Chapter 2

Overview

COORDINATING LEAD AUTHOR

Gregg Garfin (University of Arizona)

LEAD AUTHOR

Angela Jardine (University of Arizona)

EXPERT REVIEW EDITOR

David L. Feldman (University of California, Irvine)

2.1 Introduction

The first comprehensive analysis of the implications of climate variability and change[i] stated that, "the influence of climate permeates life throughout the United States" (Sprigg and Hinkley 2000, 2).

Since the report was issued, the scientific evidence, the concerns of decision makers, and demonstrated temperature trends and multi-year and decadal variability show that *climate change* also permeates life throughout the Southwestern United States. Since 2000, the region has experienced episodes of severe and sustained drought, declines in water supplies, notable floods, the widespread die-off of conifer trees, increasing temperatures, and severe wildland fires of record extent. These occurrences are related in part to climate change. They also are related to the ways in which climate interacts with other drivers (or forces) of change across the region, such as population growth, economic development, urban expansion, food production, and the extraction and consumption of natural resources, including water, timber, minerals, and energy fuels. Therefore, regular assessment of the state of climate knowledge—and of the climate-related vulnerabilities and risks to citizens and the economy—is vital to clearly define choices available to those who make decisions about the quality of human life

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and livelihoods, the well-being of communities, or the management of resources and landscapes across the Southwest.

The *Assessment of Climate Change in the Southwest United States* is a summary and synthesis of the past, present, and projected future of the region's climate, examining what this means for the health and well-being of human populations and the environment throughout the six Southwestern states—Arizona, California, Colorado, Nevada, New Mexico, and Utah—an area of about 700,000 square miles that includes vast stretches of coastline, an international border, and the jurisdictions of 182 federally recognized Native American tribes.

The report looks at climate and its effects on scales ranging from states to watersheds and across ecosystems and regions; at links between climate and resource supply and demand; at effects on sectors—such as water, agriculture, energy, and transportation—that are critical to the well-being of the region's inhabitants; the vulnerabilities to climate changes of all facets of the region, and the responses, or adaptations, that society may choose to make.

What is an assessment?[ii]

This report is an *assessment* of climate change for the Southwest region of the United States and as such is *not* a research project, review paper, or advocacy piece. We define scientific assessment as a critical evaluation of information for purposes of guiding decisions on a complex issue: climate change and its interactions with other aspects of natural systems and society. Stakeholders, who are typically decision makers, have been actively engaged in defining the scope of this report and in reviewing the document. This assessment is intended to be relevant to public policy and resource management, but our findings, judgments, and recommendations are not prescriptive; we do not present findings as "must-do's," but as options. We have summarized complexity by synthesizing and sorting what is known and widely accepted from what is not known (or not agreed upon). Written chiefly during late 2011, with revisions through mid-2012, this assessment provides a snapshot of the current state of climate change information and knowledge related to the region.

We have synthesized, through evaluation and judgment, information from a range of sources, including data sets of observations, simulations and projections from computer modeling, peer-reviewed scientific papers, case studies, and other sources. This assessment represents the consensus findings of nearly 200 authors and reviewers. In this assessment, experts and decision makers representing a variety of disciplines have discussed and made judgments about the importance and quality of information and about ways to characterize uncertainty and confidence.

Data evaluated in this assessment were collected previously (in some cases by the authors of this report) and are publicly available. Some new understanding results from synthesis. Part of our charge was to identify important gaps in knowledge about climate change and the type of research that would reduce or better define areas of uncertainty. This report focuses on the implications of the science results for management and policy and so is not limited to previously published ideas. Thus, we have clearly labeled and consistently judged the importance of information and our level of confidence in its accuracy or validity. This report is evidence-based as verified by multiple reviews.

2.2 Context and Scope

The U.S. National Climate Assessment (NCA; http://www.globalchange.gov/what-we-do/assessment; see Box 2.1) for 2013, a national report on climate change and impacts, provided the motivation to produce this regional report.

Previously, the first National Climate Assessment (National Assessment Synthesis Team 2000) received technical input from multiple geographic regions in the United States. That assessment's sixty-page Southwest region report (Sprigg and Hinkley 2000) examined the effects of climate variability and change (including projections of the future) on water resources, ranching, natural ecosystems, extractive industries (oil, gas, mining), human health, urban areas, energy, and planning for the future. The 2000 report emphasized observed climate trends and phenomena and identified potential vulnerabilities related to climate, yet gave relatively little attention to adaptation planning and risk management.

The second National Climate Assessment in 2009 (Karl, Melillo, and Peterson 2009) was summarized from twenty-one synthesis and assessment products produced by the U.S. Climate Change Science Program (CCSP). The CCSP did not solicit technical input from regions, instead focusing on key sectors (e.g., transportation, agriculture, and water resources) and problems (e.g., strengths and limitations of climate models, temperature trends, model reliability, and adaptation options for ecosystems). The five-page Southwest section of the 2009 National Climate Assessment gave increased attention to projected climate changes, impacts to vulnerable water and ecosystem resources and, to a lesser degree, agriculture and urban areas. For these topics, the second assessment built a strong foundation for this report.

