Robert M. Hirsch *was born in Illinois in 1949. He received his B.A. in geology from Earlham College, an M.S. in geology from the University of Washington, and Ph.D. in geography and environmental engineering from Johns Hopkins University. Bob began his career with the USGS in 1976 as a hydrologist. He conducted and directed research leading to methods for analysis of: the risk of water-supply shortages, water-quality trends, transport of pollutants in rivers, and flood frequency. He also was instrumental in the design and initiation of USGS programs including the National Water-Quality Assessment Program, Global Change Hydrology Program, and Watershed Modeling Systems Program. He has served as Chief, Branch of Systems Analysis of the Water Resources Division, USGS, Staff Assistant to the Assistant Secretary for Water and Science, and Assistant Chief Hydrologist for Research and External Coordination of the USGS. From August 1993 to March 1994, he served as the Acting Director of the USGS. In June 1994, he became Chief Hydrologist of the Water Resources Division. He is a recipient of the Department of the Interior Distinguished Service Award, was conferred the rank of Meritorious Executive by the President of the United States and was elected a Fellow of the American Association for the Advancement of Science. He is a recipient of the Water Management Achievement Award from the Interstate Council of Water Policy.*

U.S. GEOLOGICAL SURVEY WATER RESOURCES PROGRAMS

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It is a pleasure to be here to talk with you about the science information and data provided by the U.S. Geological Survey, in support of you in your responsibilities and endeavors to understand and manage the water resources of your state. We provide such information nationwide through our network of offices and have done so for about 120 years.

I'm going to talk about a few items, mostly from a national perspective, and then mention a few specific things here in our New Mexico program. I will talk about stream gages, in particular something we call our National Stream Flow Information Program, and some new developments in data delivery that I hope some of you are already using. I also want to show you some new technologies that we are deploying in the field, and then share a few comments about specific activities here in New Mexico.

Let me begin with stream gages. This is one of the most important things that we do at the USGS, to provide science in support of resource management. We operate about 7,000 stream gages nationwide. Basically, a stream gage is a structure beside a river bank, with some method of determining the water level (or stage) on a continuous basis, recording that water level at frequent intervals, such as once every 15 minutes (Fig. 1a). Of course, what we are mostly interested in isn't water level, but in fact, discharge (or flow). So we must, from time to time, make discharge measurements, usually using a traditional current meter, making velocity measurements in numerous verticals across the stream (Fig. 1b). The result is essentially an empirical calibration, something we call a rating curve, which relates water level to the discharge (Fig. 1c). This calibration is the most important part of the job of stream gaging. It needs to be repeated frequently because our river channels are constantly changing, so we need to make sure that this calibration between stage and discharge is always accurate. Today most of our stream gages are equipped with telemetry, which means the data goes from the gage, up to a geostationary satellite, and back down to our offices where the stage information is converted into discharge. It is then provided to all interested users, via the internet, in the form of a hydrograph (Fig. 1d).

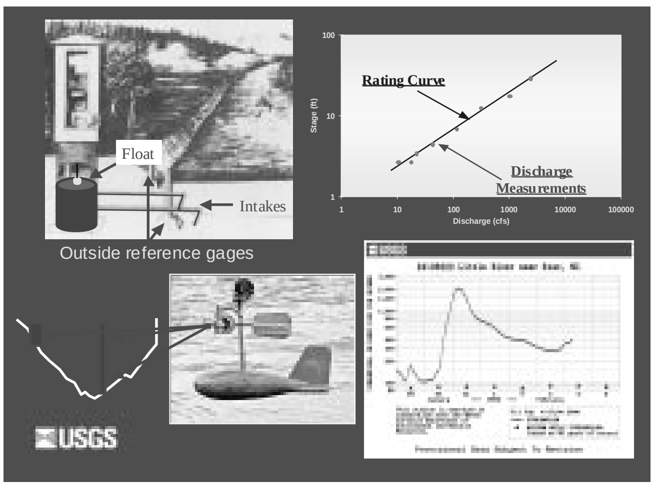


Figure 1a-d, clockwise from upperleft; a. gaging station, b. rating curve, c. hydrograph, d. current meter

The USGS stream gaging program is over 120 years old and, in fact, the entire program started here in New Mexico at Embudo. It began as an experimental activity to develop methods to train the technicians and then disperse them across the United States. And it was really the original concept of John Wesley Powell, our second director of the USGS.

