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IMPACTS OF CLIMATE CHANGE ON THE INTERMOUNTAIN WEST

HEARING

BEFORE THE

COMMITTEE ON ENERGY AND NATURAL RESOURCES UNITED STATES SENATE

ONE HUNDRED TWELFTH CONGRESS

SECOND SESSION

TO

EXAMINE THE CURRENT AND FUTURE IMPACTS OF CLIMATE CHANGE ON THE INTERMOUNTAIN WEST, FOCUSING ON DROUGHT, WILDFIRE FREQUENCY AND SEVERITY, AND ECOSYSTEMS

SANATE FE, NM, AUGUST 17, 2012

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IMPACTS OF CLIMATE CHANGE ON THE INTERMOUNTAIN WEST

FRIDAY, AUGUST 17, 2012

U.S. SENATE,
COMMITTEE ON ENERGY AND NATURAL RESOURCES,
Santa Fe, New Mexico.

The committee met, pursuant to notice, at 10 a.m. at Santa Fe Community College, 6401 Richards Avenue, Room 216 Lecture Hall, West Wing of the Main Building, Santa Fe, New Mexico, Hon. Jeff Bingaman, chairman, presiding.

OPENING STATEMENT OF HON. JEFF BINGAMAN, U.S. SENATOR FROM NEW MEXICO

The CHAIRMAN. Thank you all for coming. This is a hearing of the Senate Energy and Natural Resources Committee, a field hearing. We had a similar hearing 2 days ago up in Colorado Springs that Senator Mark Udall, who is a member of our Energy Committee, presided at. It was on a related issue, pretty similar, but not quite as broad as today's hearing.

Let me just clarify for folks so there's no confusion. We're going to try to operate this like a hearing of the committee. We'll hear from the witnesses and then I'm going to ask some questions of them and then we'll probably adjourn the hearing at that point.

If any of the folks in the audience have issues they would like to raise with the various of our panelists I'm sure they'll be here for a few minutes and you can do that at that time. But this is not a Town Hall meeting as such. So I didn't want to give anyone the false impression that it is.

So the purpose of the hearing, the focus of it, is to talk about the impacts of climate change on the Intermountain West. During the early part of this year the fire season involved intense wildfires here in New Mexico and Colorado, across the Western United States. Many of those wildfires are continuing, of course, in the Northeast or Northwest part of the country in Washington and Oregon today threatening population centers, destroying hundreds of homes. I think we lost 250 some odd homes, 253, I believe is the right number down in Ruidoso in Lincoln County. There are a great many homes lost up near Colorado Springs.

Wildfires have always been part of life in this region. But this year's fires have been exceptional in their intensity. The work of the Nation's top scientists tells us that some of the conditions contributing to the severity of this year's fire season, including drought, accompanied by above average temperatures, are now

more commonly—are common because of human induced climate change.

The National Research Council has examined historical wildfire data as part of its America's Climate Choices report. They found that quote, "Over the past 30 years large and long duration forest fires in the American West have increased fourfold. The length of the fire season has expanded by two and a half months. The size of wildfires has increased several fold." The study further attributed the increase of wildfire activity to climate change stating that climate change has likely contributed to a significant increase in big forest fires in the West.

They did a separate report, the same National Research Council, in 2011 and projected an increase in median annual area burn in parts of New Mexico and in the Sierras of over 300 percent for a global increase in temperature of just one degree Celsius. That level of warming is all but certain to be reached and exceeded in coming years.

The intent of this hearing is to receive testimony that puts these recent fires into a greater historical context to unravel the factors that contributed to their severity and to understand how climate change has and is expected to continue to change the landscape and ecosystems of the Intermountain West.

This hearing will focus primarily on the broad impacts of climate change including increased wildfires, widespread damage to ecosystems and the potential for greater drought conditions.

Of course management practices are also an important consideration. As I indicated that we had a hearing 2 days ago in Colorado Springs that focused primarily on that, chaired by Senator Mark Udall. The audio from that hearing and the written testimony from that hearing are available on the Senate Energy Committee website which is at energy.senate.gov. Let me just say for any of you that are interested in this, we are live streaming the audio from this hearing today on that same website. In the future that the audio from today's website and the testimony from today's hearing and the testimony from today's hearing will be on the website as well.

Climate change is not just an issue that will affect future generations. The impacts are being felt today in different ways all around the country and around the world. Here in New Mexico we're dealing with increased temperatures, drought and more intense fires, but citizens in places like Louisiana and Florida are dealing with the impacts of rising sea levels. It's clear that communities across the country are paying very real costs for climate change right now.

I hope that the discussion today will help to restart a national conversation about climate change. Although talk of climate change has become highly politicized, it's critical that we reduce greenhouse gas emissions here and abroad. There's a good articlein today's Santa Fe New Mexican—which many of you I'm sure saw—talking about how CO_2 emissions in the United States have fallen. It says coal and energy use are still growing rapidly in other countries, particularly China.

CO_2 levels globally are rising, not falling. Moreover, changes in the marketplace and gloom in the economy and falling coal prices, a rise in natural gas prices can stall or even reverse the shift which

has occurred here toward less use of coal and toward more use of natural gas which resulted in the main factor, resulting in lower greenhouse gas emissions here.

In the Senate I work to advance policies to reduce greenhouse gases about 20 clean energy sources and greater efficiency. Most recently I introduced the Clean Energy Standards Act of 2012. Kevin Rennert, who is sitting here right beside me and who did the preparations for this hearing, is the main author of that legislation. He put it together. I very much appreciate his work on that.

But this Clean Energy Standard Act would transition the way that the country generates electricity to a variety of clean, low carbon sources. While election year politics will keep this legislation from being enacted in this Congress. I hope it will, the legislation, will serve as a foundation for passing legislation perhaps in the next Congress.

Climate change is a tremendously pressing issue that we can't afford to continue ignoring. We need to work to address it.

We've got 5 very distinguished witnesses here today. Let me introduce them briefly. Then we'll hear from them. That's the main purpose of the hearing is to give them a chance to explain what their findings are and what their views are on this issue.

First is Governor Walter Dasheno, who is a long time friend of mine and leader in the Native American community in our state and Governor of Santa Clara Pueblo. His Pueblo has been directly affected by these fires. He can talk about some of those effects and his views as to what needs to be done.

Dr. Craig Allen, who is a Research Ecologist with the Geological Survey, U.S. Geological Survey, in Los Alamos. Thank you for being here.

Dr. Nate McDowell, who is a Staff Scientist with Earth and Environmental Sciences Division at Los Alamos National Laboratory. Thank you for being here.

Dr. Kelly T. Redmond, who is Regional Climatologist and Deputy Director of the Western Regional Climate Center in Reno, Nevada. Thank you for being here.

Dr Bill DeBuys, who is a writer and historian currently living in Chamisal and has a recent book out on this very serious issue and the effects of climate change on the Southwest.

So we're very anxious to hear from all of the witnesses. Why don't each of you take whatever time you need to explain your point of view? Your entire written testimony will be included in the record hearing. But please tell us the main points we need to understand. After everyone has testified then I'll have a few questions to ask.

Governor, why don't you start?

STATEMENT OF HON. WALTER DASHENO, GOVERNOR, SANTA CLARA PUEBLO, ESPANOLA, NM

Mr. DASHENO. Good morning, Senator. I brought with me 5 disks so we can decide when we'll finally finish my new dike.

The CHAIRMAN. OK.

Mr. DASHENO. No, I'm just kidding, Senator.

I, first of all would like to express my appreciation to you, in particular, for the opportunity to present our testimony today. For I'm

going to illustrate to you basically, to start with this, to show you a few photographs that we have taken in Valles Caldera at the Santa Clara Canyon. I know right now the Canyon is closed. So it's going to be closed for some time because of the impact in flooding that was occurring just in the early part of July. So with that I ask Janelle to show the posters.

The first poster shows the, what used to be the second pond in the left hand corner where all of the siltation from the runoff has gathered in all of the 4 ponds and 3 other ponds that we have. So today, those ponds are no longer functional. They serve as basically just a catch pool area, so we're going to have to go quite deep to remove all the siltation.

The next picture shows our former Governor Michael Chavarria. He sat on the boulder that shows that the first flooding that occurred of July of last year. The initial runoff of the flooding was at about 5 feet high. The picture to the left, in the bottom corner, shows you how much the road has been cut by the flooding that has occurred.

Initially the creek that you see in the bottom shows how deep it was. So it's gone up almost about 20 feet high based on the siltation and the debris that has come down.

The bottom shows a piece of equipment that was buried in the flooding that occurred where 4 persons that were working got caught in the flooding. Four of them got caught in the water so they had to pull themselves out. Today that shows the illustration of the dangers of what flooding could occur. It's still very dangerous and that might be a monument some say sometime down the road.

The CHAIRMAN. Now this is flooding that occurred as a result from the Los Conchas fire?

Mr. DASHENO. That's correct, Senator.

The CHAIRMAN. OK.

Mr. DASHENO. The next photographs on the next side shows you the amount of work that's occurring, at least, before the flooding that happened on July 8th. The initial poster that you saw showed it on the east side. This is on the west side so that Thomas Berry has built up shows you that it really does amazing damage.

The top photograph shows you the vehicles that are coming into to bring in some of the debris and some of the siltation that has occurred across the 4 ponds. So we're re-laying all of that back into the roads again as part of the restoration effort based on the finding that has been provided to us by BAER and by FEMA.

The top two photographs show you what Santa Clara Canyon used to look like. Beautiful area. Pristine. One of the best fishing areas in northern New Mexico. Then the drainage that we developed based on what we were going to do.

The first photograph shows the Four Pond. The second photograph shows the pond as it was draining because we were going to reintroduce the Rio Grande Cutthroat back into the area again. Today the bottom shows what it looks like today. No longer in the water. No longer any vegetation. It's all been refilled with siltation.

This is what has occurred because of the Los Conchas fire. The trees are all dead at this point. Both sides of the mountain range have been destroyed, have been devastated. This is very little vegetation at the culvery were coming down.

The bottom photograph shows you the restriction which is misleading because although it's beautiful on the ground on the bottom side it is just been devastated. So it's sad that this is a look at the creek.

Again, this is what the first pond used to look like and then the second pond.

During the course of the fire we had as many as 7 helicopters that would come in to pick up water. After one took off another one would stand in line. After that they'd come in and drop off the water here and there. So that the illustration that shows here is no longer there at this point.

This is some of the damage that has occurred. We've gone into look at the area. The top left corner shows you some forklifts being looked at by some of the people that will be doing some major reforestation and regeneration of some of the area.

While we're here I just want to mention that what the gentlemen is referring to and showing is that when the water came down at that particular location, it was about 6 or 7 feet high when the water came down. Before Governor Chavarria illustrated the issue by indicating that he was working with the authority of known individuals that were a hot shot team that was from Ohio State. He asked them to leave at that point because it was starting to rain.

What happened was as they were leaving there was 4 deer that jumped. As part of that the first deer that came in did a flip and they were wondering what happened. Anyway, the individuals thought that the person that was driving the vehicle had not stopped they would have been crushed by the blow of that truck in that area. So that's what he was showing what could have occurred.

The next photograph shows Congressman Luján coming in to do an assessment of the area that we did with him and yourself and Governor Martinez as well, been up there along with Senator Udall and have done that.

The bottom photograph shows you the damage that has occurred. What used to be a grange area and the Golden Pond, that's basically been destroyed. This photograph was taken around May of this past year, now that is no longer there. It's basically been eaten up on both sides of and devastated the canyon.

The Avanyu on the weekend of the Pika market the flooding that occurred, we had 2,000 CFS that came down from the photograph that happened in the Santa Clara Canyon. Just to illustrate to you, although it's a 2,000 CFS, the bottom picture shows you what the impact would be if it was at 20,000 CFS.

As you might recall, Senator, on the afternoon of August 21 there were two scours. One scour that was on Santa Clara Canyonsite and the other scour that was on the Bandelier slide area. If that collapsed like that had been reversed this is what would have been destroyed, Senator. Lives would have been lost. Phones would have been lost, but fortunately that didn't occur. What occurred was what happened up on top.

Although 4 persons were in the area and almost drowned, fortunately no lives were lost. But as a precaution Biscayne has been closed and was closed last year by the authorization of the Tribal

Council so that we no longer—excuse me, are able to get in to do that.

So that what I'm hoping to illustrate by this photographs is that the work that's being done on the bottom will show you at the 2,000 CFS. If the 20,000 CFS would ever occur this is what the impact is going to be. We've done some major work to do some improvement to prevent that from occurring. Today as I speak the VOR is putting in some pylons so that we'll be able to protect the home areas on both the west side and the south side of the village.

This is the effort that went into by the committee and the volunteers last year. We've had hundreds of volunteers from Los Alamo, from Santa Fe. It's been NOAA, people that were associated with the laboratory, people that were associated with the State of New Mexico, the general public and other individuals that assisted in making sure that we were able to do the work because of the affected flooding that we're looking at. So that we had those individuals that did all of the work.

We don't know how nature is going to react. So again, the bottom photograph just illustrates to you what the impact would be with the flooding. The area today could be impacted again, if we were to have more flooding. We anticipate, Senator, that that's going to continue to occur at least for the next 5 years.

These are some of the efforts that are being made, along with yourself, Senator, Senator Udall, Congressman Luján and Governor Martinez, like you all have had a chance to visit Biscayne, to show you, for us to show you, what needs to be done. So we want to thank all of you, particularly the New Mexico Congressional delegation. They're going to do a letter that wants to release the funds from FEMA. I understand it takes a little while to get FEMA to release funds, but fortunately with your assistance, we were able to turn it around a lot quicker.

However, the issue still remains that the State still has to release some fund extensions. As you know, you probably have read the newspapers these last couple of weeks. We received another billion dollars to do some work. Then we received another $5 million. But that bill has been held up in the State of New Mexico and we can't do any work.

So we asked Congressman Luján on his visit a few days ago. If we could ask you, again, to have the state, if they could please do that to get this project going.

I'll show you 2 photographs that we've taken.

One is to build a greenhouse so that we can replant and promulgate our own Douglass fir trees, our pine and other area plants of this case that we need to grow because of the acclimation of the area it requires that we have to do that. So we're using that to assist our efforts to do that.

The bottom portion of the photograph shows you 3 generations. There's actually a grandma standing up but she's not in the photograph, of 4 generations of people, that are going to start this effort to regenerate and reforest the area again. Some of the trees that were burned were as old as two and 3 hundred years old.

So the tree that we plant today is going to take us at least 300 years to be marketable. The trees that were burned this past year have been a total loss. We planted 1.5 million trees from the Cerro

Grande fire. We've logged approximately 50 to 60 percent of those trees, just to illustrate to what the impact has been with these photographs.

I'll now go to my presentation.

The CHAIRMAN. OK.

Mr. DASHENO. Thank you, Senator and Chairman Bingaman for this opportunity to testify on the critically important issue of climate change and its impact on our region in general and on the Santa Clara Pueblo in particular. My name is Walter Dasheno. I am the Governor of Santa Clara Pueblo, as well as the Chairman of the Eight Northern Indian Pueblos Council.

Senator, our Pueblo is involved in a multigenerational effort to restore our forest and our watershed after the devastating Los Conchas wildfire. Although mercifully no lives were lost and no homes in Santa Clara were burned, we still saw our traditional and treasured homeland and spiritual sanctuary, the Santa Clara Canyon, practically destroyed. This includes our land of origin, the P'opii Khanu and numerous cultural and traditional sites. In addition the loss of the forest was devastating to our wildlife and wildlife habitat, recreational resources and to the purity of our water which we use for irrigation and many traditional purposes.