The present *Assessment of Climate Change in the Southwest United States*, part of the third National Climate Assessment, emphasizes new information and understandings since publication of the 2009 National Climate Assessment and expands the scope of previous regional assessments by analyzing the effects of climate change on Native American lands and the U.S.-Mexico border area, by presenting key uncertainties associated with each topic discussed in the report, and by providing a compendium of research needed to address these uncertainties. With its regional perspective, this report also provides the basis for similar assessments to be made at state, watershed, municipal, tribal, or other local levels for decision making at finer scales.

The report uses the established Intergovernmental Panel on Climate Change (IPCC) greenhouse gas (GHG) emissions scenarios, A2 (high) and B1 (low).[iii] These scenarios were used as inputs into global climate models to project climate changes in the IPCC Fourth Assessment Report and are fully described in the Special Report on Emissions Scenarios (Nakićenović and Swart 2000). Increases in the accumulation of GHGs in the atmosphere are thought to be the main cause of twenty-first century climate change stemming from human economic development choices. While GHGs are not the only influence on climate change considered by the IPCC, estimating the amount of GHGs in the future atmosphere is probably the largest uncertainty in projecting future climate. The estimation depends on predicting such factors as the state of the future global economy, global population growth, public policies and regulations, and the rate of adoption of technologies that reduce GHG emissions. While it is unrealistic to expect to know with certainty the future variations in these factors, scientists are able to use plausible

scenarios to project likely ranges of future GHG emissions. Other published scenarios and approaches are also incorporated in this report.

The report is guided, in part, by issues identified by stakeholders[iv] within the region, solicited through a workshop convened in June 2011, three teleconferences conducted during the second half of 2011, and review of reports from other climate change workshops and needs assessments. Early in the process, regional stakeholders mentioned that they would have little incentive to read a long report. Thus, we have limited the length of the report and have provided brief summaries online (http://www.swcarr.arizona.edu), which stakeholders suggested would be useful.

Box 2.1

National Climate Assessment

The National Climate Assessment (NCA) is being conducted under the auspices of the Global Change Research Act of 1990 (GCRA). The GCRA requires a report to the President and Congress every four years that analyzes the effects of global change on the natural environment, agriculture, energy production and use, land and water resources, transportation, human health and welfare, human social systems, and biological diversity. The report examines current trends in global change (both human-induced and natural) and projects major trends for the next 25 to 100 years.

National climate assessments serve as status reports on climate change and its impacts. The assessments rely on observations made across the country and compare these observations to projections from climate-system models. As with previous assessments, the third NCA (2013) evaluates the current state of scientific knowledge relative to climate impacts and trends. But it additionally evaluates the effectiveness of U.S. activities to mitigate and adapt to climate change and identify economic opportunities and challenges that arise as the climate changes.

The objectives of the NCA are to provide information and reports in the context of a continuing, inclusive national process that will:

- synthesize relevant science and information;
- increase understanding of what is known and not known;
- identify needs for information related to preparing for climate variability and change and reducing climate impacts and vulnerability;
- evaluate progress of adaptation and mitigation activities;
- inform science priorities;
- build assessment capacity in regions and sectors;
- build societal understanding and skilled use of assessment findings; and
- recognize the global and international context of climate trends and connections between climate risk and impacts in the United States and elsewhere.

The 2013 NCA differs from previous climate assessments in that it: (1) is a continuing effort rather than a periodic report-writing activity; (2) fosters partnerships with non-governmental entities; and (3) provides web-based data and information. For a list of the U.S. assessments, see http://globalchange.gov/publications/reports.

2.3 Other Southwest Region Climate Assessments

Many other climate-change reports and assessments have been produced by federal and state agencies, non-governmental organizations, and municipalities. These documents (some of which are listed in Table 2.1) relate in whole or in part to the Southwest region. For instance, the U.S. Forest Service assessed the state of knowledge about climate-change trends and associated impacts on U.S. forests (Joyce and Birdsey 2000). The report focused on plant productivity in response to elevated atmospheric carbon dioxide levels, and the authors turned to models to explore potential changes to ecosystem succession and forest productivity. The Southwest is included, implicitly, in maps and text on changes to forest ecosystems. In a more recent federal effort, the U.S. Bureau of Reclamation (2011) examined climate variability and trends and used projections of future climate and hydrology to assess risks to water resources in the Western United States. The assessment reported on selected river basins in the Southwest: Sacramento-San Joaquin, Truckee-Carson, Colorado, and Upper Rio Grande.