There are many uses for streamflow data. I will discuss them here in somewhat of a chronological order. It may help you understand all the reasons why this gaging activity is so important.

When John Wesley Powell was looking at the development of the West, he said that the key to appropriate development was to appraise the water resources so that they could be allocated properly and not over-allocated. At that time the major concern, of course, was irrigation–how much land could be irrigated with the amount of water available in our rivers. This evolved into the issue of designing the nation's water infrastructure. If one is going to build a dam or a diversion, one needs to know how much flow is available so that one could determine the kind of yield that can be obtained. This can only be done through stream gaging.

The next issue was flood hazard planning and flood forecasting. Determining the extent of the 100-year flood plain requires a statistical analysis of the measured flood flows over a period of years. The resulting flood-frequency curve can be used to estimate the flow that would occur with an average recurrence interval of, say, 10 years or 100 years. These flood-frequency curves can be regionalized for extrapolation to ungauged streams. And with good topographic maps, they can be used to map areas that would be inundated at selected recurrence intervals.

Flood forecasting is a very important function, one carried out by our colleagues in the National Weather Service. They have the mission to provide not only the flood forecast but also stream-flow forecasts in general for the nation. In order to provide flood forecasts they need a number of things: precipitation information, temperature information, and forecasts of what the weather is going to do. They also need hydrologic models and they need the current hydrologic data to make sure that they are on track in their forecasts. Accurate models depend on both historical and current stream flow information.

Next is reservoir operations. If one has a reservoir, one needs to make sure that it is operated properly, in anticipation of flood flows, and during drought flows. To make those day-to-day, hour-to-hour operational decisions, managers must know the current rates of inflow to and outflow from the reservoir.

Recently, water quality management has become an important reason for having stream gages. Permits set for wastewater discharges depend on having flow information so that one can understand dilution and predict the effect of a wastewater effluent on the receiving water, including its level of dissolved oxygen. We have something new in all of our lives in terms of water quality, something called "TMDLs." Now some people think that stands for "too many damn lawyers." It actually stands for "Total Maximum Daily Load." What is load? Load is a concentration multiplied by flow. One can't begin to talk about Total Maximum Daily Load if one does not have flow information coupled with the water-quality information in that analysis. This is yet another critical reason for having the flow information.

The need to maintain instream flow to protect aquatic habitat is another critical issue in water management that frequently conflicts with some of the more traditional uses of the water in our urban areas and agriculture. One can't begin to determine instream flow needs without the flow information to understand what the traditional flow regimes were before the development and what they are today.

I think the previous talk really did a wonderful job emphasizing the importance of changes in the stream flow. Stream flow changes for a variety of reasons. The effect of human activity and vegetation change on the landscape is a critical reason that stream flow changes. We need to measure flow so that we can quantify what is happening as vegetation changes. In addition to that, we have issues such as long-term climate variations and even potentially long-term climate changes due to things like the greenhouse effect.

And finally, I would mention recreation uses and recreational safety. In this era where our data are available so readily on the internet, anyone who is planning to go fishing, kayaking, canoeing, rafting, you name it, will want to know what the conditions are before they go out to their favorite site for those activities. They can check that information on the internet from our data and make their decision–for example, I'm not going to waste my time and energy going out there because the conditions are not appropriate and also it will affect personal safety.

So there are a tremendous multitude of uses for streamflow data, and the list is ever growing. Some of the guiding principles behind our stream gaging network are that many partners contribute the funding, that all the data we collect are freely available to anyone, it's not just available to those who help pay for it, and we operate the network on behalf of everyone. There are often opposing parties in water disputes, and we want to provide the data on which all can agree as the basis for the national and regional and local debates for our water resources.

There have been some difficulties with our stream gauging network and reductions in its size. As a result, Congress asked us to take a look at the network and raised some questions about how well we are doing in serving the nation's needs.

