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GOVERNOR'S TASK FORCE REPORT ON CLIMATE CHANGE

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Well, Roger just told you that no one can make forecasts. But I am one of these academic guys who think that my job is to start talking about uncertain forecasts. By way of background, a couple of years ago after one of the driest summers ever reported, I gave a talk on drought down at the Sevilleta Long-term Ecological Research site. That day turned out to be the wettest recorded day in the history of the Sevilleta. My talk was interrupted at one point because the rain was falling so hard on the roof that people couldn't hear. I am here to tell you today principally about decreasing snowpack. Would anyone care to make a forecast for this evening based on that little piece of background? In case you didn't know, you are supposed to get four to six inches of snow tonight. Nevertheless, that is a weather forecast, not a climate prediction.

Over the past couple of years, I have worked with some other people to make some regional assessments that bring the global-scale perspective of organizations like the IPCC and down-scope them somewhat to the Southwest and New Mexico. Let me point out over the next couple of minutes some of the principal results that are contained in a number of reports, several of which have been published by the state. "Potential Effects of Climate Change on New Mexico" is a very nicely written overview (not written by me) put out by the state almost two years ago now, on the general effects of climate change. I did help write a subsequent report, "The Impact of Climate Change on New Mexico's Water Supply and Ability to Manage Water Resources," which came out in the summer of 2006. More recently, I wrote a short article entitled "Climate Change and Water Resources in New Mexico" for a publication called Earth Matters, put out by New Mexico Tech. Each of these reports is online.

To begin, Figure 1 is a version of the global average temperature time series that Roger has already shown you. I am sure you all have seen versions of this before. It shows the instrumental record of global temperature change, plus temperature curves that isolate ocean or land components. We see the familiar story that the observed global warming over the 20th century was about one degree Fahrenheit. All the warmest years in the record over the past decade or so are—just in case you didn't get the message—plotted in red at the end of the time series. As Roger mentioned, the consensus wisdom of the scientific community that has parsed this time-series in just about every way you could possibly imagine is that there is simply no way to explain the temperature increase in the latter part of the 20th century other than by recourse to human forcing in the form of greenhouse gas emissions.

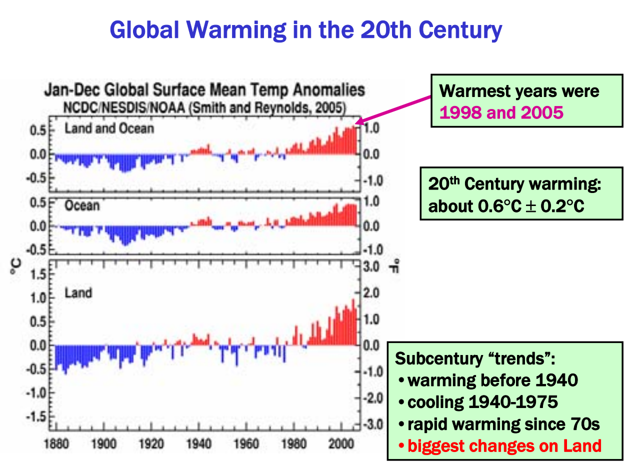

Figure 1. Global Warming in the 20th Century

If we want to down-scope that result to New Mexico, Figure 2 shows what it looks like. For this plot I have defined the "warm season" as the six months each year ending in September (By the way, you can make this plot online yourself at the Western Regional Climate Center website). There are three main points to make here:

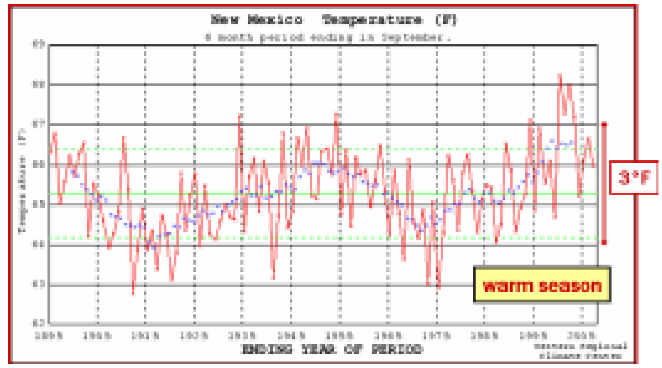

Figure 2. 20th Century Temperature Variability New Mexico Statewide

1) The principal ups and downs here basically parallel what we see in the global average. Global warming matters locally, because what we see locally in a very broad sense is parallel to the New Mexico record. We see some warming early in the 20th century, turning around in the middle part of the century, and then a rapid temperature increase in the latter part of the 20th century, with most of the warmest years in the record recently.
2) Anytime you down-scope things to a regional scale, you get way more ups and downs on an interannual basis. The climate variability from year to year, and for that matter decade to decade, is bigger on a local scale. That is true anywhere.
3) We're sitting here in the middle of the continent. The global average is 70 percent contributed from ocean. We expect on good scientific grounds that warming trends ought to be greater on the interior continents. That's us, folks.