Because the Santa Clara Canyon has been stripped of its vegetation, the Pueblo is at a tremendous risk of and need has already expressed severe flood events. The channel through the Santa Clara Pueblo does not have the capacity to carry large post-fire flows. Hundreds of residential structures including several public structures are at risk from flood and debris flows if no action is taken immediately. We live under the daily threat of the destruction of much of the Pueblo and the possible loss of life.

FEMA has just allocated significant funding to help us restore the water control structures in the Canyon and do other important work. We continue to work with other Federal agencies such as the Bureau of Indian Affairs, Army Corps of Engineers, U.S. Forest Service, Bureau of Reclamation and other agencies in the complex effort to put in place flood mitigation measures and a forest restoration program. We are grateful for the support of these agencies, although continued funding is needed to achieve success. As I said, it's not really to be measured based on what we do but what we can accomplish in getting off those tasks.

We are also very grateful to you, Senator Bingaman, for your active support. I would ask that in addition to supported Federal agency action that you also support S. 2283, which would allow tribal government to directly request a Presidential disaster declaration. This would be in fulfillment of the trust responsibility and expedite disaster recovery assistance.

For the purposes of this hearing there are two key questions.

First, to what extent did climate change contribute to this disaster?

Second, to what extent will climate change impact our recovery efforts for the next 50 to 100 years?

In regard to the first question, I believe that climate change was a significant factor contributing to the disaster. At the time of the fire, it was reported that the living trees in the Canyon had lower moisture content than the wood you would typically buy in a lum-

ber yard. This is a result of drought conditions in the Southwest that the scientific community continues to associate with climate change.

In addition, higher temperatures in general create more conducive conditions for wildfires.

Climate change was not the only reason this fire was so devastating. The forest was unhealthy with excessive undergrowth and too great a tree density, making conditions ripe for an intense fire that will kill the mature trees. As a result of managing the impact of climate change we must manage the conditions in our forest.

As for the second question, based on our preliminary research, we are very concerned that continued rapid climate change will have a significant and highly adverse effect on our efforts to regenerate the forest and restore the Canyon ecosystem. Warming alone could lead to a decline in suitable habitat with indigenous species of the Canyon. Moreover, if we continue to experience more frequent and more severe wildfires, we could reach a tipping point at which the trees may no longer regenerate.

The Los Conchas fire re-burned an area where we had planted a million trees in an effort to recover from an earlier wildfire. Theoretically, with the change in climate other plants and animal species adapted to the new climate will move in. However, we do not know how long that will take nor whether any such species actually exist or what the forest would look like after such species establish itself. The answers to these questions will determine the health of the Santa Clara Canyon and because of the Canyon's central importance to our culture, the health, well being and identity of the Santa Clara people.

Senator, it will take generations of our land to recover from the devastation of the Los Conchas fire. Because of climate change it is not clear what the future will look like. But this is our only homeland. It is a place we have been entrusted with since time immemorial.

We ask that the Federal Government support the funding necessary to understand the implications of climate change as well as to implement the necessary forest management and forest recovery fire and restoration.

Senator, I just want to say that in due course of what is going to occur to our people in the next generation to come, we are going to be in this long haul. The generations coming after us and those that will come after us for several generations to follow, they will be the recovery effort until someday in the future someone will say those men and women that were there at the time of the fire, made the best decision and the right decision. Today we can see our forests. Today we can drink the water. Today we can practice our culture. Today we can fish. Today we can hunt. Today we can see a healthy forest and a good, strong ecosystem that will benefit all the rest of the region and generations to come.

So with that, Senator, I thank you very much. God bless you. I know that you're going to be retiring sometime very, very soon in the future. With that we wish you well.

You have done well for all of us. You've illustrated being a champion for us, but not too many we can make peace with, thankfully

the future of New Mexico and we wish you the best. Please live healthy, live well and prosper, my friend. Good luck.

[The prepared statement of Mr. Dasheno follows:]

PREPARED STATEMENT OF HON. WALTER DASHENO, GOVERNOR, SANTA CLARA PUEBLO, ESPANOLA, NM

INTRODUCTION

Thank you, Chairman Bingaman and members of the Committee, for this opportunity to testify on the critically important issue of climate change and its impact on our region in general, and on the Santa Clara Pueblo in particular. My name is Walter Dasheno. I am the Governor of the Santa Clara Pueblo, as well as the Chairman of the Eight Northern Indian Pueblos Council.

As you are aware, the Santa Clara Pueblo has embarked on a multi-generational effort to restore our forests and our watershed after the devastating Las Conchas wildfire. For the purposes of this hearing, there are two key questions. First, to what extent did climate change contribute to this disaster? And second, to what extent will climate change impact our recovery efforts over the next 50-100 years?

With regard to the first question, I believe that climate change was one of several significant factors contributing to the disaster. At the time of the fire, it was reported that the living trees in the canyon had lower moisture content than the wood you would typically buy at a lumber yard. This is a result of drought conditions in the Southwest that the scientific community continues to associate with climate change. In addition, higher temperatures in general create more conducive conditions for wildfires. I must note, however, that climate change was not the only reason this fire was so devastating. The forest had become unhealthy, with excessive undergrowth and too great a tree density, making conditions ripe for an intense fire that would kill the mature trees. As a part of managing the impact of climate change, we must manage the conditions in our forests.

As for the second question, based on our preliminary research, we are very concerned that continued rapid climate change will have a significant and highly adverse effect on our efforts to regenerate the forest and restore the Canyon ecosystem. Warming alone is likely to lead to a decline in suitable habitat for the indigenous tree species of the Canyon. Moreover, if we continue to experience more frequent and more severe wildfires we could reach a tipping point at which the trees may no longer regenerate. The Las Conchas Fire reburned an area where we had planted a million trees in an effort to recover from an earlier wildfire. Theoretically, with the change in climate other plant and animal species adapted to the new climate would move in.

However, we do not know how long that will take, nor whether any such species actually exist, or what the forest would look like after such species establish themselves. The answers to these questions will determine the health of the Santa Clara Canyon and, because of the Canyon's central importance to our culture, the health, well-being and identity of the Santa Clara people.

BACKGROUND ON THE LAS CONCHAS WILDFIRE

In the summer of 2011, the Santa Clara Pueblo was devastated by the Las Conchas Fire, at the time the largest wildfire in New Mexico history (although that unfortunate record has already been eclipsed by the Whitewater-Baldy Complex Fire. Although mercifully no lives were lost and no homes at Santa Clara were burned, we still saw our traditional and treasured homeland and spiritual sanctuary, the Santa Clara Canyon, practically destroyed. We estimate that more than 16,000 acres of our forest lands burned in this fire and, together with the lands that we lost in the Oso Complex Fire of 1998 and the Cerro Grande Fire of 2000, 80% of our forests and a huge part of our heritage has been destroyed. In addition, the fire burned thousands of acres of our traditional lands that are outside our current reservation and that continue to hold cultural sites and resources of great importance to us. This area encompasses our lands of origin, the P'opii Khanu—the headwaters of our Santa Clara Creek, and numerous cultural and traditional sites. In addition, the loss of the forest is devastating to wildlife and wildlife habitat, recreational resources, and to the purity of our water—which we use for irrigation and many traditional purposes. (See attached illustration of fire impact on Santa Clara watershed.)* Throughout this tragedy, the Santa Clara people have shown grit and determination to persevere and to begin the long road to recovery so that while my generation may never see the canyon in its glory again, that will not be said of the next generation.

Because the Santa Clara Canyon has been stripped of its vegetation, the Pueblo is at tremendous risk of flooding. Over 50% of the Santa Clara Pueblo watershed burned during the Las Conchas fire. Because of the high severity of the burn, there has been a dramatic reduction in the infiltration rates in the burned area—the soil is now what is termed by soil scientists "hydrophobic." This has resulted in a four- to eight-fold increase in runoff and sediment/debris flow into the Santa Clara Creek, posing a severe threat to the lives and safety of the people of Santa Clara Pueblo and increasing the potential for widespread property damage. The channel through Santa Clara Pueblo no longer has the conveyance capacity necessary to safely pass large post-fire flows. Hundreds of residential structures including several public structures are at risk from flood and debris flows if no action is taken immediately. (See attached illustrations of the potential flood risk zone to Santa Clara for a ten-year event.)*

A mere 1 inch rain event over 8 hours, or what hydrologist refer to as an average monsoon season storm, on August 21, 2011 led to intense flooding and the emergency evacuation of Santa Clara and US Army Corps of Engineer personnel. This rain event resulted in a Presidential Disaster Declaration. As the Department of the Interior, Interagency Burned Area Emergency Response ("BAER") Team noted the intense flames from the fire burned trees and vegetation off the steep slopes of the canyon and heated the soils causing severe damage to the natural resources of the area and placing the downstream tribal members of the Santa Clara Pueblo at risk to extreme flooding. The post-fire watershed effects were rife for massive landslides and debris flows which occurred on August 21, 2011. The August 21, 2011 event produced massive debris (including boulders) and severe mud flows to the canyon bottom. The Canyon reservoirs were overwhelmed (over topped) by this average rainfall event following the fire and are now full of sediment. Flood protection emergency measures put in place after the Las Conchas fire were inches away from being compromised. It is important to note that this storm was an isolated thunderstorm over a small portion of the Santa Clara watershed (one drainage) and not over the entire watershed (what hydrologist refers to as a general storm). Another similar event occurred this past July, destroying much of the recovery work we had undertaken over the prior year. If the rain event of August 21, 2011 had occurred over the entire post fire Santa Clara Pueblo watershed, the Santa Clara Pueblo itself would have been devastated.

I live in fear of the destruction of my Pueblo and the possibility of loss of life. This has motivated my efforts, and that of the whole Santa Clara government, to secure the funding needed to put in place adequate flood control measures. In just the last few weeks, the Federal Emergency Management Agency (FEMA) has allocated very significant funding to help us restore the water control structures in the Canyon and do other important work. We continue to work with other Federal agencies, such as the Bureau of Indian Affairs, Army Corps of Engineers, U.S. Forest Service, Natural Resources Conservation Service and others in the complex effort to put in place flood mitigation measures and a forest restoration program. We have been very grateful for the support of these agencies, although continued funding is needed to achieve success.

However, we are only at the beginning of the flood mitigation and forest recovery effort. The fire has raised numerous, interrelated, short and long-term concerns for Santa Clara and other surrounding communities, almost all of which are further complicated by climate change. First, during the summer monsoon season, we have faced every afternoon the threat of a thunderstorm that would send torrents of water and debris down the Santa Clara Canyon and Creek, creating a huge risk of dam failure and catastrophic flooding for our homes, public buildings and irrigation system. Second, we must address the environmental impacts of this fire. This includes the physical health impacts from the huge quantities of smoke, as well as the devastating emotional impact to our community of such a great loss. It also includes water quality impacts as tons of ash, debris and other materials flow into the Santa Clara Creek affecting fisheries, wildlife consumption, agriculture and cultural uses, and safety issues within our Santa Clara Canyon due to the destabilized landscape resulting in falling boulders and dead and down trees. This runoff flows into the Rio Grande, affecting water quality for communities like Santa Fe that are downstream or that use the Rio Grande. Third, we are still assessing how to recover from the loss of an unprecedented amount of cultural resources and sites, from damage to sacred places, to the loss of animal and plant species that have been integral to Santa Clara cultural and spiritual practices for generations. Fourth, Santa Clara has suffered extended financial impact, including not only the direct efforts to address the fire, but also from the temporary closure of Puye Cliff Dwellings, the re-

* Illustrations have been retained in committee files.

duction in arts and crafts sales, and the decline in tourists and visitors to our hotel. Fifth, we still need fire suppression resources to protect the remaining 20% of our forests. Finally, we must address the long term restoration of the forests. This is a project that we anticipate will take many decades, but one to which we have already set our minds.

THE EFFECT OF CLIMATE CHANGE ON FOREST REGENERATION AND RECOVERY

We are still struggling with the post-fire consequences of the Las Conchas wildfire and have only just begun the infinitely more complex process of addressing the regeneration of the forest in the Canyon. However, we have looked at research into the effect of climate change on forest regeneration, including a study of the Greater Yellowstone Ecosystem undertaken by academics at the University of California—Merced (see http://www.ucmerced.edu/news/study-climate-change-increase-yellowstone-wildfires-dramatically).

The predictions of that study look a lot like both our immediate past and our likely future. For example, it predicted that the expected rising temperatures caused by climate change could increase the frequency of large wildfires in Yellowstone to an unprecedented level. While not quite on an annual basis, we have experienced the harmful effects of four major wildfires in the last 15 years, none of which were started on the Pueblo. While fire can be a natural and important part of the maintenance of a healthy forest system, fires of this intensity and frequency are very harmful. We still have sacred lands, just off our reservation which have not burned, but remain under threat.

These fires will likely create a major shift in the nature of the Santa Clara Canyon's ecosystem. We are not exactly sure what that shift might look like. In the study of the Greater Yellowstone Ecosystem, the authors predicted "fewer dense forests and more open woodland, grass and shrub vegetation, with forests becoming younger, the mix of tree species changing and some forests failing to regenerate after repeated fires. This would affect the region's wildlife, hydrology, carbon storage and aesthetics."

Of course, as the fires create a fundamental change in the Canyon's ecosystem, the affect of climate change and the nature of future fires will be changed, making both predictions and natural resource management even more difficult.

There is a risk that warming alone is likely to lead to a decline in suitable habitat for the indigenous tree species of the Canyon and the projected increase in frequency and severity of wildfires could accelerate that process to a tipping point at which the trees may no longer regenerate. Theoretically, with the change in climate other species adapted to the new climate would move in. However, we do not know how long that will take, nor whether any such species actually exist, or what the forest would look like after such hypothetical species establish themselves. In the end, there is great uncertainty regarding how the Canyon's ecosystem will be transformed. Predictions depend on which climate model is chosen, for example, and how accurate that model ultimately proves to be.

MITIGATING THE RISK OF CATASTROPHIC WILDFIRES

Santa Clara has a large forestry department, numbering some 40 personnel. This department is widely regarded as outstanding. Santa Clara fire crews and equipment were assigned and on the front lines fighting the Las Conchas Fire. We have a dedicated commitment to the maintenance and restoration of healthy forests on, around and adjacent to the Pueblo. In the management of our own resources, we have worked to ensure against the threat of forest fire. And yet, in the last decade we have faced four forest fires that have threatened our forests—the Oso, Cerro Grande, South Fork and Las Conchas fires—and none of them originated on our lands. Although fate and climate change play their part, we have suffered horrible consequences largely due to the failure of others to properly guard in some fashion against causing a fire.

For the last several years, Santa Clara has been actively working with the U.S. Forest Service, the BIA and others in an effort to establish a forest management plan and program that would have prevented this catastrophe. This effort has involved numerous meetings in New Mexico and several trips to Washington. In particular, Santa Clara was working on establishing a partnership under the Tribal Forest Protection Act with the Forest Service to begin a long-term project to address the health of the Forest Service lands around the Pueblo. We were also seeking to assure that if the Valles Caldera, which is adjacent to the reservation, was transferred to the National Park Service, that any agreements we had reached would be honored in the transfer and new agreements could be put in place with the new administrators.