It is important for people to understand where the funding for stream gauging comes from. This is the funding picture as of 1999 (Fig. 2). As you can see, at that time, it was about a $91 million venture on a nationwide basis. That is the single largest kind of activity that we have in water programs of the USGS. The only part of the funding that comes entirely from the USGS is about $5 million, which is used to support individual gages. The biggest part of the money actually comes from state and local agencies. In 1999 it was $37 million from over 800 state and local agencies nationwide; part of a matching program called the Cooperative Water Program, a program that has existed for over 100 years. The appropriations law says that we are given a certain amount of money that we may only spend if we have at least an equal amount of money coming from state and local partners, who cost share with us in order to undertake that work. Two-thirds of the program therefore is funded by state and local agencies and is driven by their needs. These agencies include the Interstate Stream Commission, here in the state of New Mexico, and a number of other agencies, cities, and counties, that are continuously providing us with very strong support for this network. We are very appreciative of the tremendous support we have received over the years. And finally, we have other federal agencies, most particularly the Army Corps of Engineers, which is a very large contributor to the stream gaging program.

But as you can see, although there is great strength in this cost-sharing arrangement, there is also some potential weaknesses. As administrations change in state governments, states go through budget crises from time to time and some of this money can dry up. That then affects the money on our side that has to go away. And we can get some real instabilities in this program. One of the crucial aspects to a program like this is the need for long-term stability. So there is a whole set of issues that arises with this National Stream Gaging Program that we have been trying to address over the years, and we have come up with a

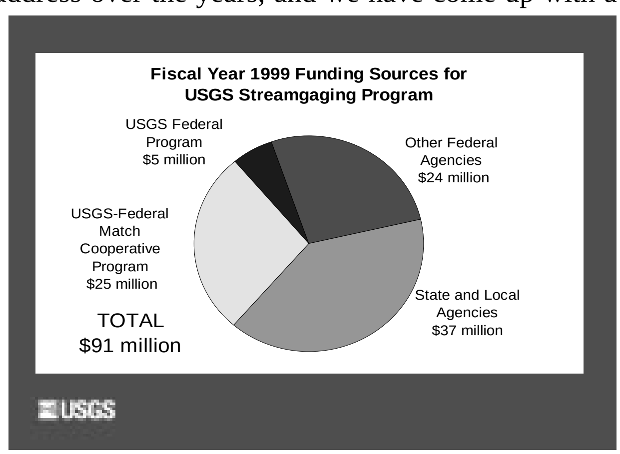


Figure 2. FY99 funding sources for USGS streamgaging program.

plan called the National Stream Flow Information Program to address them.

The first issue is the need to modernize our stations, particularly by adding telemetry to make the data available for real-time use as well as for long-term records. We need to make sure that our stations can withstand the battering they receive during a flood. We need to improve the reliability of our data delivery. There are a lot of potential breaking points in the chain of delivery, from the stream gage to your agency, or your university, or your home, and there are a lot of potential points for failure and we will continue to work on those.

We need to fill in the gaps in the network, particularly working in the upstream areas of smaller watersheds. I love the quote from the Chinese emperor a few thousand years ago, “You’ve got to protect the mountains, the headwaters, in order to protect the stream.” We need to make sure we have gages up in the headwaters areas. These are difficult to fund individually, but collectively, they provide valuable data.

The next point is assuring the availability of long-term records for regional statistics and trends–again, very much related to the previous talk. What we were seeing in the early 1990s is that we were losing long-term gages, one of our most important assets of the stream-gaging program at the USGS. Every single year, about 90 stations nationwide that had relatively long stream-flow records were being shut down for lack of funding–lack of funding in our budget as well as lack of funding in state and local agency budgets. We believed that to be an unacceptable loss, and we needed to start reactivating those stations and rebuilding. And, of course, it took funds to do so. I am pleased to say, we have been receiving some of those funds and have been able to turn the tide and put some of those stations back into operation.

And finally, a cost issue. There is a lot of infrastructure that goes into operating this network on a common basis for all users. We need to be able to step up to the plate with our own monies to make sure that the infrastructure is there, and not have it depend on all these contributors. We need to ask the cooperators to help support the individual gages as opposed to the whole data delivery and quality assurance system.

