, and output as shown in Table 4-29.

4.19.4.2.1.5 Alternative 5: Prior Operating Practices, No Action Alternative

The regional economic impacts are measured based on incremental changes from Alternative 5 conditions; therefore, the total regional impacts associated with Alternative 5 (No Action) were not measured.

4.19.4.2.2 Mesilla Valley Agricultural Use

The estimated change in economic benefits or direct impacts are unchanged for all alternatives relative to Alternative 5 (No Action) as shown in Table 4-20.

4.19.4.2.3 EPCWID Urban Use

The regional impacts stemming from El Paso Valley urban water use are based a change in the change in economic value or direct impacts as shown in Table 4-22.

Table 4-30 EPCWID, El Paso Valley urban regional impacts under the central tendency climate change scenario by alternative (incremental to Alternative 5)

EPCWID M&I, El Paso	Alternative 1	2	3	4	5
Employment	15	15	8	7	No Action
Labor Income	1,041,396	1,041,396	545,493	557,497	No Action
Output	3,603,279	3,603,279	1,887,432	857,923	No Action

4.19.4.2.3.1 Alternative 1: Continued OA and San Juan–Chama Storage, Preferred Alternative

Under Alternative 1, the value of urban water use is estimated to increase by $2.1 million (shown in Table 4-22) compared to Alternative 5 (No Action). This increase in value has a positive impact on the regional economy in terms of job, labor income, and output as shown in Table 4-30.

4.19.4.2.3.2 Alternative 2: No San Juan–Chama Project

As shown in Tables 4-22 and 4-30, Alternative 2 would be the same as Alternative 1 in terms of job, labor income, and output.

4.19.4.2.3.3 Alternative 3: No Carryover Provision

Under Alternative 3, the value of urban water use is estimated to increase by $1.1 million (shown in Table 4-22) compared to Alternative 5 (No Action). This increase in value has a positive impact on the regional economy in terms of job, labor income, and output as shown in Table 4-30.

4.19.4.2.3.4 Alternative 4: No Diversion Ratio Adjustment

Under Alternative 4, the value of urban water use is estimated to increase by $0.5 million (shown in Table 4-22) compared to Alternative 5 (No Action). This increase in value has a positive impact on the regional economy in terms of job, labor income, and output as shown in Table 4-30.

4.19.4.2.3.5 Alternative 5: Prior Operating Practices, No Action Alternative

The regional economic impacts are measured based on incremental changes from Alternative 5 conditions; therefore, the total regional impacts associated with Alternative 5 (No Action) were not measured.

4.19.4.3 Hydropower

The regional impacts are not affected by hydropower production at Elephant Butte.

4.19.4.4 Recreation

The differences in Elephant Butte Reservoir storage for all action alternatives compared to Alternative 5 (No Action) are small and would not result in significant differences in regional economic impacts.

4.19.5 Summary Conclusions

The average annual economic benefits under the central tendency climate scenario for each alternative and water use category are summarized in Table 4-31. Generally, Alternatives 1 to 4 would increase the total benefits compared to Alternative 5 (No Action). The economic benefits estimated for EBID would decrease compared to Alternative 5 for all of the alternatives except Alternative 4, while the benefits estimated for EPCWID would increase compared to Alternative 5.

The regional impacts under the central tendency climate scenario estimated for each alternative and water use category are summarized in Table 4-32. Generally, the regional impacts in the New Mexico study area (Doña Ana and Sierra Counties, New Mexico) where EBID is located decrease compared to Alternative 5 for all action alternatives.

The regional impacts in the Texas study area (El Paso and Hudspeth Counties) where EPCWID is located increase for all action alternatives compared to Alternative 5. Compared to the overall region, these changes (positive and negative) are small compared to the entire regional economies of the New Mexico and Texas study areas.

Table 4-31 Summary of economic benefits (millions of dollars) by alternative under the central tendency climate scenario

	Alternative				
Valley & Resource	1	2	3	4	5
Rincon Agriculture	-0.20	-0.20	-0.20	0.00	No Action
Mesilla Agriculture	-0.70	-0.70	-0.40	0.00	No Action
EPCWID El Paso Ag.	1.70	1.70	1.10	0.30	No Action
EPCWID Mesilla Ag.	0.00	0.00	0.00	0.00	No Action
EPCWID El Paso M&I	2.10	2.10	1.10	0.50	No Action
Hydropower	0.20	0.20	0.10	0.00	No Action
Recreation	0.00	0.00	0.00	0.00	No Action
Total	3.10	3.10	1.70	0.80	No Action

Table 4-32 Regional impacts summary (jobs, dollars) by alternative under the central tendency climate scenario