Instead of talking about one degree Fahrenheit observed over the 20th century, New Mexico experienced more like two to three. Think about double the global average as being pertinent to the Southwest. That is a good rule of thumb to think about when we start thinking about the future.

If we consider the cold season (October-March, not shown here), the main ups and downs in the 20th century temperature record are the same, and the same point can be made about most of the warmest years in the recent record. The year to year variability is bigger in the cold season and the trend is a little bit smaller.

Figure 3 shows one estimate of what could happen in the 21st century. This was done for the state report on water resources that I helped write, using the current round of IPCC models in advance of the release of this year's IPCC report. These results were derived from an average of 18 global climate models, forced by a mid-range guess for what CO_2 emissions might be. As climate scientists, we do not know what the CO_2 emissions will be like, so we don't try to make a forecast. We just run the model a bunch of times with different guesses. The models simulate what might happen with this particular guess for CO_2 emissions: warming of seven or eight degrees Fahrenheit over the course of the 21st century, roughly four times what we saw in the 20th century.

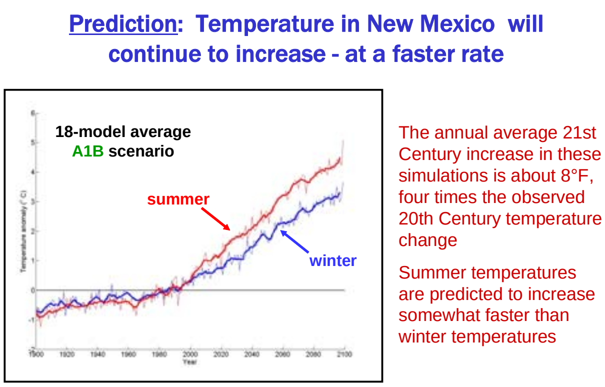

Figure 3. Simulated New Mexico seasonal temperature changes in the 21st Century, compared with model climatology (1971-2000) (Watkins/OSE 2006)

That is the major punch line when we make predictions for the 21st century: it is going to warm up. As Roger suggested before, we can choose different guesses for CO_2 emissions, but the model simulations make it very difficult to imagine a scenario in which the temperature goes down. Such a scenario would almost certainly involve other bad things that we don't want to happen, like a century's worth of intense volcanic eruptions. Our best estimate of what we ought to anticipate in the future is that it is going to warm up. The main difference between choosing one scenario over another is a matter of timing. Will temperature increase by so many degrees 50 years from now, or 150 years from now, or 200 years from now?

In terms of water resources, since this is a water meeting, there are two main points that I want to make. The first one is that, as Roger has implied, temperature is a hydrologic variable. It affects our water resources even if precipitation doesn't change. There is a large fraction of the public that doesn't understand that concept, but it is hugely important for us. For example, as temperature increases, snowpack will be reduced. The snow season will start later and end sooner. The snow line will be located higher up into the mountains. We picked a scene from southern New Mexico for the title page of the Earth Matter report because climate models suggest that all of New Mexico south of Santa Fe will no longer maintain any winter snowpack by the end of the century—well, choose your timing. That doesn't mean it will never snow there, but we should anticipate that snowpack will effectively be reduced to zero. In parts closer to the headwaters of our major rivers, we will have less snowpack that melts earlier.

Here are some scenarios from a report that was published by the US Global Research Program about a decade ago (Fig. 4). Multiple models for multiple regions across the US almost all have decreases in snow pack associated with warmer temperatures as we proceed in the 21st century. Once again, this is a temperature effect, not a precipitation effect. We are already starting to see decreases in snowpack and changes in the timing of snowmelt runoff. Figure 5 shows yet another prediction that snowmelt runoff will occur about a month earlier throughout the West by the end of the 21st century. Again we can change the timing depending on our emissions scenario.

