OVERSIGHT HEARING ON THE WATER MANAGEMENT IMPLICATIONS OF THE 1997/98 EL NIÑO

OVERSIGHT HEARING

BEFORE THE

SUBCOMMITTEE ON WATER AND POWER

OF THE

COMMITTEE ON RESOURCES
HOUSE OF REPRESENTATIVES

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FIRST SESSION

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THURSDAY, OCTOBER 30, 1997

HOUSE OF REPRESENTATIVES, SUBCOMMITTEE ON WATER AND POWER, COMMITTEE ON RESOURCES, *Washington, DC.*

The Subcommittee met, pursuant to notice, at 2:10 p.m., in room 1334, Longworth House Office Building, Hon. John T. Doolittle (chairman of the subcommittee) presiding.

STATEMENT OF THE HONORABLE JOHN T. DOOLITTLE, A REPRESENTATIVE IN CONGRESS FROM THE STATE OF CALIFORNIA

Mr. DOOLITTLE. [presiding] The Subcommittee on Water and Power will come to order.

The Subcommittee is meeting today to hear testimony concerning the water management implications of the 1997/98 El Niño. The current El Niño event is expected to be the most severe El Niño since 1982/83. Indeed, many scientists believe that it is the most severe event of this kind since records have been kept, about 150 years ago. But what does that mean for our weather? Will every quirk in the weather this season be seen as a manifestation of El Niño?

There are some pretty good indications that this El Niño will mean serious flooding in portions of the United States, probably on the West Coast. It is equally probable that we are going to have drought conditions somewhere as well. The real challenge is to know when and where these conditions are going to develop. And will we know that information early enough to make a difference?

Knowing that we have a significant El Niño event that is likely to affect our weather, it is much like knowing we are going to have a severe winter along the eastern seaboard. We still don't know whether there are going to be bitter cold temperatures or snowstorms which will shut down New York City, Boston, or Washington, DC on any given day. That information will only be known a few days in advance, and of course, like all predictions, they can be off, as we know from watching the nightly weather forecast.

Much of the press coverage and most of the speeches in the political arena might lead one to believe that flooding is the only concern. However, as important as flooding is, it is only one of the critical issues associated with the El Niño phenomenon. The impact on water supply could be almost as significant. Millions of people in this country rely on water stored in reservoirs to meet their munic-

ipal, industrial, and agricultural water supplies. The western half of the United States is particularly dependent on these reservoirs for water supplies about 6 months out of every year.

Initially, you might think that more rainfall and snowfall would translate into fuller reservoirs and expanded water supplies. Unfortunately, the reverse can happen. Every year, prior to the months when most of the precipitation occurs, the water level in reservoirs is lowered to accommodate the anticipated flood flows. However, significant water is retained in the reservoirs for water supplies in case the rain never materializes. The challenge throughout the rainy season is to respond to the storms, trying to pass the flood flows as they occur.

If good information is available, reservoir managers can provide extra protection by releasing water even before a storm begins to affect a reservoir, but there is the dilemma. If a reservoir does not refill, water shortages are a very real probability. In some cases the available advanced warning will allow time to avert flooding; in others it will not. The critical question is: How far in advance will water managers and flood control experts know that a crisis is pending in a given watershed?

With all of the general storm information available, the data to make a decision in any particular watershed will only be known 48 hours to 72 hours in advance. Many factors affect the ability to predict accurately whether a given watershed or reservoir will receive enough precipitation to justify releasing the water before the storm begins. If a reservoir manager fails to make releases, there is a greater chance there will be flooding on the river system. If the reservoir manager decides to begin releases and the water is not recovered that season, hundreds of thousands of acre feet of water can be lost that will be needed for deliveries in the summer months.

If the wrong decisions are made often enough, much of the water stored in Federal, State, and private reservoirs will be lost. Such a scenario is not only highly possible, it in fact occurred in California on a smaller scale during this past 1996/97 water season. It is possible that the El Niño brewing in the Pacific will dissipate and cause no significant impact. It is also possible that we may have a long, wet winter with storms evenly spaced over the season, which will be easier to manage. It may be that all of the storms pass over the extreme southwestern and southern part of the country, but, based on past El Niño events, it is also highly possible that we could have a long, wet rainy season with erratic and unpredictable impacts in many different parts of the country. Certainly, any portion of the western United States could be affected.

The strongest El Niño ever recorded so far occurred in 1982 through 1983. It was responsible for 2,000 deaths and $8 to $12 billion damages worldwide. The current El Niño event appears to be even stronger than that one. If we are to avoid or mitigate some of those impacts, we must build on what we know, but also realize—and I think this is key—what we don't know.

In river systems without reservoirs or with inadequate reservoir capacity, we will not be able to blunt the effects of these storms. Even in river systems with adequate reservoirs, we will not have perfect knowledge, and we run the risk of either flooding and/or re-

leasing water that will be lost for delivery when needed next summer.

We, clearly, have better data today than we had when the last big El Niño hit us in 1982/83. It gives us an opportunity to prepare much more than we had then. But while witnesses will talk about what we know now, I am asking them in their oral testimony to focus on what we still do not know. I am asking them to also focus on the difficulties facing water managers in determining when and how much water to release and what are the weak links in communications and in placing reliance on the new information.

Finally, I ask the witnesses to focus on how we can learn from this El Niño to improve our response to similar events that will come upon us in the future. I look forward to hearing our witnesses.

We have our first panel seated already, and let me ask you, please, if you will rise and raise your right hands.

[Witnesses sworn.]

Mr. DOOLITTLE. Let the record reflect that each answered in the affirmative.

And, gentlemen, thank you. You may be seated. We appreciate your coming here today.

The custom of the Committee is to use those lights before you as a rough guide to the length of your testimony, which I think with one exception is going to be 5 minutes. If you have further things to say, just because the red light goes on, don't feel obliged to stop in mid-sentence, and feel free to complete the sentence or the paragraph, and if we don't have too many Members, the time limitation is not going to be particularly relevant. But they're a guide for you, and I think the yellow light will go on at the beginning of the fifth minute.

And with that, our first witness is Dr. Elbert W. Friday, who is Director of the Office of Oceanic and Atmospheric Research for the National Oceanic and Atmospheric Administration within the Department of Commerce. Dr. Friday.

STATEMENT OF ELBERT W. FRIDAY, DIRECTOR, OFFICE OF OCEANIC AND ATMOSPHERIC RESEARCH, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, DEPARTMENT OF COMMERCE

Mr. FRIDAY. Thank you very much, Mr. Chairman. I request that my written testimony be entered into the record and I would like to give a few brief comments in response to your charge to the witnesses today.

Mr. DOOLITTLE. I appreciate that, and let me say that your statement and all others will be entered into the record, as you have submitted them. So please feel free to share with us your views during the oral testimony.

Mr. FRIDAY. Thank you, sir. It is, indeed, a pleasure to be here to address what you have identified, and I think we all agree, is a very, very important issue.

The El Niño situation that exists today is, indeed, being blamed for everything, and yet we have to be very careful that we don't overattribute meteorological and hydrological events to this particular pattern. You were very correct in pointing out that we know

a lot more today than we did in 1982 and 1983. Indeed, in the 1982/83 event, we didn't even understand that El Niño was occurring until we were about halfway through the event. We recognized during that event that we needed to learn a great deal more about it in order to be able to better respond to the next major event that occurred.

In a 10-year period, beginning in 1984, we did a remarkable number of things. We instrumented the Pacific Ocean and the tropical regions, so that we could identify changes in the ocean long before they began to affect the atmosphere, this coupled system that we have. We were able then this year, using the information from that research data base, to begin to predict the beginning of the El Niño in January, and Ants Leetmaa, who will be testifying next, was then able to go out with an actual forecast for a very strong El Niño in the springtime of this year, long before we started to see these major effects starting.

We made a conscious decision in NOAA and in the Federal Government in general that it was important, even though we were basing this on research results, that we try to provide to the user community the information that we had, recognizing that it was not complete, but recognizing it was better than not having any information at all, and that's a critical point that we need to make.

It is important also to understand—you asked for the uncertainties that we have in the process—that when we talk about the effects of El Niño, we are talking about not absolutes, but relatively shifting a probability distribution of wet or dry, of warm or cold. We're talking about loading the dice, if you would, so that they may come up slightly more frequently a 7, but they will still come up an occasional snake eyes. Our job in the forecast process is to try to understand ahead of time how they've been loaded in the various sections of the country.

The ability that we have now to integrate all of these data are based on the fact that we have been archiving data for a very long period of time. You indicated records going back 150 years. Detailed records for every meteorological and oceanographic parameter are archived in various aspects of the government, and those data are now being mined in order to be able to understand more completely how these effects occur, what kind of information that we can say about the future events.

The observation system that we have out in the Pacific Ocean has clearly demonstrated its advantage to being able to predict the onset of an El Niño, and this array of instruments out in the tropical ocean, it is absolutely critical that we continue to maintain and monitor that. And, indeed, we in NOAA are certainly looking forward to Congress supporting the operational funding of that, which we have in the President's budget this year.

NOAA has not operated by itself in this. The effort of research has been a cooperative effort across many aspects of the Federal Government. It includes National Oceanic and Atmospheric Administration, the National Science Foundation, National Air and Space Administration, and Office of Naval Research from the Department of Defense doing the initial research into this activity.

This year virtually every aspect of the Federal Government is working together, as you see from the witnesses that are here at

this table, to be able to pass the information that we have developed onto the user community, to allow them the best possible information in making their decisions.

Again, I want to stress that these are not absolutes. It is difficult to attribute any individual weather event to the El Niño. What we do know about the patterns that exist is the fact that it tends to affect the overall interactions between the ocean and the atmosphere. So it tends to affect the storm tracks. It tends to affect the jetstreams. And, yet, we still don't know the precise manner in which this is going to occur.

You were correct in pointing out, sir, that the important information for the day-to-day management of all of our activities, including reservoir management, is going to be much more short-term in the nature, on the order of two or 4 days. We are beginning to be able to extend, through the National Centers for Environmental Prediction, that forecasting capability out to 10 days, and we hope to be able to improve that, but that's an area that we really have to work on.

We have a capability now that we've demonstrated in at least one location in the country of being able to provide probability distributions of river stages out in the future going out to several weeks, and, again, that's a development effort that we need to continue to pursue and work with the user community to make sure that that can be effectively applied to all of the various users of the information.

The forecast process that we're undergoing now represents a lot of research that has gone on. We have just taken action within NOAA to announce that we are going out over the next few weeks to identify things additionally that we need to observe during this event, so that we will have the data base, we will have the information base necessary to truly evaluate this entire situation, so that we can do a better job on the next one.

Thank you, sir.

[The prepared statement of Mr. Friday may be found at end of hearing.]

Mr. DOOLITTLE. Our next witness will be Dr. Ants Leetmaa.

STATEMENT OF ANTS LEETMAA, DIRECTOR, CLIMATE PREDICTION CENTER, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, DEPARTMENT OF COMMERCE

Mr. LEETMAA. Yes.

Mr. DOOLITTLE. He is the Director of the Climate Prediction Center within NOAA and the Department of Commerce. Dr. Leetmaa.

Mr. LEETMAA. Thank you, Mr. Chairman. I welcome the opportunity to come here and talk to you. I would like to discuss, first, the nature of what the El Niño forecasts are for coming seasons, then outline some of the expected impacts, especially over the western region of the U.S., and some of the forecast issues as you alluded to, because there are many of those.

Both Joe Friday and I have with us here Dr. Danny Fread of the Office of Hydrology, who is directly involved in the hydrological forecasting. So if some questions come up regarding that, he is here to help us.

Let me start with the forecast for El Niño itself. The Climate Prediction Center is forecasting the current event to peak around the end of this year or early next year. Present observations show that the event is still slowly growing. Hence, the forecast for the next 3 months are pretty much on the mark.

At the end of the year, this event in amplitude and spatial extent will be comparable to the 1982/83 one, which until now had been considered the event of the century. Most of the model forecasts—and there are many model forecasts besides those done at the National Centers for Environmental Prediction—forecast that this event will decay toward normal or in some cases even cold conditions, La Niña conditions, by next summer. How fast it decays—and there is some disagreement here—is critical to the U.S. forecast during late winter and spring.

In 1982/83, many of the heaviest impacts were in the February-to-April period. So although the event is decaying at that time, because of the tropics are warming up, because of the annual cycle, the sea surface temperatures in fact will remain anomalously warm, and so the Climate Prediction Center is forecasting that we will basically be under the influence of strong El Niño conditions through the January-to-March period.

As Dr. Friday indicated, the onset of this event and its evolution have been well-predicted three to 6 months in advance, and this is letting us do something which we haven't been able to do before in the past, which is to anticipate what might take place and then try to mitigate potential harmful impacts.

The forecasts for El Niño are reasonably well-established. The forecast for El Niño impacts over the United States are less so. Currently, we use two primary sources of information. The historical record is stratified according to when moderate or large El Niños have taken place. This gives us an indication of what we think the average El Niño response would look like. Equally importantly, it lets us know what the probabilities are that such an event will take place or such impacts will take place. Clearly, each El Niño does not have the same impacts.

We also routinely run atmospheric model forecasts out to the next several seasons. Both of these give us very much the same picture of what might happen, but there are differences in detail. So, basically, at the present time we still base our forecasts, the seasonal forecasts, primarily on the statistics, but modify those in regions where we think the models are adding something.

One of the major issues that we face is that this event is obviously not an average El Niño, and one might ask the relevance of what using the moderate El Niño criteria, and so we anticipate and we already know that the impacts will depend on the size of El Niño. So in discussing what might happen in this particular event, we make the comparison to 1982/83, which was an event of the same size.

There was one other event comparable to both of these events in recent history, and that occurred in 1877/78, but the data for that at the present time over much of the United States is limited, and so we're limited in terms of what we can say.

Although much of the U.S. is forecast to be impacted, let me focus for this hearing on California. California, during winters with

moderate El Niños, receives about 130 to 140 percent of normal rainfall during its rainy season from November to March. This converts to about 5 extra inches of rain averaged over much of the State. During 1982/83, which is a plausible scenario, California, as much of the Southwest, received 150 to 200 percent normal rainfall. This translates over coastal California and central California and the southern Sierras to approximately 10 extra inches of rain spread over that area, and for much of northern California the amount was greater than about 16 inches. So that's a lot of water.

These two estimates, one for the average impact for moderate El Niños and what happened in 1982/83, give one estimate of the possible spread of impacts. Ranges in forecasts, however, result from both the chaotic component of Nature and the uncertainty and the limitations of our current forecast capabilities. Although research will improve the forecasts, this range in what we forecast will always remain.

If, for example, Nature could repeat the next two seasons several times over, keeping in place the same El Niño anomalies, the impacts for each of those winters, in fact, would be slightly different. For example, during 1877/78, another event of the century, central and northern California received more rain than in 1982/83, while southern California received less.

Many serious shortcomings of the current forecasts are in the nature of the forecasts themselves. We, basically, at present forecast seasonal averages. As you indicated, El Niño rains come as storms. Series of storms are what cause problems. Research is indicating that the number of storms and their intensity is a function of the strength and type of El Niño. Depending also on the type of storm, we can either get rain or snow. It's the rain events that cause a lot of flooding, although ultimately the snow melts and there can be problems then also.

So, basically, we have issues that we haven't addressed yet, which is exactly how El Niño modifies the nature of the storms, the number of the storms, the intensity, and also what's going to happen to the snow pack.

As we look toward the future, ultimately, what we want for effective water management practices is a suite of forecast products of different lead times from hours, to days, to a week, to 2 weeks, to a month, to a season, and even decadal. Currently, the Weather Service produces short-range forecasts which are the most accurate and have the most local detail. For this event, the Weather Service is also developing a weekly update, a threat assessment, trying to extend the forecast into that week two area, so we can give emergency managers a heads-up as to what potentially might be happening in terms of the intense flooding events.

The Weather Service also provides the link between meteorological forecasts and reservoir operations through the River Forecast Centers. These work side by side with the Bureau of Reclamation, the Corps of Engineers, USGS, and State personnel. As part of the Weather Service modernization, they will start using the seasonal forecasts to ultimately extend hydrologic forecasts out to several seasons also.

Let me conclude by saying that it is unlikely that in the foreseeable future or ever we will have meteorological forecasts of the ac-

curacy that water managers ideally would like to see. Nature inherently has an unpredictable component. The key is for the providers of the forecasts and the users to work together on an interagency basis, so each understands the other's capabilities and limitations and needs, and works toward enabling the transfer of this information into operations. Although we have started working in that direction, we need to accelerate the efforts.

Also, I hope that the newness and the uncertainty of the seasonal forecasts associated with this El Niño do not lead to an underestimation of the potentially harmful impacts that might take place. Thank you.

[The prepared statement of Mr. Leetmaa may be found at end of hearing.]

Mr. DOOLITTLE. Thank you.

Our next witness, who will be recognized for 10 minutes, is Dr. Mark Schaefer, Deputy Assistant Secretary for Water and Science and Acting Director of the U.S. Geological Survey within the Department of the Interior. He will be accompanied by Dr. Thomas J. Casadevall, Regional Director of the Western Region, U.S. Geologic Survey, Water Resources, and by Dr. David A. Matthews, Manager of River Systems and Meteorology within the Bureau of Reclamation.

Dr. Schaefer, you're recognized.

STATEMENT OF MARK SCHAEFER, DEPUTY ASSISTANT SECRETARY FOR WATER AND SCIENCE, ACTING DIRECTOR OF U.S. GEOLOGICAL SURVEY, DEPARTMENT OF THE INTERIOR

Mr. SCHAEFER. Thank you, Mr. Chairman, and good afternoon. We appreciate the opportunity to be here to discuss the Department's activities related to El Niño. This episode is of particular interest and concern to the Department because changes in precipitation and temperature, stream flow, et cetera, all impact our facilities and the responsibilities that we have for managing land and water resources.

Across the Nation, the U.S. Geological Survey is monitoring stream flow at more than 7,000 locations. Nearly half of these transmit information in real time that is made available to individuals through the Internet and through other means. This network will provide first indications of the effects of El Niño on rivers and streams and reservoirs, and it forms the basis for the flood forecasting and warning activities that my colleagues have just described.

The Department has been extensively involved in evaluating current El Niño forecasts. Daily stream flow data from 50 years of USGS records reveals marked increase in short-term flood during El Niño episodes, even when total seasonal stream flow is not profoundly affected. Studies also show that previous El Niños are linked with many of the most severe floods in southern California and other southwestern States. The USGS has been active in communicating these lessons to others and in incorporating this information in our management activities.

You asked about what we don't know. The predicted strength of this event raises unusual problems for us because we do not know whether the most intense El Niños simply yield more intense ver-

sions of the regional water resources and hazard effects that we typically see with El Niños, large or small, or whether they result in whole new patterns of effects. For example, during the strong El Niño of 1982 and 1983, most of the West Coast experienced substantial increases in rainfall.

The Bureau of Reclamation has been closely tracking the long-range forecasts, with support of the National Weather Service's River Forecast Centers and their Climate Prediction Center, and their Technical Service Center in Denver. Reclamation is developing a procedure to integrate all of this information into its operations at its various facilities around the country. Water operations managers in the five regional offices and in the 60 area and project offices are being kept informed of any changes in forecast. They're getting information on a weekly and daily basis, and they are going to incorporate that into any management decisions that they make.

Reclamation has also begun the process of informing all water managers of the potential impacts of this El Niño, as well as the current state of our climate predictions. The Bureau has opened dialog with its water managers and climate researchers from the National Weather Service and from other agencies. We're working together on this, and as my colleagues pointed out, we have a lot more information available to us today than we did in the early eighties, and we think we're in a good position to respond to whatever may occur.

As you know, the Bureau of Reclamation has many dams and reservoirs, and I just wanted to underscore this through one of our charts here. We have 596 dams and reservoirs, and as you pointed out, Mr. Chairman, in the western United States, in particular, individuals and businesses, farmers, and so on, depend on the decisions that the Bureau of Reclamation makes. It's a tricky balancing act to try to respond to weather predictions and ensure that we're preserving public health and safety, while at the same time maintaining the water levels we need for agriculture and for other uses.

Long-range forecasts are too general for us to target the specific watersheds and the precise locations that may be affected by storm events related to El Niño. However, past events and current information suggests that we should prepare for frequent heavy precipitation this winter in the mountains of California, Arizona, New Mexico, and other areas that affect the operations of reclamation in the mid-Pacific, upper and lower Colorado, and southern Great Plains regions. This translates into potentially high water levels in reservoirs of the Central Valley Project, Colorado River Storage Project, Lake Powell, Lake Mead, and the Rio Grande Basin Projects, as well as smaller projects in these areas.

And as you know, Mr. Chairman, the Central Valley Project is Reclamation's largest and most complex project, comprised of storage dams, reservoirs, pumping plants, canals, and so on, and delivers water throughout about a 40,000-square-mile area. The 1982/83 water year was the wettest on record throughout the Central Valley Basin, and record precipitation throughout that winter led to very large spring snowmelt runoff that lasted until June.

Reclamation is tracking weather forecasts. It's incorporating the forecasts into ongoing modeling activities, and it's planning possible management actions to respond to whatever may be on the

horizon. Significant operational actions to accommodate potential high inflows next spring are already underway. Reclamation's water operations and management activities in each project area are already in a delicate balance of supply and demand.

USGS is using El Niño forecast information in conjunction with historical El Niño flood discharge relations to evaluate the status and condition of its stream-gauging equipment in regions where floods are likely, and this will help ensure that our gauges are fully operational when storms do occur.

Our coastal and marine program, in cooperation with NOAA/NASA, is evaluating the potential land loss in coastal areas from severe storms, and USGS is developing a variety of geospatial data. It's preparing maps and other products, and these will be available on an emergency basis. We have teams that can work around the clock in order to develop whatever products are needed.

USGS is collaborating with Reclamation and various NOAA operational and research groups and State agencies to test and improve the hydrologic value of current weather and climate forecasts.

The USGS is also contributing valuable information regarding the potential for landslide occurrences associated with El Niño weather effects, and I'd like to give you an idea of what some of this information looks like. These are two maps. This shows the landslide hazard outlook for October through December this year, and this shows the outlook for January through March. Now this is a product that was developed jointly by USGS and by NOAA. In fact, I think this is the way of the future, where the agencies will work more closely to develop integrated data products that will be useful to the public and to resource managers.

But what you can see here, these are the areas of high landslide potential in the U.S. So this is the map that was developed by USGS. We overlaid that on NOAA's information related to the El Niño episode, and what you want to look for are the purple or dark blue areas, where we're expecting high precipitation and where there is already a high landslide potential. So you can see we took two fairly simple datasets and have developed some information that we think is very powerful and will be useful in helping to ensure that people are prepared in regions like this, some areas along the California coast, for this type of event.

In addition, the floods and droughts associated with El Niño can seriously affect water quality. Increased loads of nutrients and toxic chemicals may be washed into rivers during flood conditions. The USGS has a national water quality assessment program that does water quality monitoring. It does that generally over the long term, but these individuals are available on a short-term or emergency basis to evaluate water quality, if that becomes necessary in a particular area.

These planned actions are expected to meet the needs of water managers and mitigate the effects of extreme weather events that may arise from this El Niño. However, unanticipated needs may arise, some of which may require the attention of Congress. We'll work closely with you, should such needs arise.

Long-term future needs include enhanced stream-gauging operations in areas where flood probabilities are increased. I'd like to show you another visual here. This is the USGS stream-gauging

network nationwide. The network is an extensive network, obviously, but, in addition, it has decreased by 5 percent in the last 7 years, from about 7,400 stations in 1990 to about 7,000 stations in 1997.

Now that's a bit of the bad news. The good news is that the number of stations that are telemetered, that have the link to satellites, so that we can virtually instantly get that information, has gone up significantly. And let me demonstrate that in this figure.

Here you can see our overall number of stream gauges has been constant or slightly decreasing, but the proportion of stations that have the telemetry, which is indicated here by these dark bars, has actually increased, and this is what's particularly important to the Weather Service and to our managers. We get this information out on the World Wide Web typically with a 4-hour delay, and under emergency conditions we can get it out much more quickly.

So we're increasing our telemetered sites. We're decreasing slightly on our total number of sites, and we're trying to address total issue, and we're trying to make sure that we can keep adding to the telemetered sites. Right now we're at about 43 percent with no telemetry; 57 percent that have telemetry.

We look forward to working with Congress and with this Subcommittee as this unprecedented event unfolds. And, again, I appreciate the opportunity to appear here this afternoon, and my colleagues and I would be happy to try to answer any questions you may have.

[The prepared statement of Mr. Schaefer may be found at end of hearing.]

Mr. DOOLITTLE. At this point we'll recess for the vote and then reconvene for questions.

[Recess.]

Mr. DOOLITTLE. Well, thank you for waiting for us, for me.

Dr. Leetmaa, was it you that referred to the storm of—was it 1878?

Mr. LEETMAA. Yes.

Mr. DOOLITTLE. Yes.

Mr. LEETMAA. 1887.

Mr. DOOLITTLE. Thank you, 1887——

Mr. LEETMAA. 1877/78.

Mr. DOOLITTLE. 1877/78?

Mr. LEETMAA. Right.

Mr. DOOLITTLE. And I guess we don't have too much data on that, but we have some, and that was a storm, if I understood you correctly, where it was wetter in northern California than in southern California.