We know that these efforts would have eventually succeeded given enough time, but we ran out of time. We saw in the Las Conchas Fire that where the Santa Clara had completed work on fuel breaks the fires was stopped. In an area where the Santa Clara Pueblo has had 80% of its forested land base burn since the Cerro Grande fire, every sliver of green timber makes a difference to stabilizing soil. Nonetheless, in the ten years since the Cerro Grande fire, Santa Clara has planted nearly 1.5 million trees, most of which were burned in the Las Conchas fire, destroying the Pueblo's great labor of restoration of the past decade. Despite our full awareness of the threat, and our efforts to enter into partnerships and seek funding to address the threat, we ran out of time. Nevertheless, we still hope these partnerships will enable Santa Clara to play a significant role in the restoration and rehabilitation of the Forest Service lands around our current reservation. We also look to put together a forest management law that will protect our forests and which we think should influence the management of the forests around us, which have posed such a threat to our lands.

PROVIDING FOR TRIBES TO SEEK A FEDERAL DISASTER DECLARATION

Because only a state governor can set the process into motion for a Federal disaster declaration, we would ask this Committee to address why tribal governments, who have a direct government-to-government relationship with the United States, must go through state governors to request Federal disaster relief. Such relief clearly falls within the Federal trust obligation and has the potential to expedite disaster recovery assistance. We would therefore urge this Committee to support legislation that allows a tribe to directly request this relief when it is needed. In particular, I would draw your attention to S. 2283, which would provide this authority.

FEDERAL RESOURCES FOR BOTH SHORT-AND LONG-TERM PLANNING AND RECOVERY EFFORTS

The health of our community, and that of many other communities from the Inter-Mountain West, will turn on developing a greater understanding of the affect of climate change, as well as ways to both mitigate its consequences and engage in effective restoration where those consequences, such as the Las Conchas Wildfire, have already occurred with devastating effects.

CONCLUSION

Never again in our lifetime will we see our traditional and treasured homeland and spiritual sanctuary, the Santa Clara Canyon, as we have known it. It will take generations for our community and lands to recover from the devastation of this fire and, because of climate change, it is not clear what that future will look like. But this is our only homeland; it is the place we have been entrusted with since time immemorial. While we intend to devote the resources we can to the healing of our land and the protection of our community we do not have the resources to do it alone. We turn in this hour of need to our Federal trustee and ask for your sustained assistance in addressing this calamity and assuring the remediation of our sacred homeland with a long-term perspective on how this can be done during a period of what now appears to be almost inevitable rapid climate change.

The CHAIRMAN. Thank you very much, Governor. We all express our sadness about all the damage that's been done there in Santa Clara Pueblo. Again, you were very generous in giving me a tour of it last year which I appreciated.

We'll continue to work to try to have the Federal Government be responsive to the problem.

Dr. Allen, why don't you go right ahead and give us your views on the whole set of issues that we're talking about this morning.

STATEMENT OF CRAIG D. ALLEN, U.S. GEOLOGICAL SURVEY, DEPARTMENT OF THE INTERIOR

Mr. ALLEN. Thank you.

Thank you and good morning, Chairman Bingaman.

I'm pleased to be here today to discuss an important set of issues facing the Intermountain West, the emerging impacts of climate change on drought, forest stress, wildfire and ecosystem change.

My name is Craig Allen. I am a Research Ecologist with the Fort Collins Science Center of the U.S. Geological Survey. I'm also the Station Leader of the Jemez Mountains Field Station based at Bandolier National Monument here in Northern New Mexico where I've been doing field work since 1982.

My research is focused on the ecology and environmental history of the Southwestern United States working with many colleagues on intensive local studies that also address regional and global level issues. My testimony today presents information from a variety of sources in the scientific literature with details as provided in the written testimony. My focus will be on the Southwest, particularly including observations from my home landscape in the Jemez Mountains, just left of here on the other side of the Rio Grande.

I hope to leave you with two main messages.

First, there's a high level of scientific confidence that, as a result of drought impacts, coupled with warmer temperatures, forests in the Southwest are at an increasing risk of severe wildfire and tree mortality.

Second, currently observed trends are indicative of the early stages of ecosystem re-organization in response to climate stress and land management practices.

The Southwest U.S. is one of the best places in the world to determine the close linkages between climate, vegetation and fire using multiple lines of strong evidence that extend back thousands of years. Historic observation of charcoal records and tree ring studies and fire scars all show that climate has long synchronized by our activity across the Southwest with more fire in dry, warm years and dry, warm temperatures. Prior to the 1900s frequent, low severity surface fires dominated in the Ponderosa pine and drier mixed conifer which are so extensive in the Southwest. High severity crown fires also occurred historically in smaller portions of the Southwest, notably in high elevations in the spruce fir forest.

More recently Southwest forest and fire patterns also have responded to changes in human behaviors. Active fire suppression over the past century has caused formally open forests across the Southwest to become relatively dense for fuel structures that now have the support of widely spreading, relatively explosive forest fires.

In Figure 1, the first figure up here, I'll be referring to now. With the onset of drier and warmer conditions since 1990 the Southwest has seen major increases in forest disturbances. For example, between 1984 and 2008, 18 percent of the forests in this region were affected by significant tree mortality from combinations of drought stress, bark beetles, which are shown in the orangish pattern and from wildfire, which are the red areas. This does not take into account the record wildfires which has affected the Southwest in 2011 and 2012. These are from data from 2000.

The scale of these forest disturbances certainly is unprecedented in the Southwest since the start of record keeping began around 1900.

Increasingly extensive, high severity fires and drought induced tree mortality also have emerged elsewhere across the West and in many other parts of the world.

May I have the second slide, please?

For example, the first global imaging of drought and key induced tree mortality, recently documented many examples of forest die off in all major forest types worldwide from tropical rainforests in the Amazon to the spruce forests in Canada and the all forest types in between.

Also, experimental results clearly show that tree mortality is sensitive to warmer temperatures.

Dr. Park Williams, a colleague at Los Alamos National Laboratory, is leading new research that actually was accepted just today. He just got the news this morning that this article, that this research, the first article, has been accepted into the Journal of Inter Climate Change. Demonstrating that warming temperatures could drive more stress in the Southwest to unprecedented levels by the 2040s which likely would render large areas of current forest climatically unsuitable for the present dominant tree species.

Could you go to the third figure, please?

In addition, studying these recent observations document the risks of post fire conversions from forest to non-forest ecosystems in the Southwest. These conversions can be caused by large, high severity fire patches where essentially all 3 seed sources are killed across thousands of acres. This can allow in some cases, shrubs to achieve dominance before trees can re-establish.

The photograph you're looking at here is taken from the south end of the day one run of the Los Conchas fire last summer. There's not—there's essentially not a live tree in the entire field of view. The level of EPIN, I've seen a lot of fires, but I've never seen anything quite like that part of the world of this afterwards. In fact we don't know what will come next in these giant sites.

We can go to the last slide.

The CHAIRMAN. Let me just ask. This was taken at the time of the fire a year ago. Can you tell anything, so far, as to whether or not trees are going to come back?

Mr. ALLEN. I was out there a week ago, Senator. I could have—if we had had more opportunity for photographs actually, I could have taken a repeat photo. That tree has toppled actually, the dead tree there. I could have shown you a repeat.

There is still essentially almost nothing. There may be one or 2 percent vegetation covering on that side. The only thing that's coming back so far, substantively, are a few grassy plants and some of the shrubs that are starting to re-sprout.

But in terms of tree seed sources the issue is that these trees require seed trees to survive. There are none close to this location so it will be a while, which is actually the point then of this next picture. Thank you.

Which does show two photographs of a site, oh about 8 miles from the first site which was also burned in the Los Conchas fire. It was actually burned in two fires, the first fire in 1996, the Dome fire and about a third of the area. It had been a dense pine forest prior to the Dome fire in 1996. About 30 percent of that area had come back as dense shrub covering.

This is a photograph taken just a week after the Los Conchas fire, the top photograph, a week after the Los Conchas fire came through. The shrubs have been burned down to the ground. You

can't even tell they were there. They cooked the Ponderosa Pine trees that had survived the first fire. So all of those trees you can see there are dead.

The photograph below taken from the same location just a couple of weeks ago, so 1 year post fire, shows all that green are the shrubs re-sprouting. You can see what we essentially have is a shrub field now. The shrubs go as far as we can see. The trees, including the seed sources for the future have been eliminated almost entirely from an area of many thousands of acres there by this combination of the two fires.

All of these recent trends are evidence that we may already be reaching tipping points of forest ecosystem change, changes which are new to the historical era. Despite these recent trends and emerging risks there are a variety of forest management approaches available to buy time for our forests. For example through combinations of mechanical tree harvesting and managed fire treatments to reduce forest stand densities and hazardous fuel loadings. It also reduces the amount of water stress among the trees if there's fewer trees competing for our increasing limited water.

In summary, forests as we know them today in the Southwest are at risk from amplified tree mortality and high-severity fire due to increasing drought and heat stress. The recent increases in regional forest drought stress, the greater extent and severity of forest disturbances and the lack of post-disturbance tree regeneration on some sites, all suggest that if modeled climate projections of a warmer and drier Southwest come to pass we can expect to see regional forest ecosystems change beyond the observed patterns of the last few centuries. Nonetheless, forest management practices can improve forest resistance and resilience to climate stressors and associated disturbances.

Thank you again for the opportunity——

The CHAIRMAN. Thank you.

Mr. ALLEN. To testify here today.

[The prepared statement of Mr. Allen follows:]

PREPARED STATEMENT OF CRAIG D. ALLEN, U.S. GEOLOGICAL SURVEY, DEPARTMENT OF THE INTERIOR

Good morning Chairman Bingaman. I am pleased to be here today to discuss an important set of issues facing the intermountain West—the emerging impacts of climate change on drought, forest stress, wildfire, and ecosystem change.

My name is Dr. Craig D. Allen. I am a research ecologist with the Fort Collins Science Center of the U.S. Geological Survey. I am also the Station Leader of the Jemez Mountains Field Station based at Bandelier National Monument here in northern New Mexico, where I have conducted ecological fieldwork continuously since 1982. My research largely has focused on the ecology and environmental history of Southwestern landscapes, working with networks of colleagues on intensive local landscape studies that scale up to address regional and global-level issues. My testimony today will present information from a variety of sources in the scientific literature, with a focus on the Southwest, and particularly including observations from my home landscape of the Jemez Mountains.

The messages I hope to leave with you are these: There is a high level of scientific confidence that, as a result of drought impacts coupled with warmer temperatures, forests in the Southwest are at increasing risk of severe wildfire and tree mortality. Currently observed trends are indicative of early-stage ecosystem reorganization in response to climate stress and land management practices.

Recent climate trends of warming and drying conditions have corresponded to major increases in the extent and severity of forest die-off in the Southwest. The

close linkages among patterns of climate, tree growth and mortality, and fire are particularly well-documented in the scientific literature for this region, using multiple lines of strong evidence that extend back many thousands of years. This evidence includes information unlocked from the tree-rings of ancient wood that records past patterns of precipitation, temperature, stream flow, tree growth, and fire; plant pollen, other plant remains, and charcoal deposited in layers of sediment at the bottoms of lakes and bogs; and plant macrofossils and pollen preserved in the middens, or waste heaps, of ancient packrat nests.

Given that substantially warmer temperatures and greater drought stress are projected for the Southwest in coming years (Seager and Vecchi 2010; Gutzler and Robbins 2010), we should expect even greater increases in mortality of drought-stressed trees, high severity fire (Williams et al. 2010), and ultimately conversion of current forests into different ecosystems, ranging from grasslands and shrublands to new forests dominated by different tree species (Williams and Jackson 2007; Jackson et al. 2009). Increasingly frequent and severe droughts and fires favor plant life-forms that can survive above-ground stem dieback and fire damage by resprouting from below-ground tissues. Many grass and shrub species can do this. After high severity fires, successful regeneration of the main tree species in the Southwest primarily depends upon the local survival of enough mother trees to serve as seed sources.

There are several studies and recent observations that document the risks of post-fire type conversions from forest to non-forest ecosystems (Barton 2002, Savage and Mast 2005; Goforth and Minnich 2008). These conversions can be caused by the ever larger, high-severity fire patches where essentially all tree seed sources are killed across tens of thousands of acres, as observed in some recent fires (Fig. 1).* This greatly limits the rate of recolonization by some of the most common tree species such as piñon pine, ponderosa pine, and Douglas-fir, allowing dense grasslands or shrublands of resprouting species to achieve dominance before trees can re-establish. It is also beginning to be observed that once large areas of resprouting shrubs, like Gambel oak, become mixed in and around surviving post-fire conifer tree populations, a hot reburn through the shrubs can then kill nearly all of those adult survivors. Tree seed sources are thereby eliminated in sequential fashion (Fig. 2). The growing extent and severity of recent forest disturbances in this region, and the lack of tree regeneration on some sites after disturbances, are evidence that we already may be reaching tipping points of forest ecosystem change, changes which are new to the historical era.

Similar patterns of recent climate-amplified tree mortality and fire activity also are occurring more broadly in western North America, as well as in many other portions of the world. For example, a group of 20 co-authors from around the world recently conducted the first global overview of drought and heat-induced tree mortality (Allen et al. 2010), which documented many examples of extensive forest die-off in all major forest types worldwide, from tropical rainforests in the Amazon to African savannas and Mediterranean pine forests to boreal forests in Canada and Alaska (Fig. 3). But while we observe that all major forest types worldwide are vulnerable to high levels of tree mortality during periods of drought and heat stress, we cannot yet determine if forest die-off is increasing overall at a global scale due to the absence of long-term baseline information on global forest health conditions, and the continued absence of a globally coordinated observation system (Allen et al. 2010). A recent experiment on piñon pine, however, showed unequivocally and unsurprisingly that when warmer temperatures accompany drought, trees die much faster (Adams et al. 2009). This is to say, there is not only observational evidence that tree mortality is on the rise, but also experimental results showing that mortality is temperature sensitive. As climate continues to warm we can expect more tree die-off events like those we have recently observed. Changes in climate and human land uses also are driving increasingly severe fire activity in many regions around the world (Bowman et al. 2009 & 2011, Pechony and Schindell 2010, O'connor et al. 2011).

Every plant species has a particular range of climatic conditions in which it can grow, so as local climates, and associated disturbances like fire and beetle outbreaks, shift beyond the tolerance limits of the currently dominant species, today's dominant plants will die, thereby opening space for new species that can tolerate the altered climate conditions. There is, however, a major gap in scientific information about precisely how much drought and heat stress various tree species can tolerate before dying. In other words, scientists do not yet know how to "kill" trees in models with the accuracy necessary to project how much change in climate conditions they can tolerate before widespread mortality occurs (McDowell et al. 2008 &

* Figures 1–4 have been retained in committee files.

2011, Allen et al. 2010). Our understanding of climate change risks to forests in this region is enhanced by cutting-edge experimental research on the physiological effects of drought and heat stress on trees which is being conducted locally by Dr. Nate McDowell of Los Alamos National Laboratory. Dr. Park Williams, another colleague also at Los Alamos National Laboratory, is leading new research that demonstrates the risks that warming temperatures could drive forest drought stress in the Southwest to unprecedented levels by the 2040's, which likely would render large areas of current forest climatically unsuitable for their present dominant tree species. Park's work also shows strong correlations between forest drought stress and area affected annually by high-severity fires and bark beetle infestations in this region, consistent with known climate-disturbance linkages in western North America (Westerling et al. 2006, Raffa et al. 2008, Littell et al. 2009, Bentz et al. 2010, Hicke et al. 2012).