Table 2.1 Selected climate change assessments and reports pertaining to the Southwest region

Year	Institution	Report Name
2000	USDA-Forest Service	The Impact of Climate Change on America's Forests: A Technical Document Supporting the 2000 USDA Forest Service RPA Assessment (Joyce and Birdsey 2000) http://www.fs.fed.us/rm/pubs/rmrs_gtr059.pdf
2006	The Nature Conservancy	Ecoregion-Based Conservation Assessments of the Southwestern United States and Northwestern Mexico (Marshall, List, and Enquist 2006) http://azconservation.org/dl/TNCAZ_Ecoregions_SW_Ecoregional_Summary.pdf
2007	National Academy of Sciences	Colorado River Basin Water Management: Evaluating and Adjusting to Hydroclimatic Variability (NRC 2007) http://www.nap.edu/catalog.php?record_id=11857
2007	City of Denver	City of Denver Climate Action Plan (Mayor's Greenprint Denver Advisory Council 2007) http://www.greenprintdenver.org/about/climate-action-plan-reports/
2008	Colorado Water Conservation Board	Climate Change in Colorado: A Synthesis to Support Water Resource Management and Adaptation (Ray et al. 2008) http://cwcb.state.co.us/public-information/publications/Documents/ReportsStudies/ClimateChangeReportFull.pdf

Table 2.1 Selected climate change assessments and reports pertaining to the Southwest region (Continued)

Year	Institution	Report Name
2009	National Audubon Society	Birds and Climate Change: Ecological Disruption in Motion (National Audubon Society 2009) http://birds.audubon.org/sites/default/files/documents/birds_and_climate_report.pdf
2010	EPA	Climate Change Indicators in the United States (EPA 2010) http://www.epa.gov/climatechange/indicators/pdfs/ClimateIndicators_full.pdf
2010	State of California	2010 Climate Action Team Report to Governor Schwarzenegger and the California Legislature (California Climate Action Team 2010) http://www.energy.ca.gov/2010publications/CAT-1000-2010-005/CAT-1000-2010-005.PDF
2011	NOAA	State of the Climate in 2010 (Blunden, Arndt, and Beringer 2011) http://www.ncdc.noaa.gov/bams-state-of-the-climate/2010.php
2011	Bureau of Reclamation	SECURE Water Act Section 9503(c) - Reclamation Climate Change and Water 2011 (Reclamation 2011) http://www.usbr.gov/climate/SECURE/docs/SECUREWaterReport.pdf
2011	National Wildlife Federation	Scanning the Conservation Horizon: A Guide to Climate Change Vulnerability Assessment (Glick, Stein, and Edelson 2011) http://www.nwf.org/~/media/PDFs/Global-Warming/Climate-Smart-Conservation/NWFScanningtheConservationHorizonFINAL92311.ashx

States and cities have also produced climate change assessments for parts of the Southwest. A landmark executive order in California triggered a series of assessments and Climate Action Team reports to the governor (http://www.climatechange.ca.gov/climate_action_team/reports/#2010), beginning in 2006. This extensive series of reports formed the basis for numerous implementation plans. Colorado's Water Conservation Board commissioned a study (Ray et al. 2008) to determine the state of knowledge about Colorado's climate and the implications of projected future variations on the state's water resources. Several Colorado cities and municipalities inventoried GHG emissions and existing programs for emissions reduction as a foundation for climate-change planning (e.g., Mayor's Greenprint Denver Advisory Council 2007). Such assessments provide valuable local data and assessment at levels of analysis that regional and national reports cannot encompass.

Finally, non-governmental organizations have produced assessment reports for the region. Many of these assess a combination of peer-reviewed materials, new and

existing data, and internal reports. For example, The Nature Conservancy aggregated and standardized data across multiple ecoregions (large areas of land and water that are characterized by plant and animal communities and other environmental factors) and assessed the status and condition of native species, ecological systems, and natural resources such as water (Marshall, List, and Enquist 2006).

2.4 Sponsors and Authors of this Report

In July 2011, the Southwest Climate Alliance (SWCA)[v] submitted an expression of interest (EOI)[vi] to produce this regional technical input report for the NCA.[vii] The SWCA institutions and their partners have individually contributed to previous national assessments and to state-level assessments for California and Colorado. They also recently convened a Colorado River Basin workshop to assess regional capacity to perform ongoing assessments.

The SWCA team obtained funding from the National Oceanic and Atmospheric Administration (NOAA) and the Department of the Interior to convene a workshop for potential regional assessment authors and hire temporary staff to coordinate production of the report. Experts in the report subject areas were recruited to serve as assessment chapter lead authors. Report authors are primarily from university and federal research labs, with some contributors from state agencies, non-governmental organizations, and the private sector (see Table 2.2 and Figure 2.1). They have donated their time to write this report.

Table 2.2 Author affiliations for *Assessment of Climate Change in the Southwest United States*

Sector	Total Number	Number of Unique Institutions
Federal	23	13
State	5	5
University	86**	25
NGO	3	2
Private	3	3
Tribal*	1	1
TOTAL	**121**	**49**

* Authors with only tribal affiliation. Some federal and university authors also have tribal affiliations.