Mr. LEETMAA. That's right. We had several stations. We had Red Bluff, which I think is California still.

Mr. DOOLITTLE. Yes.

Mr. LEETMAA. San Francisco, Sacramento, and San Diego. And if you look at the comparison of that one to 1982/83, what you had in San Francisco for the January, February, March period, 280 percent normal rainfall versus 215 for 1982/83; Sacramento, you had 240 percent versus 200 percent in 1982/83; Red Bluff was 400 percent versus 280 percent.

Obviously, after this event, we'll have some more confidence in knowing how these big events behave. So one of the ways we obviously try to bracket what's going to happen is to try to look at comparable kinds of things. So this is one more piece of evidence that, in fact, it probably will be quite wet in not only just southern California, but central California and northern California also.

Mr. DOOLITTLE. I apologize. This speaker went off up here, and I only sort of half-heard your last two or three sentences. Could you just restate that again?

Mr. LEETMAA. As I indicated, for any given El Niño event, there is an uncertainty in how much, what the range of precipitation might be. There's an unpredictability, in essence, and one of the ways we can study that unpredictability is to look events that look similar to the ones that we've observed or we can use numerical models, and both of those would then give you some spread on what happens. So this particular event is indicating that it probably is appropriate to think about both central and northern California also being heavily impacted this year.

Mr. DOOLITTLE. Was the 1877/78 event an unusually large El Niño event?

Mr. LEETMAA. Yes, scientists look back, and when they compare sort of the characteristics, the global characteristics, it certainly was comparable to 1982/83.

Mr. DOOLITTLE. It's interesting to hear that testimony because so much focus has been given to Southern California and the extraordinary amounts of rainfall they're supposed to have, which of course may, in fact, happen, but it could also happen that Northern California instead might get that impact.

Mr. LEETMAA. Yes.

Mr. DOOLITTLE. And for cities like Sacramento, that could be particularly serious—well, for the whole State's water supply, if a reaction to this prediction or estimate is to release too much water in anticipation of the 200 or 400 percent rainfall that they had at Red Bluff over 100 years ago. And really it's going to be tough. And what I'm getting out of this is it's just a rough guess. Yes, we know a lot more than we did, but it's still a rough guess that could be right or might not be right.

Mr. LEETMAA. That's right. I think the climate forecasts are always going to have a degree of uncertainty. I mean, they're basically pushing the mean rainfalls in a certain direction, but around those mean rainfalls there will be a spread; there will be a range. And so even 10 years from now or 20 years from now, it would be unlikely if we can basically narrow that spread down. So one has to look at the historical record and get some sense of what that spread looks like.

Mr. DOOLITTLE. Was it you who said that your short-range forecasts tend to be the most accurate?

Mr. LEETMAA. Yes, that was probably in my statement.

Mr. DOOLITTLE. But, even with that, isn't there a high degree of inaccuracy, even with the short-range forecasts?

Mr. LEETMAA. Perhaps I should let Dr. Friday, who used to be the head of the Weather Service, address that.

[Laughter.]

Mr. DOOLITTLE. All right. I'd be curious to know—it seems like somewhere I heard or read that there's about 50 percent accuracy on your short-range weather forecasts.

Dr. FRIDAY. Oh, actually, I believe the 50 percent accuracy number, it's the low end of the range on some of the seasonal outlooks. The short-range weather forecast, as far as storm events are concerned, heavy rain, thunderstorms, the accuracy on those forecasts are now up in the 80 percent range. That did not used to—that was not the case five or 6 years ago, before we put in the next-generation weather radars around the country.

Mr. DOOLITTLE. Oh, OK. So we've improved dramatically.

Dr. FRIDAY. We have dramatically improved the accuracy of storm and rain event forecasting since the introduction of the modernized National Weather Service.

Mr. DOOLITTLE. Dr. Friday, I was interested—and I don't think I knew about the weather buoys, that they're floating out there, I guess in the eastern Pacific, that were installed a few years ago in order to track El Niño. I am curious to know more about that. It seems that would have been quite a feat. How many of those were installed and how far apart are they? I'd like to know a little bit about that.

Dr. FRIDAY. It is a spectacular engineering and scientific success. After we looked back after the 1982/83 El Niño and we said, "Wow, what was that that hit us?", we recognized the fact of what it was and identified the fact that we really didn't know it was coming because of the limitations of the data-observing systems of the time was so great that we didn't have anything to base understand how it evolved.

An international research program was put together with cooperation from many countries around the globe, and in the United States, as I indicated, it was supported by NOAA, NASA, National Science Foundation, and the Office of Naval Research in DOD. Technology was developed, because people had indicated that you couldn't put data buoys out in the middle of the Pacific Ocean and have them stay in one place—it was just an engineering nightmare—technology was developed at NOAA's laboratory in Seattle, the Pacific Marine Environmental Laboratory, which allowed us to install in water that was 3, 3.5 miles deep data buoys right on the equator, and within a few degrees north and south of the equator. And over a 10-year period, we have installed 70 of those data buoys, all the way from the coast of South America, all the way over to Indonesia.

Now one of our NOAA ships operates full time out there just simply maintaining these data buoys, going out and repairing components and replacing components that fail. It is this information that not only measures the surface temperature, but it also measures the temperature below the surface of the earth down to 500 meters all the way across this area, and it was the subsurface information that gave us the hint back in January that we starting to see the development of an El Niño. And it was that subsurface information, coupled with the beginning of the surface impacts, that allowed Ants Leetmaa to be able to forecast the significance of this back in the springtime of this year. So we have maintained those buoys under a research component for many years, and in

this year's Presidential budget we are asking for those to be funded as a fully operational system, so that we maintain that throughout—in perpetuity, to keep track of this phenomena.

Mr. DOOLITTLE. Could you explain how they keep these buoys in place?

Dr. FRIDAY. I was afraid you were going to ask that.

[Laughter.]

Dr. FRIDAY. The buoys themselves are relatively small, and they are connected to an anchor on a very long nylon cable, and the design of the equipment on the buoy is so that it wasn't literally carried along with the equatorial current. The specific design to dampen the vibrations that would occur and all of that—the way they handled the moorings, the way they handled the coupling, that was the engineering feat, and it was a very complex design of those systems, so that it would not be literally carried away by the current.

But, in addition to the 500 meters of instrumented cable, with temperature sensors and in some cases salinity sensors that are directly under the buoys, there is another three miles of heavy-duty nylon cable that goes all the way to the surface of the bottom of the ocean, and there are large weights attached there to hold it in place.

Mr. DOOLITTLE. So each of these buoys is actually anchored to the bottom of the ocean?

Dr. FRIDAY. Yes, sir.

Mr. DOOLITTLE. That's amazing.

Dr. FRIDAY. What I said, this was an amazing engineering feat, and it has resulted in a tremendous success story in being able to understand how the ocean and the atmosphere links together to cause the change in water resources capacity for California.

Mr. DOOLITTLE. Did somebody have to go down to the bottom of the ocean?

Dr. FRIDAY. No, sir, they're deployed from—they have been deployed from the NOAA vessels, operating research vessels, and we now have, as I indicated, one vessel, the KAIM'MIMOANA, which operates out of Hawaii, that its full-time job is to go out and maintain those buoys.

Mr. DOOLITTLE. So this is a heavy weight resting on the bottom of the ocean?

Dr. FRIDAY. Actually, it's usually three or four railroad wheels.

Mr. DOOLITTLE. Railroad weights?

Dr. FRIDAY. The wheels from a railroad——

Mr. DOOLITTLE. Oh, railroad wheels?

Dr. FRIDAY. They're very heavy.

[Laughter.]

Mr. DOOLITTLE. That's very interesting.

Dr. FRIDAY. I would invite you, sir, if you're interested in this technology, to visit the laboratory in Seattle. All the capabilities, all the engineering work has been done in the NOAA laboratories there, and it is a spectacular engineering site.

Mr. DOOLITTLE. So if it's nylon cable, I guess that has an indefinite lifespan?

Dr. FRIDAY. No, sir, it does not. It does eventually decay. Also, we have not eliminated all the problems with that. These cables ac-

tually hum a little because of the currents passing them, and sharks don't like that. So when you pull up this equipment, you find a lot of shark teeth and shark prints on the instrument chain and on the upper reaches of the moorings.

Mr. DOOLITTLE. And how many years have these been there?

Dr. FRIDAY. The network was completed in 1994, and we have been operating it as a complete network ever since. We are now involved in trying to put some additional buoys in the northern Pacific because we know that although the tropical Pacific El Niño signal accounts for a large amount of the variability, there is also some changes in the northern Pacific Ocean that we are beginning to recognize that may affect the exact way that the El Niño storm system plays out. But the difficulty is the northern Pacific is much more hostile than the tropical Pacific is. The type of storms that affect the tropical Pacific are relatively mild compared to the tremendous storms up coming off the Gulf of Mexico and in that arena, that may have waves that just are incredibly large. And so we have another major engineering feat to be able to do that.

Our laboratory in Seattle says that they have solved that problem. They have now installed two of the buoys out there, and this winter is going to tell us whether they're really solved that problem with the winter storms there or not.

Mr. DOOLITTLE. Can you describe briefly what's different about those than the ones you've got?

Dr. FRIDAY. No, sir, I can't, but I can provide that information to you.

Mr. DOOLITTLE. OK. Maybe they're just heavier weights and thicker cable or something.

[The information referred to follows:]

The ATLAS buoys in the TAO array moored along the Equatorial Pacific are 2.3m diameter fiberglass torroids. They are inexpensive to fabricate, structurally rigid, and very stable instrument platforms. However, they have high drag due to the hull shape and limited weight capability. A new buoy has been designed for the North Pacific with lower drag and increased weight capability. An effort has been made to keep the cost down by using proven design and fabrication methods employed in the production of the torroid buoys. The new buoys are approximately 30 percent larger and require larger mooring components including wire rope, nylon line, hardware, and anchors. Consequently a high latitude mooring costs more that an equatorial mooring—probably an additional $10,000 each. The top of the instrument tower is typically 4 to 5 meters above the water surface.

The initial effort to move into the North Pacific was driven by a NOAA funded project to develop a real-time Tsunami Reporting system using open ocean observations and satellite communications. (PMEL received additional funding from DARPA.) Two moorings were deployed in FY 97 and additional deployments of these moorings are scheduled in the future (see http://www.pmel.noaa.gov/tsunami-hazard/). We are also supported by the National Ocean Partnership Program to place two air-sea/upper ocean climate reference station moorings in the North Pacific during FY98-99. The first will be at Ocean Weather Station P. and the second will be NW of Hawaii near 165W. These buoys will carry a very different sensor package than the Tsunami buoys, but the buoy is the same. You correctly stated in your testimony that our goal has been to develop a mooring system that can carry out a variety of tasks in the ice-free but still very demanding North Pacific environment.

Dr. FRIDAY. There is also something to do with the exact design of the instrument chain itself, so that it's better able to ride the waves, and the fact that the mooring line itself is not taut here, but it's flexible, so that the buoy can ride up and down on that. But

I don't know—I'm sorry, I just simply don't know the precise details of that.

Mr. DOOLITTLE. Just out of curiosity, have you had problems with ships running into those or something?

Dr. FRIDAY. Every time I have an opportunity of addressing any of the marine community, I try to point out the fact that buoys are their friends. They should not be used to tie up ships and they should not be used for target practice, because that happens to frequently the buoys, not only the deep ocean buoys along the coast.

Mr. DOOLITTLE. And these buoys are 6 or 8 feet high?

Dr. FRIDAY. They're probably on the order of 20-feet tall. They're on the order of around 10-foot across, and as I indicated, the instrumentation chain goes down for about 500 meters below the surface.

Mr. DOOLITTLE. Well, that's very impressive. What did each of those cost?

Dr. FRIDAY. They cost approximately $50,000 to $60,000 apiece, but it does take the operation of one entire oceanographic research vessel to maintain them on an annual basis.

Mr. DOOLITTLE. So that just plies the waters back and forth.

Dr. FRIDAY. Back and forth. The total annual operating cost to maintain this network is approximately $5 million a year. Now that, in one respect, seems like a lot of money, but when you understand, as you read off the impacts of the 1982/83 El Niño, with the economic loss and the loss of life associated with that, that's a very small cost to pay to be able to have the information to provide advanced forecasts of the situation as it evolves.

Mr. DOOLITTLE. Well, it certainly seems to me that it's money well-spent. I commend you and the organization for being able to cause that to occur and hope you can get the next phase taken care of.

Dr. Schaefer, you indicated that a number of stream gauges have been taken offline in recent years. Could you explain why that's happening when the need for these gauges and additional data seems ever more critical?

Mr. SCHAEFER. I'll give you the beginning of the answer, and then I'd like to turn, if I may, to Dr. Casadevall to expand on that.

We've been, of course, under funding pressure in general at the USGS, and we've had to make some difficult choices to fund our projects. I think, in general, what we're seeing right now are indications that we're beyond cutting into fat, and we're beginning to cut into the meat of some parts of our program. We recognize that this is a problem, and we want to address it, and I hope to be able to address it in the coming fiscal year, and to some extent in this fiscal year.

Also, what's happening is this system is really a system that comes about through the work of many cooperators on the State and local level, and our cooperators are also under financial pressure. Most of our gauging sites actually exist because of a 50/50 cost share. So when one of the cooperators pulls out, we're not in the position to pick up the other 50 percent. Now in some cases we have been successful in finding others that are able to do that, and we've been able to retain some stations that otherwise would have been lost.

But let me, if I may, ask Dr. Casadevall to expand on that.

Mr. CASADEVALL. Good afternoon, Mr. Chairman.

With regard to the gauge system, as Dr. Schaefer showed you in the graphic, we have about 7,000 gauges nationally. The image he showed you was the coterminous U.S. We also have gauges in the States of Hawaii and in Alaska.

Over the last few years, we've decreased the number of gauges from about 7,400 down to about 7,000, but what we've increased are the number of gauges that send data in real time through radio telemetry. And for the kinds of issues that we're addressing here in relation to El Niño, it's really essential that managers, water managers, dam and reservoir managers, city planners, and others have data in real time. So, on the one hand, we've decreased the number of total gauges, but some of those gauges, remember, were only visited on a monthly basis, and data is retrieved or was retrieved from those static sites on a monthly basis. On the real-time telemetry, we can get data as frequently as every 15 minutes. This is really the essential data that planners need and that folks in the Bureau of Reclamation and the folks in the Flood Forecast Office of NOAA need to be able to make decisions that affect people's lives and safety, which really is the first priority for us in this activity.

Mr. DOOLITTLE. Could you describe a gauge? In the Sacramento River, how big would one be? How costly is it? Where is it typically located?

Mr. CASADEVALL. Well, if you've ever crossed a bridge, for example, going across a river—and on the Sacramento River we can use an example—you've probably noticed a small house that, for better comparison, it looks like an outhouse; it looks like a portapotty. It's about 8 feet tall; it's about 4 feet on a side. Often on the top you'll see an inclined panel. That's a solar panel that is used to power the electrical components that are part of the gauge. What you don't see is that extending out from the gauge house down into the river is a hydraulic sensor or a pressure sensor that passes under to the base of the river. And it's information from that pressure sensor that gets recorded in the gauge house. That information then gets—if it's a telemeter site, radio-telemetered or satellite-telemetered back to a recording station in Sacramento, for example, at our USGS Water Resources District Office.

On the other hand, if it's a site that's only visited once a month, a hydro-tech, a hydro-technician will go out and retrieve the record. The record will be recorded right there onsite.

So you'll often see these, and I invite you the next time you're on a bridge driving across the river, keep an eye out for the outhouse, and if we're smart, you'll see the new USGS logo in bright green letters. We plan to put these on our more than 7,000 stream gauges around the country.

Mr. DOOLITTLE. And that sits in the bottom of the river and measures the velocity of the water?

Mr. SCHAEFER. Well, it measures the pressure of the water on the bed or the river, and as you add more water to the stream or to the river, of course, the pressure or the hydrostatic——

Mr. DOOLITTLE. OK.

Mr. SCHAEFER. [continuing] head increases on that. In addition, we've made very precise cross-sectional measurements, and we do

what we call calibrating that gauge, so that when there is a pressure change, we know, because of calibration, we know how much additional water is now being carried by the channel.

Mr. DOOLITTLE. Does all of that data feed into, I guess in the case of California, or at least the Sacramento area, into that place on El Camino there, the State and Federal Governments joint operation center?

Mr. SCHAEFER. In El Camino—in Menlo Park, California or——

Mr. DOOLITTLE. No, no.

Mr. SCHAEFER. Oh, up in Sacramento?

Mr. DOOLITTLE. El Camino and Watt in Sacramento.

Mr. SCHAEFER. The data from our continuous telemetered sites, the majority of those in the State of California are available on the Internet, on the USGS California State website. If we had a computer here right now, we could find the river closest to your home near Sacramento and we could find what gauge was there——

Mr. DOOLITTLE. Oh, OK.

Mr. SCHAEFER. [continuing] and we could look at the stage of the river right now in real time with data that's up to 4 hours old.

Mr. DOOLITTLE. Is there a standard cost on a stream gauge?

Mr. CASADEVALL. Well, let's suppose there's a gauge already there and we wanted to add telemetry. To add telemetry, we're talking about a telemeter package costing between about $3,500 and about $5,000. To install a gauge itself, to put the outhouse-type structure in, to put the piping in, to put the pressure transducer in, and the associated equipment, I believe there's a range in prices depending on where the site it and how much hardening of the site you have to do, but my recollection from years ago, that it's in the range of $35,000 to $60,000 per site. Once again, it depends on how hard we want the site to be, how hardy the site should be, to withstand flood conditions.

Mr. DOOLITTLE. Well, I think the Committee analysis mentioned that the middle fork of the American River is not very well-monitored, and I don't know what it takes to have it be well-monitored, but, obviously, we're spending the money out in the Pacific, which is money well-spent. Are there plans to, especially in a State like California with high mountains and the short distance from the mountains to sea level, et cetera, and right there on the coast, the first to receive the brunt of El Niño or some bizarre storm—are there some plans to increase monitoring in some of those types of areas?

Mr. SCHAEFER. Well, right now in the State of California we have more than 700 stream gauges. That's about 10 percent of our network nationally. I would have to check with my colleagues to find out what the plans are for this winter, and we'd be happy to get that information for you, and——

Mr. DOOLITTLE. Well, I'd be interested in that, and interested in supporting your efforts to increase your stations, both in the ocean and on land.

[The information referred to follows:]

Mr. DOOLITTLE. I guess I'm going to have to run out for a vote again. If we ask a couple more questions, we'll excuse you folks, because it's a half hour's worth of votes, apparently.

For Dr. Matthews, how do Bureau of Reclamation managers factor snow melt and runoff into reservoir management decisions?

Mr. MATTHEWS. The Bureau of Reclamation works very closely with the National Weather Service in their forecasting systems, and we take the snow water equivalent analyses throughout the mountainous West from the National Operational Hydrologic Remote Sensing Center. Their data has up to one kilometer resolution. We incorporate that through the National Weather Service River Forecast System to forecast runoff, where that's available.

We also look at that data directly and evaluate what the snowpack snowwater equivalent is and use that. We have some research tools that are currently being used to physically estimate the runoff from both accumulated snow and temperature forecasts. So that snowpack information is used on a routine basis throughout the spring runoff season.

Mr. DOOLITTLE. We had instances in California where they've had a lot of snow, and then a tropical storm comes in and melts it. I think 1986 was one of those events. Is that likely to be the case or is it a small possibility? El Niño is a warmer phenomenon, right? So are we more vulnerable to receiving storms that might melt our snowpack?

Mr. MATTHEWS. We could be. In many of the El Niños, we have a subtropical jet stream which brings in warm air out of the subtropics, and in that case there could be an earlier snowpack meltdown, which is what happened to a certain extent in the California flood January, 1997, I believe.

Chet Bowling is the expert here from our Central Valley Operations Office. I think he would be in a better position to describe the California events than I would.

Mr. DOOLITTLE. OK, we'll come back to him.

Dr. Schaefer, Dr. Friday, in his testimony, stated that some regions of the U.S. are relatively more vulnerable to the effects of El Niño. Does the USGS concentrate its stream gauging in the areas that are more sensitive to climate variability?

Mr. SCHAEFER. In part it does, and in part it doesn't. I'm sorry to give you a two-handed answer there. The stream gauge network really originally advanced for other than flood control and monitoring reasons. It was really put in place to help people monitor water conditions for use in irrigation, for example. And so that means that it does make sense for us to step back periodically and say, all right, now that we have this dual-use for this system and we're beginning to apply it to flood-related questions, where should we look strategically to put additional sites? And that's the reason why we're not only concerned about the overall downward trend in sites, but, frankly, we'd like to have it be an overall upward trend, so that we can begin to fill those gaps.

Mr. DOOLITTLE. I'd like to encourage you, as the chairman of this Subcommittee, to get that trend going back the other direction upward, because I think it's clear we're going to need to know as much as we can. Even knowing more now than we did before, we still are in the dark to a large extent.

I will have further questions, and I'll just tender them in writing and ask you to supply the answers as expeditiously as possible, and hold the record open for that point.

[The information referred to follows:]

Mr. DOOLITTLE. And then I'll excuse the first panel, and thank you all very much for your testimony.

Yes, sir?

Mr. SCHAEFER. Sir, I'd just like to thank you. This is a very technical area, and people don't often ask questions about how our monitoring systems operate. We appreciate your interest, and we would like to work with you in making sure that we've got the most robust monitoring system that we can get.

Mr. DOOLITTLE. Thank you. We'll excuse this panel and we'll recess. When we come back, we'll begin the final panel.

[Recess.]

Mr. DOOLITTLE. I thank you, ladies and gentlemen, for persevering. We had an unusual series of votes, and they're going to have an even more unusual series shortly. So we'll try and do this in the little period between that.

Let's call up the second panel, and please come forward and raise your right hands, please.

[Witnesses sworn.]

Mr. DOOLITTLE. Let the record reflect that each answered in the affirmative.

Thank you, gentlemen. Please be seated.

Our first witness will be Dr. Konstantine Georgakakos, president of the Hydrologic Research Center, Scripps Institution of Oceanography, the University of California at San Diego. And Dr. Georgakakos, you're recognized.

STATEMENT OF KONSTANTINE GEORGAKAKOS, PRESIDENT, HYDROLOGIC RESEARCH CENTER, SCRIPPS INSTITUTION OF OCEANOGRAPHY, UNIVERSITY OF CALIFORNIA, SAN DIEGO

Mr. KONSTANTINE GEORGAKAKOS. Thank you very much, Mr. Chairman, for the opportunity to testify concerning the involvement of the Hydrologic Research Center in the forecasting and in forecasting research associated with the predicted El Niño event. The Hydrologic Research Center is a nonprofit research corporation in San Diego, California, and in this testimony I will focus in particular on Center research activities pertaining to operational stream flow forecasting (as opposed to climate forecasting) for flood warning and water resources management.

Two Center research activities are directly relevant. The first one, assisting the California–Nevada River Forecast Center of the U.S. National Weather Service in improving the short-and long-term forecasts of Folsom Lake inflow in east central California. These forecasts will be used in the operation and management of the Lake waters and flow release.

And the second one, assessing the utility of integrated forecast-control methodologies for the operation and management of reservoir systems. Case studies in Iowa and California are now being conducted for this research.

Our research relies on mathematical hydrologic models of the watershed processes and of the flow forecast uncertainty. Watershed process considered for the case studies are snow accumulation and melt, and surface and subsurface flow. The flow forecast uncer-

tainty exists for three reasons. No. 1, incomplete coverage of watershed area by sensors—and I mean by precipitation sensors, temperature, wind, and so on—No. 2, large errors in meteorological forecasts used to drive the hydrological models, and that's a very large source of uncertainty for the smaller-scale hydrological models; and then mathematical model approximations of complex, natural processes.

Our results so far support the following conclusions:

No. 1, Snowmelt volume estimates in hydrologic forecasts are strongly affected by the density of the recording precipitation sensors in mountainous areas such as California. The accuracy of the computed snowmelt volumes within the 1,800, roughly, square miles of Folsom Lake Watershed decreases substantially with decreased watershed coverage by precipitation measurement sensors. For example, there are currently large areas drained by the Middle Fork of the American River with poor precipitation sensor coverage.

No. 2, substantial improvement of operational flow forecasts is attained when the current flow forecast systems are upgraded to include models for uncertainty and updating from flow measurements in real time. The improvement is mainly in the reduction of forecast errors for unusually high or low flow rates. Thus, in many cases meteorological forecasts with large uncertainty, as obtained in mountainous California during a storm event, can be used to derive useful hydrologic forecasts.

No. 3, the third conclusion, in a case study involving data since 1904 from the Iowa River at the Iowa City gauging station in Iowa, statistically significant seasonal stream flow associations to ENSO were found. Analogous associations were not found for the American River at Folsom Lake. These studies are ongoing, and although strong associations between ENSO and seasonal stream flow volumes in extremes in the Southwestern U.S. have been found, no such statistical associations have been identified for central and northern California. It doesn't mean they don't exist. It is possible that the three-to-seven-year ENSO signal is concealed by the extreme year-to-year variability of stream flow in the Folsom Lake Watershed.