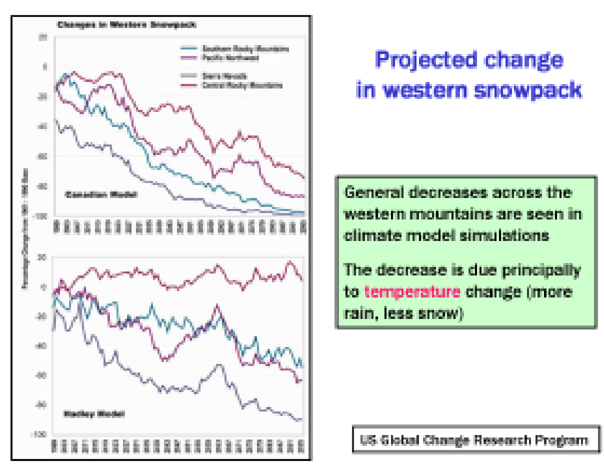

Figure 4. Projected Change in Western Snowpack

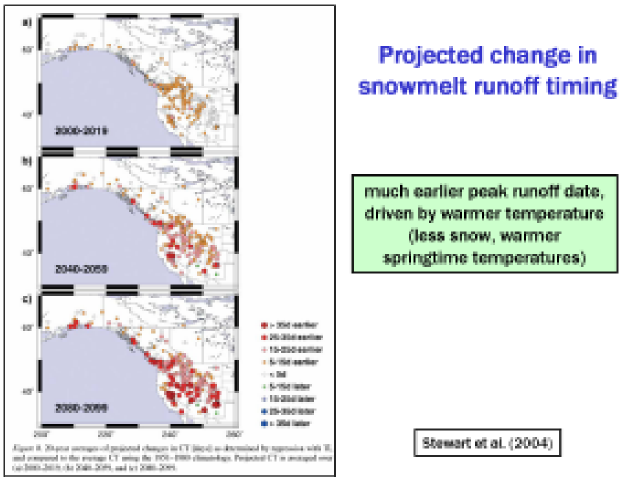

Figure 5. Projected Change in Snowmelt Runoff Timing

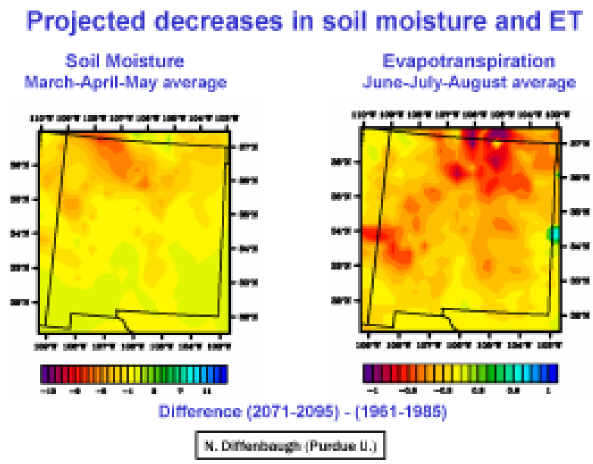

Figure 6. Snowmelt under Warmer Conditions

Perhaps we got a glimpse earlier this year into what may be climatology in the future: in Spring 2007 we had pretty close to normal snowpack through the winter that nearly disappeared during a pronounced heat wave in the month of March. So there was terrific rafting on the Rio Grande for a few weeks in March. That was good, arguably, but there are huge challenges for water management when all of that snow disappears early.

Figure 6 shows some model predictions that suggest what happens after the snow melts in a warmer climate. Soil moisture decreases, due in part to the fact that the snow that keeps the surface moist has melted earlier. Once the sun comes out and the snowpack is gone, evapotranspiration rates increase whenever there is moisture to be evaporated. We have a decrease in soil moisture in the springtime that perhaps has other effects on the monsoon circulation that I won't go into. Evapotranspiration off the surface in the summer decreases overall as the continent dries out. There is one major caveat to the projected decrease in evapotranspiration in the summer: where the surface is not water limited in a warmer climate, evapotranspiration goes way up in a warmer climate. The principal place that happens is, in our part of the world, over open water. That means that evaporative losses off reservoirs go way up in a warmer climate, posing yet another challenge for water resource management.

We'd like to quantify this projection, as was attempted a couple of years ago for the Colorado River basin. Figure 7 shows a summary diagram of a model-based projection for what happens to total storage in the Colorado River basin under one particular scenario for climate change. The basic punch line is that total storage goes down, in this case significantly (20 to 25 percent). If you plug that result into a reservoir storage management model for the Colorado River basin, the outcome is that the Colorado River Compact becomes unenforceable. There is not nearly enough water being stored to deliver a full allocation to all the people that have paper water rights to it.