Given projections of substantial further warming and increased drought stress for the Southwest in the coming decades (e.g., Seager and Vechhi 2010), the recent ramp-up in the extent and severity of climate-related forest disturbances (Breshears et al. 2005, Westerling et al. 2006, Raffa et al. 2008, Allen et al. 2010, Williams et al. 2010) may indicate that forests in this region are now approaching tipping points such that we are beginning to see substantial reorganization of ecosystem patterns and processes into new configurations (Williams and Jackson 2007, U.S. Climate Change Science Program 2009, Jackson et al. 2009, Barnosky et al. 2012).

If the climate projections of rapid warming for the Southwest are correct, then by the middle of the twenty-first century our Southwestern forests as we know them today will experience significant vegetation mortality and can be expected to reorganize with new dominant species (Littell et al. 2009, Bentz et al. 2010, Williams et al. 2010).

LONG-TERM PERSPECTIVE

The Southwest United States has an abundance of paleo-ecological records that make this one of the best places in the world to determine past patterns of climate, vegetation, and fire, using multiple lines of evidence. For example, scientists here in New Mexico have used information locked in the tree-rings of ancient wood to precisely reconstruct past patterns of precipitation, temperature, stream flow, drought stress, and tree growth and death going back as much as 2000 years (Swetnam et al. 1999 & 2011, Swetnam and Betancourt 1998, Allen et al. 1998 & 2008, Brown and Wu 2005, Fule et al. 2012, Falk et al. 2011, Margolis et al. 2011, Roos and Swetnam 2012, Touchan et al. 2010, Woodhouse et al. 2010). Even older evidence can go back many thousands of years in the form of plant pollen, other plant remains, and charcoal deposited in layers of sediment at the bottoms of lakes and bogs (e.g., Weng and Jackson 1999, Anderson et al. 2008a). These sediment records reveal how today's high mountain tree species like spruce and fir were growing at much lower elevations during the colder climate of the last ice age, before moving upslope as the world's climate moved into the current warmer interglacial period about 11,000 years ago (Anderson et al. 2008a,b). Similarly, plant macrofossils preserved in the middens of ancient packrat nests directly show how much, and how fast, the ranges of plant species have expanded and contracted geographically, moving north and south, and locally upslope and downslope, in response to climate variations (Betancourt et al. 1990). These pollen and macrofossil records also show that past vegetation communities often consisted of combinations of plant species unknown today (Betancourt et al. 1990, Weng and Jackson 1999, Anderson et al. 2008a). For example, midden and pollen evidence of ponderosa pine is almost non-existent in the Southwest during the last ice age, but with the early post-glacial warming and the associated development of our summer monsoon climate after about 10,000 years ago this pine expanded across the region to eventually become a dominant forest species (Betancourt et al. 1990, Allen et al. 1998, Weng and Jackson 1999).

During this same time period, the abundance of charcoal deposited in lakes and bogs increased markedly across the region (Anderson et al. 2008a,b, Allen et al. 2008), reflecting increased frequency and extent of fire activity on Southwestern landscapes, which likely also favored the expansion of fire-dependant species, like ponderosa pine (Weng and Jackson 1999). Charcoal records over the past 1,000 years in the West and Southwest generally show the modulating effects of climate on fire activity, with modest increases in charcoal concentrations during the Medieval Warm Period, and also some significant decline during the Little Ice Age. Both charcoal and tree-ring fire scar records from ancient giant sequoia groves in the Sierra Nevada of California (Swetnam et al. 2009) and from across the West (Marlon et al. 2009 & 2012, Power et al. 2012) show similar patterns. Overall, the world's

greatest concentration of tree-ring studies of tens of thousands of precisely dated fire scars from hundreds of forest sites across the Southwest reconstruct high-resolution spatial and temporal patterns of fire extending back about 500 years, showing high levels of frequent and widespread fire activity that were closely tied to climate patterns (Swetnam et al 1999 & 2011, Falk et al. 2011).

These pre-1900 fire-climate relationships are consistent with those that we see today (Swetnam and Betancourt 1998, Swetnam et al. 1999), with much higher levels of fire activity in warm dry years. For about two-thirds of the fire scars we can even date the season that the fire scar formed, allowing us to demonstrate that most pre-1900 fire spread occurred in the dry spring and early summer period, just as today, before the July onset of summer rains. Tree-ring reconstructions demonstrate that frequent, low-severity surface fires dominated the pre-1900 fire activity in the widespread ponderosa pine and drier mixed-conifer forests that predominate in much of the Southwest (Swetnam et al. 2009). Climate synchronized fire activity across the region, with large portions of most Southwestern mountain ranges burning in some extreme fire years (1748, for example, is the biggest fire year known in the Southwest [Swetnam et al. 1999]).

It is important to note that there is a great diversity of forest and fire patterns across the Southwest. For example, high-severity stand-replacing fires also occurred in the less extensive wetter mixed-conifer and high-elevation spruce-fir forests in the region (e.g., Margolis et al. 2011), although not as much research has been done on such fire regimes in the Southwest. Tree-ring studies also show that major climate relationships with tree establishment, growth, and death have been rather consistent for the past 1,000 and more years. That is to say, forest trees in the Southwest grow better and reproduce in pulses during wetter periods, whereas during periods of extended warm drought trees experience high levels of drought stress and mortality (Swetnam and Betancourt 1998, Allen and Breshears 1998, Swetnam et al. 1999, Brown and Wu 2005, Falk et al. 2011). Finally, the charcoal sediment records show relatively high levels of fire activity in the Southwest for most of the past 9,000 years. Charcoal sediment records for the last century, however, show an anomalous deficit of fire activity across both the Southwest (Anderson et al. 2008a, Allen et al. 2008) and West as a whole (Marlon et al. 2012, Power et al. 2012). Similarly, the abundant tree-ring reconstructions of Southwest fire histories clearly demonstrate that previously frequent and widespread surface fire activity ceased across the region between 1880 and 1900. This reduced fire activity occurred because of man-made rather than climatic reasons.

LAND MANAGEMENT PRACTICES

Over approximately the past 150 years regional forest landscapes and fire regimes have responded both to changes in human land use and land management and to patterns of climate variability. The prehistoric pattern of widespread, high-frequency surface fire regimes across the Southwest initially collapsed in the late 1800's, because with the entry of railroads to this region there was a buildup of herds of domestic livestock that interrupted the former continuity of the grassy surface fuels by widespread overgrazing, trampling, and trailing (Swetnam et al. 1999). The suppression of surface fires by overgrazing then morphed into active fire suppression and exclusion efforts by land management agencies in the early 1900's, which has continued with ever-increasing effort and expenditure to the present (Pyne 1982).

With the circa-1900 change in surface fire regimes in many Southwestern forests, the multitude of young trees that established were thinned out by frequent surface fires which had favored relatively open, grassy forest conditions. As a result, woody plant establishment exploded into the 1900s, particularly during several favorable wet climate windows for tree regeneration and growth. Twentieth century fire suppression resulted in a general pattern of forest and woodland expansion into grasslands and meadows, along with increases in the densities of many (although not all) Southwestern forests and woodlands. For example, in some common forest types, like various types of ponderosa pine and dry mixed-conifer forest, tree densities commonly increased ten-fold or more, often from less than 100 trees per acre to over 1,000 trees per acre.

In the absence of frequent surface fires, such increases in forest density also were accompanied by huge increases in surface fuel loads and the widespread development of understory thickets of small, suppressed trees. These "ladder fuels," as they are known, allow surface fires to easily spread upward into tree canopies. Thus with active fire suppression over the past century the former fire-maintained mosaic of open forests across diverse Southwest landscapes became a uniform blanket of dense forests with fuel structures that could support the initiation and spread of explosive

high-severity canopy fires. Generally wet conditions in the Southwest from 1978 through 1995 fostered rapid tree growth and further forest "woodification," but the wet conditions also helped keep wildfires in check. Thus by the mid-1990s many southwestern forests likely were near their maximum possible densities and levels of biomass accumulation at both landscape and stand scales.

The last 20 years have seen more severe fires and drought-induced tree mortality, with associated bark beetle outbreaks, in Southwestern forests and woodlands, with 18% of Southwestern forests affected by significant tree mortality from combinations of drought stress, bark beetles, and high-severity wildfire between 1984 and 2008 (Fig.4, Williams et al. 2010). (And this does not take into account the record wildfire years in 2011 and 2012.) The scale of these forest disturbances certainly is unprecedented in this region since historic record keeping began around 1900, almost certainly is unprecedented since the megadrought of late 1500's (Swetnam and Betancourt 1998), and in the case of high severity fire patches in southwestern ponderosa pine forests quite possibly is unprecedented since before modern climate, vegetation, and fire regime patterns established 6,000 years ago. Similar patterns of increasingly extensive high-severity fires and drought-induced tree mortality also have emerged elsewhere across the intermountain West (Westerling et al. 2006, Raffa et al. 2008).

Despite these recent disturbance trends and emerging risks for forests in the Southwest, there are a variety of forest management approaches available to buy time for our forests through increasing their resistance and resilience to growing climate stress to restore and maintain historically sustainable patterns of forest structural conditions, species compositions, landscape-scale patterns of fire hazard, and ecological processes (Sisk et al. 2006, Fulé 2008, Finney et al. 2005 & 2007, Ager et al. 2010, Stephens et al. 2012). For example, by using combinations of mechanical tree harvesting and managed fire treatments to reduce forest stand densities and hazardous fuel loadings, foresters can reduce excessive between-tree competition for water and other resources, thereby concurrently reducing overall forest drought stress and risk of high-severity fires, and at the same time restore historical forest ecological conditions that we know were sustainable for at least many centuries prior to 1900 (Swetnam et al. 1999, Allen et al. 2002, Fulé 2008, Stephens et al. 2012).

In summary, forests as we know them today in the Southwest are at risk from amplified tree mortality and high-severity fire due to increasing drought and heat stress. The recent increases in regional forest drought stress, the greater extent and severity of forest disturbance, and the lack of post-disturbance tree regeneration on some sites all suggest that if modeled climate projections of a warmer and drier Southwest come to pass we can expect to see regional forest ecosystems change beyond the observed patterns of the last few centuries. Nevertheless, forest management practices can improve forest resistance and resilience to climate stressors and associated disturbances.

Thank you again for the opportunity to testify here today. I would be happy to answer any questions you may have.

The CHAIRMAN. No, thank you very much for your testimony. I appreciate it very much.

Next is Dr. Nate McDowell with Los Alamos National Laboratory. Thank you for being here.

STATEMENT OF NATHAN MCDOWELL, STAFF SCIENTIST AND DIRECTOR, LOS ALAMOS ENVIRONMENTAL RESEARCH PARK, LOS ALAMOS NATIONAL LABORATORY, LOS ALAMOS, NM

Mr. MCDOWELL. Thank you, Chairman Bingaman.

You can put the first slide up if you wish.

I'm honored to speak to you today regarding current and future impacts of climate change on the Intermountain West. I am Nate McDowell, staff scientist at the Earth and Environmental Sciences Division at Los Alamos National Laboratory. My team at Los Alamos is the global leader in the study of how vegetation dies in relation to drought. We also have a strong research focus on how vegetation mortality feeds back to influence the earth's climate.

Our research is aided by the massive amounts of mortality our local forests have experienced in the last decades. In other words we live in dead forests. That photo, for example, is near where we live in Los Alamos.

I will focus the majority of my testimony on forest mortality associated with drought and insects. I will leave the discussion of fire to Dr. Craig Allen and the other invited speakers. Although, I'd be happy to comment on that later.

Insect mediating mortality during and after drought kills approximately twice as many trees as fire does in the Intermountain West.

Put the next slide up, please.

The CHAIRMAN. Could you make that statement again?

Mr. MCDOWELL. Based on two studies, insect mediating mortality during or after drought kills approximately twice as much surface area as fire.

The CHAIRMAN. OK.

Mr. MCDOWELL. In the Intermountain West.

As Dr. Allen highlighted there is strong scientific evidence for rising rates of vegetation mortality during and after drought. Mortality is accelerating and will almost certainly continue to accelerate in the upcoming decades. The negative effect of atmospheric warming appears to outweigh the benefits of higher atmospheric CO_2.

We are now experiencing what is commonly labeled a climate change type drought. Warmer temperatures raise evaporative demand, or how dry the air is, driving greater movement of water through forests to the atmosphere. Thus for every inch of precipitation a larger fraction of that water is extracted by the warmer moisture out of the air leaving less to the forests.

Water loss from plants occurs through tiny holes in the leaves called stomata. If the water loss is too great then the plants desiccate, dry out and die, similar to people without water.

Photosynthesis also occurs through the stomata. So if a plant closes the stomata to avoid drying out, which is the common response, that means they can't eat, similar to a person without food.

The combination of these stressors results in much increased vulnerability of forests to insect attack.

Since most forest plants shut their stomata and stop photosynthizing during drought rising atmospheric CO_2 has little benefit. In other words it's like if you have a million dollars in your bank account but your ATM doesn't work. It's not actually useful to the plant.

In addition warming accelerates the productivity of pathogen and insect communities in much of the Intermountain West. Therefore, what we have is compounding impacts on the forest due to the stress and promotes greater rates of forest mortality that has occurred in recorded history.

Throughout the earth's history vegetation mortality has occurred during periods of rapid temperature and moisture shifts. However the warming we experienced in the past century is at least twice as fast as any in at least the past millennium. It is forecasted by the Intergovernmental Panel for Climate Change to accelerate far

more in the next upcoming century than it has on record in the past.

The confidence in these predictions is high. These predictions suggest that the average climate in the year 2050 will be hotter and drier than that of the mega droughts of the 1200s and 1500s that caused the mass migration of ancestral pueblo into the widespread forest mortality throughout the Southwestern USA. Thus even if precipitation remains unchanged in the future the increasing evaporative demand due to warming will cause the forest to experience future drought conditions that are nearly guaranteed to cause widespread mortality.

Forest mortality induces a strong, positive feedback on climate warming due to the transfer of carbon stored in the forest to the atmosphere.

If you could show the next slide, please.

I'll just highlight if you thought that was a lot of mortality in the USA take a look at British Columbia here.

Photosynthesis by forests store approximately 33 percent of global anthropogenic CO_2 emissions annually and the forests themselves contain approximately 55 percent of all carbon stored on land globally. Dead forests in contrast have greatly reduced rates of photosynthesis and hence cannot remove carbon from the atmosphere. Because dead trees decompose, they release large amounts of carbon back to the atmosphere.

For example, British Columbia's carbon loss, shown in the slide above, from a drought and insect attack in the early 2000s was equivalent to—I believe—5 years of Canada's transportation sectors, CO_2 emissions. Therefore it influenced their national carbon policies.

Similarly the loss of forests in Western North America due to non-fire mortality alone is projected to equal 6 years of the United States fossil fuel emissions.

In Northern New Mexico the loss of forest carbon over the last decade was approximately equivalent to 25 percent of New Mexico's fossil fuel emissions. Thus continued forest mortality from both fire and drought constitutes a positive forcing on climate warming by injecting more CO_2 into the atmosphere. This is commonly referred to as the potential to dew point.

More evidence suggests that no forest is immune to drought induced mortality. We observed both a long elevation gradients in our local mountains in New Mexico as well as up the spine of the Rockies from Mexico to Canada that all forests appear to be dying at approximately similar rates and spatial magnitudes. It just happens first in the dry areas. But it still happens in the wetter areas.

This is very concerning because there's far more carbon stored in these wetter, cooler forests. Thus, the mortality of these forests with high carbon stores causes a much greater release of CO_2 to the atmosphere. Drought and insect mortality along with wildfire induced mortality are the common drivers and common possible solutions.