The fourth conclusion, substantial benefits for operational reservoir water management were obtained for the Saylorville Reservoir in Iowa, one of our case studies, when flow forecasts were used as input to the decision process with due account for forecast uncertainty, and that is important. On the basis of extensive computer simulations of the watershed-reservoir system, it was found that using coupled forecast-control methodologies reduces reservoir management sensitivities to climatic variability and to the large uncertainties associated with the forecast of such variability by current climate models. Analogous simulations are in progress for Lake Folsom in California, and my brother, Professor Aris Georgakakos of Georgia Tech, will testify to that effect.

I wish to make the following topical recommendations:

One, conduct detailed studies to quantify the uncertainty associated with the estimation of precipitation and snowmelt over the Sierra Nevada in California.

Two, advanced stream flow forecast procedures should be implemented and utilized in parallel to current operational ones to evaluate increased benefits to operations. Such procedures should include models for uncertainty of meteorological forecasts and should utilize stream flow observations to improve the forecasts continuously in real time.

Third, in parallel to No. 2 above, coupled forecast-control methodologies with due account for forecast uncertainty should be implemented in prototype watersheds. In this context, the utility of climate forecasts for increasing the benefits of reservoir management should be quantified.

Real-time flow forecasting and reservoir water management are important operational functions for mitigating natural disasters. These functions, vital for present-day communities, have their bases on hydrologic science and engineering and water resources systems analysis. As the requirements of the public for safety and reduction of damage losses from natural disasters increase, it is important to formulate a national plan for the increased effectiveness of these operational functions.

I have argued elsewhere in the scientific literature that to achieve these goals and in analogy to the establishment of our National Center for Atmospheric Research in the atmospheric sciences, it appears necessary to establish a National Center for Hydrology and Water Resources. I firmly believe that, with the establishment of such a national center, much progress will be made almost immediately on a national level by concerted efforts to enhance the flow of information from research to operations. Such a center is envisioned as a collaborative effort among universities, the Federal Government, and the private sector.

With this last important recommendation, I now conclude my testimony. I will be pleased to answer your questions.

[The prepared statement of Mr. Konstantine Georgakakos may be found at end of hearing.]

Mr. DOOLITTLE. Thank you, sir. And our next witness is Dr. Aris Georgakakos, director of the Georgia Water Resources Institute, Georgia Institute of Technology. Dr. Georgakakos.

STATEMENT OF ARIS GEORGAKAKOS, DIRECTOR, GEORGIA WATER RESOURCES INSTITUTE, GEORGIA INSTITUTE OF TECHNOLOGY

Mr. ARIS GEORGAKAKOS. Thank you, Mr. Chairman. It is, indeed, a pleasure and an honor to testify before this Committee. I'm an expert in the operational management of reservoir systems, and my testimony particularly addresses the value of climate and hydrologic forecasting in reservoir operation.

With proper management, reservoirs can provide vital services to human communities, including the mitigation of severe floods and droughts, the generation of hydroelectric energy, the provision of water supply to urban, industrial, and agricultural areas, recreation, navigation, and the sustainable management of riverine ecosystems.

However, the extent to which reservoirs succeed in providing these services depends critically upon the manner in which they are operated. Consider, for example, the Folsom Reservoir in east

central California, shown on figure 1 of my written testimony, which is expected to provide flood control, generate electricity, provide water supply for irrigation, and maintain a certain downstream flow rate in the American River for water quality and ecosystem preservation. In the interest of hydropower, the reservoir should always be full to create the highest possible hydraulic head for the turbines and maximize their power output. However, from a flood control standpoint, there is a need to draw the reservoir level down in anticipation of floods, free up storage space, and accommodate flood volumes without causing downstream damage.

In a world without uncertainty, the reservoir managers would know the magnitude of the flood precisely and could run the turbines at full power prior to the flood to lower the reservoir just enough to receive and contain the flood volume. This scenario would be ideal because it would avoid downstream damage; it would pass the entire flood through the turbines without wasting power to spillage, and it would maintain the reservoir as high as possible, maximizing its value for hydropower, flood prevention, and the other water uses.

Unfortunately, in the real world in which we live, reservoir managers can only guess the magnitude of the upcoming floods through imprecise climate, weather, and stream flow forecasts, and the challenge is to balance the risk for flood damage against the adverse impacts on hydropower and other reservoir uses. Whether their decisions are successful or not depends critically on two factors: First, the quality of stream flow forecasts and, second, the ability to fully utilize them through an integrated and flexible decision system and process.

In principle, good, quality stream flow forecasts are expected to benefit reservoir management. However, the actual benefits depend on many system-specific factors, such as the lead time and reliability of forecasts, reservoir size related to inflow volume, hydrologic characteristics of the outlet structures, turbine discharge capacities, flood damage thresholds, and the levels and timing of other water demands.

Thus, to assess the value of stream flow forecasts in the management of Folsom, I developed a computer model which includes a forecasting, a decision, and a simulation component. A brief description of this model and its underlying assumptions appears in my written testimony and will not be elaborated here, other than to say that it represents most Folsom features, which were kindly provided by the Bureau of Reclamation and the Folsom operators, and is designed to assess the relative differences in reservoir performance under different forecast scenarios of low, intermediate, and perfect skill. These assessments are made by recreating the Folsom response over the historical period from 1964 to 1995, assuming that the reservoir was operated with the guidance of the decision support system.

Folsom's performance is measured in accordance with three criteria: flood damage in millions of dollars, annual energy generation revenue in millions of dollars, and annual spillage in million cubic feet. The results indicate that Folsom would benefit substantially from improved forecast skill. Most notably, flood damage would be mitigated from approximately $5.3 billion in the case of low-skill

forecast to about $220 million in the case of intermediate-skill forecast. Relative to energy generation, the value of intermediate over low skill forecasts is approximately $1 million per year. And in the extreme scenario of perfect forecast skill, flood damages would be fully mitigated, and energy revenues would be increased by another $2 million per year.

While the previous results are annualized, the actual year-by-year benefits would be much higher. For example, figures 3 and 4 of my written testimony illustrate this comparison for the high-flow year of October 1, 1996 to September 30, 1965. For this particular period, the low-skill forecast scheme would cause heavy flood damages, on the order of $4.3 billion, whereas the other two would completely avoid flooding. Similarly, energy revenues would increase by approximately $4 million from the low to the intermediate-skill forecast scenario, and almost $8 million from the intermediate to the perfect case.

One last point to emphasize is that the above-referenced benefits can only be realized if forecasts are used in connection with dynamic decision schemes that fully account for forecast uncertainty. By contrast, static reservoir rule curves, which are traditionally used in the operation of reservoir systems, would fall short of realizing the value of improved forecasts.

I have so far argued that good quality, long-lead stream flow forecasts, coupled with appropriate decision support systems, improve reservoir management. An important and relevant question is: By how much can stream flow forecasts actually be improved?

A reliable answer to this question can only come from the continuing research on coupled climate, weather, and hydrologic prediction systems. My experience with such integrated approaches in the midwestern U.S., east-central Africa, and South America is promising, albeit at a preliminary stage.

The most concrete improvements in short-range—that is, up to one month—stream flow forecasting can be realized from the use of hydrologic watershed models. To assess the value of such models, I also conducted an experiment using an adaptation of the National Weather Service River Forecast System, coupled with the Folsom decision system, in collaboration with Dr. Konstantine Georgakakos of the Hydrologic Research Center in San Diego, California. The results were comparable to those of the intermediate-skill forecast experiment mentioned earlier, indicating that such forecast decision systems could accrue significant operational benefits.

Lastly, as a first step toward assessing the value of El Niño information in the management of Folsom, I investigated the correlation between sea surface temperatures at the equatorial Pacific Ocean and monthly Folsom inflows. I was unable to find any significant relationship between these two variables, which led me to conclude that a strong El Niño does not necessarily imply a predictable change in the weather patterns over the Folsom drainage basin. This conclusion, however, may not apply to other regions of the western United States. In fact, similar case studies have shown that, if strong enough, this correlation between El Niño and stream flows does improve forecast skill and reservoir operations.

In conclusion, I'd like to reiterate that integrated forecast decision systems can significantly mitigate flood damage, increase the value of energy generation, and potentially benefit all other water uses. However, the magnitude of these benefits are system-specific and can only be assessed on a case-by-case basis.

In addition, better forecasting procedures do not by themselves imply operational improvements. Such improvements can only be realized through coupled forecast decision systems and institutional processes. In this regard, there is a pressing need to make water resources professionals fully aware of the capabilities and benefits of integrated decision systems and processes relative to traditional operational practices. An effective means to stimulate this transfer of technology from researchers to the user community is through the support of prototype demonstration projects throughout different regions of the U.S. with the involvement of both groups. I would like to urge the Committee to support such demonstration projects through existing or new funding programs, an example of which is the GENEX Continental Scale International Project (GCIP) of the National Oceanic and Atmospheric Administration (NOAA).

Thank you for the opportunity to present this testimony on the implications of recent advances for the management of water resources.

[The prepared statement of Mr. Aris Georgakakos may be found at end of hearing.]

Mr. DOOLITTLE. Thank you, sir.

Our next witness will be Dr. Soroosh Sorooshian, professor of the Department of Hydrology, University of Arizona. Dr. Sorooshian.

STATEMENT OF SOROOSH SOROOSHIAN, PROFESSOR, DEPARTMENT OF HYDROLOGY, UNIVERSITY OF ARIZONA

Mr. SOROOSHIAN. Thank you, Mr. Chairman. As we've heard today and read in many places, we do know that this year's El Niño is the strongest yet recorded. We also know that statistical evidence points to above-average winter precipitation for the Southwest United States. However, these facts do not constitute sufficient information for water resources and emergency managers to initiate major changes in operating practices. Such decisions require reliable information about the expected arrival time of significant storm systems, their expected duration, and intensities.

A storm system that arrives during warm weather may not result in snow accumulations at high elevations, but may instead produce large amounts of runoff and potential flooding. Without accurate information about the timing and quantities of precipitation and stream flow, it is very difficult to plan timely evacuation from flood-prone areas or to pre-release large quantities of stored reservoir water to help mitigate the flooding.

On the other hand, precipitation which arrives during a cooler period may accumulate as snow at high elevations. In this case, water resources managers have greater flexibility to evaluate options and to decide on an appropriate operational strategy. Under this scenario, it would be a lot less risky to commit to other reservoir releases, knowing that melting of the above-average

snowpack will provide the water necessary to fill the reservoirs later in the season.

However, rapid warming could cause sudden large releases of melt water leading to late winter and/or spring flooding. It is critically important, therefore, that accurate estimates of the volume of water in the snowpack and timely and accurate temperature forecasts during the melt season be available.

I wish to strongly emphasize that sound water resources management decisions in the Southwest will require far more information than merely the knowledge of a strong El Niño signal. Water resources managers are rightly reluctant to order early reservoir releases without further information. In the few instances that I know of where early decisions have been made regarding reservoir releases and other water management issues, the knowledge that this will be a strong El Niño year has been only one of several useful pieces of information, but not the sole decision factor.

For instance, the Salt River Project, which supplies water to the greater Phoenix area, has incorporated the information about the strong El Niño signal into its decision to reduce ground water pumping by some 40,000 acre feet this year. This requirement will instead be satisfied from the reservoir system based on expectations that an above-average spring snowmelt runoff will fill the reservoirs to their normal level.

Water resources and emergency managers are accustomed to making decisions based on probabilistic information. While the knowledge of a strong El Niño year has enhanced the probability for a wetter-than-average year in the Southwest, it has not reduced uncertainty of many other factors critical in making decisions regarding major deviations from normal operating practices. In order to enhance the quality and usefulness of both short-term, meaning hours to days, and extended, weeks to months, forecasts, the reliability of hydrologic prediction systems for the western U.S. must be improved. The primary components of this system are the quantitative precipitation forecasts, extended stream flow prediction, and more accurate methods for estimating snow accumulation, particularly in the mountainous regions, and high resolution accurate rainfall measurements are critical for forecasting rapidly developing flood events.

The strength of the current El Niño signal has attracted a lot of media attention and has generated much-needed public attention to this climatic phenomenon. The climate research community is to be commended for developing the capability of predicting it with such a high degree of accuracy. Perhaps the greatest benefit of this prediction to the water resources management community has been in encouraging very close cooperation among the Federal and state agencies responsible for various aspects of water resources management and hydrologic services.

As an example, the cooperation over the past several months between the U.S. Bureau of Reclamation, the National Weather Service's Colorado Basin River Forecast Center, and the USGS has resulted in close coordination for sharing modeling and observational information required for improved management of the reservoir systems on the Colorado River. Continued cooperation among these agencies will be critical to the development of an operational hydro-

logic prediction system for the western U.S. to be used for water resources management in both El Niño and non-El Niño years.

It's worth noting that while statistical evidence points to a wetter-than-average year in the Southwest during a strong El Niño year, the wettest winter on record, which was 1993 in the White Mountains and the surrounding areas of southern Arizona, was not an El Niño year. A reliable hydrologic prediction system is crucial for the efficient management of western water resources, irrespective of whether we are experiencing an El Niño weather pattern or not.

Finally, most of the Southwest at the current time is below average in terms of its precipitation. In the Tucson area, we are about three inches below normal, and I hope you and other folks here will pray for us to receive the additional precipitation expected from a strong El Niño year. Thank you very much.

[The prepared statement of Mr. Sorooshian may be found at end of hearing.]

Mr. DOOLITTLE. Thank you, sir. Our next witness is Mr. Richard Andrews, director of the Governor's Office of Emergency Services, the State of California. Mr. Andrews.

STATEMENT OF RICHARD ANDREWS, DIRECTOR, GOVERNOR'S OFFICE, EMERGENCY SERVICES, CALIFORNIA

Mr. ANDREWS. Thank you, and thanks for the opportunity to speak today on the many activities underway in California in preparation for El Niño, as well as issues related to Federal policies and practices that influence our preparedness and disaster recovery efforts.

Despite the considerable uncertainties about what the impacts of El Niño will be, we are confident that State and local governments will be well-prepared to meet the challenges that severe winter weather may bring. As is well-known, California has in this decade had repeated and varied experience in coping with the consequences of natural disasters, including large fires, earthquakes, and floods. We have improved our local and State response systems after each event. California has, I believe, the most effective emergency response system in the Nation.

The El Niño forecasts have helped accelerate ongoing preparedness efforts that followed this January's historic floods in central and northern California. In January 1997, the State experienced serious flooding in 48 counties, with damages totaling nearly $2 billion. These floods came only two years after a series of winter storms in the first quarter of 1995, where losses also totaled $2 billion, led Governor Wilson to declare for the first time in the State's history all 58 counties as disaster areas.

At the height of the 1997 winter storms, Governor Wilson established the Flood Emergency Action Team to review the lessons and to establish long-term strategies to protect Californians from future flood disasters. Following a series of hearings throughout the impacted region, the Flood Emergency Action Team made more than 50 recommendations that had been implemented to improve the State's flood-fighting systems, including improving emergency response coordination between public safety agencies at the local and State level, the Army Corps of Engineers, and local flood mainte-

nance organizations, improving also and expanding existing flood data. To expand the State's existing flood data, the California Department of Water Resources has installed telemetry linking nearly 50 stream-gauging sites in areas that have high flood probability.

On October 6, Governor Wilson convened an El Niño Summit in Sacramento. In this Executive Order, signed on that date, the Governor directed that OES and the Department of Water Resources establish technical assistance teams and conduct a series of regional workshops throughout the State to review specific State and local preparedness action. Governor Wilson also signed legislation allocating $7.4 million for El Niño preparedness measures, including the prepositioning of flood-fighting resources as forecasts become more specific.

In addition to the actions being undertaken by the State, local governments, community groups, and businesses are taking unprecedented preparedness measures. Supplies have been stockpiled, storm drains cleared, evacuation procedures reviewed, and strategies for the care and shelter of individuals updated. Many cities and counties have held special flood preparedness drills and developed specific emergency plans for possible El Niño impacts. California will continue to provide the public with the best available information through the Internet, briefings and workshops, training sessions, technical assistance teams, and the stockpiling of equipment.

The Federal Government is an important partner in the State's overall preparedness effort and plays an essential role in helping communities recover from the impacts of natural disaster. In a letter to President Clinton on October 6, Governor Wilson urged action on several concerns about the current Federal policies and practices that impacted the pace of recovery from past floods and which also affect current and future preparedness and recovery efforts, including, first, urging the Army Corps of Engineers to accelerate the timetable to make repairs to levies damaged in central California in January 1997. Policy disputes between Corps officials in California and Washington slowed recovery during the spring and summer months. Progress is now being made, and if we're fortunate to have winter storms hold-off until the end of November, we have received indication from the Clinton Administration that all but one of the critical central California flood control repairs should be in place to handle the flows. We would hope that this year's experiences of unnecessary delays would not be repeated following future flooding.

In the event levies are not fully repaired, direct the Corps to undertake response preparations to improve their emergency response under Public Law 84–99. Again, we have received general assurances from the administration that these suggestions will be acted upon.

Second, direct all Federal regulatory agencies to consolidate the needed approvals for flood channel clearance. Governor Wilson has directed all State agencies to place the highest priority on expediting approvals for this work. A large number of Federal agency approvals are also needed. Local agencies need clear and consistent permit requirements and procedures from Federal agencies.

On October 24, the Corps of Engineers issued a nationwide 31 permit for channel-clearing and sediment removal in Los Angeles

County. Over this past weekend, the county began some of this important work. Governor Wilson remains concerned, however, that the Environmental Protection Agency has indicated that it will seek a policy review of the cumulative impacts of channel-clearing activities with the intention of requiring further mitigation work.

Fourth, direct FEMA and the Corps of Engineers to modify policies for local agencies that conduct flood fights on flood control works. As a result of Federal policies arising from the 1993 Midwest floods, there now exists in some important instances a disincentive for local agencies to assist in flood fights.

Finally, direct FEMA to implement the recommendations relating to public assistance processes and policies made by the California congressional delegation in a September 15th letter to the FEMA Director.

All Californians are grateful for the assistance we received from Congress and the administration as we join together on the levies to battle the flood waters of last year's storms. We are also grateful for the assistance we continued to receive in the flood's aftermath as communities and individuals worked to repair the damage and clean up homes, farms, and businesses. State agencies, local governments, community groups, and individuals are currently engaged in an unprecedented preparedness effort in advance of this year's winter. Our common goal is to reverse Mark Twain's famous aphorism: "Everybody talks about the weather, but nobody does anything about it."

Thank you very much.

[The prepared statement of Mr. Andrews may be found at end of hearing.]

Mr. DOOLITTLE. The next witness and final witness is Mr. Stephen K. Hall, executive director of the Association of California Water Agencies. Mr. Hall.

STATEMENT OF STEPHEN K. HALL, EXECUTIVE DIRECTOR, ASSOCIATION OF CALIFORNIA WATER AGENCIES

Mr. HALL. Thank you, Mr. Chairman.

As you may know, the agencies that we represent are the local agencies that are the closest to the flooding when it occurs. So we have a lot at stake in this discussion, and we thank the Committee for its interest.

I'd like to make three quick points regarding the weather in California and what we'll do about it. First, as you've heard this afternoon, and as we all well know, the weather in California is highly variable and unpredictable. In the last 20 years, we've had 2 years that have fallen into the normal range in rainfall totals. Every other year has either been dry or wet.

And there's probably no better example of the variability of weather than 1997, when we were both dry and wet. In January of this year, we received 30 inches of rainfall in the northern California watershed. Our largest flood control reservoir nearly filled in a week's time. The flooding that occurred caused $2 billion in damage; 120,000 people were put out of their homes, 9 people lost their lives. The spring that followed was the driest that we've had in 104 years, and so at the end of the irrigation season we faced the in-

credible situation of having record rainfall and flooding followed by delivery cutbacks to irrigators late in the season.

That was due in part to the extreme weather variability, but also due to the state of the system that we use to operate for flood and water supply. We've done a pretty good job—in fact, I would say a very good job—in recent years of improving our capabilities to manage the system for both flood control and water supply, but the system itself is outdated and undersized. The heart of the system is in the Central Valley, our largest watershed. It's an impressive system, has 23 reservoirs, over 1,800 miles of levies and channels, but most of that was built before modern construction techniques were available, and as the 1997 floods showed, it is very vulnerable. We will not finish all of the repairs necessary from those floods before the next flood season begins.

It also lacks storage. As an example, on the Colorado River they average 15 million acre feet of annual runoff. They have 60 million acre feet of storage, 4 years' worth of annual runoff.

On the Sacramento River system, we have 16 million acre feet of storage to take care of 22 million acre feet of runoff, less than one year. That's why we floo so often. That lack of capacity means water managers have to make a lot of tough choices. The same system that protects lives and property also serves the Nation's largest economy. Water managers will always err on the side of public safety, as they should, but that means there is even more stress to operate for water supply.

We've made great strides in stretching supplies, but the problem is getting worse because in the last 20 years our population has essentially doubled. We have done nothing to add to our flood control or water supply infrastructure.

That leads to my third point: Not only have we not grown the system, there have been substantial new demands placed on it. The Bay-Delta Estuary, which is the heart of our water supply and flood control system, is also an estuary that contains over 120 species, some of which are endangered. We have dedicated several million acre feet of water to protection of those species in the last several years. That has put a substantial additional demand on the system which is straining our water supplies even further.

I might note that the environment also suffers from floods as well as water shortages. This year biologists are very concerned about the impacts to salmon populations from the floods early in the year that wiped out substantial habitat. New storage on the system would help regulate flows to protect lives, the economy, and the environment.

From these observations that we will continue to have variable weather, we do have a system that is too small and out of date, and that we have put substantial new demands on the system in recent years, one has to conclude that we need to improve and add to our existing system. We are in support of a recently announced study by the Corps of Engineers to undertake a comprehensive reassessment of the flood control system in the Central Valley. We, likewise, appreciate what the Wilson administration is doing to prepare for the El Niño year that we're facing, and we agree with them about the need to take action at the Federal level.

Perhaps most importantly, we are actively involved in the CALFED process, a comprehensive look at the Bay-Delta to focus on ecosystem restoration, improved flood control, and improved water supply. We believe that it is our best hope in the foreseeable future to bring about the kinds of improvements necessary in our system to meet the needs of the people of the State.

We appreciate the fact that the Federal Government has been involved in the CALFED process because there is clearly a Federal interest in doing so. We look forward to working with you, Mr. Chairman, and with the Congress in future years to complete the planning process in CALFED, and then move on to implementing the plan that it produces.

Thank you.

[The prepared statement of Mr. Hall may be found at end of hearing.]

Mr. DOOLITTLE. Thank you. Well, we got through that, and I only missed one vote, but I can't miss another one. So let's take advantage of what time we have for questions.

Mr. Hall, your testimony talks about the need for additional water storage in California. Are you referring to on-stream storage, off-stream, or both?

Mr. HALL. We're certainly open to both. Certainly, there is a need for improved flood control on-stream, and there are great potential advantages to off-stream storage, even for flood control, as well as water supply. So we would support certainly a lot of off-stream storage, and in selected cases on-stream.

Mr. DOOLITTLE. Thank you.

Mr. Andrews, do you agree with Mr. Hall's general assessment about the strains on California's water supply system?

Mr. ANDREWS. Yes, absolutely, and as part of the second phase of the Governor's Flood Emergency Action Team work, we're addressing issues of the long-term strategy that's needed because, clearly, as Mr. Hall indicated, the system itself is simply limited, and we can operate it as effectively as we possibly can, using the best forecasting information available, but there are simply inherent limitations to the system that can only be addressed by a more long-term comprehensive solution.

Mr. DOOLITTLE. To what extent has the State water project been evaluated for the potential impacts of the El Niño event?

Mr. ANDREWS. Well, the Department of Water Resources is continually working with NOAA and with the National Weather Service, with the Reclamation groups, to evaluate it. David Kennedy, the Director of Water Resources, is confident that they're taking every measure that they can, given the uncertainty of the forecast right now, to try to make sure that the system can handle, to the extent it can given its overall capacity, what is now being forecast.

Mr. DOOLITTLE. Thank you.

Dr. Sorooshian, in your opinion, how well are other water agencies and utilities which operate dams, which may or may not have the flood control component, integrated in the decisions taking place between state and Federal agencies—excuse me—in the discussion taking place between state and Federal agencies?

Mr. SOROOSHIAN. Mr. Chairman, as I pointed out, it's really a wonderful thing out of this El Niño year that much closer coopera-

tion is already taking place. Certainly, once this period is over, I think the agencies should be encouraged to evaluate to see how their cooperation has improved the amount of exchange of information to minimize—for instance, in the late '80s there was an episode of warming in the Colorado which resulted in major flooding and damage to the Grand Canyon Dam. When one in hindsight looks at it, if better information exchanges had taken place, perhaps better operating policies could have been implemented to avoid situations like that.

So, in general, I am very optimistic, and we see a lot more interaction between agencies.

Mr. DOOLITTLE. Thank you.

Dr. Konstantine Georgakakos, how important is it in your opinion to be able to get real-time data from all the stream gauges, if we are to make substantial improvement of operation flow forecasts?

Mr. KONSTANTINE GEORGAKAKOS. I think it's very important, especially in view of the uncertainty in the meteorological forecasts, and probably for short hydrologic forecast lead time, say between 6 and 18 hours.