	Alternative				
Valley/Resource	1	2	3	4	5
EBID Agriculture					
Employment	-5	-5	-4	0	No action
Labor Income	(185,947)	(185,947)	(123,965)	0	No action
Output	(599,166)	(599,166)	(399,444)	0	No action
EPCWID El Paso Valley Agriculture					
Employment	45	45	29	8	No action
Labor Income	1,107,627	1,107,627	716,700	195,463	No action
Output	3,194,525	3,194,525	2,067,046	563,740	No action
EPCWID Mesilla Valley -Ag	No Change	No Change	No Change	No Change	No action
EPCWID El Paso – M&I (Urban)					
Employment	15	15	8	7	No action
Labor Income	1,041,396	1,041,396	545,493	557.497	No action
Output	3,603,279	3,603,279	857,923	563,740	No action

4.20 Environmental Justice

4.20.1 Analysis Methods and Assumptions

As informed by the Federal Interagency Working Group on Environmental Justice and NEPA Committee (2016), a disproportionately high and adverse impact on minority or low-income populations is based on a comparison of the adverse impacts on the environmental justice community relative to the impacts on the overall population of the study area, based on the particular resource analyzed in the NEPA document. As described in Section 3.15 of Chapter 3, Doña Ana, El Paso, and Hudspeth Counties are environmental justice communities, while Sierra County is not an environmental justice community. However, because the economic analysis combined Sierra County with Doña Ana County as the New Mexico study area, this combination is retained here.

4.20.2 Employment

From 1970 to 2014, employment in the four counties grew from 179,838 to 515,740 jobs, a 187 percent increase (Commerce, Bureau of Economic Analysis 2015). Tables 4-28 and 4-32 project a potential loss of 4 or 5 farm jobs in the non-environmental justice communities (Doña Ana and Sierra Counties, New Mexico study area) under the action alternatives compared to Alternative 5 (No Action). Tables 4-29 and 4-32 show that the environmental justice communities (El Paso and Hudspeth Counties, Texas study area) would experience a slight positive benefit: a potential increase of 8 to 45 farm jobs compared to Alternative 5 (No Action). Relative to 515,740 total jobs in the study area during 2014, 4 to 45 jobs is insignificant. This means there is neither a high nor disproportionate effect on environmental justice communities.

4.20.3 Income

From 1970 to 2014, personal income grew from $8,820.3 million to $33,568.8 million, a 281 percent increase across the four-counties (Commerce, Bureau of Economic Analysis 2015). Tables 4-28 and 4-32 project a potential maximum decrease in labor income in the non-environmental justice communities (Doña Ana and Sierra Counties, New Mexico study area) of $185,947. Tables 4-29 and 4-32 indicate there would be a potential maximum increase of $1,107,627 in the environmental justice communities (El Paso and Hudspeth Counties, Texas study area), an insignificant effect relative to the $34 million incomes in the counties.

5 Cumulative Effects and Other NEPA Considerations

This chapter discusses the cumulative effects of the alternatives within the context of other past, present, and reasonably foreseeable future actions. It also presents other NEPA considerations from 40 CFR 1502.16 including adverse effects which cannot be avoided should the proposal be implemented, the relationship between short-term uses and long-term productivity, and any irreversible and irretrievable commitments of resources involved in the proposal should it be implemented.

5.1 Regulatory Framework

CEQ regulations require consideration of cumulative impacts defined as:

> "…the impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (Federal or non-federal) or person undertakes such other actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time." [40 CFR 1508.7]

Following CEQ guidance, the cumulative impact study area for identifying these actions is expanded beyond the immediate project area to include actions that might affect the same water resources, biological, cultural and socioeconomic resources of the environment as those described in Chapters 3 and 4. Cumulative actions that could result in cumulative impacts are listed below.

5.2 Reasonably Foreseeable Future Actions

Actions which have the potential to create ongoing or additive effects to those of the alternatives are summarized in chronological order with the most recent documents first

5.2.1 Far West Texas Water Development Board Plan (2016) and El Paso Water Plan (2013)

The 2016 Far West Texas Water Plan prepared by the Texas Water Development Board (2016) recognizes that current and future water demand and supply sources are constantly changing and indicates water plans need to be updated every 5 years. The plans recognize the City of El Paso as one of the fastest growing cities in Texas and that throughout Far West Texas (a larger area than the study are for this FEIS), the largest category of water use is irrigated agriculture. The 2016 Far West Texas Water Plan states that irrigation water shortages have occurred in El Paso and Hudspeth Counties due to insufficient water in the Rio Grande during the recent drought and those farmers in these counties have generally reduced irrigated acreage, changed types of crops planted, or not planted crops.