** Some authors with university affiliations also have affiliations with federal agencies.

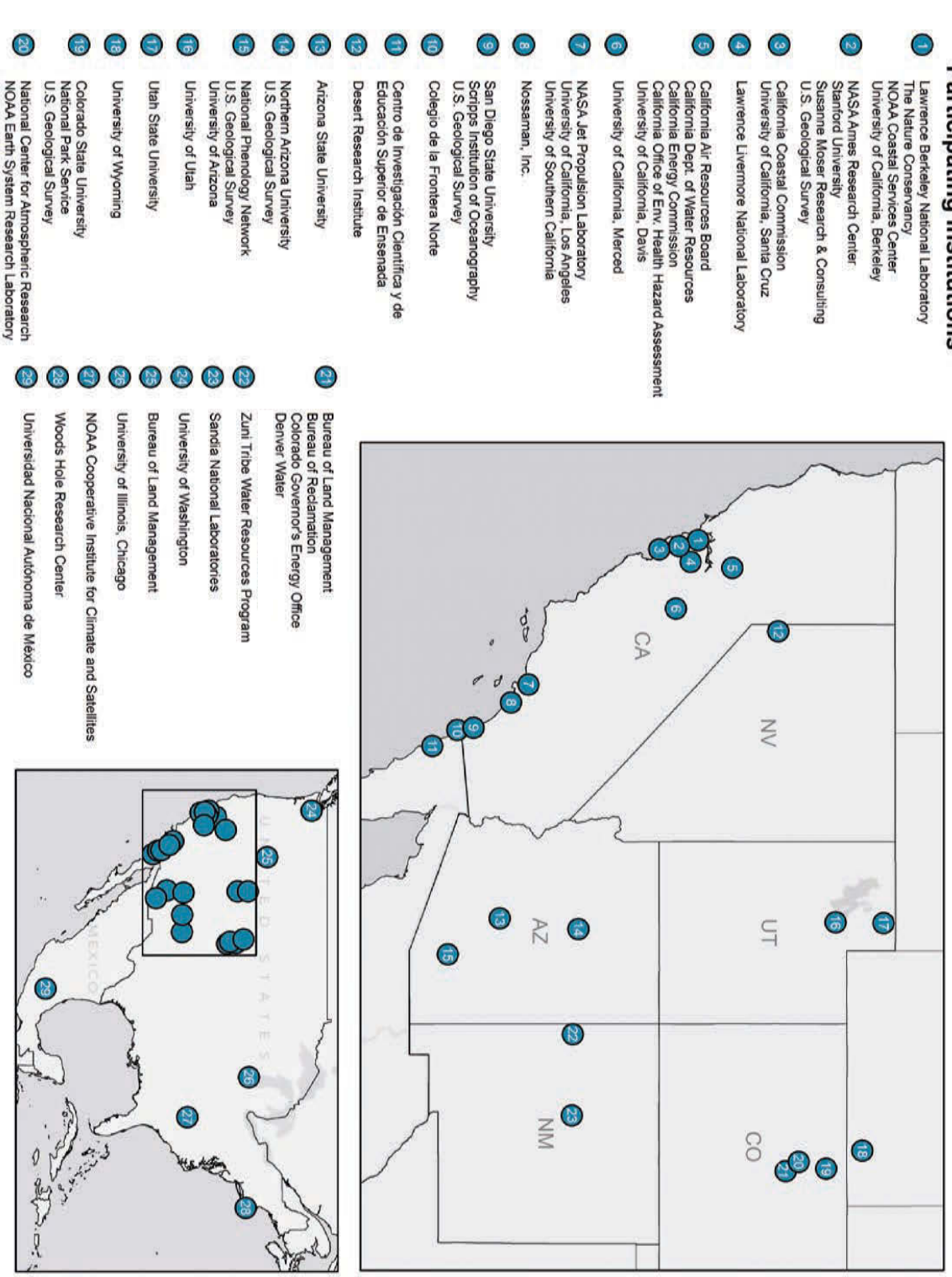

Figure 2.1 Locations of authors and their institutions contributing to this report. A total of 121 authors volunteered their time to writing this report. Map by Christine Albano.

2.5 Characterizing and Communicating Uncertainty

While climate changes have effects on human populations, human activities likewise affect the atmosphere and climate. As mentioned earlier, predicting the effects of future climate changes on the environment and society will always require estimating a range of social realities, such as population growth, economic development, new technology development, and enactment of new laws and regulations. These and other factors ultimately impact GHG concentrations in the atmosphere, for example, which in turn affect climate.

We also are limited by our present incomplete understanding of some biophysical processes that feed into global climate models to project an outcome. Consequently, these processes must be expressed mathematically in computer models and statistically in terms of *ranges*, with commentary on the confidence of the estimates. We refer to evaluation of the ranges of estimates of possible future climate and impacts—accounting for the scenarios used to drive the climate models, the information used to construct the models, and the interpretation and use of the models' data for planning and decision making—as characterization of *uncertainty*. Scientific research and assessments can provide information and characterize uncertainty in a way that facilitates choices that are *risk-based* (see Box 2.2).