Mr. DOOLITTLE. Mr. Andrews, you said that through the Department of Water Resources, California has installed nearly 50 stream-gauging sites in areas that have high flood probability. To what extent is that data collection activity coordinated with USGS?

Mr. ANDREWS. The initial intent was to have the USGS join in that effort, and my understanding is that, because of funding limitations, they were not able to deploy additional instruments or to provide real-time telemetry on additional instruments. So that the state went ahead and both installed additional instruments, but the major step was to link the 50 states with real-time telemetry.

Mr. DOOLITTLE. So, do you forward that information along to USGS anyway?

Mr. ANDREWS. Oh, yes, the information is forwarded onto USGS.

Mr. DOOLITTLE. OK.

Mr. ANDREWS. It's just that we had hoped for a more robust array than we were able to find——

Mr. DOOLITTLE. I think we're going to have to find them some more money to do their part of the bargain here.

Dr. Aris Georgakakos, you state that the benefits to reservoir management that you describe in your testimony can be realized only if forecasts are used in connection with dynamic decision schemes, but that static reservoir rule curves, which are traditionally used in the operation of reservoir systems, would fall short of realizing the value of improved forecasts. Could you elaborate some on what you mean by that, dynamic decision schemes versus static reservoir rule curves?

Mr. ARIS GEORGAKAKOS. The main difference is really the ability to incorporate the uncertainty of the hydrologic forecast. The usual, the traditional operating rules of reservoirs do not really handle that very well. While dynamic systems follow the hydrologic forecast, they incorporate the uncertainty within them and have a better sense of the operation of the system, and that's basically what I meant.

Mr. DOOLITTLE. Gentlemen, I sincerely regret that I haven't had more time to ask you and the other panel more questions. I'll ask you, if you would, please, to respond to some of our written questions.

[The information referred to may be found at end of hearing.]

Mr. DOOLITTLE. I appreciate the work that you are doing and the efforts that you have made to come here this afternoon, and now into this evening. I hope we aren't making you miss your plane flights.

We will hold the record open and would ask you to respond as quickly as possible to those supplementary questions.

And with that, the hearing is concluded.

[Whereupon, at 6:04 p.m., the Subcommittee adjourned subject to the call of the Chair.]

[Additional material submitted for the record follows.]

STATEMENT OF ELBERT W. FRIDAY, DIRECTOR, OFFICE OF OCEANIC AND ATMOSPHERIC RESEARCH, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, U.S. DEPARTMENT OF COMMERCE

Mr. Chairman and Members of the Subcommittee: The past fifteen years have witnessed remarkable advances in the observations, understanding and predictions of climate variability, especially as related to El Nino. This is an outstanding scientific success story in which NOAA research has played a leading role. We have entered a new era where we can now observe and closely monitor El Nino conditions as they develop, and can also provide measurably skillful forecasts of future conditions for at least a few seasons in advance. We have further established connections between El Nino and regional and global climate variations which can begin to be incorporated into decision making in climate-sensitive sectors, such as energy and water resources.

These are extraordinary steps forward. At the same time, it is important to keep in mind that the science of climate prediction is still in its infancy, and is developing rapidly. Therefore, much of what I describe will be products of ongoing research by NOAA and its partners and, clearly, much more remains to be done in this area. I must also emphasize that climate predictions are by their nature probability forecasts. That is, El Nino alone will not determine what happens in our Nation's weather over the next year, but rather it will shift probabilities in such a way as to make certain climate events more likely, and others less likely. Further, El Nino does not influence all parts of our Nation's weather in the same way, and some regions are relatively more vulnerable to its effects. My testimony will outline principal features of El Nino, describe the status of the current event, and summarize recent research results on climate risks associated with El Nino over the United States.

BACKGROUND

What is El Nino, and how is it related to larger scale patterns of climate variability? In brief, El Nino refers to a naturally occurring phenomenon in the equatorial Pacific Ocean which is characterized by an unusual warming of the sea surface temperatures extending from the South American coast to near the dateline. The flip side of El Nino, often called La Nina, is characterized by abnormally cold sea surface temperatures over the same region. Both El Nino and La Nina have major effects on global and regional climate. El Nino (and La Nina) events happen on average every two to seven years and, once established, persist for six to twelve months (Exhibit 1). The persistence of such conditions provides one key as to why El Nino is potentially useful for climate predictions.

A second key is that El Nino is not an isolated oceanic phenomenon but, rather, involves coupled ocean-atmospheric interactions in the tropical Pacific. The coupled phenomenon is called the El Nino—Southern Oscillation, or ENSO, where Southern Oscillation refers to systematic changes in tropical atmospheric pressure patterns. El Nino conditions, such as we are experiencing now, are associated with a pronounced weakening of the trade winds which ordinarily blow from east to west across the tropical Pacific. The tropical rainfall patterns also shift, with the heaviest rainfall moving eastward following the warmer water. The changes in tropical rainfall alter the global wind patterns and, in particular, the jet streams, which in turn affect our Nation's weather. La Nina also exerts important effects on global wind patterns through essentially the same processes, although in many cases the climate changes are reversed. For North America, the largest and most systematic effects on climate with either El Nino or La Nina events are usually experienced in winter and spring.

By the early 1980s, there was growing recognition in the climate research community that ENSO was a major source of climate variability, and that potentially useful seasonal predictability of this phenomenon was possible. However, in 1982, the onset of the largest El Nino in this century was not even recognized, let alone predicted. The failure to identify the initiation of this major event was due to inadequacies in data, to deficiencies in our conceptual understanding of fundamental causal mechanisms, and to the rudimentary nature of prediction models at that time.

To address important challenges in ENSO observations and prediction, a new research program on the Tropical Oceans and Global Atmosphere, or TOGA, was initiated in 1985. TOGA was sustained by cooperative efforts of four agencies: NOAA, the National Science Foundation, NASA, and the Department of Defense's Office of Naval Research, with NOAA leading the interagency research program on interannual climate variability since 1982. As noted in a 1996 report of the National Research Council, the TOGA program, which formally ended in 1994, has left a series of important legacies, including:

(1) an observational system supported by NOAA, called the TOGA TAO (Tropical Atmosphere—Ocean) Array, that provides a vital set of *in situ* observations for monitoring El Nino conditions and for initializing computer models for El Nino forecasts;

(2) the ability to project El Nino conditions in the tropics a few seasons in advance with measurable skill;

(3) an improved ability to estimate the global atmospheric response to projected oceanic conditions in the tropical Pacific;

(4) the increased use of climate information and forecasts as a factor in decision-making in climate-sensitive areas.

These major advances are all critical to today's discussion. As one example, unlike 1982, the current ENSO observing system has allowed us to identify and describe the evolution of this year's major El Nino event as it is occurring, rather than after the fact. The *in situ* observations also provide fundamental input data for the computer models that are now being used to forecast the evolution of this event.

The 1997 El Nino Event

NOAA is closely monitoring the evolution of the 1997 El Nino event, and is making its data and analyses available in real-time through various media, including the World Wide Web, through sites at the Climate Diagnostics Center (CDC), Pacific Marine Environmental Laboratory (PMEL), Climate Prediction Center (CPC), and Office of Global Programs (OGP). The latest TAO array data indicate that very strong El Nino conditions continue in the tropical Pacific, with sea surface temperature anomalies exceeding 4.5C (9F) in the eastern Pacific. Sea surface anomalies through much of the central and eastern tropical Pacific are at the highest observed values in at least the last 50 years, exceeding even the 1982-83 event at this time of year. It is important to note that by early last winter, the National Centers for Environmental Prediction (NCEP) coupled model was forecasting a transition to warm conditions over the summer, and by May, NCEP was confident in predicting that this would be a major El Nino event.

To get a further picture of the magnitude of the current event, it is useful to compare its evolution with that of the six prior strongest El Nino events over the last 50 years (Exhibit 2). The measure used for this purpose is an index that includes tropical winds, pressures, cloudiness and sea surface temperatures, to more accurately reflect the coupled nature of the ENSO phenomenon. By this measure, this event is by far the strongest we have seen for this time of year, and second only to the 1982-83 event in absolute magnitude, with the latter event reaching a peak in late winter to early spring of 1983. Another important aspect of the current El Nino is that it experienced the most rapid sustained growth of any event of the record, from its initiation in spring through this past summer. Although the latest data point (for August-September) suggests a leveling off, note that such behavior has also occurred in earlier events, including 1982-83, and therefore should not be taken as a clear indication that the event has peaked. It is both the rapid growth and absolute magnitude of this event which have raised legitimate concerns about adverse climate impacts, both in the U.S. and worldwide.

So far, extreme climate events associated with this event have been mainly outside the North American sector, although the strong suppression of hurricane activity in the Atlantic and Gulf of Mexico is quite likely connected to this event, as are the unusual northward paths of tropical cyclones along the west coast of Mexico into the southwestern U.S. As indicated earlier, however, the strongest and most systematic effects of El Nino on North American climate typically occur in winter and spring. I will now discuss some research results on potential future climate risks associated with this event.

Potential Climate Risks

Climate predictions are inherently probability forecasts, with the fundamental goal being to estimate how the probability distributions of various quantities, such as temperature and rainfall, will change subject to particular conditions; in this case, El Nino. An important new direction of NOAA's recent research efforts in this area is toward the development of extreme event predictions at extended range (beyond several days). A basic goal of this research is to identify regions and time periods where the risk of large-scale extreme events, such as droughts or floods, is significantly increased (or decreased).

So how do we do this? There are two basic approaches: first, through analysis of past behavior (an empirical approach) and, second, through application of numerical forecast models through a relatively new technique called ensemble predictions. The approaches are complementary, and both are being actively pursued in NOAA, although here results derived from the former approach will be emphasized.

An example is shown in Exhibit 3, and is derived from one hundred years of data. The figure shows the regions at highest risk for seasonal precipitation extremes in spring following El Nino winters and, for comparison, also following La Nina winters.

Based on past El Nino events, the areas at highest risk for much above normal precipitation in winter and spring include the Southern California coast, much of the Southwest extending into the southern Plains, and portions of the Gulf Coast and Southeast. Areas at increased risk of much below normal precipitation include portions of the far northern Rockies and northern Plains in winter and the northern Ohio Valley in late winter to early spring. Other analyses also strongly support the possibility that portions of California and the Southwest are at significantly increased risk of much above normal precipitation, and that high stream flow values and floods are much more frequent in these areas in El Nino years. For example, more detailed analyses for the lower Colorado basin suggest approximately a 60 percent chance of much above normal precipitation (defined as wettest 20 percent of all seasons) in springs following El Nino winters.

In contrast, the Southwest is particularly vulnerable to drought in springs following La Nina winters. This was the case in 1995-96, when a severe drought affected the Southwest, Texas and portions of the southern and central Plains, resulting in several billion dollars in losses. A potential positive aspect of this year's El Nino is that there is a significantly reduced risk of drought in these areas, particularly as compared to La Nina years. The strong ENSO signal in the Southwest, together with the high sensitivity of this region to hydrologic variations, suggest that this is a critical region to consider for issues concerning climate variability and water management.

It is important to briefly mention other aspects of weather and climate pertinent to U.S. water management. First, although ENSO is the most widely-recognized mode of climate variability, it is not the only one, and scientists are now studying other modes of variability, such as the North Atlantic Oscillation (NAG) and Pacific Decadal Oscillation (PDO), to gain additional predictive ability. Second, critical water management issues extend over a broad array of time scales, both shorter and longer than ENSO variability. For example, although El Nino may increase the likelihood of flooding in a given region, in general, it will not determine the timing of a specific flood event. Short range prediction of floods is the operational responsibility of NOAA, and research efforts are also underway to extend the maximum lead times for identifying risks of specific flood events. Some preliminary work between NOAA and USGS scientists for the Merced River suggests that use of ensemble model forecasts from the National Centers for Environmental Prediction (NCEP) provides useful lead time information on flow variability out to approximately ten days. An additional issue is longer-term climate variations, such as multi-year or decadal droughts, that have episodically affected large portions of the U.S., as in the 1930s. Such events would have potentially devastating consequences were they to recur. Understanding and predicting longer-term climate variability is also an area of active research by NOAA.

New climate research products discussed above and others are being developed by NOAA and its research partners for a broad array of potential applications. At present, there is ongoing coordination between NOAA and other agencies including the National Weather Service River Forecast Centers, the Bureau of Reclamation and the Natural Resources Conservation Service in developing usable information for assessing flood and drought risks in areas showing empirical ENSO-related signals.

Focused research on regional climate variations and their hydrologic impacts should rapidly increase our ability to predict extremes of high and low water availability. This new information can be put to use in water management systems, with the potential for substantial economic and other benefits. The present need is for continuing intensive research on prediction of extreme weather and climate events, the regional hydrologic response to climatic extremes, and effects of hydrologic extremes on water demand, water management, and aquatic resources generally.

Mr. Chairman, that concludes my testimony. I thank you for this opportunity to discuss El Nino and potential U.S. climate risks which may affect water management decisions. Recent substantial advances have been made in understanding and predicting climate variability, and these research advances hold great potential to benefit society. I believe the future holds even greater promise for return on our research investment.

I would be pleased to answer any questions that you or other members of the Committee may have.

Exhibit 1

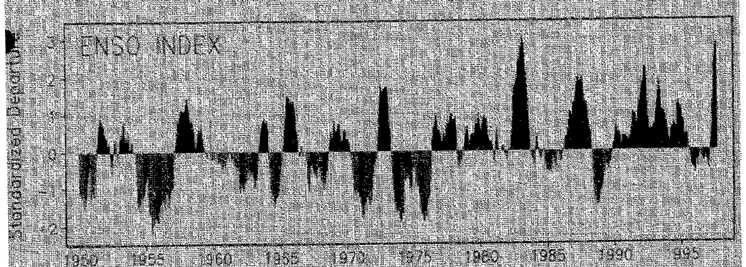


Exhibit 2

ENSO Index for the 6 strongest historic El Niño events vs. the current event

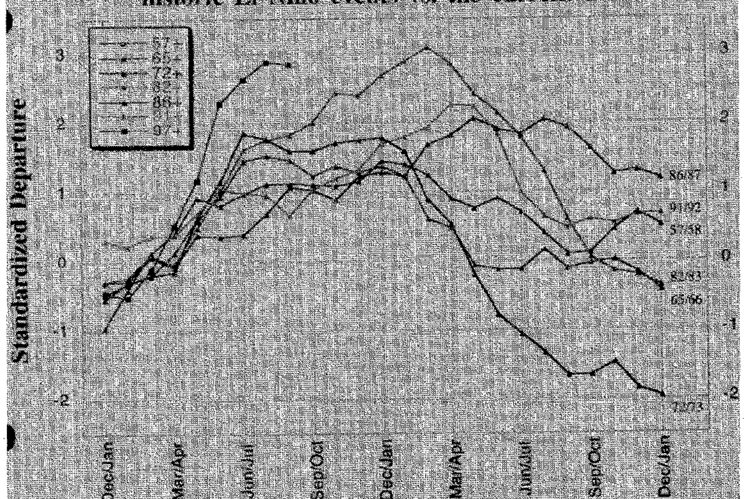
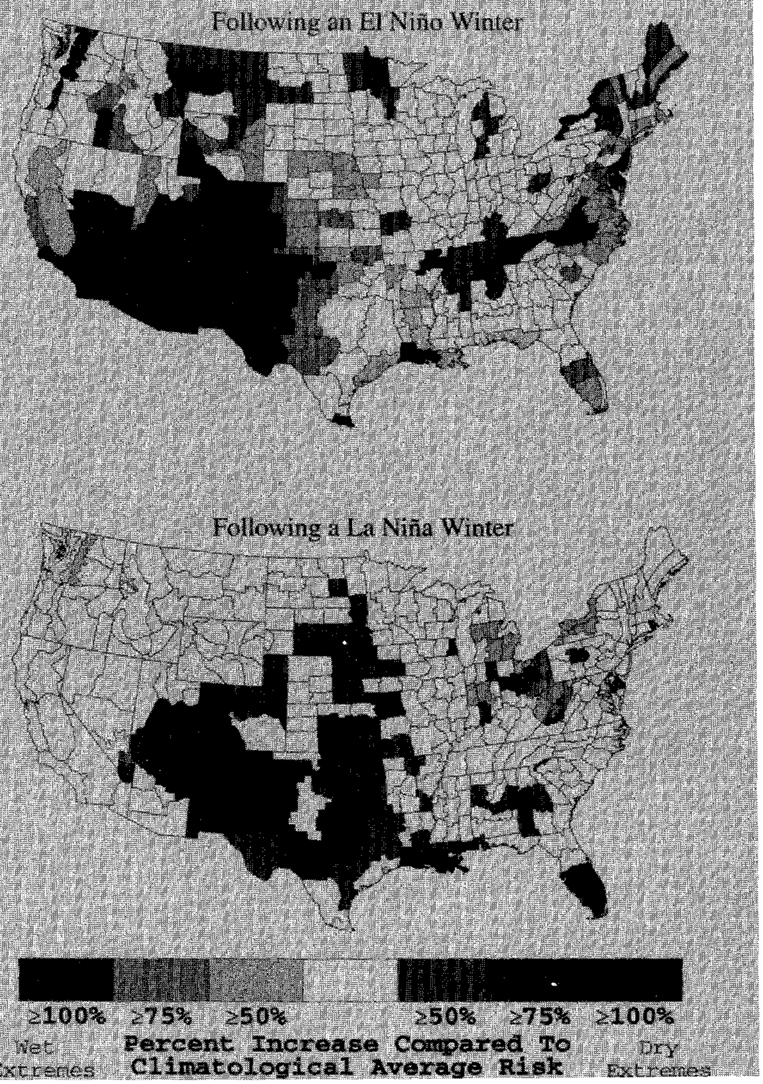


Exhibit 3

Risk of Extreme Springtime Precipitation



STATEMENT OF ANTS LEETMEA, DIRECTOR, CLIMATE PREDICTION CENTER, NATIONAL CENTERS FOR ENVIRONMENTAL PREDICTION, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, U.S. DEPARTMENT OF COMMERCE

Mr. Chairman and Members of the Subcommittee:

Fifteen years ago a small group of scientists and research managers based the development of a major research effort in climate on the premise that patterns of extreme weather were not totally random events and that the key to predictive insight lay in the interaction between the ocean and the atmosphere. That international multidisciplinary research effort today in the foundation underlying the National Oceanic and Atmospheric Administration's (NOAA) world-recognized advances in forecasting climate based on dynamical predictions of the states of El Niño. These advances are leading towards an understanding of the connections between El Niños and U.S. temperature and rainfall variability, and the possible utilization of this predictive information into decision-making in water and energy sectors. We currently are in the maturing stages of the 1997/98 El Niño which is forecast to be comparable in strength the 1982/83 event, the previous "event of the century." During 1982/83 the United States suffered roughly $3 billion in losses related to storm damages and flooding. It is appropriate for the Chairman and the Members to ask how much better prepared we are for this event and the potential eventualities associated with it than the 1982/83 one and what we might do in the future to be better prepared.

El Nino and Forecasts for the 1997/98 Event

In simple terms, the distribution of sea surface temperatures in the tropical Pacific determines the overlying atmospheric circulation. However, the overlying tropical circulation through current conditions and its past history determines the sea surface temperature. This coupled interaction between the atmosphere and the ocean results in a quasi-periodic oscillation termed the E1 Niño/Southern Oscillation (ENSO) which has a period of 4 to 7 years. When the tropical Pacific is warmer than normal, this is the El Niño phase; when it is colder than normal, this is the La Niña phase. Both phases have strong impacts on precipitation and temperature patterns over the U.S.

Forecasts for E1 Niño at NOAA's Climate Prediction Center (CPC) are made using coupled numerical models of the ocean and atmosphere that require supercomputers for their execution.

The initial conditions for the forecasts utilize ocean measurements from the ENSO observing system, measurements from satellites, and reports from volunteer observing ships. Forecasts out to a year in advance are made once a week. The first forecasts that indicated a likelihood of an El Niño episode this year were made in November of 1996. El Niño conditions began to visibly develop in March of this year; subsequently positive departures from normal sea surface temperatures rapidly increased, reaching record levels for the period August-September. The current El Niño is forecast to peak at the end of the year or early next year. At that time its magnitude and spatial extent will be comparable to the 1982/83 event, previously considered the event of the century. Conditions are forecast to return to about normal during the summer of 1998.

El Niño causes large scale shifts in the distribution of tropical rainfall. This is expected to result in a stronger than normal jet stream over the eastern North Pacific and southern United States during the 1997-98 winter and continuing through the early spring of 1998. This pattern is expected to result in wetter than normal conditions across much of the southern United States from California eastward to the Carolinas. Drier than normal conditions are forecast over the northern High Plains and Ohio valley. During 1982/83 many of the areas expected to be wetter than normal, e.g. states such as California, Utah, Illinois, Missouri, Arkansas, and Louisiana, experienced extensive flooding and storm damage.

Forecasts for United States Rainfall and Temperature

Currently the forecasts for El Niño impacts are made using both statistical techniques and dynamical forecasts. If rainfall and temperature records are ranked for the past 102 years according to when moderate or strong El Niño were present, the tendency for much of the southern third of the U.S. to be wetter than normal (and drier than normal during a La Niña) is clear (figure 1) while regions of below normal rainfall include the areas surrounding Montana and the Ohio valley. The magnitude of the impacts and the regions that are impacted vary with season. Strongest impacts are experienced during our winter. These average rankings, conditioned on the presence of a moderate or strong El Niño can be converted to percent of normal rainfall. The seasonal maps for the temperature and rainfall impacts for the United States, as well as more detailed state by state summaries for states that will be

likely impacted can be found on the web site for the CPC (http://nic.fb4.noaa.gov). The most likely scenario for given regions is that given by what has been observed for moderate El Niños, e.g. figure 1. However, since the 1997/98 event is not a moderate event, but another event of the century, what happened in 1982/83 should be considered as a plausible scenario. The dynamical model forecasts, which are just coming on line as forecast tools, suggest some truth to this plausible scenario. The impacts for California and the major river basins are discussed in the following:

California: California during winters with moderate El Niños receives about 130 to 140 percent of normal rainfall (figure 2). This converts to about five inches extra rain for most of the state. During 1982/83, an event comparable to the current one, California, as well as much of the southeast, received 150 to 200 percent of normal rainfall. Over coastal southern and central California and the southern Sierra this resulted in about ten inches extra rain for the January through March period. For much of northern California the amount was even greater at about 16 inches. This was the result of more storms during this period that on average carried more rainfall per storm. However, we don't anticipate that these storms will reach the intensity of those during last year, December 1996–January 1997, although this cannot be precluded. These drew their moisture and temperature from the deep tropics, whereas the moderate El Niño and 1982/83 storms picked up their moisture and temperature from the mid-latitude Pacific.

Colorado Basin: During moderate El Niños the Basin receives from normal rainfall in western Colorado to over 190 percent of nominal in southern Arizona. Generally the northern part of the basin has a weaker rainfall signal associated with El Niño than the southern part. Southern Arizona has the largest signal. Since the overall region receives little rainfall, the large percent of normals for a season only amount to a few inches. During 1982/83 most of the region, except for western Colorado, received greater than nominal rainfall with 125 percent of normal in the northern part to over 200 percent or so in southwest Arizona. Despite the modest rainfall amounts, the observed Colorado river water year runoff reached its largest values for the past 45 years in 1982/83 of roughly 23 Million Acre Feet or about 180 percent of normal during the spring of 1983.

Columbia Basin: For moderate El Niños in fall and winter there are weak probabilities for below normal rainfall in western Washington, British Columbia, Idaho, and western Montana. The probabilities are also increased for warmer than normal temperatures with the largest warm anomalies on average being present in March and April. These conditions lead to a lower than average snowpack in late winter and early spring with higher early spring runoffs and lower ones later. The potential exists for water allocation problems in summer. However, during the strong 1982/83 event, much of the region received above normal rainfall; hence, there is a possibility these conditions might not arise.

Upper Missouri Basin: Deviations from normal rainfall and temperature conditions over the upper Missouri regions, Montana, Wyoming, and northwestern North Dakota during moderate El Niños are much the same as over the Columbia Basin except that the likelihood of below normal rainfall is enhanced. However, over Nebraska and Kansas wetter than normal conditions are to be expected. Without feeding these impacts into river and reservoir flow models, it is not clear what the integral effects on Missouri River flows will be. During 1982/83 the pattern of above and below rainfall deviations described earlier was observed.

Other Factors Influencing Western U.S. Rainfall: Decadal Variability

The history of rainfall variations for coastal southern California, Arizona, and New Mexico since 1930 indicates that, in addition to El Niño and La Niña impacts, there have been strong decadal variations in the amount of rain received. The signal in the Pacific northwest is the opposite of that in the southwest, e.g. when the southwest tends to have above normal rainfall, the northwest tends to have below normal rainfall. The period from the mid-1940s to the mid-1970s was one where the southwest received below normal rainfall. Since then rainfall amounts have been greater than normal, e.g. a relative climatic optimum. When a La Niña has been present, the southwest almost always experiences below normal rainfall. The most recent case of this was during 1995-96 when the region experienced a severe drought which cost the nation roughly $4 billion. When an El Niño is present, conditions tend to be wetter than normal, and the probability of being wetter than normal roughly doubles.