El Paso Water is the largest supplier of municipal water in Far West Texas and the utility has implemented a water conservation program that has significantly reduced per capita water demand. The City of El Paso has historically received about 50 percent of its M&I supply from surface water and 50 percent from groundwater in the Hueco Bolson and the Mesilla Bolson.

According to Hutchison (2006), historic pumping in the Mesilla Bolson has not resulted in significant changes in groundwater levels or groundwater quality, but pumping up to 1979 in the Hueco Bolson lowered groundwater levels and led to brackish groundwater intrusion. In the 1980s, El Paso reduced its groundwater pumping in the Hueco Bolson to about 80,000 AFY by increasing surface water diversion from the Rio Grande, increasing conservation efforts, and increasing reclaimed water use. By 2002, El Paso Water pumping in the Hueco Bolson dropped below 40,000 AFY and has since remained at these levels (Hutchison 2006). Reclamation, 2014a. River Maintenance Program-Delta Channel Maintenance Project Environmental Assessment
The Delta Channel Maintenance Project maintains the existing, constructed Delta Channel to facilitate efficient delivery of Rio Grande water to the Elephant Butte Reservoir pool. It involves such activities as channel sediment removals, berm repair, site access, and staging area maintenance. River maintenance is conducted along 20.8 miles of the Delta Channel. Project-related road and staging area maintenance would be conducted within an approximately 293-square mile study area boundary in Socorro and Sierra Counties, New Mexico.

5.2.2 Reclamation River Maintenance Program-Delta Channel Maintenance Project Environmental Assessment and Finding of No Significant Impact

The Delta Channel Maintenance Project maintains the existing constructed delta channel to facilitate efficient delivery of Rio Grande water to Elephant Butte Reservoir. It involves activities such as channel sediment removal, berm repair, site access, etc. River maintenance is conducted along a 20.8 miles in Socorro and Sierra Counties, New Mexico. The project includes a suite of conservation measures to minimize or avoid adverse impacts on water quality, vegetation, species habitat, and wildlife. In addition, Reclamation is implementing recovery actions identified in the flycatcher and Rio Grande silvery minnow recovery plans.

5.2.2 USIBWC River Management Alternatives for the Rio Grande Canalization Project, River Management Plan, FEIS and Record of Decision (2014, 2012, 2009)

The USIBWC completed an evaluation of river management alternatives for the Rio Grande Canalization Project. This project affects a 105.4-mile long river reach from Percha Dam to the international boundary at El Paso and Cuidad Juarez, Chihuahua. The status is that the USIBWC is in the second phase of implementation of their 2009 Record of Decision on the River Management Alternatives for the Rio Grande Canalization Project and complying with the Service's (2012) biological opinion. The project, as proposed, would include ongoing channel maintenance and floodplain management, including levee improvements, vegetation management, habitat restoration work, and conservation of endangered birds following a flycatcher management plan. The USIBWC committed to establish flycatcher habitat and no-mow zones to enhance riparian vegetation.

5.2.3 Corps FLO-2D Model Development, Caballo Reservoir Flood Release and Court Order No. CIV-90-95 HB/WWD (2013, 2005)

As part of USIBWC's Rio Grande Canalization Project, USIBWC contracted with the Corps of Engineers who subcontracted with Tetra Tech to update the calculations of design storms affecting Caballo Dam releases. While the report is not an "action" per se, in conjunction with Reclamation and USIBWC management of Caballo flood releases, the cumulative action with cumulative effects is that there is statistically almost no chance of a 5,000 cubic feet per second (cfs) release for flood control, although historically, there have been greater than 5,000 cfs flows at the USIBWC's gage below Caballo Dam. The peak discharge is approximately 2,990 cfs, which essentially precludes overbank flooding below Caballo.

5.2.4 Corps of Engineers and CH2MHill (2012) and Rio Grande Salinity Management Program (2012)

The Corps and others have formed a coalition to reduce salinity from San Acacia to Fort Quitman. The project consists of four phases: salinity assessment, salinity management alternatives analysis, feasibility and pilot control project testing, expanded scale salinity control project and evaluation of project effectiveness. Effects of this ongoing project may result in improvements (decreases) in salinity and other contaminants in the Rio Grande through the study area for this FEIS.

