Western Water Assessment

Climate Change in Colorado

An updated report to be developed by the Western Water Assessment
Prospectus and Outline, version 4
10 June 2013

The 2008 *Climate Change in Colorado* Report

In October 2008, the Western Water Assessment released a report for the Colorado Water Conservation Board, *Climate Change in Colorado: A Synthesis to Support Water Resources Management and Adaptation*. The report covered five areas:

- The observed record of Colorado's climate (since ~1900)
- A primer on climate models, emissions scenarios, and downscaling
- The attribution of significant climate trends and events (including drought) to climate change
- Projections of Colorado's climate for the mid-21st century
- Implications of the changing climate for water resources

Based on both formal evaluation and informal feedback from users of the report, *Climate Change in Colorado* has been highly successful in helping water resource managers better understand the past and likely future climate in Colorado and apply that information to their planning. Another major success of the report was that the information was used by stakeholders outside of the water management community, reflecting the broad need for state- and region-specific climate information.

The information and graphics in the report were largely based on research and data that had been collated for the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) in 2007, and reports produced by the US Global Change Research Program in the mid-2000s. Additional analyses and synthesis were produced by WWA scientists for the 2008 report.

Justification for updating the 2008 report

In the 4+ years since the release of *Climate Change in Colorado,* there have been dozens of new research studies specific to our region documenting observed climate and its impacts, and projecting future climate and its impacts. At the national level, in 2012 the National Climate Assessment (NCA) issued a new draft report on climate change, with special regional reports coming out in early 2013. The IPCC is releasing its Fifth Assessment Report (AR5) starting in fall 2013, based on the latest generation of climate models, the output of which is already accessible today. The release of these new reports will capture the attention of numerous decision makers across Colorado, and we believe that having an updated *Climate Change in Colorado* report available at the same time will be critical to helping address climate change concerns across the state.

Although the new IPCC and NCA reports will not overturn the 2008 report's key findings about the character and impacts of future climate change, they will add important nuance and detail. In particular, these syntheses now cover critical climate-related impacts and feedbacks that were not addressed in the 2008 report, such as dust-on-snow events and bark beetle epidemics.

In addition, relatively warm and dry climate conditions have continued in Colorado since 2008, making the 14-year period since 2000 the warmest—and one of the driest—decadal periods in the century-long observed climate record for Colorado, with historically unprecedented climate impacts including water supply deficits, wildfires, and insect infestations. What do we learn when we put this period into the long context of past climate? How should we expect the rest of the 21st century to compare with its first 14 years, given the latest climate model output?

Structure of the updated report

The overall structure of the updated report will be very similar to the 2008 version. Text, analyses, and graphics will be updated using observed climate data through 2012, and will incorporate new scientific literature and assessments published through mid-2013.

The updated report will have several sections that are new or significantly expanded:

- Summary of the climate and climate impacts since 2000
- Expanded primer on weather and climate patterns and dynamics in Colorado
- Inclusion of additional drought metrics for the trend analyses in the observed climate chapter
- Expanded discussion of the paleoclimate record for Colorado
- Discussion of climate-related ecosystem and land surface changes, including dust-on-snow, bark beetle infestations, and wildfires
- Explanation of the new Representative Concentration Pathways (RCPs) used for the greenhouse-gas-emissions component of the latest climate models
- Expanded discussions of extreme weather and climate events, both observed and projected
- Comparison of the latest climate model output (CMIP5) with the previous model ensemble (CMIP3) presented in the 2008 report
- Comparison of selected downscaled climate projections with each other and the "raw" CMIP5 projections
- Expanded discussion of the implications of the changing climate for water resources
- Using climate projections to support planning and adaptation: frameworks and case studies

The 2008 report was quite concise for a climate assessment report (43 pages + references and glossary) and this no doubt contributed to its usability. The additional content outlined above will necessarily result in a longer document, but we still intend to keep the body of the report as brief as possible. The next two pages detail the content that will likely be retained, though updated, from the 2008 report, and the proposed new or expanded content. Before finalizing this outline, we will collect more input from the author team and high-level users to identify content from the 2008 report that was less useful and could be deleted from the updated report.