This decadal variability is referred to by researchers as the Pacific Decadal Oscillation (PDO). The spatial pattern of rainfall variations over the United States associated with it is quite similar to that of El Niño (figure 1). This suggests that the same kind of ocean-atmosphere interactions are responsible for both. Although understanding the origins of the PDO is still a research issue, its impacts are already

included in the CPC seasonal climate forecasts. The forecasts include a component of features that persist for 10 to 15 years. A more common appreciation of this decadal variability could be of use for water managers.

The Future

NOAA's Strategic Plan has a Goal, Implement Seasonal to Interannual Climate Forecasts, that has a focus in the implementation of a capability to forecast water resources up to several seasons in advance. This has to be a cooperative program with other Federal and State Agencies, Universities, and the private sector. Floods and droughts, especially the Great Flood of 1993, have emphasized the need for improved short term and seasonal predictions to support flood/drought and water management and damage mitigation. In addition to these improvements in hydrometeorological predictions, NOAA is modernizing its hydrologic predictions with an Advanced Hydrologic Prediction System (AHPS). AHPS builds on the current capability of the National Weather Service's River Forecast Centers who currently issue stage forecasts for only one, two, and three days into the future at most forecast points and crest forecasts out to about one week for a few selected forecast points. AHPS will build upon the skill of NOAA's seasonal forecasts to provide new hydrologic forecast products out to seasons in the future. The seasonal forecasts are required to predict the likelihood of extreme events such as droughts and floods happening, whereas, the short term forecasts are needed to predict the details and magnitude of such events. The allocation of water among competing demands (e.g. fisheries, irrigation, hydropower and municipalities) looms as a national problem. AHPS and the NWS River Forecast Centers are the logical links to the operations; practices of the Bureau of Reclamation and the Corps of Engineers. AHPS has been implemented in the Des Moines River Basin and in that location has successfully demonstrated the coupling between hydrology, meteorology, and climatology on daily, weekly, monthly, and seasonal time-scales. Demonstrable products for the Des Moines AHPS project can be seen at http://www.crh.noaa.gov/dmx/ahps.

Significant challenges still remain to be overcome in order to fully integrate the effects of El Niño and decadal variability into the operating practices of agencies that manage water resources. Many of these are technical and no doubt will be more fully described by the other experts at this hearing. Nevertheless, one can anticipate that the general tone of their testimonies is one of optimism that the time is here to start this process. Indeed the current event has initiated a number of studies into seeing what the limitations currently are and how far the current technology can be pushed in bringing the climate forecasts down to the river basin scales. These studies over the next six months will significantly accelerate the progress towards utilization of climate forecast in water management.

One of the lessons from this event will be that an enhanced focus resulting from urgency gets people's attention and cooperation. The challenge after this event will be to maintain this momentum. No one Agency has all the required expertise. Getting the necessary Agencies to work towards a common focus, especially under current budgetary constraints will not be easy. What can be done, what needs to be done, the directions to be taken, and the potential partnerships will be much more evident as the 1997/98 El Niño proceeds.

Mr. Chairman, that concludes my testimony. I want to thank you and the Committee for this opportunity to discuss the current El Niño and the possible impacts on water resources in the west. Let me finish by giving a partial answer to the question I posed at the beginning of my testimony—"How much better prepared we are for this event and the potential eventualities?" In 1982/83 we did not know until September of 1982 that we were in an event, let alone the "event of the century," nor what the potential regional impacts would be over the United States. For this event the forecasts started indicating a likelihood of an event about a year ago, and we knew from the forecasts and the observations that this would be a major event by late May of this year. We also knew by that time the potential for heavy rainfall in California and much of the southwest this coming winter for this coming winter—a full six months in advance!

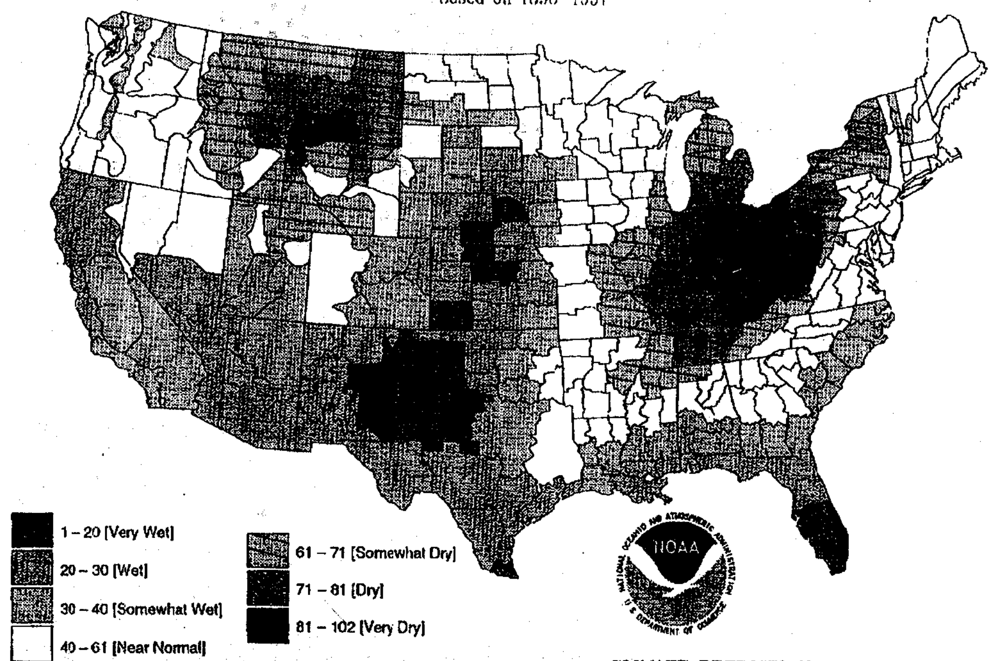
I would be pleased to answer any questions that you or other members might have.

F:GURE 1.

AVERAGE JANUARY – MARCH [3–month] PRECIPITATION RANKINGS DURING ENSO EVENTS

1915 1919 1941 1958 1966 1969 1973 1983 1987 1992

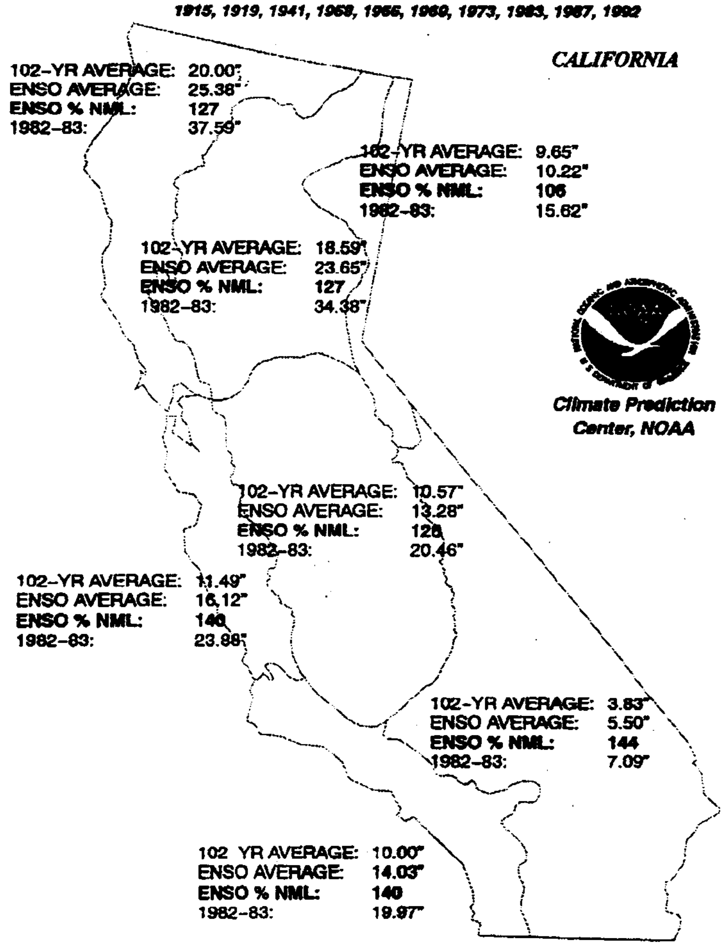
Based on 1895 1997



CLIMATE PREDICTION CENTER, NOAA

102-YEAR [1895 - 1996] NORMAL vs. ENSO-AVERAGE PRECIPITATION (inches)
BY CLIMATE DIVISION
JANUARY - MARCH
1915, 1919, 1941, 1958, 1966, 1969, 1973, 1983, 1987, 1992

FIGURE 2



Statement of Dr. Mark Schaefer,
Deputy Assistant Secretary for Water and Science
U.S. Department of the Interior

before the
U.S. House of Representatives
Committee on Resources
Subcommittee on Water and Power

October 30, 1997

Mr. Chairman, I appreciate the opportunity to be here today to address the Department's involvement in evaluating current El Niño forecasts and our plans for operating dams and other facilities in the western United States during the predicted strong weather events. I will also discuss the Department's participation in forecasting research and its monitoring functions associated with an El Niño event.

Background

The shifts in typical patterns of ocean and atmospheric circulation in the tropical Pacific region brought about by El Niño will also affect atmospheric pressure, storm tracks, precipitation, and temperature patterns across the northern Pacific and the North American continent. Of particular concern to the Department are changes in precipitation, temperature, and streamflow because of our responsibilities for managing land and water resources.

Previous El Niño events have resulted in an increase in the number and severity of winter storms along the California coast and wetter than normal winter weather in the Southwest. In contrast, Hawaii, the Pacific Northwest, the northern Rockies, and the upper Great Plains have experienced warmer and drier winters. These changes may occur as early as October but typically are strongest in winter and early spring.

The National Weather Service (NWS) and other agencies are tracking the present El Niño event. Their observations to date indicate that the present El Niño is the strongest episode of the past 50 years. NWS experts expect this El Niño to produce wetter than normal conditions over most of the extreme southern United States this winter.

Across the nation, the U.S. Geological Survey (USGS) is monitoring streamflow at nearly 7,000 locations, about half of which transmit information in real time. This network will provide the first indications of the effects of El Niño on rivers and reservoirs and forms the basis for flood forecasting, warning, and mitigation activities throughout the country.

Department's Involvement in the Evaluation of El Niño Forecasts

The Department has been extensively involved in evaluating current El Niño forecasts. The USGS has provided the historical basis for understanding and using current long-range forecasts of El Niño consequences for water resources and water hazards in the western United States. El Niños are associated with increased precipitation and runoff, and in particular with increased frequency of extreme hydrologic events–rainstorms, snowstorms, and floods. Of these three, the increase in extreme floods tends to be the most pronounced. Daily streamflow data from 50 years of USGS records reveal a marked increase in short-term floods during El Niños, even when total seasonal streamflow is not profoundly affected. Studies show that previous El Niños have caused many of the most severe floods in southern California and other southwestern States. The USGS has been active in communicating these lessons from its long-term streamflow records to water managers in California and the West.

The predicted strength of this event raises unusual problems because we do not know whether the most intense El Niños simply yield more intense versions of the regional water resources and hazard effects typically associated with El Niños, large and small, or whether they result in whole new patterns of effects. For example, during the strong El Niño of 1982-83, most of the West Coast experienced substantial increases in rainfall. Like the meteorological community, USGS is working to determine whether the 1982-83 El Niño is an appropriate analog for the coming winter and is reassessing the hydrologic effects of that episode.

The Bureau of Reclamation (Reclamation) has been closely tracking long-range forecasts with the support of the National Weather Service's River Forecast Centers and Climate Prediction Center and its Technical Service Center in Denver. Reclamation is developing a procedure to integrate these forecasts into Reclamation operations at all sites. Water operations managers in the five regional offices and 60 area and project offices will be kept informed in real time via the Internet as well as through monthly distribution of forecast information. As individual storms approach, Reclamation offices will, as always, closely monitor short-term forecasts in areas above reservoirs to determine the potential for flooding.

Reclamation has also begun the process of informing water managers of the potential impacts of this El Niño, as well as the current state of climate prediction capabilities. The bureau has opened a dialogue between its water managers and climate researchers from the NWS and other agencies. It will continue to inform its water operations staff throughout the West about the formulation of forecasts and the level of confidence in these forecasts.

Reclamation is also developing detailed hydrographs of previous El Niño events at key river gauges to provide water managers with specific comparisons for their water management models. To improve water management models and to link mountain precipitation from winter storms to water management efforts, Reclamation is partnering with USGS, National Oceanic and Atmospheric Administration's (NOAA) National Operational Hydrologic Remote Sensing

Center, and the Operational Support Facility of the Next Generation Radar System (NEXRAD), the National Weather Service's Doppler Radar System, which gauges rainfall intensity over large geographic areas. The partners are intensifying efforts to improve current methods for analyzing and predicting snow water content, to improve streamflow forecasts, and to provide that information in real time to Reclamation water managers.

Regarding long-range forecasting and planning, Reclamation has hosted or participated in three workshops this year involving weather and climate modeling for improved water resource management. These workshops have helped define for the climate modeling and forecasting community the real-world needs of water managers. They have also helped water managers to understand the implications and limitations of climate forecasting and to see how forecasting can assist them in making better water management decisions. In addition, Reclamation, USGS, and NOAA's National Center for Environmental Prediction are collaborating on research to improve streamflow forecasts used by water resource managers.

Operation of Facilities and Emergency Response During the Predicted El Niño Event

We are very concerned about the potential impact of this El Niño event on Reclamation's 596 dams and reservoirs (attached) and on its water management activities if the long-range forecasts prove accurate. Of greatest concern is the potential for increased precipitation in southern areas and warm, dry weather in northern areas.

Long-range forecasts are too general for us to target the specific watersheds and precise locations that may be affected by storm events related to El Niño. However, past events and current information suggest that we should prepare for frequent heavy precipitation this winter in the mountains of California, Arizona, New Mexico, and other areas that affect the operations of Reclamation in the Mid-Pacific, Upper and Lower Colorado, and southern Great Plains regions. This translates into potentially high water levels in reservoirs of the Central Valley Project, the Colorado River Storage Project, Lake Powell, Lake Mead, and the Rio Grande Basin Projects, as well as a host of smaller projects in these areas. Conversely, northern projects on the Columbia, Snake, and Upper Missouri Rivers may experience warm, dry conditions resulting in the need to increase their conservation storage pools.

The Central Valley Project (CVP) is Reclamation's largest and most complex project, comprising storage and diversion dams, pumping plants, canals, and distribution facilities that deliver water throughout 40,000 square miles. The 1982-83 water year was the wettest of record throughout the Central Valley basin. Record precipitation throughout the winter led to a very large spring snowmelt runoff that lasted until June. Above-average runoff into CVP reservoirs required continuous above-average releases. Releases never reached levels that caused significant flooding, but many concerns were expressed about the damage to agriculture from seepage.

Reclamation is also preparing for the possibility of increased storm events associated with this El Niño. It is tracking weather forecasts, incorporating the forecasts into ongoing modeling activities and planning possible management actions to respond to storms. Significant operational actions to accommodate potential high inflows next spring are already underway. Reclamation's water operations and management activities in each project area are already in a delicate balance of supply and demand. Reclamation will prepare and plan for the likelihood of storm events associated with this El Niño in all project areas that may be affected. However, day-to-day operations and management decisions will continue to be made on a short-term basis. Reclamation will change its water management and operations in response to short-term weather forecasts that target specific storms.

Similarly, USGS is using El Niño forecast information, in conjunction with historical El Niño-flood discharge relations, to evaluate the status and condition of its stream gauging equipment in regions where floods are likely. This will help ensure that stream gauges will be fully operational during extreme conditions should they develop, thereby providing NWS with uninterrupted real-time streamflow data for its flood forecasting operations.

The USGS Coastal and Marine Program in collaboration with NOAA and NASA is evaluating the potential land loss in coastal areas from severe storms. Three sections of the Pacific coast between Point Grenville, Washington, and San Diego, California, totaling roughly 200 miles each, are being surveyed by an Airborne Topographic Mapper scanning laser survey to determine changes in the coastline over the coming winter season. This and related information will be made available on the Internet (http://marine.usgs.gov/). The airborne data is being combined with ongoing studies of coastal processes to enable USGS to assess and understand the erosional impact of the storms along the West Coast.

USGS geospatial data – topographic maps, digital elevation models, and other products – are critical to emergency preparedness and relief efforts by Federal, State, and local agencies. Special USGS response teams are on call 24 hours a day to ensure that topographic and special maps are in the hands of State and Federal emergency coordinators within hours. When Hurricane Andrew struck the Florida and Louisiana Coasts in 1992, USGS rushed nearly 232,000 maps of the affected areas to emergency response officials.

Department's Participation in Forecasting Research and Monitoring

The USGS is collaborating with Reclamation, various NOAA operational and research groups, and State agencies to test and improve the hydrologic value of current weather and climate forecasts. NOAA's National Center for Environmental Prediction and Climate Diagnostics Center, as well as some local Weather Service offices, will provide past and future weather forecasts for use in experimental hydrologic models in California, Colorado, and the Northwest. Time scales of the forecasts range from days to weeks. Monthly to seasonal-scale climate

forecasts are being obtained through the International Research Institute for Climate Prediction (at the Scripps Institution of Oceanography) and the NOAA Climate Prediction Center for use in longer term hydrologic-forecasting experiments. Research on the linkages between weather and climate predictions and existing hydrologic models will improve the usefulness of medium-range weather forecasts to water managers.

The USGS is investigating the predictability of hydrologic conditions in the Sierra Nevada mountains, using National Center for Environmental Prediction (NCEP) forecasts of temperature and precipitation. Preliminary results of this work are encouraging. It is probable that 7-day temperature and precipitation forecasts issued by NCEP will allow USGS to successfully forecast 7-9 days in advance, the timing and magnitude of flooding such as that which occurred on the Merced River last December. The USGS is continuing these modeling experiments to evaluate the limits of medium-range flow forecasting in conjunction with El Niño.

The USGS is also contributing valuable information regarding the potential for landslide occurrences associated with El Niño weather effects by combining its computerized national landslide susceptibility map with national climate outlook maps produced by NOAA (attached). NOAA's maps depict the predicted distribution of El Niño-induced precipitation and temperature anomalies for 1997-98. This combination of USGS and NOAA information will indicate where and when rainfall- and snowmelt-induced landsliding may occur this coming winter and spring. We will frequently update and refine this information and make it available on the Internet (http://geohazards.cr.usgs.gov), and we will indicate broad regions of the Nation that have increased potential for landslides during the coming El Niño climatic episode.

In addition to regional hazard assessments, USGS is involved in a variety of landslide investigations at a more detailed level including:

- production of maps of landslide and debris-flow hazards in the San Francisco Bay and Los Angeles areas;
- studies of the increased potential for landslides in the aftermath of brush and forest fires that may occur as a result of unusually dry conditions; and
- investigation and monitoring of recent major and potential landslide events in the Seattle and Denver areas, in northern New Mexico, near Sacramento, California, and in the Central Appalachians.

These detailed studies provide the quantitative basis for assessing landslide and debris-flow hazards nationwide and also provide site-specific information critical to emergency response agencies tasked with managing crises and mitigating hazards.

The floods and droughts associated with El Niño can seriously affect water quality. Increased loads of nutrients and toxic chemicals may be washed into rivers during flood conditions. Conversely, during a drought, the lower water levels may increase the concentrations of harmful substances in the river. The USGS National Water-Quality Assessment Program collects water-

quality information at selected rivers in 50 large river basins in the United States for use by water managers at State and local agencies. The primary objective of the program is to determine the distribution of chemicals over the long term, but water-quality information collected after specific severe storms can be provided to water managers on very short notice.

Like the water-quality assessment program, USGS biological studies are not directly targeted at El Niño issues but will be useful in tracking changes in various biological communities. For example, in northwest Washington, ongoing studies of juvenile Pacific salmon growth patterns may detect changes related to El Niño effects. Following the 9-month El Niño drought of 1991-92, researchers documented declines in six populations of forest birds in Hawaii and the Pacific Territories. Additional information regarding El-Nino and other subjects can be found on the USGS Internet homepage (http://www.usgs.gov/).

Future Needs

These planned actions are expected to meet the needs of water managers and mitigate the effects of extreme weather events that may arise from this El Niño. However, unanticipated needs may arise, some of which may require the attention of Congress. We will work closely with Congress should such needs arise. Long-term future needs include enhanced stream gauging operations in areas where flood probabilities are increased. Nationally, the network has decreased by 5 percent in the past 7 years, from 7,363 stations in 1990 to 6,959 in 1997. By working with its many partners in State and local agencies, as well as other Federal agencies, USGS is making every effort to continue operation of gauges needed for river flood forecasts. Longer lead times on flood forecasts would be of significant value to managers of water facilities.

We look forward to working with Congress and this Subcommittee as this unprecedented weather event unfolds. We will continue to monitor conditions and respond to immediate concerns while at the same time adding to our store of knowledge about extreme weather and its effects. The lessons we learn will be useful in the future as we work to protect lives and property.

Again, I appreciate the opportunity to appear before the Subcommittee and I will be happy to answer any questions you may have.

USGS
science for a changing world

El Niño and the National Landslide Hazard Outlook for 1997-1998

he U.S. Geological Survey (USGS) has recently epared maps of National landslide hazard utlook for 1997 and 1998 by combining fore-st information for precipitation from the ational Oceanic and Atmospheric Administra-on (NOAA) *(http://nic.fb4.noaa.gov/products/alysis_monitoring/)* with a USGS map show-g landslide incidence and susceptibility for the nterminous United States.

recast of a major El Niño event is causing ounting concern that 1997 and 1998 may be ars of exceptional landslide activity. Such ents are indicated by a strong warming of uatorial waters in the western Pacific Ocean at spreads eastward to the Western emisphere. Events occur every few years, and me events are much larger than others. The st major El Niño event during the winter of 82-83 was marked by widespread landsliding different parts of the Western Hemisphere. cording to news reports, the current El Niño ent may be the largest of this century, and ile long-term forecasting is very generalized, strong possibility exists for increased precipi-tion that could lead to increased landsliding.

part of the USGS response to El Niño, the ndslide Hazards Program is currently combin-g the newly-digitized USGS National Landslide verview Map (Godt, 1997) with NOAA's ational Climate Outlook Maps. The digital ndslide map (Godt, 1997), and the original om which it is derived (Radbruch-Hall and oth-s, 1982), delineate areas where large numbers of landslides have occurred and areas that are susceptible to landsliding in the conterminous United States. NOAA's National Climate Outlook Maps show contours of probability that El Niño-induced precipitation will be above, near, or below normal for 1997-1998. We have not included the below normal contours in the combined maps, since dry conditions are not conducive to landsliding. The resulting National maps, which will appear at *http://geohazards.cr.usgs.gov* during 1997 and the early part of 1998, will indicate where there may be coincidence between potential landsliding and predicted above-normal precipitation this coming winter and spring.

In the digital National Landslide Overview Map, landslides are characterized as any downward and outward movement of earth materials on a slope. Thus the term landslide includes translational and rotational slides, where material moves down and out on a hillslope on a thin surface of slippage, and earth and debris flows, where movement is slow to rapid (Varnes, 1978). Susceptibility to landsliding (1) is defined as the probable degree of response of geologic formations to natural or artificial cutting, loading of slopes, or to anomalously high precipitation and (2) is classified as being high, medium, or low. Since individual landslides could not be shown at this small scale, the percentages used for classifying the incidence of landsliding (number of landslides) are defined according to the percentage of the area observed to be involved in landslide processes.

Area involved in landsliding	Incidence
>15%	High
1.5–15%	Medium
<1.5%	Low

High, medium, and low susceptibility are delimited by the same percentages used for classifying the incidence of landsliding. Susceptibility is not indicated where it is the same as or lower than incidence. The susceptibility categories are largely subjective because insufficient data were available for precise determinations.

The NOAA National Climate Outlook Maps used to prepare the National landslide hazard outlook map are based on precipitation patterns obtained from a composite of past strong ENSO (El Niño Southern Oscillations) events and depict, for each 3-month period, the number of times during past strong El Niño episodes that the mean precipitation ranked among the wettest or driest third of a 102-year record dating back to 1895. For example, the October through December precipitation map was constructed from data on 11 strong El Niños. These data show, in particular, that for coastal Southern California seven of the El Niño years were among the wettest third, three were among the middle third, and only one of the eleven was among the driest third. While the probability of precipitation anomalies is very strong from a climate prediction standpoint (up to 25 percent from normal in some areas), the absolute probability that precipitation will exceed normal within the map area is no greater than about 60 percent.

These predictive maps, prepared in cooperation with Dr. Robert E. Livezey of NOAA's Climate Prediction Center, show contours of precipitation anomalies and zones of landslide susceptibility and incidence for large areas of the country. Because these highly generalized maps were prepared at such a small scale using limited precise landslide and climate information, they are not intended for local planning or actual site selection. These maps, which will be updated frequently during 1997 and 1998, do, however, indicate broad regions of the U.S. that have increased potential for landsliding during the coming El Niño climatic episode.