So we have laid out our plan for what this network ought to look like. I won’t go into all the details of this plan: the network itself, the specialized collection of data during floods and droughts, the regional and national assessments to look at these trends, the statistics, a better information delivery, and some methods developed in research. These are the basic goals of our national stream flow information program that will drive where the stations are placed. We have a preliminary design for this and the folks who are here from the USGS office in Albuquerque can provide you with more information regarding the details of what we envision this network to look like ultimately in New Mexico.

We want to be able to help people understand interstate and international transfers and movement of water, help them with the Weather Service’s need for stream flow forecasting, understand the outflows of major river basins–something we call sentinel watersheds. This gets back to the concept of small watersheds, to understand what’s happening on the landscape. We also need stream gages that will help support water quality. And this is, in fact, what the federally funded national network would look like (Fig. 3). Federal funding would cover about 4,000 of the 7,000 gages in the country, enough to provide a base level of knowledge in order to fulfill our national mission. And the ones in red here are those already in operation, but we have also indicated ones we believe should be reactivated and ones operated by other agencies, and then some new sites that we think need to be added to the network. I won’t dwell on this, in the interest of time, but this is just to give you an indication of some of the planning we have for the new stations that are needed to fill out this network and really make it whole.

Figure 3. NSIP proposed network of USGS funded stations.

I want to show you the funding situation with tim and this is really the good news story (Fig. 4). What represented here is the dollars that have bee appropriated for stream gaging during fiscal years '9 '02. It represents that blue wedge of the funding p that I talked about before (Fig. 2), the monies th provide a base level of support to this overall nation effort. You can see it was declining through budg cutbacks coming from the Office of Management ar Budget and the Congress during most of the 1990s. W finally saw a turnaround and it began to grow in tl year 2000 and then had a very substantial increase (about $10 million in 2001, and then it has been esse tially level through 2002. Now we have a long way to go in terms of the need for growth in this if we are going to have the network ultimately that we think we need, but we are pleased to see that we are headed in the right direction. This only happens because of very strong support that comes from the grass roots. And we are quite appreciative of continued support that so many of the users of this information are providing.

I'll say just a little bit on the progress that we have made with this new money nationwide. This includes 37 new stream gages over the last couple of years, 73 reactivated stream gages, upgrades of equipment, flood hardening, extended rating curves, which is very helpful to the weather service, and a number of gages that have been converted to 100% USGS funding because we think they are so critical from an interstate, national, and international perspective. The new funds are already helping us. There is a site in Minnesota where we used some of these new funds and literally within days after we had the gage in operation, a river in the area was hit by a flood (Fig. 5). I was delighted to take that up to Congress and show them that the money was already being put to work.

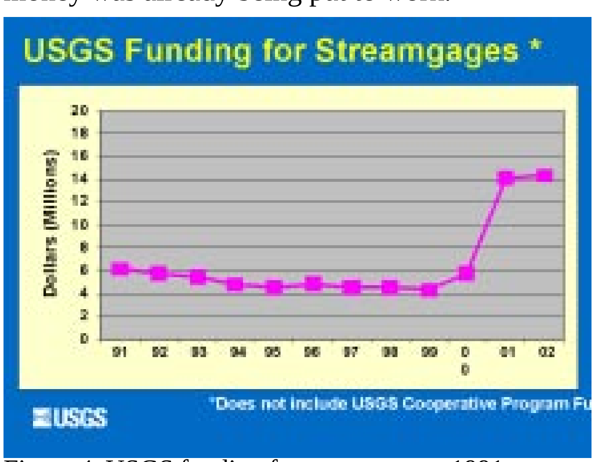


Figure 4. USGS funding for streamgages, 1991-2002.

Figure 5. Minnesota River near Jordan, MN, 2001.