Proposed chapters, sub-chapters, and key figures, tables, and sidebars for the updated report

Black: Content similar to the 2008 report, but updated with latest research and data
Blue: New or much expanded content
Green: New start/end dates for analyses

Executive Summary
Sidebar ES-x. Communicating Uncertainty

1 Introduction
1-1. Colorado's climate since 2000: A preview of the future climate?
1-2. Purpose of the report
Sidebar 1-x. How to Interpret the Timescales in This Report
1-3. Context of the report
Table 1-x. Climate Assessments Conducted Since 2008
1-4. Structure of the report

2 The Observed Record of Colorado Climate
2-1. Observing Systems in Colorado
2-2. The Climate of Colorado [expanded]
Figure 2-x. Annual Average Temperature and Precipitation in Colorado (1950–2010)
Figure. Seasonal distribution of precipitation across Colorado
2-3. Local and Regional Climates of Colorado
Figure 2-x. Temperature at Nine Observing Stations, adjusted vs. unadjusted observations
Figure 2-x. Water Year Precipitation at Nine Observing Stations, adjusted vs. unadjusted observations
Figure 2-x. Seasonal Temperature Trends (1957–2012) [statewide rather than selected regions]
2-4. Statewide Average Temperature, 1900 to present
Figure 2-x. Colorado Annual Mean Temperatures (1900–2012) [using new NOAA GRDD data]
2-5. Elevation
Sidebar: Gridded Climate Products (PRISM, DAYMET, GRDD)
2-6. Trends in Hydroclimatic Variables: Temperature, Precipitation, Drought Indices, Snow, and Streamflow
Figure 2-x. Trend in March Average Minimum Temperature on Days with Precipitation
Figure 2-x. Trend in Winter Snow vs. Rain
Figure 2-x Trend in timing of streamflow
Figure 2-x Trend in selected drought indices
Sidebar: The Changing 30-year Normal
2-7. Extremes
Figure 2-x. Trend in extreme precipitation events
Figure 2-x. Trend in heat waves
Sidebar 2-x. IPCC SREX report
Figure 2-x. Seasonality of Extremes in Colorado
2.8. Paleoclimate
Figure 2-x. Reconstructions of Streamflow for selected Colorado gages

3 A Primer on Climate Models, Emissions Scenarios, and Downscaling
3-1. Anatomy of a Climate Model and the CMIP5 Archive
Figure 3-x. Hydrologic Component of General Circulation Models
Sidebar 3-x. Time and Space in Models
Figure 3-x. Model Grid for the Atmospheric Component
Sidebar: Earth System Models
3-2. Representative Concentration Pathways: Emissions Scenarios Under a Different Name
Figure 3-x. Global Mean Surface Temperature and Model Projections
3-3. Climate Model Evaluation

Figure 3-x. Elevation on Global and Regional Climate Model Grids
Table 3-x. Seasonally Averaged Climate Biases of the IPCC AR5 WGI Climate Models in Temperature and Precipitation for Colorado

3-4. Downscaling Methods
Table 3-x. Strengths and Weaknesses of Statistical versus Dynamical Downscaling
Figure 3-x. Progression of Data and Models from Climate Models to Streamflow
Table 3-x. Available downscaled projection data sets

3-5. The Future of Global Models

4 Climate Attribution: What is causing the observed changes?

4-1. The Global Consensus

4-2. A Telescoping View
Figure 4-x. Observed Annual Average North American Surface Temperature (1950–2012)
Figure 4-x. Modeled Annual Average North American Surface Temperature (1950–2012)

4-3. Recent Drought in Colorado and the West
Figure 4-x. Intensity and Extent of Drought in Colorado (1895–2012)
Figure 4-x. Precipitation and River Flow in the Upper Colorado Basin (1895–2012)
Sidebar: Dust-on-snow and bark beetle infestations

4-4. Attribution of Other Recent Extreme Events

5 Climate Projections

5-1. Temperature and Precipitation Projections
Figure 5-x. Temperature and Precipitation Changes over North America Projected for 2050

5-2. Exploring the Differences between CMIP3 and CMIP5

5-3. A Closer Look: Downscaled Projections
Figure 5-x. Location of Precipitation and Temperature Projections
Figure 5-x. Projected Monthly Temp & Precip near Grand Junction, CO (2050) [redo these 3 figures to simplify but still convey trend vs. variability]
Figure 5-x. Projected Monthly Temp & Precip near Steamboat Springs, CO (2050)
Figure 5-x. Projected Monthly Temp & Precip near La Junta, CO (2050)
Figure(s) 5-x. Comparisons of selected downscaled projections