References

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October, November, December 1997

PRECIPITATION OUTLOOK

Probability of Occurrence
(in percent)

Above	Near Normal	Below
33.3 - 38.3	33.3	28.3 - 33.3
38.3 - 43.3	33.3	23.3 - 28.3
43.3 - 48.3	33.3	18.3 - 23.3
48.3 - 53.3	33.3	13.3 - 18.3
53.3 - 58.3	33.3	8.3 - 13.3

January, February, March 1998

PRECIPITATION OUTLOOK

Probability of Occurrence
(in percent)

Above	Near Normal	Below
33.3 - 38.3	33.3	28.3 - 33.3
38.3 - 43.3	33.3	23.3 - 28.3
43.3 - 48.3	33.3	18.3 - 23.3
48.3 - 53.3	33.3	13.3 - 18.3
53.3 - 58.3	33.3	8.3 - 13.3
58.3 - 63.3	33.3	3.3 - 8.3

EXPLANATION

LANDSLIDE INCIDENCE

Low (less than 1.5% of area involved)

Moderate (15-1.5% of area involved)

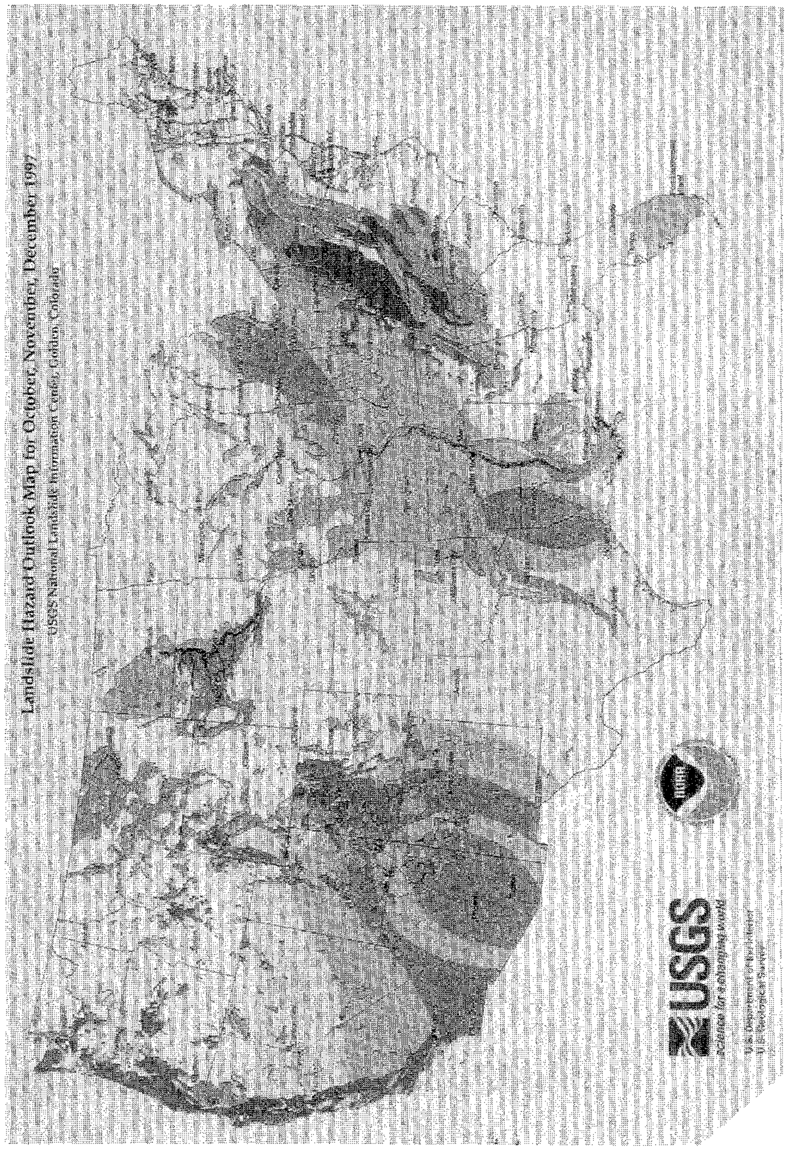
High (greater than 15% of area involved)

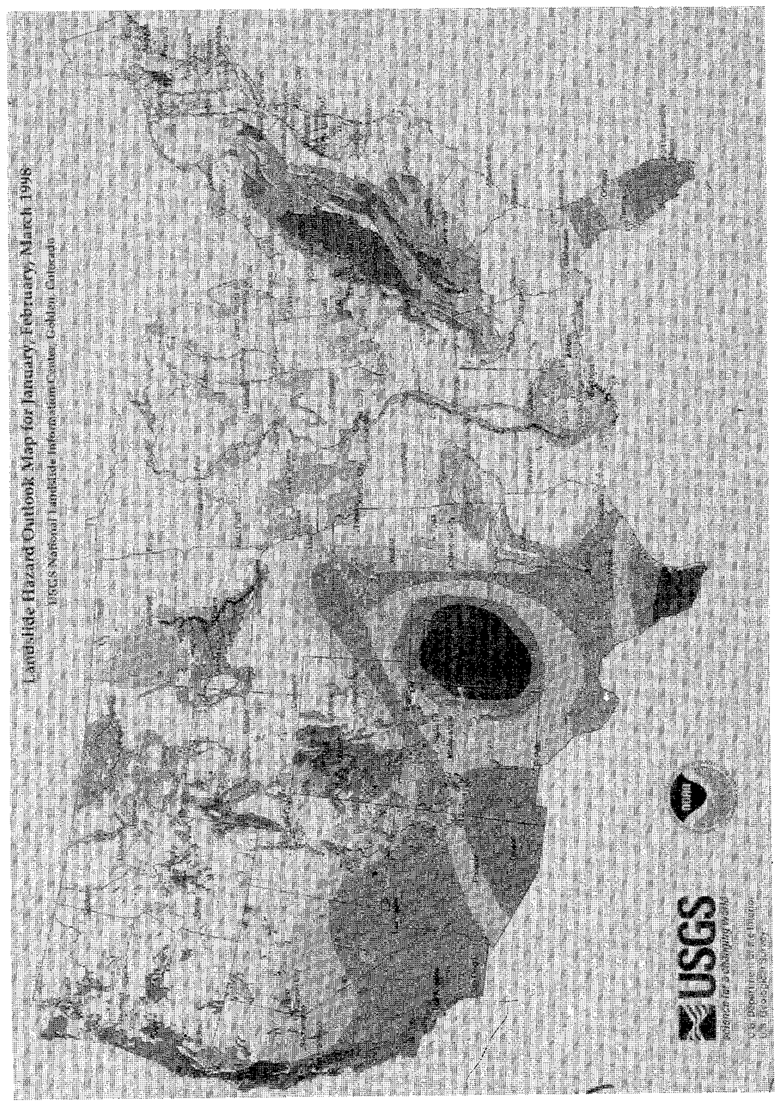
LANDSLIDE SUSCEPTIBILITY/INCIDENCE

Moderate susceptibility/low incidence

High susceptibility/low incidence

High susceptibility/moderate incidence


Landslide Hazard Outlook Map for October, November, December 1997
USGS National Landslide Information Center, Golden, Colorado
USGS


Landslide Hazard Outlook Map for January, February, March 1998
USGS National Landslide Information Center, Golden, Colorado
USGS
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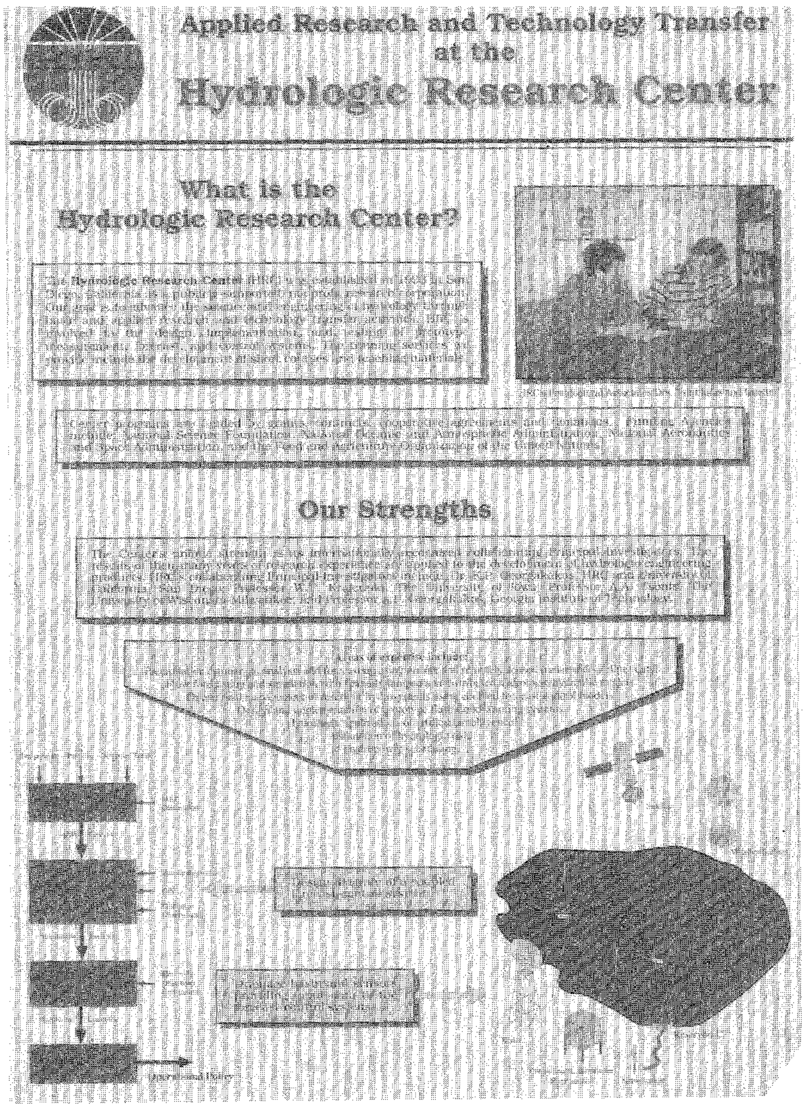
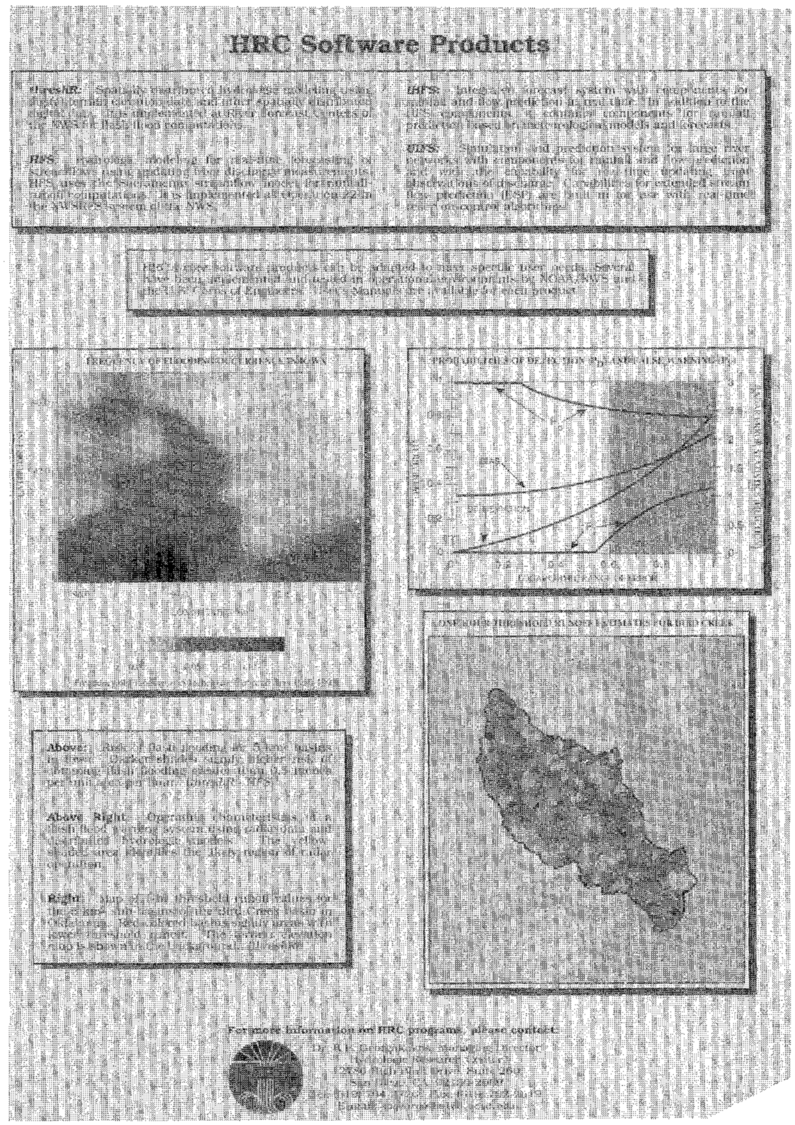
BUREAU OF RECLAMATION PROJECTS


Applied Research and Technology Transfer
at the
Hydrologic Research Center
What is the
Hydrologic Research Center?
Our Strengths


HRC Software Products
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STATEMENT OF KONSTANTINE P. GEORGAKAKOS, SC.D., PRESIDENT, HYDROLOGY RESEARCH CENTER, SAN DIEGO, CALIFORNIA

Mr. Chairman and members of the Subcommittee, my name is Konstantine Georgakakos. I am the President and Founding Director of the Hydrologic Research Center, a nonprofit research corporation in San Diego, California. I am also a Research Scientist IV with the Scripps Institution of Oceanography of the University of California in San Diego. I consider it an honor to be here and to be invited to testify concerning the involvement of the Hydrologic Research Center in the forecasting, and in forecasting research, associated with the predicted El Niño event. In this testimony I will focus in particular on Center research activities pertaining to operational streamflow forecasting for flood warning and water resources management.

Two Center research activities are directly relevant:

(a) Assisting the California–Nevada River Forecast Center of the U.S. National Weather Service, in improving the short- and long- term forecasts of Lake Folsom inflow in east central California. These forecasts will be used in the operational management of the Lake waters and flow releases.

(b) Assessing the utility of integrated forecast-control methodologies for the operational management of reservoir systems. Case studies in Iowa and California are now being conducted for this research.

Both activities were initiated earlier this year and in both cases, the El Niño Southern Oscillation (or ENSO) phenomenon is an important consideration. These activities are funded by the Federal Government, the former by the Bureau of Reclamation and the latter by the National Oceanic and Atmospheric Administration.

Our research on the aforementioned issues builds on earlier research results obtained for the midwestern and south-central U.S. It relies on proven mathematical hydrologic models of the watershed processes and the flow forecast uncertainty. Watershed processes considered are snow accumulation and melt, and surface and subsurface flow. The flow forecast uncertainty exists for three reasons:

—incomplete coverage of watershed area by sensors;

—large errors in the long lead-time meteorological forecasts used to drive the hydrologic models;

—mathematical model approximations of complex natural processes.

Our results so far support the following conclusions:

(1) The accuracy of the computed snowmelt volumes within the Folsom Lake watershed decreases substantially with decreased watershed coverage by precipitation measurement sensors. For example, there are currently large areas drained by the Middle Fork of the American River with poor sensor coverage. The Middle Fork drains approximately 28 percent of the 1861-square-mile Lake Folsom watershed. In the record flood of 1964 it contributed more than 40 percent of the peak flow rate of 148,000 cubic feet per second.

(2) Substantial improvement of operational flow forecasts is attained when the current flow forecast systems are upgraded to include models for uncertainty and updating from flow measurements in real time. The improvement is mainly in the reduction of forecast errors for unusually high or low flow rates.[1]

(3) In a case study involving data since 1904 from the Iowa River at the Iowa City gauging station in Iowa, statistically significant seasonal streamflow associations to ENSO phenomenon were found.[2] For example, for El Niño conditions, there is a 70 percent chance to have above-normal streamflow, lagged three to five seasons from the reference time of El Niño. Such associations may be used in long-lead forecasting operations. Studies, in progress using streamflow data from the American River, have not revealed a strong statistical association with ENSO. It is possible that the 3-7 year ENSO signal is concealed by the extreme year-to-year variability of streamflow in the Folsom Lake watershed.

(4) Substantial benefits for operational reservoir water management were obtained for the Saylorville reservoir in Iowa when flow forecasts were used as input to the decision process with *due account for forecast uncertainty.* On the basis of extensive computer simulations of the watershed-reservoir system it was found that using coupled forecast-control methodologies reduces reservoir-management sensitivities to climate variability and to the large uncertainties associated with the forecast of such variability by current climate models. Analogous simulations are in progress for Lake Folsom in California collaboration with Professor Aris Georgakakos of the Georgia Institute of Technology. Preliminary results show again the effectiveness of such coupled forecast-control methodologies.

I wish to make the following topical recommendations:

(1) Conduct detailed studies to quantify the uncertainty associated with the estimation of precipitation and snowmelt over the Sierra Nevada in California. Such studies should be supported by newly established special dense sensor networks, which should be left in place for 5-10 years. The effects of such uncertainty on the streamflow forecasts for Rivers draining the Sierra Nevada may be then quantified, and steps may be taken to improve the accuracy and reliability of the streamflow forecasts.

(2) Advanced streamflow forecast procedures should be implemented and utilized in parallel to current operational ones to evaluate increased benefits to operations. Such procedures include models for uncertainty of meteorological forecasts and utilize streamflow observations to improve the forecasts continuously. Several watersheds within the U.S. should be identified prototypes for this effort.

(3) In parallel to (2) above, coupled forecast-control methodologies with due account for forecast uncertainty should be implemented in the suggested prototype watersheds to evaluate increased benefits to operational reservoir management. In this context, the utility of climate forecasts for increasing the benefits of reservoir management should be quantified. Our studies to date make me confident that it is through the research and implementation of such methodologies we will be able to utilize the uncertain long-range climate forecasts.

Mr. Chairman and members of the Subcommittee, real-time flow forecasting and reservoir water management are important operational functions for mitigating natural disasters. These functions, vital for present-day communities, have their basis on Hydrologic Science and Engineering, and Water Resources Systems Analysis. As the requirements of the public for safety and reduction of damage losses from natural disasters increase, it is important to formulate a national plan for the increased effectiveness of these operational functions. I have argued elsewhere in the scientific literature that to achieve this goal and in analogy to the establishment of our National Center for Atmospheric Research in the Atmospheric Sciences, it appears necessary to establish a National Center for Hydrology and Water Resourcest.[4] I firmly believe that with the establishment of such a national center much progress will be made almost immediately on a national level by concerted efforts to enhance the flow of information from research to operations. Such a center is envisioned as a collaborative effort among universities, the Federal Government and the private sector. With this last important recommendation I now conclude my testimony. I will be pleased to answer your questions.

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[1] Hydrologic Research Center Technical Report 1, June 1996: Implementation and Testing of the HFS Operation as Part of the National Weather Service River Forecast System (NWSRFS); *Hydrologic Research Center Technical Note 3, May 1996*: Improvement of Hydrologic Model Forecasts Using a Real Time Updating Technique.

[2] Guetter, A.K., and K.P. Georgakakos, 1996: Are the El Niño and La Niña Predictors of the Iowa River Seasonal Flow? *Journal of Applied Meteorology,* 35(5), 34-35.

[3] Georgakakos, K.P., Bae, D.-H., Mullusky, M.G., and A.P. Georgakakos, 1995: Hydrologic Variability in Midwestern Drainage Basins: Diagnosis, Prediction and Control. Chapter II-2 in *Preparing for Global Change. A Midwestern Perspective,* SPB Academic Publ. bv, 61-90.

[4] Georgakakos, K.P., 1995: On the Establishment of a U.S. National Center for Hydrologic Research and Technology Transfer. *Journal of Hydrology,* 172, 15-21.

Follow-up Address for

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Summary of Comments and Recommendations to the
U.S. House Subcommittee on Water and Power Resources
30 October 1997

- Climate and hydrologic forecasting systems can significantly mitigate flood damage, increase the value of energy generation, and potentially benefit all water uses of a reservoir system. However, the magnitude of these benefits are system-specific and can only be assessed on a case-by-case basis.

- Better forecasting procedures do not by themselves imply operational improvements. Such improvements can only be realized through **coupled** forecast-decision systems and institutional processes. In a preliminary study with the Folsom reservoir in east-central California, improved streamflow forecasts are shown to lead to notable reductions in flood damage and considerable hydropower benefits.

- There does not seem to exist significant correlation between sea surface temperatures (SST) at the Equatorial Pacific Ocean and the monthly inflows to Folsom. Thus, a strong El Niño does not necessarily imply a predictable change in the weather patterns over the Folsom drainage basin. This conclusion, however, may not apply to other regions of the Western United States.

- There is a pressing need to make water resources professionals fully aware of the capabilities and benefits of integrated forecast-decision systems and processes relative to traditional operational practices. A recommendation is made to the Committee to support the development of prototype demonstration projects throughout different regions of the U.S. with the involvement of both researchers and water resources professionals.

"Impacts of Climate and Hydrologic Forecasts on Reservoir Management"

Testimony of

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before the

U.S. House of Representatives
Committee on Resources
Subcommittee on Water and Power

30 October 1997

Committee on Resources

Testimony

Subcommittee on Water and Power
Thursday, October 30, 1997
1324 Longworth HOB, 2:00 P.M.

TESTIMONY OF
Professor Aris Peter Georgakakos
School of Civil and Environmental Eng., Georgia Institute of Technology, Atlanta
on
"***Impacts of Climate and Hydrologic Forecasts on Reservoir Management***"
before the
House Subcommittee on Water and Power Resources

30 October 1997

Mr. Chairman and Honorable Members of the Committee: My name is Aris Peter Georgakakos, and I am a Professor at the School of Civil and Environmental Engineering at the Georgia Institute of Technology in Atlanta. I am an expert in the operational management of reservoir systems, and my testimony particularly addresses the *value* of climate and hydrologic forecasting in reservoir operation.

Reservoir Operation Challenges

With proper management, reservoirs can provide vital services to human communities, including the mitigation of severe floods and droughts, the generation of hydroelectric energy, the provision of water supply to urban, industrial, and agricultural areas, recreation, navigation, and the sustainable management of riverine ecosystems.

However, the extent to which reservoirs succeed in providing these services depends critically upon the manner in which they are operated. Consider for example the Folsom reservoir in east-central California [Figure 1] which is expected to provide flood control, generate electricity, provide water supply for irrigation, and maintain a certain downstream flow rate in the American River for water quality and ecosystem preservation.

In the interest of hydropower, the reservoir should always be full to create the highest possible hydraulic head for the turbines and maximize their power output. However, from a flood control standpoint, there is a need to draw the reservoir level down in anticipation of floods, free-up storage space, and accommodate flood volumes without causing downstream damage. In a world without uncertainty, the reservoir managers would know the magnitude of the flood ***precisely***, and could "run" the turbines at full power prior to the flood, to lower the reservoir just enough to receive and contain the

flood volume. This scenario would be ideal because it would avoid downstream damage, it would pass the entire flood through the turbines (without wasting power to spillage), and it would maintain the reservoir as high as possible maximizing its value for hydropower, drought prevention, and the other water uses.

Unfortunately, in the real world, reservoir managers can only ***guess*** the magnitude of the upcoming floods through ***imprecise*** climate, weather, and streamflow forecasts, and their challenge is to balance the risk of flood damage against adverse impacts on hydropower and other reservoir uses. Whether their decisions are successful or not, depends critically on two factors: (**1**) the quality of streamflow forecasts and (**2**) the ability to fully utilize them through an integrated and flexible decision system and process.

Assessments Using Folsom as a Case Study

In principle, good quality streamflow forecasts are expected to benefit reservoir management. However, the *actual* benefits depend on many, system-specific factors such as the lead time and reliability of forecasts, reservoir size relative to inflow volume, hydraulic characteristics of the outlet structures, turbine discharge capacities, flood damage thresholds, and the levels and timing of other water demands.

Thus, to assess the value of streamflow forecasts in the management of Folsom, I developed a computer model which includes a forecasting, a decision, and a simulation component. A brief description of this model and its underlying assumptions appears in the Appendix, and will not be elaborated here, other than to say that it represents most Folsom features (kindly provided by the Bureau of Reclamation and the Folsom operators) and is designed to assess the relative differences in reservoir performance under different forecast scenarios ranging from low to perfect skill. These assessments are made by recreating the Folsom response over the historical period from 1964 to 1995 assuming that the reservoir was operated with the guidance of the decision support system.

Tables 1 and 2 summarize the model results using 60- and 30-day streamflow forecasts respectively. In each case, three different forecast schemes are tested. The first, labeled "Low Skill Forecast", exhibits the highest forecast uncertainty, commensurate to the uncertainty exhibited by the historical streamflow record. The second, labeled "Intermediate Skill Forecast", exhibits 25% less forecast uncertainty than the first, and the third, labeled "Perfect Skill Forecast", assumes perfect knowledge of the actual inflows and serves to define an upper performance bound. Folsom's performance is measured in accordance with three criteria: Annual spillage (i.e., water bypassing the turbines) in million cubic feet, flood damage in million dollars (assuming flood damage follows the function shown on Figure 1), and annual energy generation revenue in million dollars.

