Written Testimony Committee and Energy and Natural Resources
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Current and Projected Impacts of Climate Change in the Intermountain West
Impacts on Drought, Wildfire and Ecological Systems

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Chairman Bingaman, and other Members of the Committee, thank you for the opportunity to discuss with you today these matters pertaining to our knowledge of past, present and future climate in the Intermountain West. The high temperatures and smoke-filled skies around the West as we speak serve as testament to the relevance of these issues.

Background

I grew up in the West, in Southwest Montana, and aside from an excellent university education on the East Coast and in the Midwest, have spent my professional career in meteorology and climatology in the western United States. I love the West, and my current position of regional climatologist for the 11 westernmost continental states, Alaska, Hawaii, Pacific Islands, almost perfectly suits my interests and inclinations. I have served in this capacity since 1989, working at the Western Regional Climate Center (WRCC) in Reno Nevada. WRCC is one of six such NOAA-administered centers in the US, and is housed at the Desert Research Institute, a component of the Nevada System of Higher Education. Prior to this time I served as state climatologist for Oregon for six years. My interests span all facets of climate and weather behavior, their physical causes and variability, how climate interacts with other human and natural processes, and how such information is acquired, used, communicated, and perceived.

I am also very involved in numerous national and regional drought activities, and along with Mike Hayes at the National Drought Mitigation Center (U Nebraska) serve as co-chair of the NIDIS (National Integrated Drought Information System) Program Implementation Team.

The clientele for our primary program (the Regional Climate Centers, RCCs) consists of all segments of the public from individuals to organizations, private enterprise from small to large, government agencies at local, state, regional and national levels, and educational and media sectors. We address a wide spectrum ranging from how and why weather and climate vary through time and across the western landscape, measurement and monitoring functions, rapid and efficient access to climate information, how human and natural systems respond to climate, and how people and organizations incorporate knowledge of climate into their decision processes at multiple scales. Though not our ongoing reason for existence, we also include climate change as a component of our efforts because it is such a major issue within our discipline.

1. Aridity seems likely to persist or increase

In the arid landscapes of the West, drought is a frequent visitor that has shaped the cultural and biological characteristics of societies and their environment in innumerable ways. Drought has been present somewhere in the West during each of the 13 years since the initiation of the US Drought Monitor. From instrumental and earlier proxy records (tree rings, lake sediments, etc) we have recently acquired a far better appreciation of the regional vulnerability to extended drought. The tan and brown landscape is a perpetual visual reminder of that circumstance that complements our knowledge from measurement and scientific inference.

In the West, precipitation nearly always increases with elevation, and streamflow in most major river systems is disproportionately influenced by small areas at high elevations. Furthermore, a great deal of this precipitation falls as mountain snow, in winter, and is then metered out through the snowmelt process in spring and summer. As a broad generality -- from the standpoint of streamflow, hydrology, and soil water recharge at shallow and deep levels -- not all precipitation is equal: cool precipitation is more effective than warm precipitation. In most locations, precipitation is seasonally concentrated in one, sometimes two, or occasionally three portions of the annual cycle. Droughts with the most impact involve the loss of one or more of these precipitation seasons.

Akin to a household checkbook, in every location a water budget can be formulated: “revenue” as precipitation, streamflow, and groundwater recharge, versus “expenses” from evaporation, plant transpiration, groundwater withdrawal and outflow, and municipal and industrial consumption. Water is also stored in various surface and underground reservoirs, which fluctuate up and down, and are tied to gain and loss processes. Interbasin transfers represent one other loss or gain. When the rate of loss exceeds the rate of supply for sufficiently long that water buffers are drawn down to unusually low levels, we call this drought. Furthermore, we seek corroboration in the form of impacts of such deficiencies on human and ecological systems. Following such logic, drought is essentially defined by its impacts.

Though supply and demand for water are clearly influenced by precipitation, many of the above processes are affected by temperature, sometimes strongly, and at times in addition by wind and humidity (eg, drying of forests and other vegetation). Temperature also affects whether precipitation falls as rain or snow at a given altitude, the elevation at which the rain/snow transition occurs, the length of the snow accumulation season, and the timing and rapidity of melt. Temperature thus is a significant hydrologic factor and important for drought. All other things being equal, a warmer drought is more consequential than a cooler drought. The local or regional water budget can become more negative from temperature effects alone, with no change in total annual precipitation.