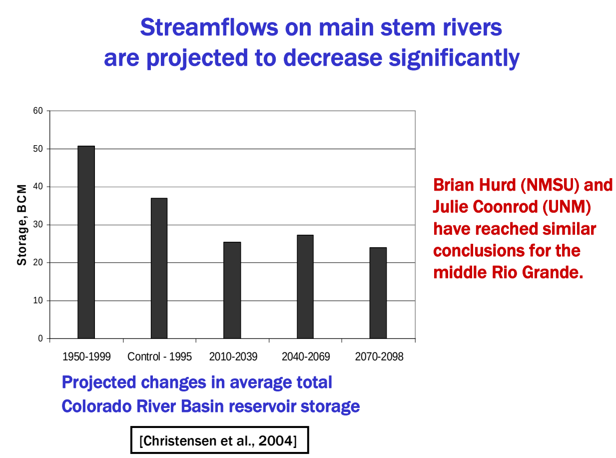

Figure 7. Model-Based Projection for Total Storage in the Colorado River Basin

Our best guess is that you could make the same statement for the major basins in this state, including the Rio Grande. Yesterday at this meeting Julie Coonrod reported on an initial attempt by Hurd and Coonrod to develop such a scenario for the Rio Grande, and later this morning Al Rango will describe an ambitious project to improve the hydrologic underpinnings of such studies for the Rio Grande. Hurd and Coonrod reach the general conclusion that we are going to have less water, and perhaps a lot less water, flowing down the Rio Grande in the 21st century as a result of climate change. We ought to anticipate that happening and start planning for it, which is an easy thing for me to say, but a very difficult challenge involving hard choices about our water consumption priorities.

Climate variability is an important part of our story, and some would argue the most important part of the story. It is easy for us to lapse into talking about average conditions when we talk about long-term climate changes, but we know that the term "average conditions" barely has any relevance to the state of New Mexico. If we know anything at all from the past climate record, average hardly ever happens. Figure 8 is an estimate of precipitation in northern New Mexico based on tree-ring data that goes back 1,000 years, taken from the Governor's Task Force report on climate change and water resources. The time series goes way down and way up and way down and way up. We know that huge droughts—severe and lengthy—are an endemic part of the climate system here. Arguably, the real 21st century doomsday story for water management, if we want to tell such a story, has nothing to do with the average trend in temperature or precipitation. Rather, it is how we get our way through these bad drought times that we would be insane not to anticipate happening again in the 21st century. I can't stand here and tell you when the current big drought across western North America might end, or when the next big one might happen later on in the century, but we would be utter fools to assume that it is not going to happen again in a warmer climate for all of the reasons I've been telling you about for the last ten minutes. With higher population, lower streamflows, and more depletions (from higher evapotranspiration), future droughts are going to be harder to get through. How are we going to manage our way through the next bad drought in a warmer climate?

More speculatively, some climatologists have suggested that the frequency and intensity of drought periods is itself correlated with average temperature. Tree ring data indicate that droughts were more frequent and more intense 1,000 years ago, when the