5.2.5 City of Las Cruces Wastewater System Master Plan Update (CDM 2008) and 40-Year Water Development Plan (2007)

The City of Las Cruces has had a water and wastewater plan in place since 1995. In 2007, it prepared a 40-year water development plan. In 2008, the City updated their water and wastewater plan which projected that by 2025, with low growth demand it would need a total of 20,549 acre-feet per year; with high growth demand it would need a total of 33,307 acre-feet per year (CDM 2008:6-4). As of 2008, the City's water supply is groundwater from wells in the Mesilla and Jornada groundwater basins. The City's plans include three elements: conjunctive use of surface and groundwater, water conservation, and reclaimed water use. The City anticipates that some but not all of any increase in groundwater pumping would require offsets. The City's director of utilities (Garcia 2008) indicated that they have been acquiring and leasing some surface water rights through EBID with verification from the NMOSE. The City's strategy is to concentrate on surface water supply. Working with EBID, they have implemented a Special Water Users Association. The City of Las Cruces has not contracted with EBID and Reclamation for conversion of irrigation water to municipal and industrial uses.

5.2.6 New Mexico State Parks, Elephant Butte Lake State Park Management Plan (2006)

This is a resource management plan guiding recreation and the management of public recreational opportunities at Elephant Butte Lake State Park. NM State Parks also manages recreational areas at Caballo, Percha, and Leasburg Diversion Dams.

5.2.7 New Mexico Lower Rio Grande Regional Water Plan (2004)

This plan, with a revision currently in progress, provides population projections through 2040 for three different rates of regional growth to provide a high estimate, a medium-range estimate, and a low range estimate. Projected public water supply requirements for the area are made through the year 2040 for the low, medium and high growth scenarios. This plan includes other public water supply systems located within the planning area with relevant estimates of the population served and the total amount of water provided by these systems.

5.2.8 NMOSE Active Water Resource Management Initiative (2004)

This project of the NMOSE, initiated in 2004, could have ongoing effects in the cumulative impact study region. Under this initiative, the NMOSE declared the Lower Rio Grande a "priority basin" (NMAC 19.25.13). The objective is to supervise the physical distribution of water to protect senior water right owners, to assure compliance with interstate stream compacts and to prevent calls by senior water rights holders for administration of water rights. In addition, these rules fulfill the mandates of Section 72-2-9.1 NMSA, requiring the state engineer to adopt rules for priority administration based on appropriate hydrological models and facilitate marketing within water master districts subject to priority administration.

5.2.9 Reclamation Elephant Butte and Caballo Reservoirs Resource Management Plan, Record of Decision and FEIS (2003, 2002)

This is Reclamation's resource management plan designed to guide Reclamation and other Federal, state, local, and participating agencies in managing, allocating, and appropriately using Elephant Butte and Caballo Reservoirs' land and water resources. The RMP was also designed to assist Reclamation in making decisions regarding the management of recreation resources.

5.3 Cumulative Impacts by Resource

This section projects cumulative impacts of the reasonably foreseeable future actions listed in Section 5.2 on resources described in Chapters 3 and 4 of the FEIS.

5.3.1 Water Resources including Reservoir Storage, Elephant Butte Reservoir Elevations, Allocations, Releases, Diversions, Farm Surface Water Deliveries

Effects of the Federal actions listed above were included in the modeling of the effects of the alternatives, so there would be no additional cumulative effects to water resources. While water management plans of the Cities of Las Cruces and El Paso and of Far West Texas (Texas Water Development Board 2016) are listed as cumulative actions above, due to uncertainties, future effects of these municipal plans have only partially been incorporated in Chapter 4 water resource analyses. The original 1920 Act contracts with the City of El Paso were done in 1940 which allowed the city to purchase 2,000 acres of irrigated farmland for conversion of the water allocated to that land to M&I supply. By the 1950s (President's Commission 1950), El Paso and Albuquerque had experienced water shortages. Back then, El Paso began buying additional lands from landowners within the RGP to obtain rights to water under arrangements with EPCWID. These effects were part of the modeling of water resources analyses in Chapter 4 (Sections 4.1 to 4.12). The City of Las Cruces, through its 40-Year Water Plan, is considering a similar strategy of acquiring or leasing surface water rights through EBID. While their plan is considered a cumulative action, there are not enough data or details to model how this might occur.

5.3.2 Groundwater

The assumption of the Chapter 4 groundwater analyses (Sections 4.9 to 4.11) is that irrigation water requirements that are not satisfied by RGP surface water deliveries are met through supplemental groundwater pumping. For groundwater elevations, the model projects that the differences that would be caused by implementing one or another of the alternatives would be less than the differences that might arise due to future climatic conditions.

Increases in future groundwater pumping by the Cities of Las Cruces or El Paso were not modeled, but could be anticipated to result in lower groundwater levels in the future unless offset by decreases in pumping in other parts of the aquifer. No data or models are presently available to Reclamation to quantify groundwater effects of the cities' future actions related to groundwater uses.