The West has been warming for whatever reason since the middle 1970s, by about 1 C / 2 F, so that recent droughts have been warmer than previous droughts. Projections from climate models lead to an expectation of further warming of at least another 2-3 C / 4-6 F, slightly more in summer, slightly less in winter. These same models indicate that such warming will likely not be steady, but rather punctuated by interruptions lasting a year or two up to a decade or two. Temperature rises are superimposed on the typical up and down fluctuations that have always characterized climate, and temporary downturns are found in many of these climate models and are anticipated as the future unfolds.

From 1895 to the middle 1970s, annual mean temperature in the western states fluctuated up and down with little net trend. Starting in the middle 1970s, temperatures have increased over the past 35 years. Since about 2000 they have remained approximately flat at their newly elevated levels, and the past 3-4 years have cooled by about half this 35-year increase in parts of the West. We do not know the reason for this flattening or for the recent cool period. The Southwest states have not participated as much in these recent trends, and in general have continued to warm. Furthermore, much of the western rise in temperature has been at night rather than during daytime. We really don't know why. This does not appear to be an artifact of the observing process (for example, thermometers in urban heat islands), but the reason needs to be better understood.

From north to south, the year-to-year variations in precipitation expressed in percent of average generally increase. Especially in the arid Southwest, annual precipitation is highly variable from year to year, the greatest in the US. Unless trends are large they will be hard to detect without observations from many years. As with day-to-day forecasts, precipitation is inherently more difficult to project than is temperature at longer climatic time scales. Nonetheless, there is general agreement among climate models that western precipitation will increase near the Canada border, and decrease near the Mexico border, by approximately 5-7 percent in the next 20-30 years, with a zone of little change approximately at the latitude of Interstate-80 across the West. These same models are indicating that winter precipitation may increase, whereas spring and summer precipitation decrease. This implies wetter winters, but a longer vegetative drying season centered on summer, which in this projected period receives less precipitation than now from the Mexico to the Canada border. Another implication is higher probability of extreme wet events in winter (more floods) but a longer and warmer summer dry season (more drought), a seemingly paradoxical possibility that actually does make physical sense. In addition, especially in more southerly latitudes of the U.S., winter is reliant on a few big storms to produce a significant fraction of the annual total. Thus, in the more southerly mountain ranges of the West, a reduction or occasional lack of such storms would lead to winter drought and subsequent low summer streamflow.

Precipitation averaged over the 11 westernmost states shows little trend over the past 120 years. Starting around 1980 and continuing until today, the West entered a period marked by much greater year-to-year variability than the prior 30 years. Some of these sizable excursions from long term means have lasted 4-6 years. These variations test infrastructure and planning and keep water managers awake at night. The projected increases in annual precipitation along the Canada border do not appear to have begun yet. Along the Mexico border, precipitation has declined since the late 1990s, somewhat in line with the projections, but the entire Southwest is coming down from a lengthy maximum in moisture that included the 1980s and early 1990s, and it seems premature to conclude very definitively that this is a consequence of climate change. In many places, the vegetative growth spurt of that era has furnished the fuels for the large and numerous wildland fires of the past 15 years.

At least some portions of the Intermountain West has been significantly affected by drought every year since the winter of 1995-96, which eventually led to the passage of legislation creating NIDIS. The most widespread drought during this time was in 2002, with exceptionally low flows on the Colorado River. Flows from the meager snowpack in 2012 have rivaled those in 2002. This drought has been warmer than previous droughts, a factor that has heightened its impacts. Drought has lowered the resistance of trees to pests, and higher temperatures have enabled pests to reproduce in larger numbers, and millions of acres of trees have died.

The region has seen an upsurge in area burned by wildland fire over the past decade and a half. Field reports of unprecedented fire behavior in terms of energy release and intensity have been common. Of the 11 western contiguous states, 7 have seen the largest fire in their state's recorded history during this short interval, and some of these states have broken such records only to see them re-broken in the last few years. As of mid-August 2012 the national area burned by wildland fires stands at over 6 million acres, compared with an average of about 5 million, and a significant portion of the fire season has yet to occur in some locations. Clearly something very different is happening.