Dr. Allen has addressed those briefly. I'd be happy to address those more during the time for question and answer period.

In conclusion there are strong scientific certainty that future droughts will promote the loss of forests in the Western United

States. This will occur through both increased severity of drought stress upon forests and subsequent insect and pathogen attack and through wildfire. Without significant changes in the global energy portfolio and increased investment into sustainable forest management, the loss of forests in the Western United States is unavoidable.

Thank you for the opportunity to appear before the committee.

[The prepared statement of Mr. McDowell follows:]

PREPARED STATEMENT OF NATHAN MCDOWELL, STAFF SCIENTIST AND DIRECTOR, LOS ALAMOS ENVIRONMENTAL RESEARCH PARK, LOS ALAMOS NATIONAL LABORATORY, LOS ALAMOS, NM

INTRODUCTION

Good morning Chairman Bingaman, Ranking Member Murkowski, and members of the committee. I am honored to speak to you today regarding current and future impacts of climate change on the intermountain west. I am Nate McDowell, staff scientist within the Earth and Environmental Sciences Division at Los Alamos National Laboratory, and director of the Los Alamos National Environmental Research Park. My team has published approximately 20 papers on vegetation mortality in relation to climate change. We are the global leaders in the study of how vegetation dies in relation to drought, both currently and in the future (Figure 1).* We also have a strong research focus on how vegetation mortality feeds back to accelerate warming of the earth. Our research is aided by the massive mortality our local forests have experienced in the last decade (Figure 2). Bark beetle-associated mortality during and after drought kills approximately double the amount of forests as fire in the intermountain west (J. Hicke unpublished results, Williams et al. in revision). With the exception of management implications, I will leave the discussion of drought and fire in this hearing to Dr. Craig Allen and the other invited speakers. The focus of my testimony today will be on the impacts of climate change on vegetation mortality and the associated carbon and climate consequences of vegetation death.

My main message today is that there is strong scientific evidence for 1) rising rates of vegetation mortality during drought at the global scale and within the intermountain west, 2) forest mortality will continue to accelerate, despite CO_2fertilization, and 3) the consequences of forest loss to drought-associated mortality include but are not limited to a strong positive feedback on climate warming due to the transfer of carbon stored in forests to the atmosphere. There are multiple research and mitigation options that should be pursued in the very near future if we are to stem the tide of forest mortality and associated carbon release to the atmosphere.

Vegetation mortality is rising in northern New Mexico, throughout the intermountain west, and globally (Figure 2-3, Raffa et al. 2008, van Mantgem et al. 2009, Allen et al. 2010, Peng et al. 2011, Hicke et al. 2012, Williams et al. in revision). The bulk of the evidence suggests this rise is a result of climate warming and in some ecosystems, forest management. It is most strongly correlated with rising air temperature (van Mantgem et al. 2009, Allen et al. 2010, Peng et al. 2011). There is a wide range of evidence to explain why rising temperature has, and will continue, to accelerate mortality of vegetation.

Forest mortality will continue to accelerate. Everyone can understand the general idea that drought kills plants because of a lack of water. The details of the process of drought-induced mortality are relevant to expand upon within this testimony, however, because combining the current climate forecasts with the mechanisms by which climate causes plant stress paints an ominous picture for the future of forests in the intermountain west.

Large-scale vegetation mortality events have occurred throughout the history of the earth. These events were typically associated with rapid changes in climate, in particular, rapid increases in temperature or decreases in moisture (McElwain and Punyasena 2007, McDowell et al. 2011). The term "rapid" is important in this context, because the change in climate we are currently experiencing is more rapid than any in the geologic record.

* Figures 1–7 have been retained in committee files.

The rise in temperature from 1900 to 2000AD was approximately twice that of any other century going back to 750AD, and the forecasted temperature growth will four-to ten-fold more rapid by 2100 AD (IPCC AR4).

Warmer air holds more moisture, thus increasing temperature raises evaporative demand (Figure 4) and drives greater movement of water from forests to the air; this is called evapotranspiration. Evapotranspiration exacerbates the impact of droughts because for every inch of precipitation, a larger fraction of that water in the soil and plants is extracted by the moisture-hungry air, thus causing current droughts to induce greater stress upon plants than past droughts have caused (McDowell et al. 2008). This has been referred to as climate-change-type drought (Breshears et al. 2005).

The primary determinant of plant survival in the intermountain west is the supply and demand of water because in this region the supply is low relative to the demand. Plants move water to their leaves through a process similar to the movement of water in a straw: tension is placed upon the top of the straw by the dry air, thus pulling the water upwards from the soil and through the plants. Insufficient soil water or a large pull on the top of the straw can cause cavitation, or the formation of air bubbles in the straw. This blocks further water flow and if un-repaired, results in further decreases in water flow, a process we call hydraulic failure (Figure 5, McDowell et al. 2008, 2011). Plants avoid this problem through closure of their stomata, or the tiny pores on their leaves that allow release of water and uptake of CO_2 into the leaf (i.e. photosynthesis), and thus they reduce the risk of hydraulic failure. However, stomatal closure means that no photosynthesis occurs. During this period of minimal photosynthesis they must rely on stored carbohydrates, akin to the fat stores of mammals, to stay alive and defend themselves against pathogens such as bark beetles. If drought is prolonged, this can result in carbon starvation, or the loss of carbohydrate stores, so that life cannot be maintained and defense against attack agents, such as beetles, may fail (Figure 5, McDowell et al. 2008, 2011). There is strong evidence that both hydraulic failure and carbon starvation are occurring throughout the intermountain west during the prolonged drought that has extended from 1996 through 2012.

Increasing temperature has three additional impacts on vegetation survival. First, temperature is exponentially related to the loss of carbon through metabolism, so temperature rises can drive elevated loss of the carbohydrate stores needed to support life and fight off biotic agents such as bark beetles (Amthor 1994, Atkin et al. 2007, McDowell 2011). Second, biotic agents such as bark beetles grow faster and achieve more generations per year with rising temperature. Thus attacks on trees by bark beetles increase with rising temperature both due to increasing tree stress and increasing beetle population size (Raffa et al. 2008). The net effect is that rising temperature increases the risk of vegetation mortality. Third, as described by Dr. Craig Allen, rising atmospheric demand due to temperature increase the rate of spread of fire.

Forest mortality will continue to accelerate because evaporative moisture demand by the year 2100 will have increased approximately 34% from the 1950-2000 due to rising temperature (Figure 6a,b, Williams et al. in revision, CMIP3). This is extremely likely to force widespread vegetation mortality throughout western USA even if precipitation remains fairly steady (Figure 6c, d, Williams et al. in revision) with a simulated carbon loss by 2100 equal to six years of the United States fossil fuel emissions (Figure 7, Jiang et al. in review). There is very strong evidence that we are already witnessing the consequences of increased evaporative demand on widespread bark beetle outbreaks and forest fires since the late 1990s (Williams et al. 2010, in revision). Future projections suggest that the average climate in Southwestern USA will be a stronger drought than any of the last 1000 years, including the mega-droughts of the 1200's and 1500's that caused the mass-migration of ancestral Puebloans and the widespread forest mortality throughout Southwestern USA (Figure 6). Thus, even if precipitation were to remain unchanged, the increasing evaporative demand due to rising temperature will cause the forests to experience future drought conditions that are nearly guaranteed to cause widespread mortality. In other words, increasing forest mortality over the next century is almost certainly going to occur in some regions of the world, including the intermountain west.

Recent forest growth in response to CO_2 fertilization does not provide significant benefit to vegetation survival during severe drought (Franks et al. in revision). This is because the elevated CO_2 only benefits plants whose stomata are open to allow photosynthesis to occur; both low precipitation and high evaporative demand force stomatal closure, thus preventing photosynthesis. This has been shown in numerous observations and experiments (reviewed in Franks et al. in revision). Therefore, rising CO_2 does not prevent mortality during drought.

Mortality from both fire and bark beetle/drought has numerous consequences on ecosystems including a strong feedback by which forest death leads to accelerated climate warming. Live forests store approximately 33% of anthropogenic CO_2 emissions annually and contain approximately 55% of carbon stored in terrestrial ecosystems (Bonan 2008). The loss of these forests to mortality and replacement vegetation with lower carbon storage such as shrubs (as described in Dr. Allen's testimony) reduces the ecosystems ability to extract CO_2 from the atmosphere, and furthermore, the mortality results in the release of large amounts of CO_2 from the decomposition of dead trees (Harmon et al. 1990, Hicke et al. 2012). For example, British Columbia's carbon loss from drought/insect attack in the early 2000's was equivalent to six years of Canada's transportation sector CO_2 emissions and influenced national carbon policy (Kurz et al. 2008a, b). Similarly, the loss of forests in Western North America due to non-fire mortality alone is projected to equal six years of United States fossil fuel emissions (Figure 7, Jiang et al. in revision). In northern New Mexico, the loss of forest carbon in northern New Mexico over the last decade was equivalent to 25% of New Mexico's fossil fuel emissions. Thus, the continued growth of forest mortality from both fire and drought will drive a positive forcing on climate warming. The impacts of mortality on climate warming via CO_2 release are mirrored with similar impacts on hydrology and energy budgets, not to mention aesthetics, timber production, tourism and other ecosystem services provided by forests (Adams et al. 2010).

Many people, scientists included, have assumed that primarily forests in drier systems, such as lower elevations or lower latitudes, are vulnerable to climate-change-type drought. We now know this assumption is incorrect. Recent work in my lab has observed two key results across elevation gradients within New Mexico's Jemez and Sangre de Cristo Mountains and up the spine of the Rockies from Mexico to Canada. In both studies, the more arid low elevation or low latitude forests die first, but wetter forests at higher elevations and latitudes followed suit a few years later with mortality of equal spatial magnitude. Perhaps more importantly, these wetter forests store far more carbon than more arid forests, thus the loss of the wetter forests causes a much greater release of CO_2 to the atmosphere (Jiang et al. in revision). Thus, no forest appears safe from rising temperature and more intense droughts, and thus we can expect widespread mortality and significant feedbacks to accelerate future climate warming.

Recommendations: drought and insect mortality, along with wildfire induced mortality, have common drivers and common possible solutions. Rising rates of both of these forms of mortality are due in part to the declining moisture content of the forest that results from rising air temperature. The most effective, but most difficult solution is to curb the release of anthropogenic CO_2 to the atmosphere. The exclusion of fire since the arrival of livestock and the Smoky the Bear policy has caused the forests to become far denser than the historical average, allowing far more fuel to build up in the forests and thus promoting more fires and greater competition for scarce water. Sustainable forestry that lowers the fuel load and promotes more old-growth characteristics is the only management option I can see that will mitigate the threat of continued growth of massive wildfires and insect outbreaks. Such thinning should emphasize removal of smaller trees to promote survival of tall trees that are more resistant to fire damage and to reduce competition for water and nutrients.

In addition, I feel valuable long-term solution to this rising threat of forest loss due to climate change is education of society. Without knowledge of the current and potential future impacts, the common public can become unaware of the magnitude of what is occurring and will occur in the future. Lastly, we urgently need more research to understand why and where some trees die while others do not. This information is essential so that we can inform management and policy options to maximize the likelihood of forest survival, carbon storage, and the other ecosystem services our society values.

In conclusion, there is strong scientific certainty that future droughts will promote the loss of forests in the Western United States. This will occur through both increased severity of drought stress upon forests and subsequent insect and pathogen attack, and through wildfire. Without significant changes in the global energy portfolio and increased investment into sustainable forest management, the loss of forests in the Western US is inevitable.

Thank you for the opportunity to appear before the Committee

Much of our work was made possible by the Laboratory Directed Research and Development Program, which makes it possible for the Laboratories to invest in cutting edge R&D that anticipates emerging national needs. Details of the LDRD program can be found at tri-lab.lanl.gov.

The CHAIRMAN. Thank you very much.

Why don't we go ahead? Obviously there are lots of questions that need to be asked and answered.

But Dr. Redmond, why don't you go ahead?

STATEMENT OF KELLY T. REDMOND, REGIONAL CLIMATOLOGIST/DEPUTY DIRECTOR, WESTERN REGIONAL CLIMATE CENTER, DESERT RESEARCH INSTITUTE, RENO, NV

Mr. REDMOND. OK. Thanks for the opportunity to speak here this morning. My present position is Regional Climatologist for the Western United States. So I cover the weather in western states and Alaska and Hawaii. I deal with climate issues of every sort ranging from the physical side to the way people use information about climate in those vocations.

I didn't bring any visuals today. I just spent a week in Montana at my mom's house. I couldn't see the forest or the mountains because of the smoke and the same way coming back to Denver and into Reno, couldn't see the Sierra Nevada. I deal a lot with drought issues and just spent 3 days at the International Boundary and Water Commission down in El Paso dealing with drought issues on the Rio Grande and the Bravo River there.

I decided to make 4 points in this presentation.

First of all that aridity is going to persist and very likely to increase in the western states.

Second, that the climate events and extremes are just as important as gradual change in the region.

A third is that observations and monitoring are critical to response and adaptation.

The fourth is we should not let this problem intimidate us too much despite what you keep hearing about it.

So a drought to me represents an imbalance. If you think of a water checkbook we have a certain amount of income and a certain amount of outgo. When the outgo exceeds the income for long enough in an accumulated sense our buffers are going down and we start to see impacts.

Now basically we think of drought as being defined by its impacts. We've seen a lot of drought in the western states over the last 13 years or so, since the U.S. drought monitor was instituted. Every year we've had drought of some sort. Sometimes border to border like in 2002 and we are in a pretty deep drought this year again.

You've already heard the point made that we think of drought as being determined by precipitation but temperature and a few other variables like wind and humidity also play a role in droughtiness because they influence the demand side for water. Not all precipitation is equal. Cool precipitation is generally better than warm precipitation as a broad generality and if it warms up it sort of like getting less precipitation.

Temperature in the west began to increase—I've looked at it over the last 120 years or so, began to increase around the mid 70s. It's risen by about two degrees Fahrenheit in that time. In the last 10 years or so it has kind of leveled off and it's even dropped in the last 3 or 4 years. We don't know the reason why.

The models predict that this is going to continue to rise by probably another 4 to 6 degrees Fahrenheit during this century. Nighttime temperatures have gone up more than daytime temperatures. We don't know the reason for that.

Precipitation, really, in the western states in general has exhibited no trend that I'm able to see. There is a change in the variability of precipitation in the year to year variability in about the mid 70s has been much more variable from year to year in the last 30 years or so compared to the previous 30 years. The projections are for precipitation to increase maybe 5 to 7 percent in the next 20 to 30 years or so along the Canadian border and to decrease by about 5 to 7 percent along the U.S./Mexico border.

I can't see the evidence yet for an increase in the northern end, but the decrease in the southern end it has come down over the past several years. But we're coming down from a very high peak in the 80s and 90s which allowed the forests to grow quite a bit. That's why the biomass built up, partly contributed to the fires that we're seeing these days because there is more biomass there. So it's a little hard to interpret what that means is drying out that we've seen in the recent years.

You've heard about the fires burn. In 7 of the eleven western states we've had the biggest fires in their recorded history in the past 15 years or so. A couple of those states have had that record re-broken in this interval. So something—and right now so far I think we have about 6 and a half million acres that has burned so far this summer compared to an average of around 5 or so. So we're on another big fire year obviously, as you know.

So there's really something very different from our last century of experience that's underway right now.