In this report, we have adopted guidance from the National Climate Assessment (http://www.globalchange.gov/images/NCA/Draft-Uncertainty-Guidance_2011-11-9.pdf) to characterize and communicate uncertainty[viii]. We have attempted to frame questions or problems to allow appraisal of the level of knowledge or understanding in the context of the question or problem. We review the range of scientific information for each question and describe the information used, the standards of evidence applied, and the confidence of the authors in their results. In reporting key findings, we have followed these steps to communicate our level of confidence in key conclusions:

1. We framed a manageable number (three or four) of key questions or issues that address the most important information needs of stakeholders.
2. We evaluated the available information, considering the type, amount, quality, and consistency of evidence, summarizing the level of evidence as strong, fair, or weak.
3. We formulated well-posed conclusions that can be confirmed or falsified.
4. We identified key uncertainties and briefly describe what monitoring, research, or other work is needed to improve the information base.
5. We assessed the levels of confidence (high, medium-high, medium-low, or low) by considering (a) the quality of the evidence and (b) the level of agreement among experts with relevant knowledge and experience. Confidence is a subjective judgment, but it is based on systematic evaluation of the type, amount, quality, and consistency of evidence, and the degree of agreement among experts (Table 2.3).
6. Especially for findings that identify potential high-consequence outcomes, we estimated uncertainty probabilistically (i.e., provided a likelihood that the outcome could occur under a stipulated scenario or conditions). Likelihoods can be based on quantitative methods, such as model results or statistical sampling, or on expert judgment. Some authors may use standardized ranges (<5% likely, <33% likely, 33–66% likely, >66% likely, or >95% likely).

7. To ensure transparency in reporting uncertainty and confidence, we prepared brief traceable accounts that describe the main factors that contributed to a particular conclusion and level of confidence.[ix]

Box 2.2

Risk-based Framing[x]

The National Climate Assessment and the *Assessment of Climate Change in the Southwest United States* use a risk-based management approach to describe statements about key vulnerabilities to climate change and how they may change over time. A key vulnerability has:

- a large magnitude;
- early onset of impacts;
- a high degree of persistence and irreversibility;
- a wide distribution (e.g., across levels of society, or spatially);
- a high likelihood of occurrence; or
- great importance (based on perceptions).

The motivation for using this risk-based approach is based on research (IPCC 2007; NRC 2010a, 2010b) and interaction with climate information user communities, such as the Department of Defense.

Risk is defined as the product of likelihood of occurrence of an event or condition and the consequence of that occurrence, where:

- consequence ("importance") can be assessed using metrics ranging from physical impacts to vulnerability;
- vulnerability depends on exposure to a climate phenomenon or stimulus, sensitivity (the degree to which a vulnerable system responds to the climate phenomenon or stimulus), and adaptive capacity, or ability to adapt, respond, or rebound to the climate phenomenon or stimulus;
- likelihood depends on sensitivity to the climate phenomenon or stimulus, and the associated climate variability.

Risk management can be based on either quantitative or qualitative representations of likelihood and consequence. For qualitative information, the report authors use rigorous methods to describe likelihood and consequence. The authors have submitted traceable accounts of the sources used and the rationale behind the quantitative and qualitative judgments regarding risk. Qualitative techniques are useful in circumstances in which there may be a range of future likelihoods or consequences. This report focuses attention on highly likely impacts and vulnerabilities, but also on lower likelihood impacts and vulnerabilities that carry high consequences. The latter is in recognition of stakeholder concerns about climate extremes and rare events that may have significant impacts on infrastructure and investments.

2.6 Accountability and Review

To ensure transparency in developing this regional report's conclusions and key findings, we also have cited all sources of information, as is common peer-review practice, and sources of data for all graphics and tables.

For the key findings in each chapter's Executive Summary, the respective authors have submitted traceable accounts, as suggested in guidance from the National

Climate Assessment (http://www.globalchange.gov/what-we-do/assessment/nca-activities/guidance).

In addition, the report received two independent reviews. The first review was by three experts, who were nominated in late 2011 by the chapter lead authors and the report editors. The second was at an open review in spring 2012. For both, independent review editors evaluated the review comments to ensure that authors adequately addressed the review comments.

Table 2.3 Factors contributing to assessment confidence associated with key findings

Confidence Level	Examples of Combinations of Factors that Could Contribute to this Confidence Evaluation
High	Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus
Medium-High	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus
Medium-Low	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought
Low	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

Source: Moss and Yohe (2011).

2.7 Organization of This Report

The report comprises twenty chapters:

Chapter 1: Summary for Decision Makers describes the key issues found in Chapters 3–20.

Chapter 2: Overview describes the basis for, and methods used to create, this report.

Chapter 3: The Changing Southwest describes the important characteristics that affect exposure and sensitivity of the Southwest to climate change. Chapter 3 examines general socio-economic and land-use patterns and trends for the region. These include a brief examination of the physical context, human demographics and population trends, key laws relevant to resource management, and institutions conducting climate-assessment or policy initiatives.

Chapter 4: Present Weather and Climate: Average Conditions describes baseline characteristics of current climate and hydrologic parameters, such as temperature,

precipitation, and snowpack, as well as the factors that contribute to the unique climates of the region. Chapter 4 discusses the main factors contributing to regional climate variability, and describes important climate hazards and impacts, such as droughts, floods, wildland fires, air quality and extreme temperatures.

Chapter 5: Present Weather and Climate: Evolving Conditions assesses weather and climate variability and trends in the Southwest, using observed climate and paleoclimate records. Chapter 5 analyzes the last 100 years of climate variability in comparison to the last 1,000 years, and links the important features of evolving climate conditions to river flow variability in four of the region's major drainage basins. The chapter closes with an assessment of the monitoring and scientific research needed to increase confidence in understanding when climate episodes, events, and phenomena are attributable to human-caused climate change.