Drought is by far the most costly US hazard. Since enacted as law in 2006, the National Integrated Drought Information System (NIDIS) has been very successful in addressing drought issues across a broad array of activities, from research to monitoring to preparedness to public understanding. Another goal of NIDIS is to contribute to and benefit from the rich national conversation that now accompanies the production of the US Drought Monitor every week. Drought comes in many different flavors, and NIDIS has emphasized as a national theme the need for place-based and application-specific products and services. The Western Governors Association and the Western States Water Council have been strong supporters of NIDIS and its goals, and will be seeking re-authorization in the coming year.

A long term goal in the western states should be a thorough understanding of all the major components of water budgets on spatial scales small enough to be relevant to each of the river basins in the region. These components include precipitation (and separately, snowfall), evaporation, transpiration, and soil and aquifer recharge (with special attention to mountain block recharge). In addition, tools that help visualize this picture for both water professionals and for the public are very much needed.

2. Climate events and extremes are as important as gradual and incremental change

Our first impression is that climate consists of the mean condition of the atmosphere, and surface and upper soil, averaged over a sufficiently long time. However, brief reflection will help us to conclude that climate may also be viewed as an unending sequence of a large number of small discrete events intermingled with a few large and sometimes extraordinary events with lasting effects. Both the human and the natural world respond to slow accumulations that reach trigger points, and to major disturbances that alter, sometimes substantially, and at times forever, an existing set of relationships. Examples are floods, windstorms, droughts, fires, heat waves, and regional frosts, which can leave their mark for decades or centuries.

Indeed, in our local setting today, the Santa Fe Institute has been a global leader in the studies of complex systems, which can be approximately defined as systems whose overall behavior cannot be predicted or often even imagined from studies of the parts in isolation. Climate is such a system, because ultimately the climate of Santa Fe is a product of processes taking place on, above, and below the surface of the earth and ocean, across the entire globe. Future states of such systems can only be predicted to a certain degree, in a piecewise, partial, incomplete, inexact and intermittent manner. Nonetheless there is often enough predictability to be useful in helping with decisions. Our best example is day-to-day weather prediction, which has improved demonstrably and substantially over the past half-century. We must exploit all sources of predictability to the maximum degree possible, while maintaining a realistic sense of the limitations.

Many aspects of this rich area of inquiry are gradually making their way into the popular lexicon: tipping points, emergence, feedback loops, cascading failures, chaos, sequencing, system memory, local and remote connections, stochastic behavior, nesting, nonlinear (disproportionate) response, and the like. All represent a body of thought that is a major departure from the "clockwork universe" conception of prior centuries about how the world around us works.

The reason for bringing this up is that human systems, ecological systems, and the climate system, are exceedingly complex, and their interactions yet more complex. Disturbances such as fire, insect outbreaks, wind storms, epidemics, are at once both results and sources of complex interacting systems, with a large dosage of luck and randomness. Organisms strive to take advantage, with winners and losers, and the makeup of ecosystems and relationships among components are in a constant state of mutual adjustment.

Climate – including its variations in time and space -- is but one of many stressors on human and natural systems. Limitations are imposed by availability of water, energy, raw materials, arable land, needs for recreational psychological sensibilities, geology, topography, and other factors. However, climate is pervasive and inexorable, always exerting some kind of influence, always a factor in the environment and in our own lives.

With warming, extreme heat is expected to occur more often, and extreme cold less often (though it will not disappear). This has consequences for individual humans, but also to ecosystems. For example, many pathogens and pests are held in check by temperatures exceeding cold thresholds, like frosts, or for pine beetles, extremely cold winter temperatures. Winters without such temperatures permit more pest generations to survive and feed upon formerly less vulnerable foliage. Drought or other climate sequences can also reduce the defenses of trees and other vegetation. Repeat photography has shown the effects of a single night of severe frost in the Grand Canyon earlier in the 20th Century have lingered into the present day.