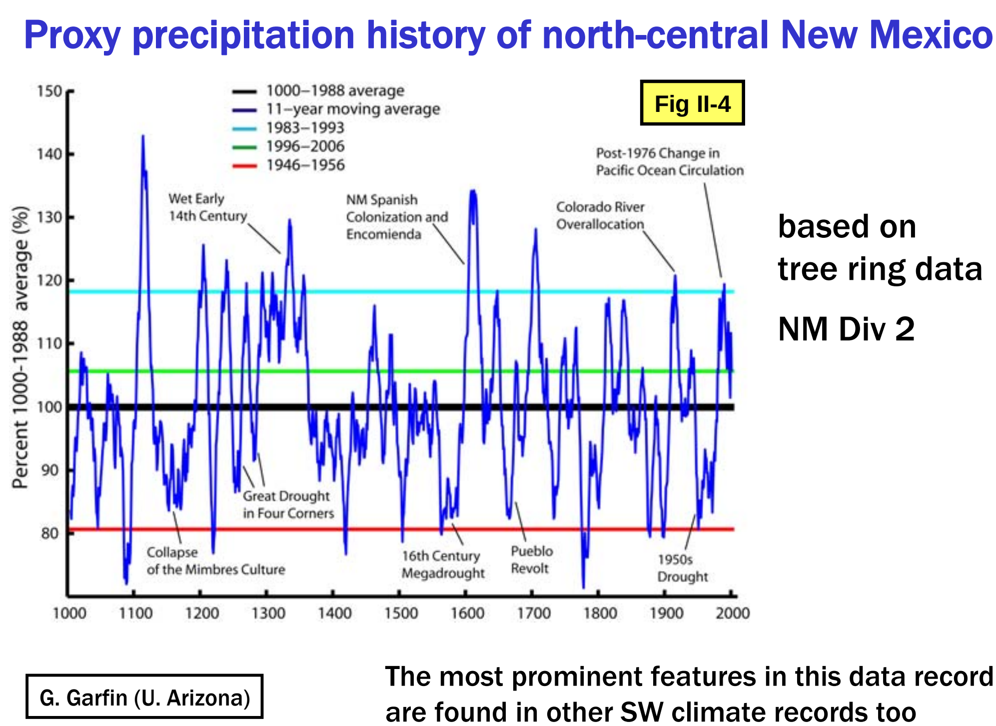

Figure 8. Precipitation Estimates for Northern New Mexico Based on Tree-Ring Data AD 1000 - 2000

temperature was closest to what it is now across the Southwest. As climate has warmed rapidly in the 20^{th} century continuing on into the 21^{st} century, this could mean that we are reverting from a relatively drought free millennium back to something that looks like it did 1,000 years ago. In other words, we are making our drought story even worse than simply saying more big droughts will happen in a warmer climate.

So far everything we've discussed is a temperature effect. We should anticipate significant warming to continue and perhaps accelerate, and there are hydrologic consequences to that. Just to make things worse, let's go back to the precipitation scenarios that Roger alluded to. I'll amplify those a little bit. Before I do that, I want to emphasize that the precipitation part of the climate change projection story really is significantly less certain than the temperature change. I really like to treat them separately because I think we are stupid if we don't anticipate the very large probability of warmer temperatures. The projected precipitation changes we are about to discuss are not so certain, in my opinion. I think we would be foolish to disregard them, but from the point of view of talking to the public, I think it is very important for us as scientists to make a clear distinction based on our confidence levels in our ability to predict climate systems. Nevertheless, let's talk about precipitation change.

Unlike temperature, there is no discernible trend in 20^{th} century precipitation in New Mexico. As in the longer time series based on tree-ring data, there is pronounced variability, including the 1950s drought, and a very wet period—some would say the wettest period of the millennium—in the 70s, 80s, and early 90s, then the drought in the early 21^{st} century, as well as a whole lot of other annual variability. Current model projections suggest that we might start seeing a precipitation trend, however. Models want to expand the Hadley circulations significantly, principally in the cold season, which would lead to significant decreases in cold season precipitatation in the global subtropics, including the American Southwest.

If we take the data points for those model runs in the state of New Mexico for one particular scenario, which is what we did for that OSE report, we get the time series shown in Figure 9. There is no clear trend in summertime monsoon precipitation (bottom curve). The top curve illustrates the "doomsday scenario"—a huge decrease in winter precipitation, whose effects would add to the impact of warmer temperatures across New Mexico and extend up into the southern Rockies. There is significantly less precipitation over the course