Chapter 6: Future Climate: Projected Average presents climate-model projections of future temperature, precipitation, and atmospheric circulation (long-term weather patterns) for the Southwest. Chapter 6 also examines projections of hydrologic parameters, such as snow water equivalent, soil moisture, and runoff for a subset of basins in the region, including the Colorado River Basin.

Chapter 7: Future Climate: Projected Extremes summarizes current scientific understanding about how specific weather and climate extremes are expected to change in the Southwest as global and regional temperatures increase. Chapter 7 examines heat waves, cold snaps, drought, floods, and weather related to wildland fires. The chapter also examines possible changes in weather patterns associated with climate extremes, such as atmospheric rivers and Santa Ana winds.

Chapter 8: Natural Ecosystems addresses the observed changes in climate that are associated strongly with observed changes in geographic distributions and phenology (recurring phenomena of biological species such as timing of blossoms or migrations of birds) in Southwestern ecosystems. Chapter 8 also examines disturbances such as wildfires and outbreaks of forest pathogens and discusses issues associated with how carbon is stored and released in Southwestern ecosystems, in relation to climate-change threats.

Chapter 9: Coastal Issues examines climate-change threats to coastal ecosystems and human habitats, as well as available management and adaptation options such as insurance incentives. The chapter describes and evaluates key climate-induced impacts, including sea-level rise, erosion, storm surges, and oceanographic factors, including nutrient upwelling, ocean acidification, and oxygen-depleted zones. Chapter 9 also describes interactions between existing vulnerabilities (such as human development in coastal ecosystems).

Chapter 10: Water: Impacts, Risks, and Adaptation focuses on societal vulnerabilities to impacts from changes in sources, timing, quantity, and quality of the Southwest's water supply. The chapter addresses both vulnerabilities related to environmental factors (such as wildfire risk and increased stream temperatures) and issues related to water management (such as water and energy demand, and reservoir operation). Chapter 10 describes water management strategies for the coming century, including federal, regional, state, and municipal adaptation initiatives. (Note: Surface hydrology is addressed in Chapters 4–7.)

Chapter 11: Agriculture and Ranching reviews the climate factors that influence crop production and agricultural water use. The chapter discusses modeling studies that use climate-change model projections to examine effects on agricultural water allocation and scenario studies that investigate economic impacts and the potential for using adaptation strategies to accommodate changing water supplies, crop yields, and pricing. Chapter 11 concludes with sections on ranching and drought and on disaster-relief programs.

Chapter 12: Energy: Supply, Demand, and Impacts describes the potential effects of climate change on the production, demand, and delivery of energy. Chapter 12 describes climate effects on peak energy production and examines the vulnerability of infrastructure to climate change. The chapter describes direct and indirect climate effects on the generation of electricity, with analyses of different methods of generation, such as natural gas turbines, hydropower, and thermoelectric. The chapter concludes with an assessment of the evolution of fuel mixes for energy generation and transportation, and offers mitigation strategies for the present and future.

Chapter 13: Urban Areas describes the unique characteristics of Southwest cities and the ways they will be affected by and contribute to future climate changes. The chapter draws particular attention to six large urban areas: Albuquerque, Denver, Las Vegas, Los Angeles, Phoenix, and Salt Lake City. Chapter 13 addresses ways in which cities may contribute to climate change through their urban metabolisms—flows of water, energy, materials, nutrients, air, water, and soil impacts. The chapter also examines key pathways through which cities will be affected, including fire, water resources, flooding, urban infrastructure, and sea-level rise.

Chapter 14: Transportation examines climate change issues across a broad range of transportation sectors in the Southwest, including land transportation (passenger and freight), marine transportation, and air transportation, beginning with current trends. Chapter 14 analyzes possible direct and indirect impacts to transportation infrastructure and to the economy. The chapter concludes by examining vulnerabilities and uncertainties with respect to potential disruptions to the transportation system.

Chapter 15: Human Health reviews the state of knowledge with regard to climate-related public health threats, including those related to extreme heat, air quality (including respiratory ailments, dust, and fire-related particulate matter), and changes to disease vectors (such as mosquito populations). Chapter 15 examines factors that interact with and complicate disease transmission and risk. The chapter concludes by discussing public health planning and adaptation planning.

Chapter 16: Climate Change and U.S.-Mexico Border Communities evaluates some factors unique to the U.S.-Mexico border that affect the vulnerability of human populations to climate change, including border demographic changes, urban expansion, and socio-economic issues. Chapter 16 also addresses border climate and ecosystem issues, such as climate extremes, wildfires, and potential climate effects on the Colorado River estuary. The chapter includes a discussion of border adaptation measures, with an emphasis on the role of cross-border collaboration.

Chapter 17: Unique Challenges Facing Southwestern Tribes evaluates observed climate effects on Native American lands, and discusses the intersection of climate and the unique cultural, socioeconomic, legal and governance contexts for addressing these

issues in Indian Country. Chapter 17 highlights some preparedness-, mitigation-, and adaptation-planning initiatives currently underway in the Southwest.