Let me quickly say a few things about some new data delivery systems. Something called Water Watch and another called NWIS Web. Water Watch presents a map that looks like this (Fig. 6). It is updated every few hours on the internet. Every dot on this map represents a stream gage, and those stream gages are ones that have at least 30 years of record and are also telemetered. You can see the ones in New Mexico that are of that type. The color coding is a relative scale of wetness to dryness that is coded into the historical record of that location. A red dot, for example, would indicate that today's flow is the lowest on record for this date for that particular site. Whereas, a black dot would represent the highest flow for this date for that particular stream. It is a probability scale that is evaluated at every one of those stations. That gives you an overall picture of the nation. Then you can zoom in and click on the state of New Mexico and bring up a picture of what the state looks like (Fig. 7). You then click on an individual station on the screen, the text will indicate what station it is, what the flow is, and where it ranks in its historical record. It then takes you immediately to the actual hydrograph including data just a few hours old, and the long-term median values (Fig. 8). I think it is a real asset to get a hydrologic picture of what is happening nationally, regionally, and locally.

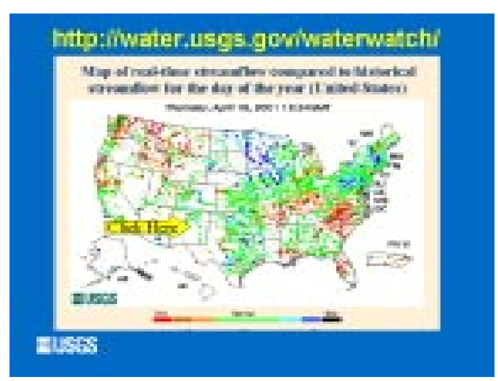


Figure 6. Real-time streamflow compared to historical streamflow, April 19, 2001.

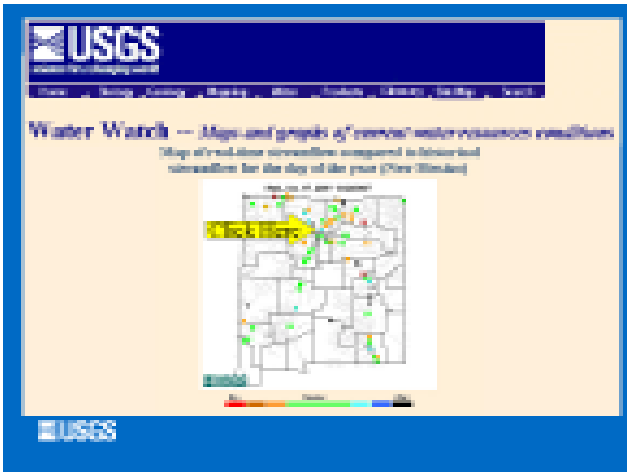


Figure 7. Water Watch web page for New Mexico.

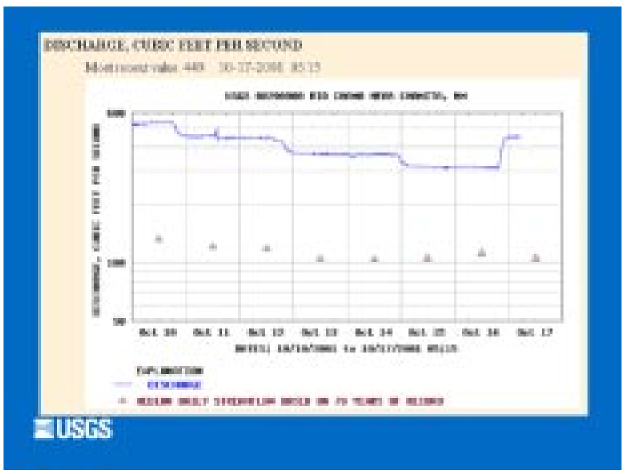


Figure 8. Example of 7-day hydrograph from Water Watch.