5.3.3 Water Quality

Since the 1950s, quality of surface water in the Rio Grande has been documented as degrading from the San Luis Valley to Fort Quitman (President's Commission 1950), although in the latest 303d report of New Mexico (NMED 2016: 175-178), water quality has improved in Elephant Butte Reservoir. When the effects of the alternatives are added to those ongoing effects from Reclamation's Delta Channel Maintenance Project and low flow conveyance channel, water quality in the reservoir is expected to be within the ranges historically documented with possible impairments due to mercury, nutrients and polychlorinated biphenyls. Likewise, cumulative impacts to water quality in Caballo Reservoir are expected to fluctuate over time with the quantity of water in storage, but with ongoing impairments due to high nutrient levels.

Downstream of Caballo Reservoir in the USIBWC Rio Grande Canalization Project, water quality should improve over time when the effects of the alternatives are added to those of USIBWC's Record of Decision implementation (2012, 2009), which includes more efficient water delivery, soil erosion prevention, and habitat restoration, water quality should improve slightly over time. Also, the Corps' Salinity Management Program and work of El Paso Water should result in cumulative improvements to water quality.

5.3.4 Vegetation and Weeds

As described in Sections 3.6 and 4.13, the existence of the reservoirs, combined with USIBWC's Rio Grande Canalization Projects downstream of Caballo Reservoir has led to the present status of vegetation communities across the cumulative impact study area. At the inflow area to Elephant Butte Reservoir, ongoing effects of Reclamation's Delta Channel Maintenance Project would continue to help moderate potential impacts from inundating vegetation and vegetation loss or degradation in Elephant Butte Reservoir.

The reservoir pool elevations would continue to fluctuate under all alternatives and these fluctuations would continue to affect individual plants throughout the reservoir area. Although given the low probabilities of the reservoir surface water remaining at one elevation for a prolonged period, it is unlikely that whole patches of vegetation would be affected or that there would be a net loss of habitat for nesting birds.

Downstream of the RGP reservoirs, the Rio Grande was canalized between 1938 and 1943, and the vegetation in most areas is managed by the USIBWC and monitored as part of USIBWC's and Reclamation's ESA commitments. There are sections of the downstream environment where some native vegetation is being managed by USIBWC to improve wildlife habitat and there are ongoing beneficial effects due to their non-native plant control program (USIBWC 2012). These beneficial effects are expected to continue into the future.

While there is some potential for noxious weeds to grow or increase in the short-term, however as a cumulative impact of management by both the USIBWC and Reclamation noxious weeds are managed under an integrated pest management framework. As a result, no increase in cumulative impacts to weeds is expected.

5.3.5 Wetlands and Floodplains

No additional cumulative impacts to wetlands and floodplains would be anticipated based on the cumulative actions listed in Section 5.2. There are patches of emergent marsh plants in the sediment delta inflow area to Elephant Butte Reservoir, but these patches are not expected to become jurisdictional wetlands due to the repeated cycles of wetting and drying: the fluctuations are unlikely to support the development of hydric soils.

For floodplains in the cumulative impact study region, between the USIBWC's and Reclamation's ongoing actions of managing releases from Elephant Butte and Caballo Dams and actively managing the river segments, there would be no change in base floodplains and no construction proposed in the 100- or 500-year floodplains that has not undergone prior NEPA analysis.

As stated by the USIBWC (2007, 2009a, b), the Rio Grande floodplain was enclosed by a levee system and dredged river channel beginning in 1938 and completed in 1943. The canalization extends some 105.4 miles along the Rio Grande from below Percha Dam in Sierra County, New Mexico to American Dam in El Paso, Texas, and along the river to Fort Quitman, Texas. The USIBWC increased flood containment capacity as a result of raising levees between 4 – 12 feet in height and dredging the river channel in a series of past actions; and these effects of managing the floodplains to meet Federal Emergency Management Agency certification requirements would continue into the future (USIBWC 2007, 2009b).

5.3.6 Wildlife and Special Status Species

The potential cumulative impacts to terrestrial wildlife (defined by NEPA, not ESA) and special status wildlife species are essentially the same as the projected effects for vegetation. As described in Section 4.14, the flycatcher and the cuckoo are seasonally present in Elephant Butte Reservoir and their habitats may be degraded, expanded, or enhanced depending on the duration at which the water surface elevations remain at a particular elevation. None of the actions listed in Section 5.2 would create cumulative impacts on wildlife or special status species that have not been included in the Section 4.14 analysis or the consultation with the Service.

Along the Rio Grande below Caballo Dam, cumulative impacts to wildlife from the actions of the USIBWC have been described in a series of environmental assessments, environmental impact statements, and consultations (USIBWC 2007, 2009a, b; 2012, 2014a). The USIBWC committed to work on restoring riparian shrub communities suitable for breeding flycatchers in this reach. When Reclamation’s action of releasing water from Caballo Dam is added to the actions of the USIBWC, there should be no cumulative impacts to vegetation, wildlife or special status species that have not already been consulted upon.