The results in Table 1 indicate that Folsom's performance would benefit substantially from improved forecast skill with a lead time of 60 days. Most notably, flood damage

would be mitigated from approximately 5.3 billion dollars in the case of low skill forecasts to about 220 million dollars in the case of intermediate skill forecasts. Relative to energy generation revenues, the value of intermediate over low skill forecasts is approximately one million dollars per year, that is from 58.5 to 59.5 million dollars per year. On the other hand, perfect knowledge of the upcoming inflows could fully mitigate flood damages and would increase energy revenues by another two million dollars per year. The table and Figure 2 show that spillage and forecast skill are inversely proportional with better quality forecasts leading to less spillage.

While, the previous results are annualized, the actual year-by-year benefits could be much higher. For example, Figures 3 and 4 illustrate this comparison for the high flow year of October 1, 1964, to September 30, 1965. For this particular period, the low skill forecast scheme would cause heavy flood damages (i.e., 4.3 billion dollars), whereas the other two would completely avoid flooding. Similarly, energy revenues would increase by approximately 4 million dollars from the low to the intermediate skill forecast scenario and almost 8 million dollars from the intermediate to the perfect case.

The results of the 30-day forecast lead time experiment in Table 2 exhibit similar features, but cause somewhat more flood damage and generate less energy revenues than the 60-day forecast lead time case. The conclusion from this comparison is that Folsom would benefit from long-lead, seasonal forecasts.

One last point to emphasize is that the above-referenced benefits can only be realized if forecasts are used ***in connection with*** dynamic decision schemes that fully account for forecast uncertainty. By contrast, static reservoir rule curves, which are traditionally used in the operation of reservoir systems, would ***fall short*** of realizing the value of improved forecasts.

Using El Niño Information in Reservoir Management

I have shown that good quality, long-lead streamflow forecasts coupled with appropriate decision support systems improve reservoir management. An important question is: By how much can streamflow forecasts actually be improved?

A reliable answer to this question can only come from the continuing research on coupled climate, weather, and hydrologic prediction systems. My experience with such integrated approaches in the midwestern U.S., east-central Africa, and South America is promising, albeit at a preliminary stage.

The most concrete improvements in short range (up to one month) streamflow forecasting can be realized from the use of hydrologic watershed models. To assess the value of such models, and in collaboration with the Hydrologic Research Center in San Diego, California, I also conducted an experiment using an adaptation of the National Weather Service River Forecast System coupled with the Folsom decision system. The results were comparable to those of the 30-day intermediate skill forecast experiment, indicating that such hydrologic forecast-reservoir management systems

would accrue significant operational benefits.

Lastly, as a first step toward assessing the value of El Niño information in the management of Folsom, I investigated the correlation between sea surface temperatures (SST) at the Equatorial Pacific Ocean and monthly Folsom inflows. I was unable to find any significant relationship between these two variables, which led me to conclude that a strong El Niño does not necessarily imply a predictable change in the weather patterns over the Folsom drainage basin. This conclusion, however, may not apply to other regions of the Western United States.

Concluding Remarks

In conclusion, I would like to re-iterate that integrated forecast-decision systems can significantly mitigate flood damage, increase the value of energy generation, and potentially benefit all other water uses. However, the magnitude of these benefits are system-specific and can only be assessed on a case-by-case basis.

Better forecasting procedures do not by themselves imply operational improvements. Such improvements can only be realized through **coupled** forecast-decision systems and institutional processes. In this regard, there is a pressing need to make water resources professionals fully aware of the capabilities and benefits of integrated decision systems and processes relative to traditional operational practices. An effective means to stimulate this transfer of technology from researchers to the user community is through the support of prototype demonstration projects throughout different regions of the U.S. with the involvement of both groups. I would like to urge the Committee to support such demonstration projects through existing or new funding programs.

Thank you for the opportunity to present this testimony on the implications of recent advances for the management of water resources. I will be happy to address any related questions.

Table 1: Folsom Simulation Statistics for a 60-day forecast lead time

	Flood Damage (Million Dollars)	Energy Value (Million Dollars)	Annual Spillage (Million Cubic Feet)
Low Skill Forecasts	5,338	58.5	10,834
Interm. Skill Forcsts.	220	59.5	9,501
Perfect Skill Forcsts.	0	61.3	6,156

Table 2: Folsom Simulation Statistics for a 30-day forecast lead time

	Flood Damage (Million Dollars)	Energy Value (Million Dollars)	Annual Spillage (Million Cubic Feet)
Low Skill Forecasts	5,340	58.3	10,664
Interm. Skill Forcsts.	540	59.0	9,661
Perfect Skill Forcsts.	0	60.1	7,426

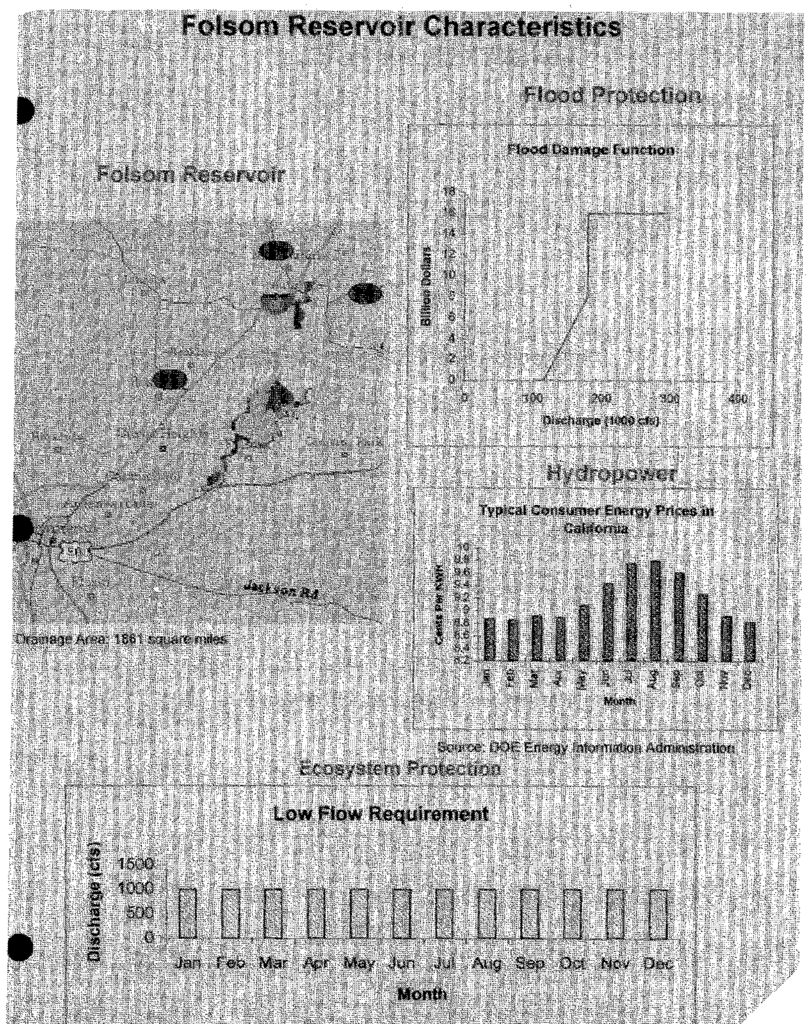

Folsom Reservoir Characteristics
Flood Protection
Flood Damage Function
Billion Dollars
Discharge (1000 cfs)
Folsom Reservoir
Drainage Area: 1861 square miles
Hydropower
Typical Consumer Energy Prices in California
Cents Per KWH
Month
Source: DOE Energy Information Administration
Ecosystem Protection
Low Flow Requirement
Discharge (cfs)
1500
1000
500
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Month

Figure 1

Folsom Spillage Sequences

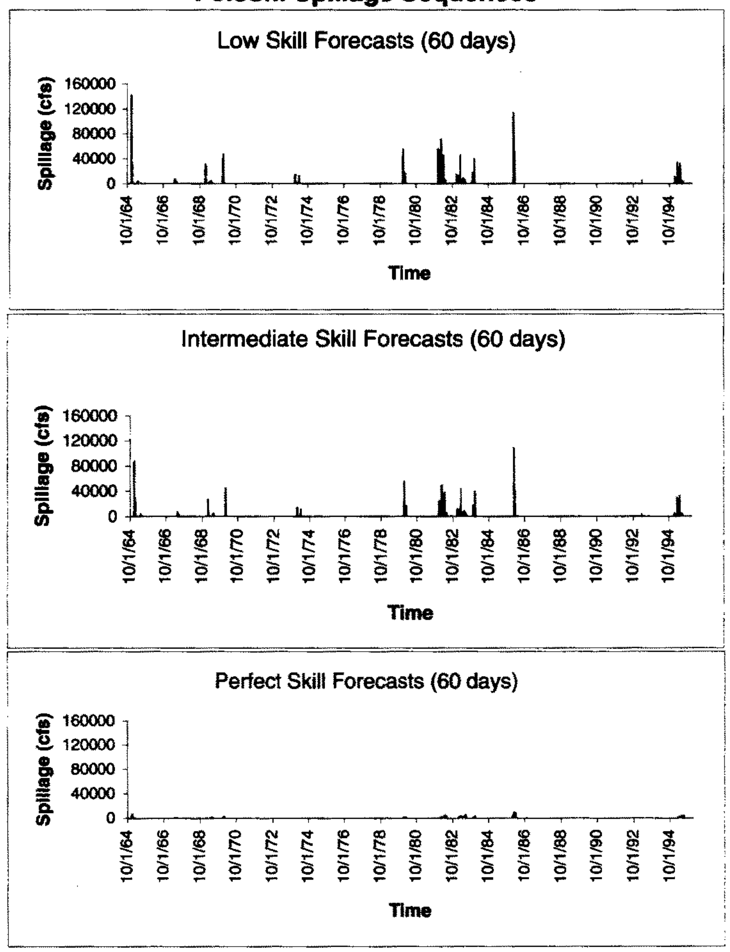


Figure 2

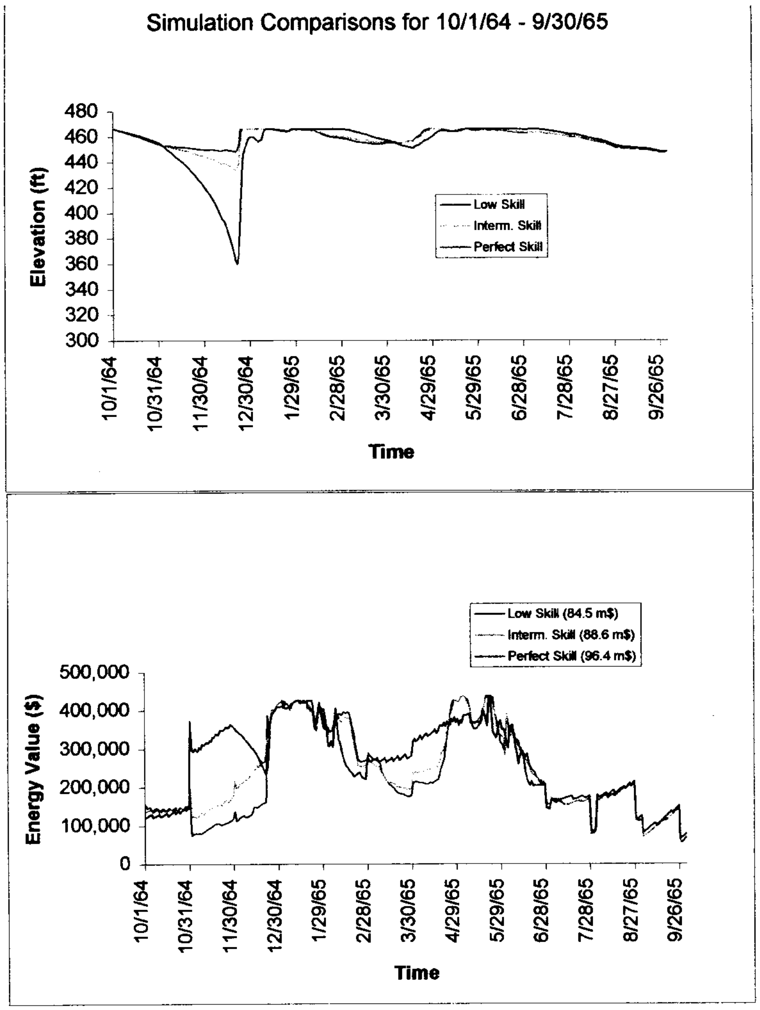

Simulation Comparisons for 10/1/64 - 9/30/65
Elevation (ft)
480
460
440
420
400
380
360
340
320
300
Low Skill
Interm. Skill
Perfect Skill
10/1/64
10/31/64
11/30/64
12/30/64
1/29/65
2/28/65
3/30/65
4/29/65
5/29/65
6/28/65
7/28/65
8/27/65
9/26/65
Time
Low Skill (84.5 m$)
Interm. Skill (88.6 m$)
Perfect Skill (96.4 m$)
Energy Value ($)
500,000
400,000
300,000
200,000
100,000
0
10/1/64
10/31/64
11/30/64
12/30/64
1/29/65
2/28/65
3/30/65
4/29/65
5/29/65
6/28/65
7/28/65
8/27/65
9/26/65
Time

Figure 3

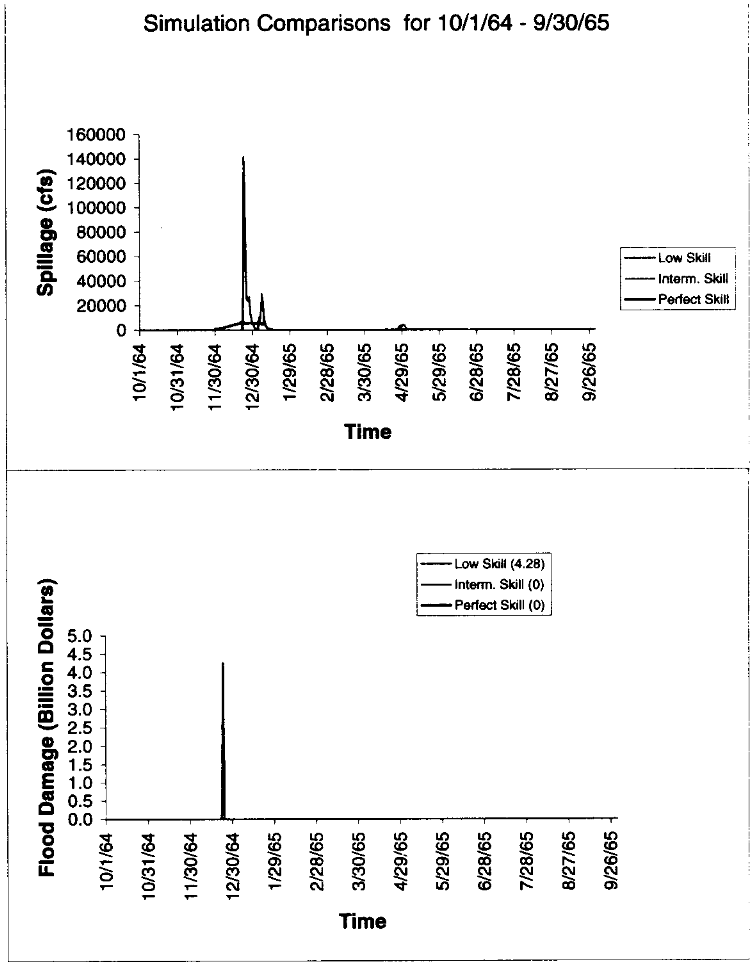

Simulation Comparisons for 10/1/64 - 9/30/65
Spillage (cfs)
160000
140000
120000
100000
80000
60000
40000
20000
0
10/1/64
10/31/64
11/30/64
12/30/64
1/29/65
2/28/65
3/30/65
4/29/65
5/29/65
6/28/65
7/28/65
8/27/65
9/26/65
Time
Low Skill
Interm. Skill
Perfect Skill
Low Skill (4.28)
Interm. Skill (0)
Perfect Skill (0)
Flood Damage (Billion Dollars)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
10/1/64
10/31/64
11/30/64
12/30/64
1/29/65
2/28/65
3/30/65
4/29/65
5/29/65
6/28/65
7/28/65
8/27/65
9/26/65
Time

Figure 4

Appendix

Brief Description of Folsom's Computer Model

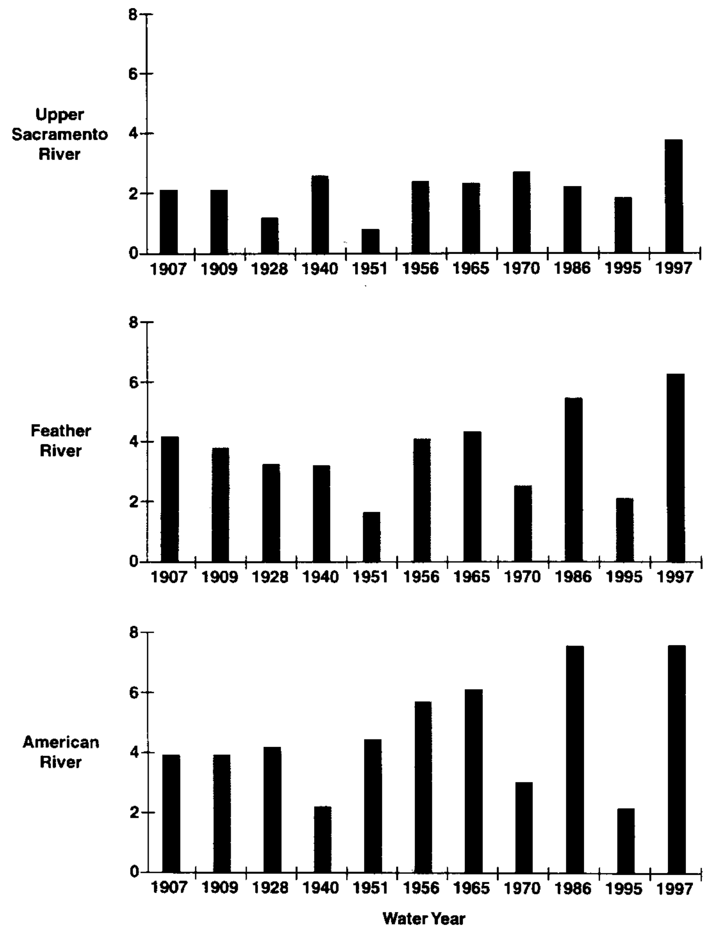
The forecasting component of the computer model can provide 30- or 60-day streamflow forecasts with skill which ranges from very low to perfect. At the low extreme, the model generates an ensemble of inflow sequences from the historical record corresponding to the current operational period. This ensemble constitutes the inflow forecast and its spread characterizes the forecast uncertainty. At the perfect extreme, the model "knows" the actually observed inflows. For forecasts of intermediate skill, the ensemble uncertainty around the actually observed sequence is reduced by a factor of 25 percent.

In addition to the forecasting, component, the computer model includes a decision module based on a dynamic optimization scheme (developed at Georgia Tech by Professor Georgakakos and his research associates). This module represents Folsom's hydraulic, power, and operational characteristics, explicitly utilizes forecast uncertainty, and determines daily release policies which minimize spillage and flood damage, maximize the value of hydropower (reflected by typical monthly consumer energy prices), and mitigate droughts.

Lastly, the forecast-decision scheme is embedded within a simulation procedure which implements the policies of the control model on a day-by-day basis and assesses Folsom's performance over the period of recorded inflows.

Comparison of Flood Sizes (to Median)

Three-Day Volume Divided by Median



Source: Department of Water Resources

Exhibit 1

STATEMENT OF SOROOSH SOROOSHIAN, PROFESSOR, DEPT. OF HYDROLOGY AND WATER RESOURCES, THE UNIVERSITY OF ARIZONA, TUCSON, ARIZONA

Honorable Chairman and Members of the Subcommittee:

As early as last winter, the scientific evidence based on observations and model simulation results clearly indicated that a strong El Nino weather pattern has been developing in the western equatorial Pacific Ocean. With further observations, it has become clear that this El Nino is going to be one of the strongest weather patterns on record. Several coastal countries located near the Equator have already been impacted. The west coast of Mexico experienced disastrous consequences as a result of Hurricane Pauline. Chile is experiencing record amounts of rainfall, resulting in major flooding.

The effects on the United States (so far) have been relatively small. The exception is the precipitation resulting from Hurricane Nora, which was mostly confined to southeastern California, western Arizona, extreme southeastern Nevada, and the southwest portion of Utah. However, the current predictions are that *higher than-average* precipitation will occur in California and the Southwest United States between November and February.

The impact of a strong El Nino on water resources is expected to be significant. Statistical analyses correlating historical precipitation amounts over the Southwest U.S. with El Nino years indicate a strong *likelihood* of above-average precipitation (and associated runoff). Water resources managers are, therefore, evaluating the potential impact of El Nino on their decisions and strategies for operation of water resources systems. Reservoir releases for the purposes of water supply and power generation, etc., must be scheduled, and emergency management plans must be drawn up to minimize the adverse impact of potential flooding. These decisions pose a major challenge, due to the type of information which is required.

We do know that this year's El Nino is the strongest yet recorded, and that the statistical evidence points to above-average winter precipitation for the Southwest United States. However, these facts *do not* constitute sufficient information for water resources and emergency managers to initiate major changes in operating practice. Such decisions require reliable information about the expected arrival times of significant storm systems, their expected durations, and intensities, etc. A storm system that arrives during warm weather may not result in snow accumulation at higher elevations, but may, instead, produce large amounts of runoff and potential flooding. Without accurate information about the timing and quantities of precipitation and streamflow, it is very difficult to plan timely evacuations from flood-prone areas or to pre-release large quantities of stored reservoir water to help mitigate the flooding. On the other hand, precipitation which arrives during a cooler period may accumulate as snow at higher elevations. Water resources managers then have greater flexibility to evaluate options and to decide on an appropriate operational strategy. Under this scenario, it would be a lot less risky to commit to early reservoir releases, knowing that melting of the above-average snow pack will provide the water necessary to fill the reservoir(s) later in the season. However, rapid warming could cause sudden large releases of meltwater, leading to late-winter and/or spring flooding. It is critically important, therefore, that accurate estimates of the volume of water in the snow pack and timely and accurate temperature forecasts during the melt season be available.

I wish to strongly emphasize that *sound* water resources management decisions in the Southwest will require far more information than merely the knowledge of a strong El Nino signal. Water resources managers are, rightly, reluctant to order early reservoir releases without further information. In the few instances that I know of, where early decisions have been made regarding reservoir releases and other water management issues, the knowledge that this will be a strong El Nino year has been only one of several useful pieces of information, but not the sole deciding factor. For instance, the Salt River Project—which supplies water to the greater Phoenix area—has incorporated the information about the strong El Nino signal into its decision to reduce ground-water pumping by some 40,000 acre-feet for this past year. This requirement will instead be satisfied from their reservoir system, based on expectations that an above-average spring snowmelt runoff will fill the reservoirs to their normal level.

Water resources and emergency managers are accustomed to making decisions based on probabilistic information. While the knowledge of a strong El Nino year has enhanced the probability for a wetter-than-average year in the Southwest, it has not reduced the uncertainty of many other factors critical in making decisions regarding major deviations from normal operating practice. In order to enhance the quality and usefulness of both short-term (hours to days) and extended (weeks to a month) forecasts, the reliability of the hydrologic prediction system for the West-

ern United States must be improved. The primary components of this system are: the Quantitative Precipitation Forecasts (QPFs), Extended Streamflow Prediction (ESP), more accurate methods for estimating snow accumulation, particularly in the mountainous regions, and high-resolution accurate rainfall measurements critical for forecasting rapidly developing flood events.

The strength of the current El Nino signal has attracted a lot of media attention and has generated much-needed public attention to this climatic phenomenon. The climate research community is to be commended for developing the capability of predicting it with such a high degree of accuracy. Perhaps the greatest benefit of this prediction to the water resources management community has been in encouraging very close cooperation among the Federal and state agencies responsible for various aspects of water resources management and hydrologic services. As an example, the cooperation over the past several months between the U.S. Bureau of Reclamation, the National Weather Service's (NWS) Colorado Basin River Forecast Center (CBRFC), and the U.S. Geological Survey (USGS) has resulted in close coordination for sharing modeling and observational information required for improved management of the reservoir system on the Colorado River. Continued cooperation among these agencies will critical to the development of an operational hydrologic prediction system for the Western U.S. to be used for water resources management in both El Nino and non-El Nino years. It is worth noting that, while statistical evidence points to a wetter-than-average year in the Southwest during a strong El Nino year, the wettest winter on record (1993) in the White Mountains and the surrounding areas of southern Arizona was *not* an El Nino year. A reliable hydrologic prediction system is crucial for the efficient management of western water resources irrespective of whether we are experiencing an El Nino weather pattern or not.

SUPPLEMENTAL SHEET

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STATEMENT OF RICHARD ANDREWS, DIRECTOR OF EMERGENCY SERVICES

Mr. Chairman and Members of the Subcommittee. I am Richard Andrews, Director of Emergency Services for Governor Pete Wilson.

Thank you for the opportunity to speak today on the many activities in California in preparation for El Nino and issues related to Federal policies and practices and their influence on our preparedness and disaster recovery efforts.

Background

As has been widely publicized, a large El Nino event is underway and is forecast to continue through the winter months. Though the specific forecasts continue to be updated and, at this time, remain uncertain, we have been told by various meteorologists and climatologists to expect substantially more rainfall than normal, especially in the central and southern coastal areas of California. Some forecasts suggest that the storms may come as early as November and, if the initial rains are sufficient to soak the ground, we could have an early and long flood season. Based on the records from past El Nino episodes, the flood risk would be higher in the coastal and mountain areas of southern California and not as great on major Central Valley rivers arising in the Sierra.