One thing about drought, I think a really, a long term research operational goal in the West should be to acquire a thorough understanding of all the components of the water budget on the scales needed to understand drought. The income terms, the outgo terms, the storage in the soil and the deep aquifers and even the Trans basin diversions as well which are all part of the water budget. If we don't understand that and how each of those is affected by climate change it's going to be harder to come up with the right policies.

Climate extremes, we often think of fluctuations, climate fluctuations as gradual changes. But really many ecosystems and human systems are different by rare and memorable events. They have the potential to alter the ecological histories and trajectories. This is how climate change will be experienced and remembered.

The climate system is an incredibly complicated system. It involves literally the climate here in Santa Fe is a result of everything happening on the surface of the earth, up in the atmosphere, down in the soil, all around the earth. It's a highly connected system. Because of this it's not fully predictable. We have to expect surprises in how it will shape out.

We're seeing more of the warming streams as temperatures going up, fewer of the coolant streams. But cool temperatures are not going to go away. They'll just be seen less frequently.

When it comes to precipitation, there's a general expectation and an observation that in the United States heavy precipitation has

increased over most of the United States, like the wettest day of the year. It's decreased a little bit less in the Pacific Northwest. It shows not as much trend in the Southwest. It's been, sort of, flat, except for the very shortest durations of less than a day, like several hours long.

Driving up here from Albuquerque last night I wasn't able to go 70. I just went about 4 with the heavy rains and there's a lot of flooding and the alluvials passed along the way. That's indicative of the kind of thing we expect to see more often.

The third point I wanted to address was observations and monitoring. I deal with this a lot. We just tracked western climate for people, for all kinds of purposes.

When we can't predict everything really well that means that heightens the role of observations and monitoring. We have to keep our attention to this very much. It's very frequently looked at.

Observations are everybody's second priority. The observational systems that we use to keep track of what's going on that people use for their research are constantly under threat, especially in a budget environment. We need to resist the attempts to reduce those as much as possible.

One of the things that we could do in the west, we have a lot of Federal systems that are out monitoring climate for a variety of purposes by the different agencies. I think we could have better coordination of those. Make them serve double and triple duty by having higher level coordination and ensuring that we get more bang for our observing buck.

The fourth point I wanted to address is this whole issue of this is just such a, society speaking, this is such a giant problem. It just seems so large and complex people have a hard time getting their hands around it. It seems to me that there are many different parts of the solution path to it.

But it's a problem that we've gotten into bit by bit. I think part of our solution process has to be to sort of get out of it bit by bit. Human beings are the most adaptable organism the earth has ever seen in its history. It's because of that that we have helped cause this problem to come about. But that very same adaptability and the cleverness and so forth that we have, I think is suitable to be harnessed in service of a remediation of this problem.

This problem has, you know, because we end up talking to the public about this issue a lot. It has so many different facets you can't even go through them all here. But, you know, the time lag that it takes between the gas in the atmosphere and the effects that we're seeing. There's a timelines built into the system. If we wait for those to occur through observation. In many cases it's too late. You can think of analogs in health and so forth to that thing.

Another thing that has sort of stuck me is this. It seems that we require a pretty high burden of proof before we take action on this. Yet we routinely make highly consequential individual choices based on patchy, incomplete and uncertain information.

I use examples of like who are you going to marry? What house are you going to buy? What university are you going to attend? What job to take? Which car to purchase? What investment to make? Whether to run for the Senate or not? All those kinds of things.

You know, we don't need perfect information to act. Yet we seem to act like we do. So while we're still trying to acquire more information and I don't think that's the reason we should be doing anything.

So I guess just a couple more points that I wanted to make is we want to have national coherence and commonality in our overall vision of how we address these issues. But most of the practical issues we run into pertaining to climate are experienced at the regional, the state and the local levels. To this end there are about a half dozen major Federal and state sponsored agencies. There's already programs and activities underway.

In my career I've kind of been part of every one of those. They seem really complicated and sometimes overlapping to people who are not familiar with them. But having watched them from the inside I don't really think that's the case.

But we're working very diligently to try to make sure that we're getting the best use of the taxpayer dollar in all these different kind—like the Climate Science Centers, the Regional Integrated Science and Assessments Program of NOAA, Regional Climate Center Program, these landscape conservation cooperatives and so forth under the Department of Interior. So I think there's some really good opportunities there to be working together. A lot of us are having the side conversations to do that.

One other thing I might point out is that we, as with our first speaker here, the people have been present in the Intermountain West for a millennia and they acquired a really significant store of experiential, traditional knowledge about climate and the environment, what I call the wisdom of antiquity. Then we have the more recent science based approaches. I think we really need both of these. Neither one of them is sufficient. But when we put them together we have enough, we may have enough information on which to act.

So I guess, you know, personally I'd just say I really like hard problems. This is one of the hardest problems I can think of. It's really a worthy challenge in this regard.

I just don't think it's insoluble. But we just have to look. Have to have the will power to do something about it.

Thanks.

[The prepared statement of Mr. Redmond follows:]

PREPARED STATEMENT OF KELLY T. REDMOND, REGIONAL CLIMATOLOGIST/DEPUTY DIRECTOR, WESTERN REGIONAL CLIMATE CENTER, DESERT RESEARCH INSTITUTE, RENO, NV

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 19th 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.

The CHAIRMAN. Thank you very, very much.

Our final witness today is Dr. William deBuys. Bill, go right ahead.

STATEMENT OF WILLIAM DEBUYS, WRITER AND HISTORIAN, CHAMISAL, NM

Mr. DEBUYS. Thank you very much, Chairman Bingaman.

I'm grateful to have this opportunity to appear before you today. My name is William deBuys and I'm a writer and historian. I published 7 books on the land and people of the Southwest.

For the past 4 and a half years I've made a particular study of climate change in the region. That resulted in a book called, A Great Aridness: Climate Change and the Future of the American Southwest. In the course of my research one scientist I spoke to summarized the environmental future of the region in 5 words. He said, "Drought, dust, and dead trees."

Certainly the current drought has caught people's attention. Thousands of new high temperature records have been set. By midsummer this year a larger portion of the country was in a state of drought than at any time since the 1950s. More counties have been declared agricultural disaster areas this year than ever before.

Of course, there have always been droughts. What's different now is that our droughts are hotter. Dr. Allen, who is here with us today and some of his colleagues have shown that the drought of the early 2000s from the first 4 years of the decade was one to one and a half degrees Centigrade hotter than the drought of the 1950s. Because greater heat means greater evaporation, our droughts have become effectively more arid than comparable droughts of the past placing greater heat and water stress on vegetation of all kinds from agricultural crops to forest trees.

Even so, drought may be a misnomer. Drought is exceptional. We don't say that the Sahara Desert is experiencing drought. The Sahara is dry by nature, not by exception.

A strong body of research suggests that the climate of the Southwest is moving to a new base state similar to the drought conditions of the 1950s and 1930s. Droughts and wet periods will still occur, but they will be superimposed on this new base state. In time what we currently conceive as drought will be understood as the new normal.

The implications for water resources are, of course, severe. A widely studied—a widely cited study by a team led by Chris Milly of the Geophysical Fluid Dynamics Laboratory in Princeton, predicted that the Southwest will experience declines of surface stream flow on the order of 10 to 30 percent by mid-century. Surface stream flow is basically the yield of rivers and streams. It's the water, apart from ground water, that is available for human use.

Given that Southwestern water resources are, in many cases, already fully or even over allocated such an extreme diminution of supply will undermine the well-being of the region in profound ways.

Predictions like those of the stream flow study are based on climate modeling which is as sophisticated as any science being conducted in the world today. Although the science of climate modeling is difficult for the average citizen to understand, the predictions that emanate from it appear to be holding up very well. Except in one important respect, the changes are happening faster than predicted and the recession of Arctic sea ice is a good example of this.

Usually when we talk about climate change and increasing temperatures we're talking about mean temperatures, as Dr. Redmond spoke of an increase of 4 to 6 degrees Fahrenheit during this century. These temperatures, however, are means. There is reason to expect that the heated, more energetic climate of the future will produce extreme temperatures that are proportionately even larger. Extremes will shape out the world even more profoundly than the means, triggering yet more forest fires, water shortages, crop failures and even waves of human mortality. It's worth remembering that approximately 50,000 human deaths were attributed to the European heat wave of 2003.

Just a brief word about dust, which we haven't covered yet so far today. Higher temperatures and increased water stress will trigger the exposure of more soil to the air. As vegetation dies back and as farmlands are fallowed and as forests and woodlands are consumed by fire, we'll see more and more dust picked up, partly by the increased vehemence of the winds of our more energetic future. With inevitably high levels of soil disturbing human activity this is a recipe for extreme dust storms of the kind that Phoenix has recently been suffering. Lacking a name for them Phoenix has borrowed the word from Arabic and now haboob has entered the regional lexicon.

Atmospheric dust does more than make like uncomfortable for residents of the region. Deposited on mountain snowpack, dust lowers albedo, the reflectance of the snow and promotes the absorption of heat from sunlight. Significantly accelerates the melting of accumulated snow, lowering natural storage and increasing the vulnerability of downstream farms and communities to shortages.

I won't repeat some of the information that we've already heard about forests and fires and insects. But I will underscore something that Dr. McDowell said. That is that it's important to note that western forests account for 20 to 40 percent of all carbon sequestration in the United States.

If is now seems likely under the assault of climate change. We are to lose the greater part of our forest to fire, insects and heat death. Our forest lands will at some point become net emitters of atmospheric carbon instead of storehouses, thereby intensifying buildup of greenhouse gases.

Similarly because drought inhibits the ability of plants of all kinds to conduct photosynthesis and absorb carbon dioxide from the atmosphere, prolonged drought would also contribute to warming. These kinds of feedbacks, like the better known release of methane from thawing permafrost, have the potential to plunge us, ever more rapidly, into an overheated and much altered future.

How sure can we be that these changes are the result of anthropogenic climate change and not simply the manifestations of natural variability?

Actually, climate scientists are progressively achieving a very high degree of certain certainty.

Climate science has passed a threshold. The modeling studies on which it long depended did not permit the attribution of climate change as a cause of specific events. A scientist, asked about a certain drought or a rash of forest fires, might say, if climate change is occurring, this is the kind of event that our models would predict. But he or she could not say climate change caused this.

Lately this limitation has diminished. A new subset of climate investigations, termed "attribution studies," is emerging, which uses statistical analysis to determine the probable occurrence of specific weather events with and without the contributing influence of climate change. The Bulletin of the American Meteorological Society recently published a small collection of such studies, including one that asserted that climate change made last year's drought and heat wave in Texas twenty times more likely.

If I could get my image up on the screen.

Also a team led by James Hansen of NASA's Goddard Institute for Space Studies at Columbia in New York goes further. According to their analysis, the probability that the 2011 heat wave in Texas or the 2010 heat wave in Russia would occur without the influence of climate change was less than 0.2 percent. These graphs are taken from a study by Dr. Hansen and his team. It would take some considerable time to get, kind of, tease out the meaning from these things in full.

But if I can address your attention to the lower set of graphs which have to do with Northern Hemisphere land. What they are basically graphing is world temperature of the area of the planet experiences a certain kind of temperature during the summer months. Basically what this graph is showing is that cold weather in the summer months is disappearing from 1950 to 2010, cold weather is going away.

Warm weather, anomalously or unseasonably warm weather is becoming more and more normal. These are 3 different degrees of departure from the norm. The last here is of extremely hot weather

occurring. During the base period of 1951 to 1980, that extremely hot weather would have occurred on less than 0.2 percent of the earth's surface. Today it's occurring on 10 percent and at times more than 10 percent of the earth's surface.

If we can go to the next slide.

These maps depict that same information graphically or geographically. Here we see, sort of, the brown here. It's that 2010 heat wave in Texas and Oklahoma. Here we see the 2011 heat wave in Texas and Oklahoma. Here the 2010 heat wave in Russia and Siberia, Western Siberia and the Great Drought in Northeastern Africa.

Basically what Hansen and his colleagues are saying. These manifestations are so extreme. They are so anomalous that only climate change can account for them. So they're saying these things were caused by climate changes, departure from the way scientists have presented things in the past.

Given all this, what should we do and what particularly should we do in the Southwest?

First and foremost we must limit, act to limit the magnitude of the changes still ahead. This means moving to limit and reduce greenhouse gas emissions with the utmost urgency. To shirk this responsibility is to steal the atmospheric resources of future generations and to assure suffering and instability throughout the world.

It's that simple.

Second, we must adapt to the changes that cannot be prevented. This means establishing and living within drought resilient water budgets community by community across our region. Adaptation will require water conservation that is both extensive and intensive. But, and this is the hard part, the water saved by conservation must be managed in a way that contributes to drought resilience and does not merely fuel continued land development and population growth with consequent heartening of demand, as is typically the case.

In addition to crafting realistic water budgets, every inter related group of water users should develop enforceable shortage sharing agreements and where applicable, prepare for transfers of water from agriculture to municipalities in advance of the inevitable emergencies.

Where our forests are concerned we must find ways to reverse the penetration of residential housing into landscapes vulnerable to fire. We must continue fuel reduction efforts, especially at the wild land urban interface and in areas of high biodiversity with redoubled energy.

Many other actions might be recommended and these can be in all areas of policy and management, from agriculture to wild land, but none is more important than the purpose implicit in this hearing, which is to build public understanding of the seriousness of the challenges we face. As a society, we must first agree on the facts of climate change in order to achieve consensus on how to respond to them. These facts are to be seen all around us, if only we open our eyes.

No set of facts will be more determinative of the future of our land and society. No set of facts calls on us more emphatically for informed, deliberate and immediate action.

I thank the Chairman for the opportunity to discuss these matters.

[The prepared statement of Mr. deBuys follows:]

PREPARED STATEMENT OF WILLIAM DEBUYS, WRITER AND HISTORIAN, CHAMISAL, NM

Chairman Bingaman, thank you for the opportunity to appear before you to examine the current and future impacts of climate change on the Intermountain West, focusing on drought, wildfire frequency and severity, and ecosystems. My name is William deBuys. I am a historian and have published seven books dealing with the land and people of the Southwest. For the past four and a half years I have made a particular study of the effects of climate change in the region, which resulted in a book published by Oxford University Press last year entitled A Great Aridness: Climate Change and the Future of the American Southwest.

My work on climate change focused on the Southwest, defined broadly. This hearing addresses the "Intermountain West" which, by any definition, overlaps the Southwest extensively, but the experience of some northern portions of the Intermountain West may differ from the rest of the region, if, as expected, "wet places get wetter and dry places drier" in the changed climate of the future.

To speak specifically of the Southwest, one scientist whom I interviewed summarized its environmental future in five words: "drought, dust, and dead trees."

[DROUGHT]

Let me begin with drought.

Certainly the current drought has caught people's attention: thousands of new high temperature records have been set; by mid-summer a larger portion of the country was in a state of drought than at any time since the 1950s; and more counties have been declared agricultural disaster areas than ever before.

Of course, there have always been droughts. What is different now is that our droughts are hotter. Drs. David Breshears, Craig Allen, and colleagues have shown that the drought of the early 2000s was 1° to 1.5°C hotter than the drought of the 1950s. Because greater heat means greater evaporation, our droughts have become effectively more arid than comparable droughts of the past, placing greater heat and water stress on vegetation of all kinds, from agricultural crops to forest trees.