Warm air is able to "hold" more water as vapor than cold air; a 5 C / 9 F rise in temperature allows the limit on atmospheric water content to rise by 35-40 percent. One expectation of a warmer climate is thus that the atmosphere would likely contain more water, which would thus be available to rain out at a higher intensity. Intensely heavy precipitation is caused or abetted by a variety of factors, each of which may become more or less prevalent, and very likely do so differently according to season, latitude, geographic and topographic setting, and so forth. Studies have shown that in most of the US, very wet days have increased in frequency, as has the water content of the atmosphere on very wet days. Such trends toward more very wet days are more notable in the eastern US, but not so much so in the Pacific Northwest, and seem to be absent in the six Southwest states, fur durations of a day or more. However, there does seem to be evidence that the very wettest of shorter events, of a few hours' duration, have become wetter and more frequent in the Southwest in the past few decades.

The topic of very heavy precipitation is starting to be closely scrutinized, because such events have enormous social and engineering costs, and all civil structures in the country must be built to standards set by analysis of past climate records (per past practice). The climate and engineering professions are struggling to develop methods that permit those standards to slowly evolve through time. There are thorny physical, statistical, observational, and social issues (the methods have to be accepted by the engineering community) that attend this process. This is a vital area of current exploration and needs to be actively supported.

3. Observations and monitoring are critical to response and adaptation

Our knowledge of the world around us derives from two sources: observations, and theoretical constructs that explain the observations. Both are necessary to claim understanding. But in almost every instance, observations lead in this perpetual dance.

Much of what we know about national, regional and local weather and climate is the result of long-term monitoring efforts made either to satisfy curiosity or to serve an application. Our knowledge of variations and trends in climate is based on long-term records, not necessarily always begun with such an application in mind. Climate studies place an extra requirement on measurement programs, an imperative for *consistency through time*. Otherwise we are unable to distinguish between changes in the climate and changes in the measurement process. The latter can include changes in very local environments near the thermometer or gauge, changes in instruments, changes in observational processes and procedures, changes in the way in which measurements are reported, and even changes in the way quality control is performed.

The consensus view among climate and atmospheric specialists would be that there is no conceivable way actual observations are ever going to be replaced by simulation, though we continue to improve in that regard. Good quality long-term observations are indispensable, and serve as a real-world reality check on our favorite speculations.

Though they are crucial, a common refrain is that "observations are everybody's second priority." Observing networks that meet necessary standards are under constant threat of reduction or elimination. This pressure has to be resisted, even as we seek methods to harness technology to improve the way we measure long-familiar quantities (temperature, precipitation, humidity, wind, solar radiation). There is continual need to support reference networks that generate records of essentially unimpeachable quality, against which other available measurements with insufficient documentation, unknown provenance, poorly known histories, and other uncertain properties, can be compared. In the middle 2000s, the Climate Reference Network (CRN) of about 120 stations was deployed nationwide for such a purpose. An effort to establish a Regional CRN (first 1000, later 538 stations, on a national grid) began in the Four-Corner states in the late 2000s, as a pilot, and many were installed. A second phase of this pilot extended to the five states of CA, NV, OR, WA, and ID. The western states were chosen first as a reflection of western drought needs identified by NIDIS. This program, intended as a many-decade national commitment, was abruptly canceled in 2011 because of budgetary emergencies.

This leaves us with the venerable National Weather Service Cooperative Network ("Coop"), manual measurements by volunteers from a program that extends from the 19^{th} Century, but now being revamped to allow daily electronic entry via the Web using a system called WeatherCoder. About 85 percent of the 7500 total stations now use this system, a major improvement for daily updates to drought monitoring and many other climate purposes. The entire Coop network will soon be completely "paperless." Considering its innumerable benefits to the nation, the very wide demand for information from this network, the century-plus period of operation, and the relatively low cost of its maintenance, this important network is a very efficient and valuable investment that should be supported indefinitely.

Observations acquire value through use, and thus an important function that goes hand in hand with measurement is monitoring: turning observations into information, by means of synthesizing and summarizing procedures that enable us to see temporal and spatial patterns in the data. The Regional Climate Center (RCC) Program and the American Association of State Climatologists (AASC) have, along with others, been strong and consistent advocates of such applications, and have developed tools to help others manipulate raw data to create products and applications desired by a variety of sectors.