Higher ocean levels are expected, one-third to one-half foot above normal. Coastal damage and erosion are most severe when storm waves coincide with peak high tides. Potential coastal impacts include: structural damage from wave overtopping, onshore flooding and wave impact, and land loss due to cliff failure and beach erosion.

Public lands and infrastructure, as well as private property, are at risk. State beaches are some of the most vulnerable properties, with bulkheads, seawalls, parking lots and restrooms in danger. Boating facilities and boats are also at risk. During the winter of 1982-83, also a strong El Nino period, over $100 million of damage occurred to the public and private coastal infrastructure. One third of the damage (approximately $35 million) occurred to public recreational facilities along the coastline in Central and Southern California. Farther north, while the Central Valley

flood control system performed well, ten Delta islands were flooded due to levee failures.

Impacts to inland watersheds could be highly variable. The Department of Fish and Game notes that the impact to California's inland rivers and streams will depend upon the condition of the watersheds. For watersheds that are stable, the high volume of rainfall and runoff that frequently accompanies an El Nino may wash sediment out of the gravel, thereby improving spawning conditions for fish. For unstable watersheds, El Nino may pose a more severe threat, as it can cause hillsides to collapse into rivers or streams.

State Preparedness

Despite the considerable uncertainties about what the impacts of El Nino will be, we are confident that the state and local governments will be well prepared to meet the challenges that a severe winter weather season may bring. As is well known, California has, in this decade, had repeated and varied experience in coping with the consequences of natural disasters, including large fires, earthquakes and floods. We have improved our local and state response systems after each event; California has, I believe, the most effective emergency response system in the nation.

The El Nino forecasts have helped accelerate on-going preparedness efforts that followed this January's historic floods in central and northern California. In January 1997 the state experienced serious flooding in forty-eight of the state's fifty-eight counties, with damages totaling nearly $2 billion. These floods came only two years after a series of winter storms in the first quarter of 1995—where losses also totaled $2 billion—led Governor Wilson to declare all fifty-eight counties as disaster areas, the first time in the state's history that the entire state was impacted by a natural disaster.

At the height of the l997 winter storms, Governor Wilson established the Flood Emergency Action Team (FEAT) to coordinate the review of the lessons learned from the historic flooding and to establish long-term strategies to protect Californians from future flood disasters. Following a series of hearings throughout the impacted region, the FEAT's final report made more than fifty recommendations that have been implemented to improve the state's flood fighting systems, including:

- Improving emergency response coordination between public safety agencies at the local and state level with the Army Corps of Engineers and local flood maintenance organizations.

  The Office of Emergency Services (OES) has conducted a series of workshops on evacuation procedures, emergency alerts, the requirements for care and shelter of large numbers of evacuees, procedures for handling evacuations of livestock and pets, and the emergency closure of the Sacramento-San Joaquin Delta waterways during flood conditions.

  Together with the Department of Water Resources, OES has worked with reclamation officials on procedures for requesting resources and coordinating with the state's Standardized Emergency Management System. OES's training facility at San Luis Obispo is conducting training courses specifically focused on flood fight management.

- Improving and expanding existing flood data. To expand the state's existing flood data, the California Department of Water Resources has installed nearly 50 stream gauging sites in areas that have high flood probability. Earlier this year the state called on the U.S. Geological Survey to expand its surface water data collection program so that we might obtain better and earlier data about flood threats. Unfortunately, due to budget limitations, the Federal Government has indicated that such expansion is unlikely.

On October 6, Governor Wilson convened an El Nino summit in Sacramento for all state agencies and local leaders. In his Executive Order signed on that date, Governor Wilson directed the Office of Emergency Services and the Department of Water Resources to establish technical assistance teams and conduct a series of regional workshops throughout the state to review specific state and local preparedness actions. The first workshop was held in Long Beach on October 24, a second will be held in San Diego on November 3, with six additional workshops scheduled across the state in the coming weeks.

Governor Wilson also signed legislation allocating $7.4 million for El Nino preparedness measures, including the propositioning of flood fighting resources as forecasts become more specific. Moreover, Governor Wilson declared this week, October 27-31 as Winter Storm and Flood Preparedness Week throughout the state, with a series of events being held to provide continuing focus on the need for all residents, businesses and local governments to take basic emergency preparedness measures.

In addition, all state agencies have been carrying out El Nino preparedness measures, including:

- California was one of the first entities to provide comprehensive information on El Nino on the Internet. The Office of Emergency Services' home page contains comprehensive information on preparedness measures, current weather forecasts, and situation reports. CERES, the California Environmental Resources Evaluation System, one of the world's largest environmental web sites, provides comprehensive information on the El Nino phenomenon, and links to other home pages containing pertinent information.
- The California Conservation Corps, one of the state's most valuable emergency response resources, is offering sandbagging workshops throughout the state.
- The Department of Parks and Recreation, who's facilities sustained significant damage in the 1982-83 El Nino, is cleaning drainage channels and taking general preparedness measures at its facilities.
- The state Department of Transportation, as part of its general winter preparedness efforts, is stockpiling additional emergency response and road clearing resources at its facilities throughout the state.

In addition to the actions being undertaken by state agencies at the direction of Governor Wilson, local governments, community groups and businesses throughout the state are taking unprecedented preparedness measures. Supplies have been stockpiled, storm drains cleared, evacuation procedures reviewed and strategies for the care and shelter of individuals who may be displaced by the winter weather developed. Many cities and counties have held special flood preparedness drills and developed specific emergency plans for possible El Nino impacts.

California will continue to provide the public with the best available information through the Internet, briefings and workshops, training sessions, technical assistance teams and the stockpiling of equipment. Local and state agency preparedness will continue throughout the coming weeks.

Coordination with Federal Water Management Agencies

There are several areas of coordination between state and Federal agencies that need to be enhanced.

The state's Department of Water Resources has the primary responsibility for working with Federal water management agencies. Flood operations and reservoir management can be divided into five major geographical regions in California where there are significant flood control reservoirs on the major river and stream systems. Most flood control reservoirs are multi-purpose in that flood control is one of several purposes for which the reservoirs were authorized and constructed.

In California, most reservoirs that have Federal flood control reservations are operated by State, Federal or local water management agencies. The flood control reservation and seasonal operation rules are predetermined by the U.S. Corps of Engineers. Any deviation from the Corps' reservoir operation rules must be coordinated with the Corps. Last January, local, state and Federal coordination was exceptional.

The regional scenarios for this winter include:

- San Francisco Bay Area—Significant damage occurred in 1982-83 from high winds and high tides, and localized flooding, particularly in the Alviso district of San Jose. The potential for damage this winter depends on the timing and intensity of storm systems, and whether storms occur during high tides.
- Sacramento River Watershed—Forecasts indicate that rainfall and runoff are expected to be slightly above normal. A review of historical records indicates that extreme events, like those experienced in February 1986 and January of this year, do not correlate with strong El Nino events. In 1982-83 rainfall and runoff was well distributed through the flood season and the flood control system—with the exception of the Sacramento-San Joaquin Delta—was able to safely regulate runoff through the flood control reservoirs and the levee system. Peak releases from flood control reservoirs were much less than experienced this past January. For example, Oroville Dam released a maximum of 60,000 cubic feet per second (cfs) in 1982-83 versus 160,000 cfs in January 1997; Folsom Dam released 35,000 cfs in 1982-83 vs.115,000 cfs this January.
- Sacramento-San Joaquin Delta—While the levied Sacramento Flood Control System performed well during the last strong El Nino, in 1982-83 the Sacramento-San Joaquin Delta experienced significant problems. High tides combined with the nearly half-foot rise in sea level as a consequence of El Nino, causing levee failures at five Delta islands. The state has expended nearly $100 million to strengthen Delta levees.
- San Joaquin River Watershed—In 1983 an extremely large snowpack and spring runoff impacted the San Joaquin. This year, runoff from a similar event would likely be regulated safely through the flood control reservoirs; but, the levied flood control system in the San Joaquin valley would likely experience high water for a long period. Considering the vulnerable condition of the newly

repaired flood control levees to erosion and under seepage, a heightened state of alert will need to be in place for this critical watershed.

• Tulare Lake Basin Watershed—As in the San Joaquin, snowmelt runoff in the spring will likely be safely regulated through the flood control reservoirs. However, excessive runoff—similar to that of 1983—will likely flood the Tulare Lakebed and potentially threaten surrounding communities.

• South Coast Basin Watershed—This region was hardest hit by the 1982-83 El Nino. Coastal wave damage was severe as were flash floods in the interior counties. Flood control reservoirs and debris basins, primarily operated by local flood control agencies, performed well in the past and are expected to perform effectively this winter. Flood control reservoirs and debris basins, primarily operated by local agencies to Corps regulations, performed well in 1982-83. Since that time, reservoir operational plans have been updated as a result of changes in channel capacities and conditions downstream of reservoirs. Earlier notification procedures have been implemented in recent years for warnings based on reservoir operations.

Issues Requiring Additional Attention

The Federal Government is an important partner in the state's overall preparedness efforts and plays an essential role in helping communities recover from the impacts of natural disaster.

In a letter to President Clinton on October 6, Governor Wilson urged action on several concerns about current Federal policies and practices that impact the pace of recovery from past floods and winter storms and will also affect current and future preparedness and recovery efforts, including:

- Urge the Army Corps of Engineers to accelerate the timetable to make repairs to levees damaged in central California during the January 1997 floods. Policy disputes between Corps officials in California and Washington slowed recovery during the spring and summer months. Progress is now being made, and if we're fortunate to have winter storms hold off until near the end of November, we have been assured by the Administration in an October 24 response to Governor Wilson's letter that all but one of the critical central California flood control repairs should be in place to handle the flows. We would hope that this year's experiences of unnecessary delays would not be repeated following future flooding.
- In the event the levees are not fully repaired, direct the Corps to undertake necessary response preparations to improve the Corps emergency response under Public Law 84-99. Some steps in implementing this strategy have already been taken; several others are needed. In advance of high water, the Corps should used their authority under Public Law 84-99 to do the following:
    - Direct emergency repairs at the most critical sites if rainfall interferes with the construction schedule. This could be accomplished through appropriate contract provisions change orders.
    - Redesign the repairs at unrepaired critical sites to employ materials and equipment appropriate for wet condition if rainfall impacts construction.
    - Award contracts with construction firms and aggregate suppliers in the central valley in advance of high water. These time and materials contracts would allow the Corps to simply direct the contractor to make repairs even as the repair is being redesigned.
    - Secure equipment and materials that are difficult or time consuming to obtain during an emergency. Examples include expandable vinyl bladders for raising effective levee heights, and barges for working in the waterway. Items could be mobilized or stockpiled upon forecasts for high water, provided they are secured in advance.
- Direct all Federal regulatory agencies to consolidate the needed approvals for flood repair and preparation work. Governor Wilson has directed all state agencies to place the highest priority on expediting approvals for this work, a large number of Federal agency approvals are also needed. Local agencies need clear and consistent permit requirements and procedures from Federal agencies. Governor Wilson has designated the Department of Water Resources the principal state agency to coordinate needed state agency approvals. Such a "one stop shop" strategy should be considered for future permitting processes for essential public safety related facilities.

On October 24 the Corps issued a Nationwide 31 permit for channel clearing and sediment removal. Over this past weekend Los Angeles County began some of this important work. Governor Wilson remains concerned, however, that the Environmental Protection Agency has indicated that it will seek a policy review

of the cumulative impacts of channel clearing activities with the intention of requiring further mitigation work.

- Direct the Federal Emergency Management Agency (FEMA) and the Corps of Engineers to modify policies for local agencies that conduct flood fights on flood control works. As a result of Federal policies arising from the 1993 Midwest floods, there now exists a disincentive for local agencies to assist in flood fights. The Federal Levee Policy asserts that the Corps is the primary Federal agency for flood fighting. Since the adoption of this policy, FEMA has established a virtual "hands off" policy for funding flood fighting on any flood control work. FEMA states that the Corps is responsible for flood fighting on all flood control works, and that FEMA is therefore prohibited by the Stafford Act from funding such efforts. At the same time, the Corps has responsibility for conducting flood fighting operations, but finds itself, in extreme events like the January storms in California, overextended and unable to respond in a timely manner to every request. The Corps is forced to prioritize its limited resources, omitting or deferring some essential flood fighting projects. Because of the requirements for prompt action, local agencies cannot wait for the often cumbersome Corps contracting processes to be implemented. However, if they take action to meet immediate flood fight needs without going through the Corps, the local agencies find themselves unable to receive reimbursement from either FEMA or the Corps. This illogical Federal policy creates a perverse disincentive that results in more damage than necessary.
- Direct FEMA to implement the recommendations relating to Public Assistance processes and policies made by the California Congressional delegation in their September 15, 1997 letter to the FEMA Director.

Conclusion

All Californians are grateful for the assistance we received from Congress and the Administration as we joined together on the levees to battle the floodwaters of last year's storms. We are also grateful for the assistance we continue to receive in the flood's aftermath as communities and individuals work to repair the damage and clean up homes, farms, and businesses.

State agencies, local governments, community groups and individuals are currently engaged in an unprecedented preparedness effort in advance of this winter's weather. While the exact outcome of El Nino remains to be seen, we still have time to undertake needed common-sense actions to prepare for the worst, and prevent the loss of life and property damage we suffered earlier this year and in the last El Nino.

STATEMENT OF STEPHEN K. HALL, EXECUTIVE DIRECTOR, ASSOCIATION OF CALIFORNIA WATER AGENCIES (ACWA)

I. Introduction

Mr. Chairman and Members of the Subcommittee, thank you for providing me an opportunity to submit this statement regarding the water management implications of the 1997/98 El Niño on behalf of the Association of California Water Agencies (ACWA). ACWA is a statewide, non-profit association which represents more than 440 public water agencies who collectively manage and deliver 90 percent of the state's urban and agricultural water.

It is important to understand the role our members play in managing water resources, the uniqueness and fragility of California's water system and how a weather event like El Niño can play havoc on a water system already stressed to the breaking point.

Local water agencies serve several functions in California's water management system, but the responsibilities most relevant to the discussion of El Niño are flood control and water supply. While there has been a deluge of attention on the disastrous flooding that can be caused by an El Niño, much less attention has been given to the water supply issue. There are several points that need to be made about California's flood control and water supply system in such a discussion.

First, California's weather is hard to predict and extremely variable. The norm is arrived at by averaging the extremes of drought and flood. So-called "normal years" rarely occur.

Second, California's water managers at the Federal, state and local level have done an excellent job of managing flood control and water supply given the constraints under which they operate. However our constraints are enormous. Much of California's water system was built decades ago, before modern construction techniques were available. Not only is California's system outdated, it is inadequate.

Our storage capability is far below what we see on other river systems. This outdated, undersized system has created tension between flood control and water supply for those charged with managing this system.

Third, added to the tension between managing our system for flood control and water supply, we have placed substantial new demands on the system by releasing large quantities of water for fish and other environmental purposes.

These observations lead to the inescapable conclusion that we must act now to shore up our existing system and expand it in order to meet California's legitimate flood control, environmental and water supply needs.

In California, water agencies routinely balance flood control and water supply needs. Specifically, water managers must keep enough reservoir storage space available to manage floods during heavy precipitation, while ensuring that adequate water is stored to meet water supply needs for cities and farms and to protect against drought.

II. California's Weather Picture: Feast or Famine

Even without an El Niño in the mix, California's weather is highly unpredictable. Planning for a new water year is often akin to reading tea leaves.

According to the California Department of Water Resources, weather in our state has become increasingly unpredictable over the last 50 years. Whether that variability is due to global warming, cyclical changes or some other explanation, erratic swings from too much to not enough make it very difficult to map out management plans for the state's water systems.

Adding insult to injury, we have the variability of El Niño, which could bring either floods or drought to the state. During California's protracted seven-year drought, an El Niño in 1991-92 helped cause a critically dry year. Conversely, a strong El Niño in 1982 caused devastating floods similar to conditions predicted for this current El Niño.

Since 1950, California has experienced 12 El Niño events; eight of which have been similar in strength to the current El Niño. Of those 12, five have led to drier than normal conditions, while seven have resulted in above normal precipitation.

In the past 20 years, California has experienced only two years that experts can call "normal"—where water supplies for the year have ended up close to the average. And even in those years—1989 and 1993—large swings in the weather pattern surprised forecasters and planners. Large amounts of rain can come in the first few months of fall, and that could be the last rain we see all year. Such was the case in 1997—a year of devastating floods. (See Exhibit 1.)

III. 1997: Floods and Drought

Water officials recently closed the book on a 1997 water year that included some of the worst flooding we've seen this century. While not an "El Niño year," the 1997 floods are being viewed as a model, due to their warm, El Niño-like characteristics.

Over the three-day period centered on New Year's Day, more than 30 inches of rain poured onto Sierra Nevada watersheds already saturated by one of the wettest Decembers on record.

The deluge overwhelmed many of the water systems in Northern California. The sheer volume of runoff exceeded the flood control capacity of Don Pedro Dam on the Tuolumne River and Millerton Reservoir on the upper San Joaquin River with large, uncontrolled spills of excess water. In just a week's time Shasta, the largest reservoir in our system, filled to near capacity 1.4 million acre-feet—taking in nearly two million acre-feet. At its peak, inflow was measured at a record 236,700 cubic-feet-per-second. Most of the other large dams in Northern California were full or nearly full at the end of the storms.

The effects of last January's storm have been far-reaching. Total flood damages reached nearly $2 billion, including $300 million in damage to flood control facilities and $206 million in damages to various public facilities. Nearly 300 square miles of agricultural land were flooded, causing close to $300 million in damage to agriculture. In addition, 120,000 people were forced from their homes and nine lives were lost.

The damage could have been even more catastrophic. State and Federal water projects stemmed the worst of the floods, due in large part to the changes to the system implemented after the 1986 flood. Millions of homes and businesses were spared as a result.

1997 was the third wet year in a row for Northern California. State water officials say total runoff statewide was 145 percent of average. But, perhaps even more dramatic than the deluge of rain in January was the lack of rain that followed. The spring of 1997 was the driest in 104 years. The wet pattern began in November, culminated in January, then shut off like a switch for the rest of the year.

Water shortages forced the Bureau of Reclamation to cut some deliveries by 10 percent. Statewide, we begin the next water year with only average supplies in storage.

IV. California's Flood Control and Water Supply System

To deal with California's weather extremes, flood control plans were established for the Sacramento Valley beginning in the late 1880s to improve navigability and protect population centers. Once called the "Nile of the West," the Sacramento River yields about 35 percent of the state's water supply.

The flood plan evolved into one of the most complex flood management and water distribution systems. Today's integrated Federal, state and local flood management network includes 23 reservoirs with flood detention space and 1,760 miles of Federal levees, channels, and overflow bypasses and weirs in the Central Valley.

This network, in concert with other Federal, state and local facilities, also supplies fresh water for urban, agricultural and commercial demands—the majority of which are in the drier regions of central and southern California—and flood protection for the Sacramento and San Joaquin valleys. Water supply provided by these projects also helps to fuel California's $800 billion economy.

Key projects include the Federal Central Valley Project (CVP) and California's State Water Project (SWP). The CVP has a storage capacity of 11 million acre-feet and delivers about 7 million acre-feet of water to agricultural and urban uses. The SWP delivers about 2 million acre-feet annually to farms and cities. The single most important aspect of California's complicated water system is the Sacramento-San Joaquin River Delta. Its channels through the state and Federal projects provide drinking water for two-thirds of the state, in addition to irrigation water for more than 4.5 million acres of the nation's most productive farmland.

This is an impressive system, but it is far less than what we see on other river systems. According to the California Department of Water Resources, total storage on the Sacramento River system with average annual runoff of 22 million acre-feet is less than one-year or 16 million acre-feet. In comparison, the Colorado River system—with an average annual runoff of only 15 million acre-feet—boasts a storage capacity of 60 million acre-feet or enough for a four-year supply.

The lack of storage capacity has led to the tension between operating the system for flood control, the protection of life and property, and operating the system for water supply to meet the needs of the nation's largest economy. And the problem is growing worse. Since the last major element of our water management system was added in the early 1970s, the state's population has essentially doubled. Local water managers have done a good job in balancing this tension. Urban water managers have managed to meet the needs of the rapidly growing population through conservation, reclamation and innovative water transfers and exchanges. Meanwhile, California agriculture is today producing 50 percent more in food and fiber with the same amount of water that it was using 20 years ago. We're also doing a better job of protecting lives and property. It is widely acknowledged that the floods that have occurred in recent years could have been far more devastating had it not been for strong efforts to coordinate the local, state and Federal flood control operations.

However, the experience of 1997 has shown the deficiencies in our system that not even innovative management can overcome. The devastating floods of January 1997, followed by water delivery cutbacks later in the year, point out that our existing system must be irked and expanded in order to protect California from floods while maintaining a healthy environment and a strong economy.

Governor Pete Wilson reinforced this theme in a recent letter sent to President Bill Clinton, In the letter, Wilson expresses concern about the state of the Central Valley's levee system severly damaged by last year's floods. Wilson stated, ". . . I am deeply concerned that the Corps' work will not be completed in time . . . There is a substantial risk that not all repairs will be completed prior to this November when heavy rains are expected throughout California."

V. The Environmental Factor

The experience of recent years also points out that we have new demands on the system unrelated to growth in our population or economy. The Bay-Delta system—the hub of our water management system—also forms the largest estuary on the west coast and serves as a unique habitat for the more than 120 species of wildlife, some of which are protected under the Federal Endangered Species Act (ESA), such as the winter run Chinook salmon and delta smelt.

Fisheries are also affected by weather extremes. Many experts are concerned that this year's El Niño may be bad news for already-depleted salmon and trout populations. Many fish populations were decimated due to damage from last year's high

waters. With another year of heavy rainfall predicted, concern is mounting for salmon populations especially—as one expert put it, “For salmon, there’s a strong apprehension bordering on mild panic.”

While fresh water flows are by no means the only consideration in producing healthy fish populations, those flows are certainly one of the factors viewed as essential to produce healthy habitat throughout the system. To the extent our water management system falls behind in meeting our environmental water supply and flood control needs, conflict over those competing priorities will continue to increase.

VI. How The System Is Being Operated Today

As we review the statistics from the extraordinary storms of 1997 and others which preceded it, we are reminded that tremendous precipitation and runoff do not necessarily equate to a bonanza in terms of water supply benefits. Several times over the past two decades, vast quantities of fresh water ran out to the Pacific Ocean because we don’t have enough reservoirs to store the water. Capturing storm runoff which is excess to Delta environmental needs could provide sorely-needed water for urban, agricultural and environmental needs.

As water managers struggle to maintain the balance between flood control, environmental and water supply needs working within existing storage constraints, water supply tends to suffer the most.

Again, the 1996-97 water year is a case in point. With a tremendously wet January, water delivery commitments were made from both the state and Federal projects including voluntary operations in the Bay-Delta to benefit fisheries. As the wet months turned to dry, the state and Federal projects strained to make all delivery commitments to urban and agricultural water users. In the end, Federal customers did not receive full deliveries.

Initiated in 1994 as part of the historic Bay-Delta Accord, the CALFED Bay-Delta Program, a joint state-Federal partnership, has been charged with developing a long-term plan to address the environmental decline and water supply reliability issues in the Bay Delta system. Included within the scope of work is the need to better address Bay-Delta conflicts such as those brought about by balancing flood control with water supply and environmental needs.

As dictated by the accord, further constraints have been applied to both the CVP and SWP to protect fisheries. Approximately 850,000 acre-feet of project yield in critical periods is now being dedicated to the environment—over and above the original 3.65 million acre feet required under prior water rights decisions.

In addition to efforts by CALFED, the U.S. Corps of Engineers is preparing a comprehensive reassessment of the CVP flood supply system, which is sorely needed. We must rethink our overall approach to flood control and water supply as we prepare to meet the needs of California into the next century.

VII. Conclusions

Through the benefit of our collective experiences, water agency managers and environmental regulators are beginning to reach common ground on the need and potential strategies to improve our approach to flood control and water supply issues.

First, there is general agreement that we need to improve our overall water system by addressing the need for additional water storage and by improving our water delivery system. This will also necessitate a need for even tighter operating regimens.

Second, there is general recognition that both have a tremendous stake in finding workable solutions to these challenges, including the need to expand the ever-shrinking water pie.

As this testimony has sought to highlight, the time to act on the consensus to improve our water management system is now. Those of us in the water management community believe that CALFED provides the best opportunity to take such action. That is why we are strongly supporting CALFED and are participating actively in the CALFED process. We believe it is imperative that CALFED produces a plan that will restore the ecosystem comprised of the Bay-Delta and its watershed as well as produce an implementable plan to improve our water supply and flood control capabilities into the next century. There is consensus in California along those lines, and we hope and trust the U.S. Congress will agree that there is not only a state but a Federal interest, and that the Federal Government will actively participate in preparing and implementing the CALFED plan.

I appreciate the opportunity to speak before you today to underscore the importance of focusing on the water supply implications of weather events like El Niño and opportunities that exist to deal with those impacts.