5.3.7 Aquatic Resources and Special Status Fish Species

The existence of the RGP dams and reservoirs led to the extirpation of native fish, as discussed in Sections 3.8 and 4.15, but dam existence is in the baseline and cumulative effects are restricted to Reclamation’s Delta Channel Maintenance Project that extends the river into Elephant Butte Reservoir and provides additional occupied habitat for riverine species, including the endangered Rio Grande silvery minnow. Conservation measures included in the project provide habitat features in the channel to support the minnow’s life stages and avoid harming the fish during construction and maintenance. No other cumulative effects to aquatic resources and special status fish are expected to occur through 2050.

Similar to the other biological resources, the range of releases to the Rio Grande from the alternatives is within the range of historical operations. When all the actions listed above are added to the potential effects of the alternatives, no additional cumulative effects to aquatic resources and special status fish species are expected to occur through 2050.

5.3.8 Cultural Resources

Management of historic properties within the cumulative impact study areas is being conducted by Reclamation and the USIBWC as part of their respective Section 110 compliance responsibilities. No other undertakings are reasonably foreseeable that have not undergone Section 106 or 110 compliance; thus, no cumulative effects to historic properties are expected to occur through 2050.

No adverse impacts to Indian sacred sites or resources of tribal concern would be anticipated from the alternatives (as described in Section 4.17); therefore, no cumulative effects would apply to these resources.

5.3.9 Indian Trust Assets

The Rio Grande is recognized as aboriginal territory of the Apache and the Pueblo of Ysleta del Sur has interests in the area around El Paso, but no ITAs have been identified in the cumulative impact study area. As a result, there would be no adverse impacts of the alternatives to ITAs and no cumulative effects on ITAs. The Federal agencies are committed to government-to-government consultation with these Indian tribes, going into the future.

5.3.10 Socioeconomics, Including Farmland

The primary purpose of the RGP is irrigated agriculture and maintaining the water supply for this purpose would continue into the future under all the alternatives. When the cumulative impacts of the actions of the USIBWC are added to those in this FEIS, there are no anticipated changes to farmland in production. As noted by the USIBWC (2009), measures associated with their Integrated Land Management Alternative were selected and are being implemented to minimize the conversion of farmland to non-agricultural uses. As the USIBWC found, no significant impacts on prime farmland are anticipated.

Simulation and analysis of project operations was carried out to evaluate relative changes in the storage, release, and delivery of project water to diversion points for EBID, EPCWID, and Mexico from the five alternatives under future possible climate and hydrologic conditions within the project area, but with the assumption that future M&I demands would be consistent with recent demands. This assumption allows for analysis of changes in project operations because of alternatives, without confounding effects of changes in M&I demand or uses.

The modelling for the FEIS assumes that future pumping for M&I uses would be consistent with recent pumping and there would be no reasonably foreseeable change into future. This assumption is consistent with water plans of the cities in the study area, as cited above.

5.4 Unavoidable Adverse Effects

As described in Chapters 4 and 5, implementation of any of the alternatives, combined with climate change, could result in adverse impacts to birds listed under the ESA and on designated or proposed critical habitat. However, with careful monitoring and reservoir management, and coordination with the Service, adverse effects to birds or their habitat should be avoided or reduced below the level of significance. No other significant adverse effects to resources are projected by the FEIS.

5.5 Relationship between Short-term Uses of the Environment and Maintenance and Enhancement of Long-term Productivity

To assess the relationship between short-term uses and maintenance of long-term productivity, Reclamation considers the period through 2050 to be short-term when compared with the long history of the RGP or the indefinite period beyond 2050 when the RGP continues to be operated and maintained. Within this short-term time frame, Reclamation’s implementation of the OA would result in increased certainty to the RGP water users, given the increased flexibility afforded by carryover allocation and adjustments for project efficiency projected by the diversion ratio. With this FEIS, the RGP water users should have a better understanding of how the system would operate in the future under climate change. There will be times when the districts experience a smaller allocation of surface water which would translate into a smaller surface allocation of water to farms and possible future M&I users, which would be supplemented by groundwater at the discretion of each farmer. Conversely, during wetter climatic conditions, the districts would receive larger surface water allocations resulting in more water to farms and possible future M&I users, which would translate to less groundwater use, all water use dependent on crop types and population.

5.6 Irreversible and Irretrievable Commitments of Resources

The CEQ’s regulations at 40 CFR 1502.16 require consideration of irreversible and irretrievable commitments of resources. This is interpreted to mean decisions affecting non-renewable resources such as land, or causing a species to become extinct, or a resource to be destroyed or removed. The term irreversible also describes the loss of future options.