Even so, "drought" may be a misnomer. Drought is exceptional. We don't say that the Sahara Desert is experiencing drought: the Sahara is dry by nature, not by exception. A strong body of research suggests that the climate of the Southwest is moving to a new base state similar to the drought conditions of the 1950s and '30s. Droughts and wet periods will still occur, but they will be superimposed on this new base state. In time, what we currently conceive as drought will be understood as the new normal.

The implications for water resources are severe. A widely cited study by a team led by Chris Milly of the Geophysical Fluid Dynamics Laboratory in Princeton predicted that the Southwest will experience declines of surface streamflow on the order of 10-30% by mid-century. (Surface streamflow is the yield of rivers and streams; it is the water, apart from groundwater, that is available for human use.) Given that southwestern water resources are already fully or even over-allocated, such an extreme diminution of supply will undermine the well-being of the region in profound ways.

Predictions like those of the streamflow study are based on climate modeling, which is as sophisticated as any science being conducted in the world today. Although the science of climate modeling is difficult for the average citizen to understand, the predictions that emanate from it appear to be holding up well, except in one important respect: the changes are happening faster than predicted.

For example, in 2007 the Intergovernmental Panel on Climate Change predicted our region would warm approximately 4°C by the end of this century. We appear to be already about 0.8°C along that journey, almost a quarter of the way, but seven-eighths of the century still lie before us. Clearly, if temperatures increase at a linear rate, or faster, we are on track to exceed the 4°C target.

These temperatures, however, are means. There is reason to expect that the heated, more energetic climate of the future will produce extreme temperatures that are proportionately even larger, and the extremes will shape our world even more profoundly than the means, triggering yet more forest fires, water shortages, crop fail-

ures, and even waves of human mortality. Bear in mind that approximately 50,000 human deaths were attributed to the European heat wave of 2003.

[DUST]

A word about dust. Higher temperatures and increased water stress will trigger the exposure of more soil to the air, as vegetation dies back, farmlands are fallowed, and forests and woodlands are consumed by fire. Combined with the fierce winds of a more energetic atmosphere, and with inevitably high levels of soil-disturbing human activity, this is a recipe for dust storms. In recent years Phoenix has suffered periodic dust storms of unprecedented magnitude. Lacking a name for them, Phoenix has borrowed a word from Arabic, and now haboob has entered the regional lexicon.

Atmospheric dust does more than make life uncomfortable for residents of the region. Deposited on mountain snowpack, dust lowers albedo (reflectance), promotes the absorption of heat from sunlight, and significantly accelerates the melting of accumulated snow, lowering natural storage and increasing the vulnerability of downstream farms and communities to shortages.

[DEAD TREES]

The fearsome increase in the destructiveness of forest fires throughout the region is well known. The drought of the early 2000s bred fires that set records in Arizona, New Mexico, and Colorado for both size and damage. The past two years have seen almost all of those records broken by still larger and more destructive fires. A century of misguided management that included the suppression of all fire contributes prodigiously to the fire danger we face today, but climate is equally influential: we know that fire season is now at least two and a half months longer than it was thirty years ago and fire behavior, driven by high winds and higher temperatures, is becoming ever more extreme.

A comparison of the Cerro Grande fire of 2000 and the Las Conchas fire of 2011, which ignited in adjacent, nearly identical areas in the Jemez Mountains, bears consideration. The Cerro Grande fire burned approximately 43,000 acres over the course of two weeks. Most observers thought its like would not be seen soon again, at least not in the same location, but last year the Las Conchas fire burned 43,000 acres, equaling the achievement of Cerro Grande, in its first fourteen hours. Ultimately more than 150,000 acres were consumed.

Fire is not the only threat to our forests. Insect outbreaks, like the bark beetle irruption of the early 2000s in Arizona and New Mexico that killed pines across an area twice the size of Delaware, will doubtless become more frequent, for the simple reason that warmer temperatures favor increased insect reproduction.

We can also expect heat and moisture stress, alone, without the intervention of fire or insects, to kill large numbers of trees, as they did last year, when between 2 and 10 percent of all the trees in Texas succumbed.

It is important to note that western forests account for 20 to 40 percent of all carbon sequestration in the United States. If, as now seems likely under the assault of climate change, we are to lose the greater part of our forests to fire, insects, and heat death, our forest lands will at some point become net emitters of atmospheric carbon, instead of storehouses, thereby intensifying buildup of greenhouse gases. Similarly, because drought inhibits the ability of plants of all kinds to conduct photosynthesis and absorb carbon dioxide, prolonged drought will also contribute to warming. These kinds of feedbacks (like the better known release of methane from thawing permafrost) have the potential to plunge us ever more rapidly into an overheated, much altered future.

[ATTRIBUTION STUDIES]

How sure can we be that these changes are the result of anthropogenic climate change and not simply manifestations of natural variability?

Actually, we are progressively achieving a very high degree of certainty.

Climate science has passed a threshold. The modeling studies on which it long depended did not permit the attribution of climate change as a cause of specific events. A scientist, asked about a certain drought or rash of forest fires, might say, "If climate change is occurring, this is the kind of event our models tell us to expect," but he or she could not say, "Climate change caused this."

Lately this limitation has diminished. A new sub-set of climate investigations, termed "attribution studies," is emerging, which uses statistical analysis to determine the probable occurrence of specific weather events, with and without the contributing influence of climate change. The Bulletin of the American Meteorological Society recently published a small collection of such studies, including one asserting

that climate change made last year's drought and heat wave in Texas twenty times more likely.

A team led by James Hansen of NASA's Goddard Institute for Space Studies goes further. According to their analysis, the probability that the 2011 heat wave in Texas or the 2010 heat wave in Russia would occur without the influence of climate change was less than 0.2 percent. One way of interpreting this figure is to say that neither event should have occurred more often than once in five centuries. The team further found that similar, highly unlikely events now cover, not 0.2 percent of Earth's surface, as was the case during the reference period of 1951-1980, but approximately 10 percent. This extreme anomaly, they say, can only be explained by climate change.

[ACTION RECOMMENDATIONS]

Given what we know, what should we do?

First and foremost, we must act to limit the magnitude of the changes still ahead. This means moving to limit and reduce greenhouse gas emissions with the utmost urgency. To shirk this responsibility is to steal the atmospheric resources of future generations and to assure suffering and instability throughout the world. It is that simple.

Second, we must adapt to the changes that cannot be prevented. This means establishing and living within drought-resilient water budgets, community by community, across the region. Presently the Lower Basin of the Colorado River, chiefly the states of Arizona and California, operates at an annual deficit of 18 percent. This is to say that the Lower Basin over-drafts its account by withdrawing from Lake Mead 1.2 to 1.4 million acre-feet more than its allocation of 7.5 million acre-feet. Such behavior is unsustainable under any circumstances. In an era of climate change and declining river flow, it is irrational and dangerous.

Adaptation will require water conservation that is both extensive and intensive, but (this is the hard part) the water saved by conservation must be managed in a way that contributes to drought resilience, and does not merely fuel continued land development and population growth, with consequent hardening of demand, as is typically the case.

In addition to crafting realistic water budgets, every interrelated group of water-users should develop enforceable shortage-sharing agreements and, where applicable, prepare for transfers of water from agriculture to municipalities in advance of the inevitable emergencies.

Where our forests are concerned, we must find ways to reverse the penetration of residential housing into landscapes vulnerable to fire, and we must continue fuel-reduction efforts, especially at the wildland-urban interface and in areas of high biodiversity, with redoubled energy.

Many other actions might be recommended—in all areas of policy and management from agriculture to wildlife—but none is more important than the purpose implicit in this hearing, which is to build public understanding of the seriousness of the challenges we face. As a society, we must first agree on the facts of climate change in order to achieve consensus on how to respond to them. These facts are to be seen all around us, if only we open our eyes. No set of facts will be more determinative of the future of our land and society, and no set of facts calls on us more emphatically for informed, deliberate, and immediate action.

I thank the chairman and his committee for the opportunity to discuss these matters.

The CHAIRMAN. Thank you very much.

Thank all of the witnesses.

Why don't before I ask a few questions, it occurred to me as I've listened to the testimony, let's take a short break. Anyone who has to leave can do so. Then we'll proceed and have another few minutes of hearing after the break.

But let's take about a 10-minute break.

[BREAK]

The CHAIRMAN. We'll go for another 10 or 15 minutes here.

Let me just ask a few questions that occurred to me as a result of all the excellent testimony.

First of all, this paper, Dr. Allen, I believe you referred to the fact that a paper dealing with the issue of climate change has been

accepted by Nature to be published. Could you give us any more information about who was involved in the preparation of it and what the conclusions of it are? That you indicated you thought it was an important document.

Mr. ALLEN. Yes, well the lead author for that is Park Williams. So I think, yes, right there is Park.

The CHAIRMAN. Congratulations.

Mr. WILLIAMS. Thank you.

Mr. ALLEN. Actually he would be the best person that you could ask——

The CHAIRMAN. Yes. Please just give us the highlights of what you concluded in this paper that we're going to see published.

Mr. WILLIAMS. So we used tree ring records from about 13,000 individuals throughout the Southwest from like 335 sites to develop a 1,000 year long record of tree health in the Southwestern U.S. These are from 3 main species of conifers in the Southwest.

Then for the last hundred years which overlap with the observed climate record we were able to compare that record of tree health to climate variables, climate data and isolate the exact climate variables and seasons that really influence tree health the most. There is two variables. It turned out to be wintertime precipitation which is no surprise with the amount of snow that accumulates on the ground. Summertime atmospheric moisture demand which is, as everybody here has already said, influences areas driven by temperature and humidity and influences the rate at which the moisture is pulled out of the soil and pulled into the atmosphere.

What was very interesting is those two variables, wintertime precipitation and summertime moisture demand in the atmosphere, were approximately equal in importance. So that means even if we continue receiving a consistent amount of precipitation during the wintertime in the next century, if we have temperatures increase therefore evaporative moisture demand in the atmosphere increasing in the next 100 years then that alone should cause substantial change in forest health in the next century.

Because we can quantify the impact of wintertime precipitation and summertime moisture demand on forest health then we could use future potential scenarios of climate to forecast forest health, quantitatively. By doing that you find that by 2050, forest health is about the same as it was during the worst mega droughts in the last millennium. The worst mega droughts were in the late 1200s which influenced the ancestral Puebloans in a tragic way in the late 1500s, which we believe caused the amount of the forest in the Southwest to be reduced substantially.

The difference between the drought that we expect to be occurring by mid-century and the 1500's drought is that the drought that we expect to be occurring by mid-century should not change. It should not rebound. We will have warm periods and cool periods still. But each warm period will be warmer. Each cool period will be cooler.

On average we'll be continuing on trend toward dry conditions. Whereas after the 1500's drought, it got wetter and cooler again and the forests were able to re-establish. So in other words——

The CHAIRMAN. Each warm period will be warmer, but each cool period would be cooler or warmer?

Mr. WILLIAMS. Yes, it will be warmer.

The CHAIRMAN. Yes. Right.

Mr.WILLIAMS. So the take on this is that decade by decade we're getting warmer on average. It will be harder and harder for trees to re-establish in the places where they die due to these mega drought type conditions. So by the year 2100 you'll be looking at a quite different landscape than what we see today.

My analysis shows that by the 2040s, barring some huge inaccuracy in life models, we should be looking at a very different landscape that what we see today, just like the landscape we see today is quite different than what we saw in the 1980s.

The CHAIRMAN. Very good.

Congratulations on the work and getting it accepted.

Mr. WILLIAMS. Thank you.

The CHAIRMAN. The education, it's terrific.

Let me ask about the reference to Dr. McDowell. You said that you made a reference to solutions. then didn't elaborate in your testimony.

Could you give us, I mean, obviously we should be doing what's possible to reduce greenhouse gas emissions? We should be taking the steps necessary to adjust to the warming and the climate change that we can't head off in any way.

Are there more specific solutions that you see that we ought to be pursuing?

Mr. MCDOWELL. I think that's a great question, Chairman. At a local scale, a regional scale, a western North American scale, forest management can be employed in a sustainable manner to reduce the risk of fires and reduce water stress.

As Dr. Allen pointed out, we stopped fires a little over 100 years ago. The ladder fuels have grown. We had these catastrophic fires.

So, the mechanical thing of the understory trees, the smaller trees, leaving the big ones that are adapted to survive the small fires, should reduce the catastrophic wildfires. It also will help with bark beetle attacks which are rampant across the Northern hemisphere because they'll have less stress. In other words, they're not competing for resources with their neighbors as much.

That's my main suggestion.

The CHAIRMAN. The other part of this, which I don't know what to ask you folks to respond to. But regular gas emissions have been coming down in the U.S. here recently because of the switch to more use of natural gas verses use of coal in electricity generation. That's what the newspaper article says.

Then go out worldwide and most of the growth in greenhouse gas emissions for the coming decades is expected to occur in emerging countries. It's not going to be occurring here cause we're not adding generation capacity like they are. We don't have the increased demand for energy that they do.

It just strikes me that this is one of those issues where we could do what we can do here in Santa Fe County, in New Mexico, in the Southwest, in the Intermountain West, to try to accommodate the situation. But we almost have to engage the rest of the world in order to significantly affect greenhouse gas emissions and significantly affect the long term trends. Is that an accurate?

Maybe I should ask you, Bill, if that's your conclusion that we just have to have a global solution to the problem or else it's not a problem that gets solved?

Mr. DEBUYS. Yes, Mr. Chairman, I would agree we need a global solution. I don't think that we can achieve a global solution in practical terms, however, unless the United States becomes a global leader. Without the United States leadership on the business of limiting greenhouse gases, I don't think we'll be able to bring China and India along as we need to.

Europe has already exercised some leadership. But I think the lack of participation in these issues by the United States has undermined that effort considerably. So the world still respects the United States a great deal. If we lead maybe we can achieve something.

The CHAIRMAN. Dr. Redmond, do you folks attempt, in any of the work that you're doing, do you try and engage other countries, particularly emerging countries in what needs to be done and monitoring efforts and all the rest of it?

Mr. REDMOND. No, not so much.

Actually, I decided a while back to just really concentrate on the Western states because there's dozens of climate issues there. They need attention. Rather than spread my own attention too thin, it was a conscious decision to just stick with the West.

It's where I grew up. I really love it here.

So, I think regarding Bill's point and the question you just asked is we, as part of our leadership role in the world, would be to help other countries see that it's in their self interest to limit greenhouse gases.

I think there's one other point that's worth bringing up here. It's not the climate issue directly, but it's the ocean acidification issue which is purely a chemical thing of carbon dioxide going into the oceans. The oceans belong to all of us. We all need healthy oceans.

This is totally separate from the climate change problem. But it has equally big consequences. They're just as frightening to me as climate change is.

We don't have to be hung up on this issue of whether you believe in climate change or not for that to be an issue. It's a separate issue that's so much a concern it's yet another driving force that's maybe a leverage point to, for us, to be able to deliver this needed leadership without getting so hung up on these discussions we're having all the time about the climate side of things.

The CHAIRMAN. Let me ask, Dr. McDowell. Your work there at Los Alamos, my impression is you are the cutting edge as far as what's being done to try to verify the extent of greenhouse gas emissions worldwide? Be in a position where we have needed information about where the problem is the worst and where the problem is and how much of it is naturally caused and how much of it is manmade.

It seems to me that getting worldwide attention up will depend on having very good information about precisely where the problem is coming from and who is to blame and who is fixing it and who is ignoring it. Is this something that you folks are doing as part of your effort there at Los Alamos?

Mr. MCDOWELL. The answer is yes. The lab, as a whole is, well it's an effort by many, many scientists to do exactly what you said.