Chapter 18: Climate Choices for a Sustainable Southwest describes challenges to implementing mitigation and adaptation plans, given specific governance issues related to states, municipalities, and regional institutions. The chapter discusses new environmental management initiatives in the region, and gives examples of current climate-change mitigation and adaptation initiatives and successes. Chapter 18 analyzes the barriers to implementing solutions, and highlights the practical opportunities afforded through maximizing the co-benefits of mitigation and adaptation, and minimizing costs and environmental and social harms.

Chapter 19: Moving Forward with Imperfect Information builds on information from previous chapters, focusing on uncertainties, monitoring deficiencies, and data challenges. Chapter 19 summarizes the scope of what we do and do not know about climate in the Southwestern United States, and outlines those uncertainties that hamper scientific understanding of the climate system and potentially impede successful adaptation to the impacts of climate change. The chapter emphasizes issues related to climate and impact models, and scenarios of the future.

Chapter 20: Research Strategies for Addressing Uncertainties builds on descriptions of research and research needs articulated in earlier chapters. The chapter describes current research efforts and the challenges and opportunities for reducing uncertainties. It explores strategies to improve characterization of changes in climate and hydrology, and emphasizes the application of research strategies to decisions, including methods such as scenario planning.

References

Blunden, J., D. S. Arndt, and M. O. Baringer. 2011. State of the climate in 2010. *Bulletin of the American Meteorological Society* 92: S1–S236, doi:10.1175/1520-0477-92.6.S1. http://www.ncdc.noaa.gov/bams-state-of-the-climate/2010.php.

California Climate Action Team (CCAT). 2010. *2010 Climate Action Team report to Governor Schwarzenegger and the California Legislature.* N.p.: CCAT. http://www.energy.ca.gov/2010publications/CAT-1000-2010-005/CAT-1000-2010-005.PDF.

Cayan, D. R., A. L. Luers, G. Franco, M. Hanemann, B. Croes, and E. Vine. 2008. Overview of the California climate change scenarios project. *Climatic Change* 87 (Suppl. 1): S1–S6, doi:10.1007/s10584-007-9352-2.

Glick, P., B. A. Stein, and N. A. Edelson, eds. 2011. *Scanning the conservation horizon: A guide to climate change vulnerability assessment.* Washington, DC: National Wildlife Federation. http://www.nwf.org/~/media/PDFs/Global-Warming/Climate-Smart-Conservation/NWFScanningtheConservationHorizonFINAL92331.ashx.

Hayhoe, K., D. Cayan, C. B. Field, P. C. Frumhoff, E. P. Maurer, N. L. Miller, S. C. Moser, et al. 2004. Emissions pathways, climate change, and impacts on California. *Proceedings of the National Academy of Sciences* 101:12422–12427.

Intergovernmental Panel on Climate Change (IPCC). 2007. *Climate change 2007: Synthesis report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, eds. R. K. Pachauri and A. Reisinger. Geneva: IPCC. http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf.

Joyce, L. A., and R. Birdsey, eds. 2000. *The impact of climate change on America's forests: A Technical Document supporting the 2000 USDA Forest Service RPA Assessment*. Gen. Tech. Rep. RMRS-GTR-59. Fort Collins, CO: U.S. Forest Service, Rocky Mountain Research Station. http://www.fs.fed.us/rm/pubs/rmrs_gtr059.pdf.

Karl, T. R., J. M. Melillo, and T. C. Peterson, eds. 2009. *Global climate change impacts in the United States*. Cambridge: Cambridge University Press. http://downloads.globalchange.gov/usimpacts/pdfs/climate-impacts-report.pdf.

Marshall, R., M. List, and C. Enquist. 2006. *Ecoregion-based conservation assessments of the southwestern United States and northwestern Mexico: A geodatabase for six ecoregions, including the Apache Highlands, Arizona-New Mexico mountains, Colorado Plateau, Mojave Desert, Sonoran Desert, and southern Rocky Mountains.* Tucson, AZ: The Nature Conservancy. http://azconservation.org/dl/TNCAZ_Ecoregions_SW_Ecoregional_Summary.pdf.

Mayor's Greenprint Denver Advisory Council. 2007. *City of Denver Climate Action Plan: Final recommendations to Mayor Hickenlooper*. Denver, CO: City of Denver. http://www.greenprintdenver.org/about/climate-action-plan-reports/.

Moss, R. H., and G. Yohe. 2011. Assessing and communicating confidence levels and uncertainties in the main conclusions of the NCA 2013 Report: Guidance for authors and contributors. N.p.: National Climate Assessment Development and Advisory Committee (NCADAC). http://www.globalchange.gov/images/NCA/Draft-Uncertainty-Guidance_2011-11-9.pdf.

Nakićenović, N., and R. Swart, eds. 2000. *Special report on emissions scenarios: A special report of Working Group III of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press.

National Assessment Synthesis Team. 2000. *Climate change impacts on the United States: The potential consequences of climate variability and change*. Report for the U.S. Global Change Research Program. Cambridge: Cambridge University Press.

National Audubon Society. 2009. Birds and climate change: Ecological disruption in motion. http://birds.audubon.org/sites/default/files/documents/birds_and_climate_report.pdf.