The other data delivery system is something we call the NWIS (National Water Information System) Web, which is a way of taking the treasure trove of data that we have from over 100 years of data collection and making it readily available. The website is water.usgs.gov/nwis. Just to give you a flavor of what this website contains, there are 21,000 sites where we have at sometime or other collected stream flow data. There are 181 million daily stream flow values on this website, plus all the peak discharges. So as an example of how you can utilize this, if there was a flood, you could look at that map, select a site, and see that it's flowing at 5,000 feet per second. How does that compare to the big floods of history at that particular site? You could then immediately look at the peak flow values historically and you could say, "Oh, 5,000 cfs is higher than we have ever seen before", or on the other hand, "no, that's been exceeded 20 times in the last 50 years," to put it in some kind of context of understanding of what's going on at an individual site. This system has about 7,500 sites with real-time data. That's not only stream flow, but about 600 water quality sites and some groundwater sites as well that are real-time–a lot of water quality information and a lot of groundwater information–7.2 million individual groundwater levels from a total of 1.4 million wells from which we have taken some kind of observation over the history of the USGS. (And, 63 million chemical analyses both of surface water and groundwater.) So we are really making our data a lot more available than it's ever been before and we hope you are using it and sending us feedback to tell us how the system is working to meet your needs.

Now, just a couple words about some new technology that we are excited about at the USGS. The first one is something called tethered doppler (Fig. 9). We are moving toward new ways of measuring stream flows beyond those that we used 100 years ago. One is the doppler technology, which is mostly applicable to larger rivers. I know that you don't have a lot of really large rivers in New Mexico, but at times of flooding, this can be a very valuable technique. To quickly make a measure-ment, we can put a doppler on a little tethered boat. Here's a guy on a cableway (Fig. 10), with the boat, in the stream. This can also be done from a bridge. Simply by moving from one bank to the other, a discharge measurement is made automatically through the doppler profiling system. This is a major advance that will streamline the way we do business in collecting stream flow information.

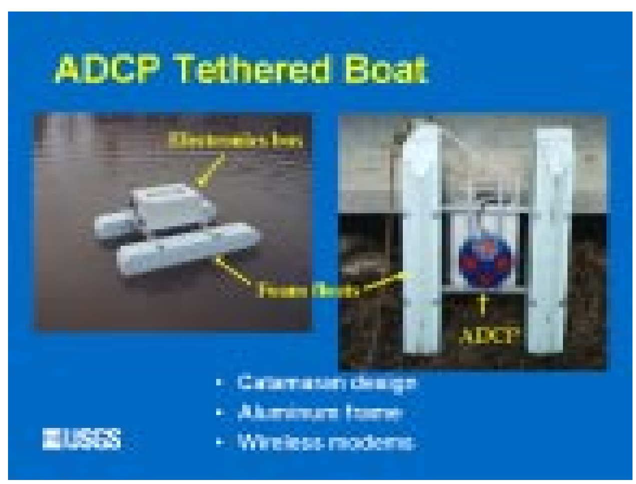


Figure 9. Tethered doppler current profiler.

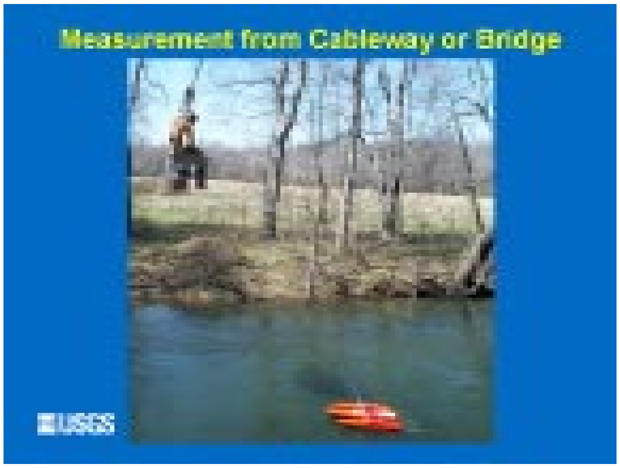


Figure 10. Using a Doppler to take a measurement via a tethered boat.

Sometimes you have stream flow situations where no instrument of any kind can be put into the water safely to make a measurement (Fig. 11). This is an example of a really extraordinary flood in Central America. How in the heck would you even get a velocity estimate on this so that later on one could make an attempt to determine the discharge?