My particular role is understanding the forest carbon uptake and release and trying to find well how much does tree death actually matter. It seems like it matters a lot. But we're still working on that.

There are other people, though, that focus quite a bit on the fossil fuel emissions, for example or on land use change and deforestation, etcetera.

But I totally agree. There's a lot of interest in pursuing that so that we are prepared when and if the world takes things like carbon trading more serious than they do.

The CHAIRMAN. It seems that all of the feedback groups, if that's the right word to describe what's happening here, all feedback groups lead us to a worse outcome rather than a better outcome. That's what you describe the dead forests rather than the living, carbon dioxide rather than absorbing carbon dioxide. Bill referred to dust over the snow that, of course, causes melting to occur more quickly and thawing from permafrost and all the rest of it. It seems as though as the warming progresses the acceleration of the warming also progresses.

Is that a fair conclusion? Is that a scientifically agreed upon conclusion?

Mr. MCDOWELL. The Intergovernmental Panel on Climate Change is the world's authority on the question that you just asked which is synthesizing all of the evidence are there more positive feedbacks than negative? Positive meaning it gets warmer then it gets even warmer, like you said.

There are negative feedbacks in their system. But the current consensus from the IPCC is there's far more positive feedbacks. In other words, you're right that most of the changes should accelerate warmth.

So let's say ice sheet melting in the Northern hemisphere in the Arctic. That allows the water to absorb more heat. It becomes warmer. So it's a positive feedback, the same for the forests.

So that's the consensus.

The CHAIRMAN. OK.

I thought you could give us some examples of negative feedbacks which would encourage us.

Mr. MCDOWELL. We have more cloud formation, for example, that might reflect more light off of the surface of the earth from the sun. That's an example.

The CHAIRMAN. I see.

Mr. MCDOWELL. It gets cloudier in some areas.

The CHAIRMAN. OK.

It's hard to know what else to ask.

Let me ask about the time lags. One of the obvious problems in trying to find a policy solution to this kind of problem is, I think, Dr. Redmond, you were referring to the fact that, you know, sometimes you can't wait to see the evidence of the problem before you take action or it's too late.

The other time lag, which is, always seem to me to be the major problem in getting attention to climate change or finding a solution to climate change is that once the greenhouse gases are in the at-

mosphere they're going to be there for multi decades or hundreds of years. So trying to head that off is—there is no immediate benefits that you can see from taking immediate action to reduce greenhouse gas emissions because the greenhouse gas emissions that have previously been put in the atmosphere are going to continue the trends that we're talking about here.

I don't know if there's any better way to make that case to people than has been made in the past. If any of you have any great insights.

Bill, you've put your mind to this over the last several years and published a great book on the subject. How do you suggest that?

I remember Russell Long, who was in the Senate when I was first elected. He told me at one point early on. He wasn't talking about climate change when he said, the best or the worst mistake a politician can make is to solve his constituent's problem before his constituent knows he has it.

[Laughter.]

The CHAIRMAN. That was probably good advice in the context he was talking about. But unfortunately this is a problem that needs to be solved, perhaps before a lot of people know they've got the problem. I don't know exactly how we overcome that obstacle.

Do you have any insights that you could give us?

Mr. DEBUYS. I wish I had a silver bullet for this one because it's a really tough one. Even if we stopped all greenhouse gas emissions tomorrow, the climate would still continue warming for probably another generation. Which is to say that if we do all the right things, we don't get the payoff, really, in our lifetimes.

That is one heck of a tough sell to sell people on. But it's still what we have.

The CHAIRMAN. Our planning horizon in Washington is usually 2 years.

Mr. DEBUYS. Yes.

[Laughter.]

The CHAIRMAN. Because that's when we have the election. That's not quite long enough, but one thing I would say about forests. I mean, there's the global vacation this year in terms of greenhouse gases and that obviously is the point. Deforesting will continue if the concentration of those continue to rise. There's that set of issues.

There is the whole set of issues though, the adaptation issues. What can we do? You know, here we are today, many of us. We've talked a little bit about it.

But in terms of forests, when I think about this, is forests have been providing—well, of the excess CO_2 that humans have been putting into the atmosphere every year? About half of it, the planet has been performing a free service for us by removing about half of that excess every year. OK?

About half of that half, so a quarter of the total, is being absorbed into the oceans in the way Kelly was describing. Basically it's just higher concentrations in the air and more into the oceans. It has that side effect of acidification of the oceans.

But the other half of the half, about a quarter of the total extra humans put into the atmosphere, is being absorbed by terrestrial ecosystems, to a large degree, forests. Forests have been providing

this important ecosystem service in terms of reducing the rate of greenhouse gas concentration rise in the atmosphere. So what we can do in the short run, one of those in the immediate run now, is care for our forests the best we can. Try to increase their resilience, their resistance to what seem to be growing climate stresses.

So the kind of efforts, you know, like the Forest Restoration Programs that you've sponsored in the past. I mean, these are very helpful and important initiatives. We need to be thinking about, and I noticed the Governor was talking about it. I mean, they are very concerned in thinking about to restore forests to these landscapes and re-spore.

Out of all the many services forest provide, but one of them is does feed back to the atmosphere.

The CHAIRMAN. That's a very good point. I think you're right that trying to maintain the health of our forests is a big part of what we can do now.

Dr. McDowell, let me ask you this question that Kevin prepared here that I had failed to earlier ask.

You showed two maps in your testimony of forests with high levels of beetle kill in New Mexico and then in the rest of the U.S. My understanding is that beetles have now made their way into Canada into forests that previously did not have problems of beetles at any significant scale. What is going on in Canada and other parts of the world with relation to this beetle problem? What's your expectation of the path that beetles will take now that they are in Canada?

Is that something you've looked into?

Mr. MCDOWELL. We can only speculate on how far they will migrate. There's all kinds of complexities associated with entomology and insects. But yes, the British Columbian mortality event is, to our knowledge, the largest on our estimate so far.

It's been Lodgepole Pine, which is the same species that died all over Colorado in the last couple of years. It's the same insect, the Mountain Pine Beetle.

So the entire spine of the Rockies has just been really, really damaged. So one could expect that it is quite possible and look at what our experts on this have suggested. It could be possible for it to migrate throughout the Boreal forest and toward the eastern seaboard.

I don't know how likely that is. It requires them to change their—the insects to change the species of pine tree that they attack. But Jack Pine, which is very, very similar to Lodgepole Pine grow. They grow together in Northern BC and in the Yukon and then the Jack Pine goes to the Eastern seaboard.

So if the insects can learn to use Jack Pine, then it is a very significant risk.

The CHAIRMAN. Now is there any community action that we can take, as a society, to head off the spread of these beetles that hurt forests, in the Eastern part of the country as well as?

Mr. MCDOWELL. Yes. That depends on if there's a practical issue there. I mean, a whole, whole lot of insecticide might work. But that's a huge amount of land mass. There's all kinds of negative side effects of spraying insecticide across the landscape.

It may be thinning. Sustainable forestry and up in Canada would be important to reduce the stress. But barring some incredible change in the forecast of temperature rise, I don't think it's—that that seems almost insurmountable to stop that if the insects figure out how to use a new species of tree.

The CHAIRMAN. OK.

I'd like to be able to finish this hearing on a high note, but I can't think how to do that.

[Laughter.]

The CHAIRMAN. So, let me just again thank all the witnesses and appreciate all of you who have interest in the subject being here today. We hope that people will pay attention to the information that's been provided today. I hope we can get the national debate and discussion on climate change re-energized.

So thank you all very much. We'll stop the hearing with that.

[Whereupon, at 12:02 p.m. the hearing was adjourned.]

[The following statement was received for the record.]

STATEMENT OF DENISE D. FORT, PROFESSOR OF LAW, UNIVERSITY OF NEW MEXICO SCHOOL OF LAW, AND DIRECTOR, UTTON TRANSBOUNDARY RESOURCES CENTER

Drought, climate change and its effect on forests and wildfire has been well covered by the distinguished members of the panel. I appreciate the opportunity to add comments about the effect of climate change on agriculture and ecosystems in the Inter-mountain West. I will focus on the Southwest, where the effects of climate change are said to be the most pronounced in the United States.

The shift to a drier and hotter climate in the Southwest is now linked to the drought that we are experiencing and that is predicted for the future. I will direct my comments towards two aspects of water policy that are affected by climate change: agriculture and ecosystems.

CLIMATE CHANGE AND AGRICULTURE IN THE INTER-MOUNTAIN WEST

The term "drought" is a misnomer for the change in climate that we are experiencing. In terms of water diversions for agriculture and municipal uses, water storage has provided a needed cushion for dry years. But, as reservoirs are drawn down and deliveries curtailed, the necessity of addressing the new reality of climate change cannot be avoided. Thus to use the term "drought" or "variability" is subtly misleading, because the salient question is how a diminished and altered supply of water will be managed. If the operating assumption is that there will be a return to "average" flows, for example, one makes different decisions than if one acknowledges that the average is changing. The implications of a changed climate should be taken into account in federal farm policy and in federal water policy.

Federal payments for drought, loan subsidies, and direct payments affect agricultural decisions. The changed reality of climate in the Southwest calls for a reexamination of federal agricultural policy. The Conservation Reserve Program should be expanded, rather than cut, because it provides multiple benefits to society and farmers. For the Southwest the question is how to encourage the agricultural sector to utilize information about the changing climatic conditions to make good decisions. Federal subsidies can distort this process.

Federal water policy also needs to respond to the changed realities of climate. The Bureau of Reclamation is examining the gap between "demand" and supply ("demand" does not have a rigorous meaning, but rather is a compilation of all wished for amounts by water users) and considering alternatives to address the gap. This process is part of a helpful conversation about the limits imposed by the changing climate and a widespread conversation about how society should address this new reality. It would be a mistake for the Congress to attempt to meet this gap with expensive federally funded projects. In a recent NRDC report we argue that many water importation projects lessen the resilience of communities and impose high energy costs.[1]

[1] Barry Nelson and Denise Fort, Pipe Dreams, Water Supply and Pipeline Projects in the West, Natural Resources Defense Council, 2012.

There is a great deal of literature about environmental governance and how to address natural resources decision making.[2] The decisions about how to respond to a changed climate should involve a wide range of interests, not be made by the traditional "iron triangle" of state engineers, federal agency heads, and members of Congress. While there is a continuing role for the federal government, we have new governance models that should be utilized to involve many more Americans in considering the water and land use of the next generations. Requiring beneficiaries to pay will go a long way towards reining in the most far etched proposals.

Efficiency measures, water transfers and water reuse are the sorts of measures that will need to be used under these conditions of increased scarcity. But, without new initiatives, they will not address the ecological losses imposed by a changing climate.

THE EFFECT OF CLIMATE CHANGE ON ECOSYSTEMS

The second point I wanted to make relates to the ecological effects of drought, and how we can ameliorate some of these effects. In particular, western fishes and other species associated with our waters are imperiled by climate change. Federal and state action is needed to protect the ecological values of our rivers, streams, springs, and other aquatic environments. Because these ecosystems and species lack the legal standing and economic clout of those with rights under our water laws, natural systems will bear the highest costs from climate change, unless we take affirmative steps to protect them.

We are facing a crisis in our native fishes populations, one that is exacerbated by climate change. I quote from a recent memorandum prepared for the Utton Center:[3]

> "Water dependent species in particular are facing rapid declines in population due primarily to the modification of natural stream and river flows, the introduction of invasive species, and poor agricultural practices. Climate change will potentially exacerbate these effects shown through reduced mountain snow-packs, increased water temperatures, further decreased surface flows, and alteration of the timing of environmental cues many species rely on, as well as altering the climatic events such as flooding and droughts.[4] Fish are the most imperiled vertebrate species in the Southwest with 48% of the fishes found in the region in jeopardy. Native plant species are imperiled as well, with about 40 species identified as imperiled in the Southwest region."[5]

The evidence of ecological loss for aquatic ecosystems led a consortium of wildlife agencies to propose a set of guiding principles for action.[6] These goals are a useful framework for federal action:

- Goal 1: Conserve habitat to support healthy fish, wildlife and plant populations and ecosystem functions in a changing climate.
- Goal 2: Manage species and habitats to protect ecosystem functions and provide sustainable cultural, subsistence, recreational, and commercial use in a changing climate.
- Goal 3: Enhance capacity for effective management in a changing climate.

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[2] For examples, see: Backlund, Peter, et. al. The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity (Inter-agency review Draft) http://climatescience.gov/Library/sap/sap4-3/sap4-3-draft3.pdf)

[3] Prepared by Kari Olson, UNM School of Law (J.D. expected 2014)

[4] Comprehensive Wildlife Conservation Strategy. Chapter 5: Assessments and Strategies for SGCN and Key Habitats Statewide distributed Riparian Habitats (From wildlife.state.nm.us) pages 220- 230, at Page 223; Backlund, Peter, et. al. The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity (Inter-agency review Draft) http://climatescience.gov/Library/sap/sap4-3/sap4-3-draft3.pdf at page 150; Potential Effects of Climate Change on New Mexico. Agency Technical Work Group. State of New Mexico. December 30, 2005 (from www.southwestclimatechange.org) at Pg. 18, Citing: Covich et al. 2003, Chapter 8: Natural Ecosystems II. Aquatic Systems, in Wagner, F.. (ed.), Preparing for a Changing Climate. The Potential Consequences of Climate Variability and Change. Rocky Mountain/Great Basin Regional Climate-Change Assessment. A Report of the Variability and Change. Rocky Mountain/Great Basin Regional Assessment team for the U.S. Global Change Research Program.

[5] Bogan, M.A. 1998. Changing landscapes of the middle Rio Grande. In: Mac, M.J., P.A. Opler, C.E. Puckett Haecker, and P.D. Doran (eds.). Status and trends of the nation's biological resources: vol. 2. Washington, D.C.: U.S. Geological Survey. p. 562-563. at pg. 564

[6] U.S. Fish and Wildlife Service, National Oceanic and Atmospheric Administration, with support by the Association of Fish and Wildlife Agencies, The National Fish, Wildlife and Plants Climate Adaptation Strategy, http://www.wildlifeadaptationstrategy.gov/goals.php

- Goal 4: Support adaptive management in a changing climate through integrated observation and monitoring and improved decision support tools.
- Goal 5: Increase knowledge and information on impacts and responses of fish, wildlife and plants to a changing climate. Goal
- 6: Increase awareness and motivate action to safeguard fish, wildlife and plants in a changing climate.
- Goal 7: Reduce non-climate stressors to help fish, wildlife, plants, and ecosystems adapt to a changing climate.

We know much of what we need to do to achieve these goals. The Congress should incorporate these goals into the statutory missions of the federal water management agencies. The federal ESA has shifted agency actions in specific situations, but the traditional missions have far out-shadowed efforts on behalf of restoration.

Finally, I believe that the Australian response to long term drought is a model that the congressional and executive branches should consider. Australia faced the loss of biodiversity in its major river basin, the Murray-Darling Basin. In short, it committed to the environmental values of the basin, providing funding from the national government to ensure adequate flows for the species that were dependent on the river.[7] The U.S. should consider a similar investment in ecosystem health. Indeed, the billions of dollars spent by the federal government on development of western rivers should be balanced by expenditures for sustainability. From the agricultural interests' perspectives, a fair price for water rights may be a better bargain than the future that agriculture faces in the most arid regions.

Thank you, Senator Bingaman, for your long standing commitment to tackling climate change, and for your commitment to New Mexico's environment.

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