5-4. Hydrologic Changes [expanded to include basins other than Colorado River]
Figure 5-x. Projected Changes in Annual Runoff (2041–2060)
Table 5-x. Projected Changes in Colorado River Basin Runoff in the Mid-21st Century from multiple studies
Table 5-x. Projected Changes in Runoff in Other Basins in Colorado in the Mid-21st Century
Figure 5-x. Projected Change in Colorado River Basin Snowpack [change to map, using Reclamation VIC data]
Figure 5-x. Projected Soil Moisture Changes for Colorado for 2050
Figure 5-x. Projected Changes in Drought Metrics for 2050
Sidebar: Three interrelated studies: JFRCCVS, CRWAS, Basin Study

5-5. Extremes
Figure 5-x. Projected Changes in Heat Waves
Figure 5-x. Projected Changes in Cold Spells
Figure 5-x. Projected Changes in Extreme Precipitation Events

6 Implications of Changing Climate for Water and other Resources [expanded]
Table 6-x. Challenges Faced by Water Managers
Sidebar: Revisiting the "Unresolved Issues" from the 2008 report

7 Using Climate Projections to Support Planning and Adaptation

7-1. Frameworks for Risk Assessment, Planning, and Adaptation

7-2. Case Studies: Local and Regional Planning for Water Resources

Production Plan and Timeline

We will develop the updated report during the remainder of calendar 2013, with the final report to be released in PDF and print form by February 2014. We will complete and release an advanced draft of the key section (Chapter 5) describing the latest climate projections (CMIP5) by October 2013, to coincide with the release of the first part of the IPCC Fifth Assessment Report. This advanced draft of Chapter 5 will then be revised and included in the final report as well. We will hold webinar events to roll out the advanced draft of Chapter 5, and also for the release of the final report, to summarize findings and answer questions.

We will also make available on our website key datasets and analytical products that are presented in the report, to promote access to and exploration of these data.

WWA Senior Research Associate Jeff Lukas will serve as project coordinator and lead author. Other WWA team members who will serve as authors include Kristen Averyt, Joe Barsugli, Eric Gordon, Imtiaz Rangwala, and Klaus Wolter. Nolan Doesken (Colorado State Climatologist, CSU) and Marty Hoerling (NOAA ESRL) will also contribute to the updated report.

As with the 2008 report, we will have the draft chapters peer-reviewed by colleagues in both the climate science community and from stakeholder entities, to ensure the content is accurate, clear, and usable. The set of reviewers (~ 20 individuals) will include representatives of organizations such as NOAA, NCAR, CSU, USGS, CWCB and other state agencies, Reclamation, municipal water agencies, consulting firms, and NGOs. We will stagger the completion and review of draft chapters so as to reduce the burden at any given time on reviewers; the overall review process will roughly extend from September through November.

CU Proposal No.

PROPOSED BUDGET DETAILS

Institution: The Regents of the
University of Colorado
572 UCB
Boulder, CO 80309-0572

Title: Climate Change in Colorado: An update to the report for the Colorado Water Conservation Board

Principal Investigator: K. Averyt

Duration: 9/1/2013-8/31/2014

A. Salaries and Wages	**Total**
Principal Investigator: K. Averyt	
25% time, 1 month	2,146
Co-PI: J. Barsugli	
50% time, 1 month	3,816
Co-PI: J. Lukas	
50% time, 3.5 months	9,610
Research Associate: K. Wolter	
50% time, 1 month	3,787
Research Associate: I. Rangwala	
75% time, 1 month	3,276
Research Associate: Computer System Support	
23% time, 1 month	1,749
Total Salaries and Wages	24,384
B. Fringe Benefits	
PI/Co-I/RA: 30.9% of salary	7,535
Total S/W and Fringe Benefits	31,919
C. Travel	
None	
D. Other Direct Costs	
Two reviewer meetings: Lunch and meeting materials	400
Publication costs (layout & printing)	5,100
Total Other Direct Costs	5,500
E. Total Direct Costs	37,419
F. Indirect Costs	
Off-campus research: 20% of TDC per existing agreement [Colorado Revised Statutes 23-31-801 section 7] with CWCB	7,484
G. Total Costs	44,903