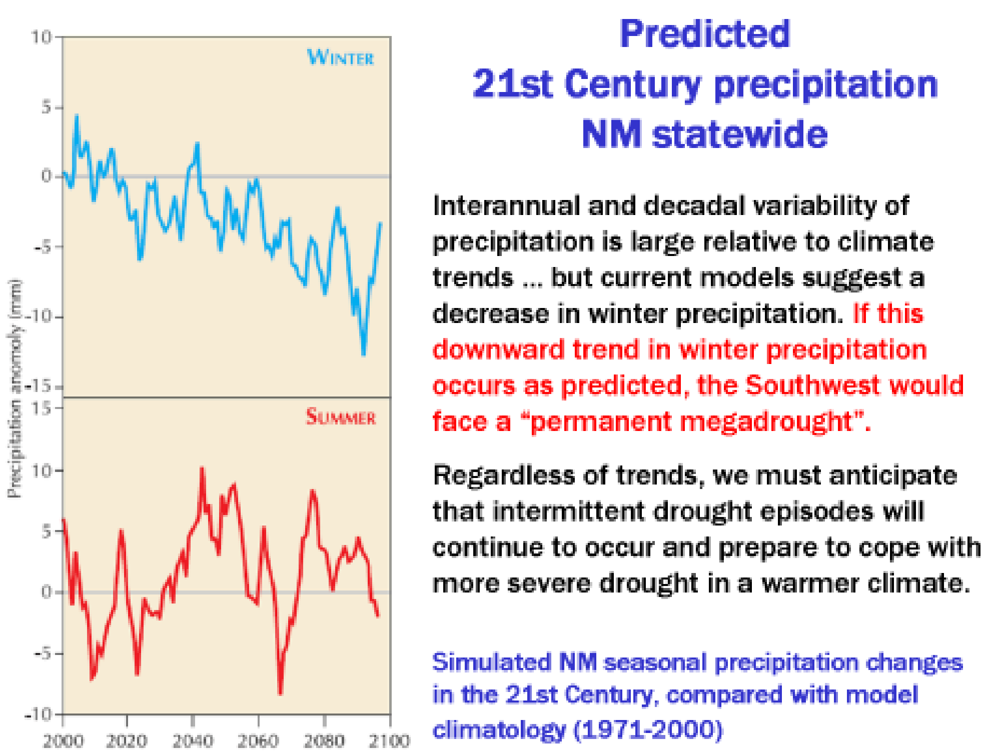

Figure 9. Projected 21^{st} Century New Mexico Precipitation

of the 21st century so people throw around terms like permanent megadrought. Figure 10 shows another rendition of the same set of model runs, showing you there is some significant model to model variability. By the end of the 21st century, however, the IPCC models all show this sort of precipitation decrease, leading to projections of a "permanent megadrought" across the Southwest. I do not know what we would do to manage water in the face of that precipitation trend, should it occur.

Let me just make one or two more points and then stop. Obviously, it is not just supply of water that matters in a warmer climate, it is human demand for water. We can actually put some numbers to this for the city of Albuquerque, where water demand actually turned around fifteen years or so ago. That is because Albuquerque is starting to get serious about water conservation. We can model the year-to-year change associated with climate variability, especially for summer residential demand. It probably will not astonish you to learn that when we have dry or hot summers, water demand goes up. Warm and dry tend to go together, but we might continue to develop water demand models like this to start thinking about the demand side for projected climate change.

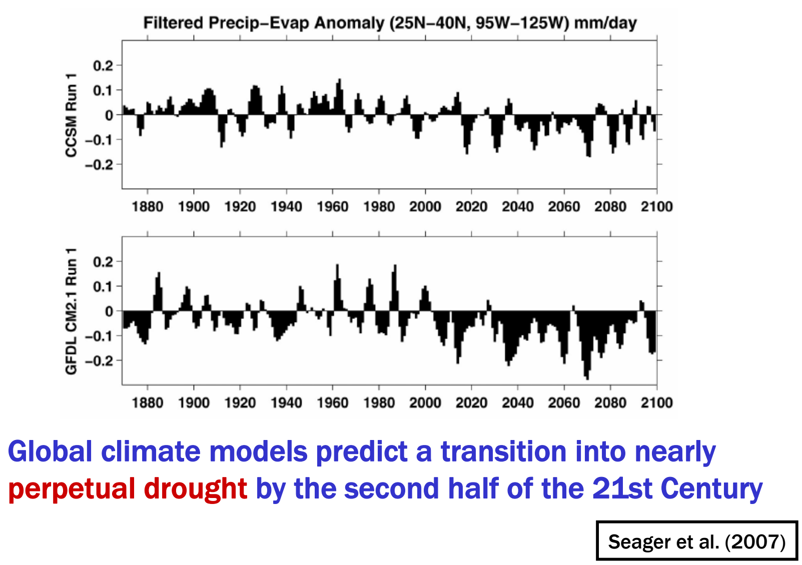

Figure 10. Projected Hydrologic Changes in the Late 21st Century American Southwest

Finally, to try to bring this all together and set the stage for other talks, Figure 11 is an estimated water budget for the Middle Rio Grande taken during the latter part of the 20th century when the climate was wet. There was a lot of precipitation falling in the mountains during the latter part of the 20th century. We have a water budget with most of the water in the Rio Grande coming in at the Otowi gauge. Inflows are shown on the left and depletions on the right. We can ask, "What are the projected changes in these inflows and depletions associated with the data for climate change?" I will illustrate those with little arrows here. Inflows decrease. Now, I can't put numbers to those yet, but that is part of what we would like to do as part of the project that Al Rango will talk about later today. As I have suggested already, we should expect less flow coming down the Colorado River and in the major tributaries of the Rio Grande. One of the largest inflows right here comes out of the Albuquerque water treatment plant, but even that will decrease as Albuquerque converts its water supply to San Juan-Chama surface water. So we expect inflows to go down as a result of climate change.