National Research Council (NRC). 2007. *Colorado River Basin water management: Evaluating and adjusting to hydroclimatic variability*. Washington, DC: National Academies Press.

—. 2010a. *Adapting to the impacts of climate change*. Washington, DC: National Academies Press.

—. 2010b. *Informing an effective response to climate change*. Washington, DC: National Academies Press.

Ray, A., J. Barsugli, K. Averyt, K. Wolter, M. Hoerling, N. Doesken, B. Udall, and R. S. Webb. 2008. *Climate change in Colorado: A synthesis to support water resources management and adaptation*. Boulder, CO: Western Water Assessment. http://cwcb.state.co.us/public-information/publications/Documents/ReportsStudies/ClimateChangeReportFull.pdf.

Sprigg, W. A., and T. Hinkley, eds. 2000. *Preparing for a changing climate: The potential consequences of climate variability and change, Southwest.* A report of the Southwest Regional Assessment Group for the U.S. Global Change Research Program. Tucson, AZ: Institute for the Study of Planet Earth.

U.S. Bureau of Reclamation (Reclamation). 2011. *SECURE Water Act Section 9503(c) – Reclamation Climate Change and Water, Report to Congress*. Denver: U.S. Bureau of Reclamation. http://www.usbr.gov/climate/SECURE/docs/SECUREWaterReport.pdf.

U.S. Environmental Protection Agency (EPA). 2010. *Climate change indicators in the United States*. http://epa.gov/climatechange/science/indicators/download.html.

Endnotes

i The phrase "climate variability and change" is used many times in this document. Climate variability refers to the inherent variability of climate, for instance, from year to year or decade to decade; climate change refers to ways in which systematic trends in some climate factors, such as increases in heat-trapping gases in the atmosphere (greenhouse gases) and associated increases in temperature, alter the climate system and its variations.

ii This section is based, in part, on remarks from Dr. David Stephenson (University of Exeter, UK) and text from the National Climate Assessment.

iii Taken together, the A2 and B1 scenarios provide reasonable estimates of what "high" and "low" global GHG emissions might be throughout the remainder of the twenty-first century. For example, scenario A2 (referred to in this report as the "high-emissions scenario") assumes a future with a high global population growth rate, slow global economic development rate, slow global technological change, and global fossil fuels use at rates slightly lower than observed in historical records. This combination of conditions would result in relatively high GHG emissions that continue to rise throughout the twenty-first century at an increasing rate (to a concentration of approximately 900 parts per million (ppm) in 2100), and substantially increased global temperatures. In contrast, scenario B1 (referred to in this report as the "low-emissions scenario") assumes a future in which global population peaks in the year 2050 and economies shift rapidly toward the introduction of clean and resource-efficient technologies, with an emphasis on global solutions to economic, social, and environmental sustainability. In the B1 scenario, greenhouse gas (GHG) emissions reach a peak in the mid-twenty-first century and then decline, resulting in carbon dioxide (CO_2) concentration of approximately 540 ppm in 2100, and smaller increases in global temperatures than those resulting from the A2 scenario. As has been emphasized in the IPCC study results and in prior regional climate change assessments, the outcomes of different mitigation strategies (as expressed by the A2 and B1 scenarios), in terms of the cumulative GHG concentrations and resultant climate changes, do not become very clear until after the middle of the twenty-first century, when the warming and other impacts from the B1 low-emissions scenario begin to be clearly exceeded by those of the A2 (and other) high-emissions scenarios (Nakićenović and Swart 2000; Hayhoe et al. 2004; IPCC 2007; Cayan et al. 2008).

iv Stakeholders are natural resource managers whose decision making relies in part on understanding how climate related variables impact their domains.

v The Southwest Climate Alliance consists chiefly of three NOAA-funded Regional Integrated Sciences and Assessments projects (California-Nevada Applications Program [http://meteora.ucsd.edu/cap/], Climate Assessment for the Southwest [http://www.climas.arizona.edu/], and Western Water Assessment [http://wwa.colorado.edu/]) and the Department of the Interior-funded Southwest Climate Science Center (http://www.doi.gov/csc/southwest/index.cfm), as well as a number of partner universities and federal research laboratories.

vi Federal Register / Vol. 76, No. 134 / Wednesday, July 13, 2011 / Notices http://www.gpo.gov/fdsys/pkg/FR-2011-07-13/pdf/2011-17379.pdf.

vii This technical report is only one of several for which EOIs were submitted. As far as the editors of this report know, this was the only EOI intending to produce a comprehensive regional report.

viii These were the October 27, 2011, NCA pre-decisional draft guidelines, which were the guidelines available to the authors of this report during the report draft and review periods.

ix Traceable accounts consist of (1) the reasoning behind the conclusion, (2) the sources of data and information contributing to the conclusion, (3) an assessment of the amount of evidence and degree of agreement among sources of evidence, (4) an assessment of confidence in the finding, and (5) an assessment of uncertainty associated with the finding.

x Many of the remarks here are drawn from National Climate Assessment guidance documents and insights from National Climate Assessment and Development Advisory Committee co-chair, Gary Yohe.