One area could stand to see considerable improvement. A variety of networks have been deployed, particularly in western states, by federal agencies, in service of mission needs. With modest improvements, many of these stations and platforms could serve multiple overlapping needs, sometimes beyond the immediate needs of an agency, but of wide benefit for many other applications. From a taxpayer standpoint, the value of improved coordination and cooperation, including improved data sets, is an easy sell. However a number of barriers seem to deter what seems natural, many rooted in institutional and sometimes governmental cultures, with ambiguous rewards or perceived penalties for potential "mission creep" for going beyond narrowly defined mission boundaries to serve the common good. This seems like a perpetual Catch-22. This is not an argument to reduce the total number, but rather to make them all more useful for more purposes, such as drought monitoring. The complex topography of the West, and close juxtapositions of very different climates, necessitate a much higher spatial density of stations – when seen in plan view – than in the flatter eastern states.

Watching and working with western data sets and their managers over many years has led to one main conclusion. Most of the barriers to improved networks and use of data from networks have little to do with aluminum and copper, and far more to do with people, with institutional cultures and related behavioral barriers, a subject squarely in the realm of social science to help sort out.

4. We should not let this problem intimidate us too much

The climate problems we are wrestling with might be thought of as death from a thousand cuts. Problems associated with global climate change are the result of innumerable individual actions around the world, some direct and others indirect, acting through others (eg, thousands of individuals collectively creating a need for a power plant). We have worked our way into this dilemma bit by bit. It may be that a bit-by-bit approach would provide a viable and natural way out of the dilemma.

Humans are the most adaptable organisms that the earth has ever witnessed over its history. This adaptability has led us to inhabit all manner of environments, and to concoct ingenious methods to improve our comfort and well-being, with the consequences to climate already noted. This very same adaptability that has caused this problem to arise can be likewise harnessed in service of its remediation, and indeed is our only real hope.

The climate problem poses many peculiar and vexing dilemmas. One of these is the long lag time between cause and effect. By the time we see convincing evidence of a particular outcome, it likely has become too late to take action, no matter how earnest and active the efforts. Because we have not faced this problem before, there is little track record to provide the certitude we seek. It seems striking that we require such a high burden of proof, and certainty, before taking action. We routinely make highly consequential individual choices based on patchy, incomplete and uncertain information: which one to marry, what house to buy, what university to attend, which job to take, which car to purchase, what investment to make, and others. We seem to operate by a different standard when making these choices compared with those pertinent to today's discussion. Perhaps this is because the decision is individual rather than collective. But are we fated to forever follow this deeply rooted behavior, or can we change ourselves?

A variety of activities are under way to address the human and physical components of current climate-related issues. Many state climate programs have been in existence for 50-60 years, longer in some cases, shorter in many others. The Regional Climate Center Program within NOAA has been present since 1986, emphasizing but not restricted to data, monitoring, and observations. The NOAA Regional Integrated Sciences and Assessments (RISA) program has four projects of 2-3 states each in the western continental United States. RISAs are experiments in the provision of climate services, using a "learning by doing" methodology, and are primarily a research activity. NOAA recently created a system of Regional Climate Services Directors (RCSD) to help coordinate among various partners in the climate arena. The Department of Interior, which manages nearly half of the western states, has just stood up eight Climate Science Centers to address concerns raised within 6-8 agencies within the Interior Department (DOI). Also under DOI, a system of 22 Landscape Conservation Cooperatives has been established, with more emphasis on management issues, wherein climate plays a role but not always a dominant role. Some of us are working in a variety of ways with all of these efforts in order to bring about just the right amount of overlap, not too much and not too little, and to help insure that the participants themselves, and the public at large and its political representation, can see the bigger picture, how these efforts are complementary, and actually are coordinating and collaborating.

People have been present in the Intermountain West for millennia, and have acquired a significant store of experiential traditional knowledge about climate and the environment, the wisdom of antiquity. The more recent immigrants from Europe and elsewhere have trained the lens of science and its systematic style of analysis on the same subject. Neither method of learning or knowing is inherently superior to the other. Both traditions bring something unique to the table, and both are ultimately needed to claim complete understanding. Eventually they will merge, arriving at the same point by different pathways.

Our present impasse over what to do will not be resolved by simply more facts, about what climate could or might do. It seems that observations and related experiential processes will carry the day.

Personally, I like hard problems. The climate change issue is certainly a worthy challenge in this regard, but it is not insoluble.

Thank you very much.