What about depletions? Open water evaporation, as I have suggested, goes up. Riparian evapotranspiration goes up. With warmer temperatures, there is a longer growing season for riverside plants that aren't limited by water as long as there is water in the river. I put depletions going up a lot off Elephant Butte Reservoir. I have not put an arrow on depletions due to agriculture, which seems to be a huge question to me. How much water will be available and will we devote to irrigation, which is pretty much the only way people will carry out significant agriculture in this part of the world, considering all of the other pressures on this water budget as a result of climate change? That involves pretty profound social questions for New Mexicans.

So we end with two main points: the climate is going to warm up, and because of that, the way our water supply works, we should expect pretty significant decreases in nature's supply of water to the state of New Mexico and concomitant increases in the natural depletions associated with evapotranspiration. Secondly, there are more speculative cautionary projections that perhaps on top of that, precipitation in the winter could actually go down over the course of

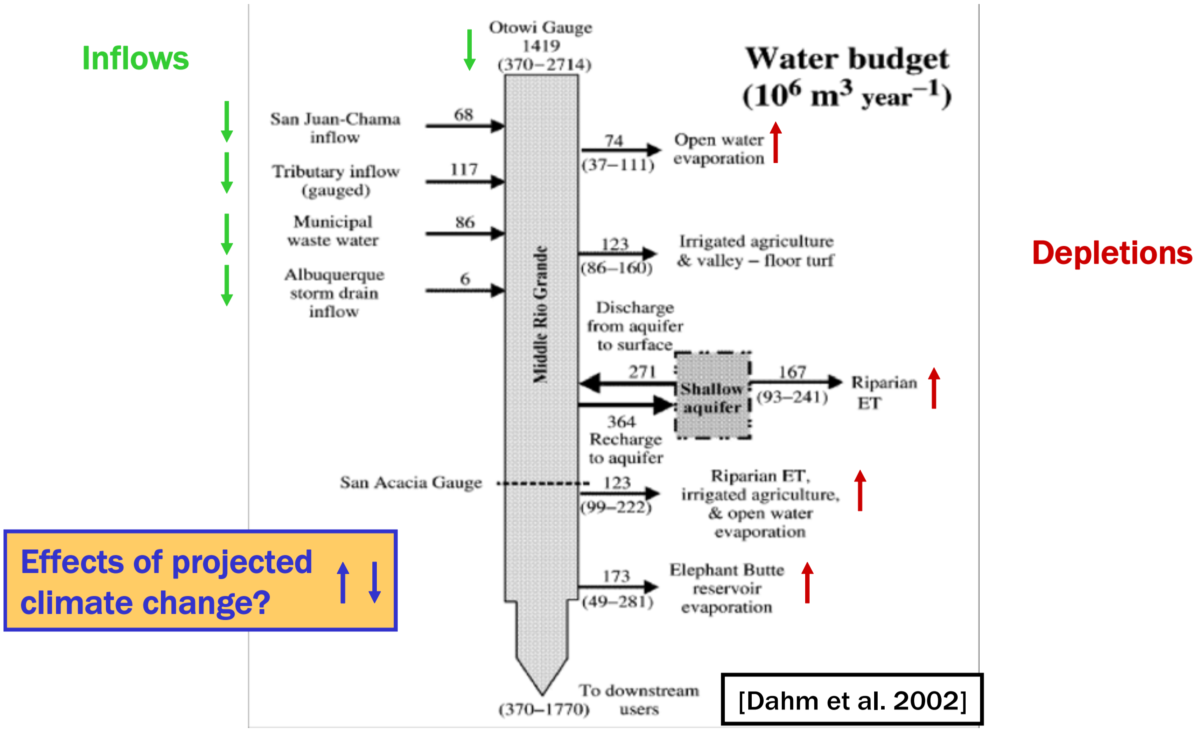

Figure 11. Estimated Water Budget for the Middle Rio Grande

the 21st century, which would make that whole situation way worse. All of this means that water resources are going to be under increasing pressure in general. Where that really hits home is when the next drought or droughts occur. It is not an average that matters; it is how we get through multi-year droughts, which we just know are going to happen sooner or later every few decades. Thank you very much.