None of the alternatives has or would result in an irreversible or irretrievable commitment of resources. The proposed action would ensure that the RGP water would continue to be managed consistently and efficiently with respect to the RGP authorization, the districts’ rights, the 1906 treaty, and other applicable laws, court decrees, agreements, and contracts.

6 Preparers, Consultation and Coordination

This chapter details the consultation and coordination among Reclamation and other Federal, state and local agencies, American Indian tribes, and the public in preparing this FEIS. The public scoping process was described in Section 1.9 of the FEIS. This chapter also includes the list of preparers.

6.1 Cooperating Agency Involvement

Reclamation invited nine agencies to cooperate in the NEPA process. Three agencies either declined or did not respond to the request: HCCRD, the New Mexico Interstate Stream Commission, and ABCWUA. Six agencies signed a memorandum of understanding with Reclamation to become cooperating agencies. In October 2015, the City of Santa Fe Water Division ended its role as a cooperating agency. The five agencies cooperating throughout the process are:

- Colorado Division of Water Resources
- Elephant Butte Irrigation District of New Mexico
- El Paso County Water Improvement District No. 1
- Texas Rio Grande Compact Commissioner
- U.S. Section, International Boundary and Water Commission

Reclamation hosted periodic cooperating agency meetings throughout the preparation of this FEIS to ensure that the agencies were informed of and involved in the process based on their legal jurisdiction or special expertise.

6.2 Tribal Consultation

Following Executive Order 13175, Consultation and Coordination with Indian Tribal Governments, Reclamation sent letters on June 24, 2014, asking the two tribes with potential interests in the RGP: Ysleta del Sur Pueblo of Texas and the Mescalero Apache Tribe of the Mescalero Reservation, New Mexico, if they wished to be consulted or had issues or concerns with the proposed action. In October 2015, Reclamation reached out to the tribes via phone call and follow-up e-mail. To date, no response has been received from either tribe.

During the preparation of the SEA covering the OA from 2013 to 2015, the Mescalero Apache Tribe, whose aboriginal territory lies within the project area, expressed concerns about native plants growing along the irrigation canals in the service areas of EBID and EPCWID. Tribal members collect plant material for cultural purposes. This is identified as a resource of tribal concern in the cultural resources analysis (Section 4.17.2).

6.3 Other Consultations and Coordination

6.3.1 U.S. Fish and Wildlife Service

To comply with ESA Section 7(a)(2), Reclamation submitted a biological assessment to the Service on August 20, 2015. Reclamation's finding was that Alternative 1 "may affect, but is not likely to adversely affect" the Rio Grande silvery minnow (*Hybognathus amarus*). The finding was that Alternative 1 "may affect, and is likely to adversely affect" the flycatcher, the cuckoo, and "may affect, is likely to adversely modify proposed or designated critical habitat" for the birds. The finding for the mouse was no effect, because the species is not present in the action area. On May 25, 2016, the Service issued its biological opinion.

6.3.2 Consultation with the Government of Mexico

The USIBWC served as a cooperating agency and assisted Reclamation in conforming to the requirements of Executive Order 12114 regarding effects of proposed Federal actions in other countries. This FEIS describes water deliveries to Mexico, but the modeling assumptions or descriptions in this FEIS are not intended to constitute an interpretation or application of the Treaty with Mexico or to represent current U.S. policy or a determination of future U.S. policy regarding deliveries to Mexico.

6.3.3 New Mexico State Historic Preservation Officer

To comply with the NHPA, Reclamation consulted with the New Mexico Historic Preservation Officer on October 29, 2015, requesting concurrence on the determination of "no historic properties affected." Reclamation received concurrence on November 25, 2015 (see Appendix D).

6.4 Final EIS Distribution

The notice of availability of this FEIS was sent to area libraries, other Federal, state and local agencies, American Indian tribes, and the public. All parties listed in Table 6-1 received a CD or electronic version of the FEIS. Copies may be reviewed at the locations listed below:

- Reclamation, Albuquerque Area Office, 555 Broadway NE, Albuquerque, NM 87102
- Reclamation, El Paso Office, 10737 Gateway West, Suite 350, El Paso, TX 79935
- Natural Resources Library, U.S. Department of the Interior, 1849 C Street NW, Main Interior Building, Washington D.C. 20240-0001
- Elephant Butte Irrigation District, 530 South Melendres Street, Las Cruces, NM 88005
- El Paso County Water Improvement District No. 1, 13247 Alameda Avenue, Clint, TX 79836

A copy of the FEIS is available on Reclamation's website at: http://www.usbr.gov/uc/envdocs/eis.html

Table 6-1 Distribution list

Affiliation	Name
Federal:	
US Environmental Protection Agency	Houston, Robert
U.S. International Boundary and Water Commission	Anaya, Gilbert
U.S. Fish and Wildlife Service	Tuggle, Benjamin
State or Quasi-state:	
Colorado Division of Water Resources	Sullivan, Mike
Colorado Attorney General	Wallace, Chad M.
Colorado Compact Commissioner	Wolfe, Dick
Colorado Department of Law	Wallace, Chad M.
Counsel for EPCWID	Speer Jr., James M.
El Paso Water Control and Improvement District, No. 1	Stubbs, Johnny
Elephant Butte Irrigation District of New Mexico	Salopek, James
New Mexico Attorney General	Balderas, Hector
New Mexico Department of Game & Fish	Wunder, Matt
New Mexico Environment Department	Flynn, Ryan
New Mexico Interstate Stream Commission	Dixon, Deborah K.
New Mexico Office of the State Engineer	Verhines, Scott
New Mexico State Historic Preservation Office	Pappas, Jeff
New Mexico State Parks	Tafoya, Christy
Texas Rio Grande Compact Commissioner	Gordon, Pat
Local Agencies:	
Albuquerque Bernalillo County Water Utility Authority	Sanchez, Mark
City of Las Cruces	Miyagishima, Ken
Stein & Brockman for the City of Las Cruces	Stein, Jay F.
American Indian/Tribal:	
Mescalero Apache	Chino, Frederick
Ysleta del Sur	Paiz, Frank
Libraries:	
New Mexico State University Library	Carter, Stephanie
University of Texas at El Paso	Gaunce, Charles
Organizations and Individuals:	
Audubon New Mexico	Bardwell, Beth
Individual	Welsh, Heidi
New Mexico B.A.S.S. Nation	Earl Conway
Paso del Norte Watershed Council	Keyes, Conrad
Southwest Environmental Center	Bixby, Kevin
Wild Earth Guardians	Pelz, Jen

6.5 List of Preparers

This FEIS was prepared by Reclamation's Upper Colorado Region, Albuquerque Area Office, with contributions from the Denver Policy Office, with assistance from Environmental Management and Planning Solutions, Inc. (EMPSi), Santa Fe, New Mexico. The names of persons who prepared various sections, provided information, or participated to a significant degree in reviewing the document are listed in Table 6-2.

Table 6-2 List of preparers

Name and Title	EIS Responsibility
Reclamation Preparers:	
Cortez, Filiberto, special assistant	Technical coordination, water resources
Coulam, Nancy, environmental protection specialist	Technical coordination, environmental justice
Coykenall, Arthur, biologist	ESA policy and biology review
Cunningham, Catherine, environmental protection specialist	NEPA policy and review
Engel, Paula, economist	Socioeconomics
Ferguson, Ian, civil engineer	Hydrology, climate change, water resources
Garcia, Hector, environmental protection specialist	Technical coordination, quality control
Graham, Rhea, special project officer	Project manager
Heffernan, Beverly, division manager	NEPA policy and review
Llewellyn, Dagmar, hydrologist	Hydrology, climate change, water resources
Painter, M. Jeff, resource management specialist	Technical coordination, quality control
Environmental Management and Planning Solutions, Inc. (EMPSi):	
Batts, David, principal-in-charge	Technical coordination, quality control
Cordle, Amy, administrative planner	Quality control, editing
Crump, Sarah, administrative	Document and administrative record support
Doyle, Kevin, project manager	Technical coordination, cultural resources
Estep, Melissa, engineer	Water resources
Gahli, Zoe, environmental planner	Socioeconomics, environmental justice
McCarter, Molly, environmental planner	Administrative record support
Parker, Nicholas, environmental planner	Technical coordination, quality control
Patterson, Katie, legal reviewer	Legal sufficiency
Prohaska, Holly, environmental planner	Quality control
Rice, Kevin, biologist	Biological resources
Rickey, Marcia, GIS specialist	Maps, figures
Ricklefs, Chad, environmental planner	Cumulative effects, quality control
Schad, Cindy, administrative	508 compliance, formatting
Vankat, Drew, planner	Cumulative, consultation and coordination
Varney, Randy, technical editor	Document editing

Tetra Tech, Inc.:	
Barna, Jeff B., ecologist	Biological resources
Marcus, Mike, biologist	Biological resources
Martz, Merri, biologist	Biological resources
Pershall, Alaina, environmental scientist	Biological resources
Precision Water Resources Engineering, Inc. (PWRE):	
Coors, Shane, engineer	Water resources
Erkman, Caleb, engineer	Water resources
Gacek, Heather, engineer	Water resources
Powell, Anthony, engineer	Water resources
Winchester, John, engineer	Water resources

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