Question: How do we make projections with regard to riparian vegetation and how they respond to climate change?
Gutzler: I am not sure that I can give you a great quick answer to that, in part because the riparian system is so actively managed right now. A lot depends on water availability. My sense, and I am not a biologist, is that an awful lot of riparian activity depends on water availability, both in terms of how much water is flowing down the river and how much we allow the river to move back and forth. So, riparian vegetation ought to thrive, unless people somehow restrict the water supply to those plants via river management. Hence the climate change arrow might go up in terms of total evapotranspiration. But obviously there are a lot of variables that go into that.

Question: We are seeing recently that there is a big social change going on because of the cost of a barrel of oil. This has also had really profound effects on agriculture and what crops farmers are choosing to grow. There is a real, real big impact on water resources, and New Mexico has a lot of energy development as a state. Are you planning on adding the impact of energy development on water resources, especially for that question mark you had there of what agriculture will do?
Gutzler: How does the price of oil factor into all of this? As a climatologist, the way it factors in is our choice of emissions scenario. That is where we bury that particular bucket of uncertainty. Different possibilities for the future price of oil and possible regulation of fossil fuel burning go into those emissions scenarios. However, you have raised sort of a different question about how the future of oil affects the state locally. A task force has been appointed by the governor to try to think about carbon emissions in general. I am not enough of an expert on New Mexico economics to be able say anything very authoritative, other than the motherhood statement that obviously oil prices will affect the state's economy in important ways. As groups of us try to think about this issue, we will need to bring people to the table that actually know about this stuff.

Question: From the global standpoint and its effects on the West, we have four time zones in America. I am wondering how much the climate models are thinking about the effect of the Eurasian continent, which is mostly permafrost, becoming a productive zone as it adapts to a warmer globe. Now there is a land mass full of photosynthetic capacities that spans 11 time zones full of plants and growth that is coming out of the Russian steppes, that in the current climate have been reduced in their production of oxygen and their absorptive capacities of greenhouse gasses. Now this new bread basket spanning across three times the land mass of America, what are the models projecting of that? Are those kind of impacts also going to swirl around the globe and have any other kind of impact? Are the models looking at that on a global and regional level in the Southwest?

Gutzler: The one-word answer is "yes." I just mentioned the first bucket of uncertainties has to do with developing emissions scenarios. The next step in making a climate change projection is to put those emissions scenarios into what we call a carbon cycle model that calculates how much of the greenhouse gasses that we emit into the atmosphere stay there. At present, on the order of a quarter of all the emissions that people emit are taken up by plants, principally in the northern hemisphere. The carbon cycle models are designed to take land surface changes as projected in the 21st century, including what will happen in Eurasia as the climate warms up, and allow the land surface to exchange CO_2 and methane with the atmosphere, so that you get an estimate of how much of the emissions actually stay in the atmosphere. So these models are designed to do exactly what you have described. How good are they? We think they are pretty good, but all of these models have uncertainties associated with them. One of the bazillion dollar questions in the climate change business is how long land plants can continue to take up about a quarter of anthropogenic emissions. Will that uptake increase as a result of land surface changes or will it decrease because we have effectively overfertilized the garden and it can't take up anymore just like you can't continue to fertilize your plants in your garden forever? Once again, there is considerable uncertainty. As you go farther north you get into permafrost and tundra with buried methane. Will these methane clathrates melt and release a whole bunch of methane? We think these models are getting better all the time. They are continually being tested against the sparse observations that we have, but we will continue to try to make that part of the projections better.

Roger Pulwarty: Just one quick backup: there are models that try to take that into account. It is a question that we have looked at. The issue has to do a lot with what David is saying. How do you know when the biosphere is "full"? There is an issue with the oceans right now and whether or not we might actually see increases. Are the oceans saturated or can they be in the future? The issue further north is a big one. I sort of question whether or not that impact will be much greater than the positive impact that you are suggesting.

There is one other question that is related to the input. Our experience has been that we hear about where the growth is and where extra water will come from on the supply side. We talked about water transfers and whether or not that is the way we want our states to go, but there is a huge other issue. All of the other recommendations we have on balancing the inputs and outputs have been sort of water banking. The water came from the environment in the successful water banks. Sure, agriculture and the environment provide a whole lot of services that are not just economic when we start to think in terms of these larger inputs and outputs. What is the input of the water balance model that comes from the environment? We are beginning to face a lot of that kind of issue.