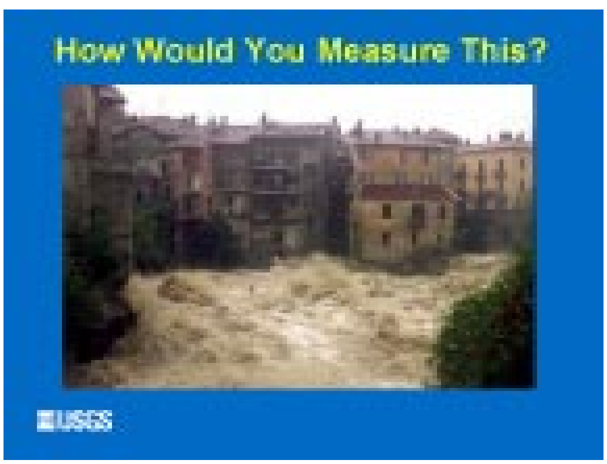
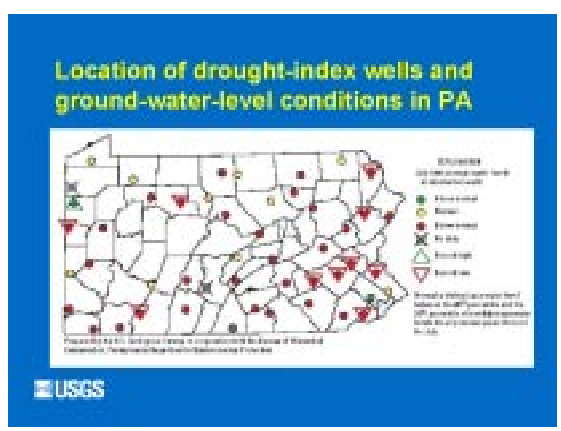


Figure 11. Flood in Central America.

We are working with radar guns, essentially like police radar guns (Fig. 12). I know all of you believe that police radar guns are biased and that they always say that the speed was much higher than it really was. We are checking it out for water to determine if it is an accurate way of getting surface velocity, then developing the techniques whereby we can get a quick estimate of discharge in situations where it would be very difficult to gage by conventional techniques.

I want to mention something about real-time groundwater data. Figure 13 is a map of the state of Pennsylvania, where for the last few years we have had a statewide network of real-time wells. These are observation wells connected to a data collection platform that transmits the data to a satellite. A map such as this one can be produced literally any day. In this particular case it was in a drought, and the triangles, for example, indicate some record low conditions for those wells for that time of year. The governor of Pennsylvania appointed a drought commission to discuss emergency procedures, and we were able to provide up-to-date information on what was happening in the aquifers. We were also able to look at things like wet weather systems as they came through the area, and whether we're getting recovery of the groundwater or not. I think the wave of the future is to get more and more groundwater level information on the internet. I think it also will help a lot with public awareness and understanding of groundwater resources. People in communities will be able to see what is happening to their aquifer on a day-in, day-out basis. Another example (Fig. 14) shows the water levels in one particular well in Pennsylvania that any citizen could look at to see what is going on during this particular drought. This is a simple installation on one of these wells with a data collection platform (Fig. 15).

Figure 12. Radar guns are used to measure surface velocity.



Figurre 13. Pennsylvania's network of real-time wells.

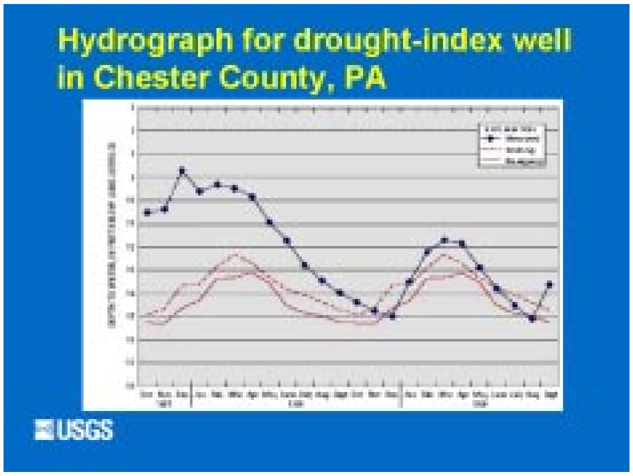


Figure 14. Hydrograph for drought-index well in Chester County, PA.

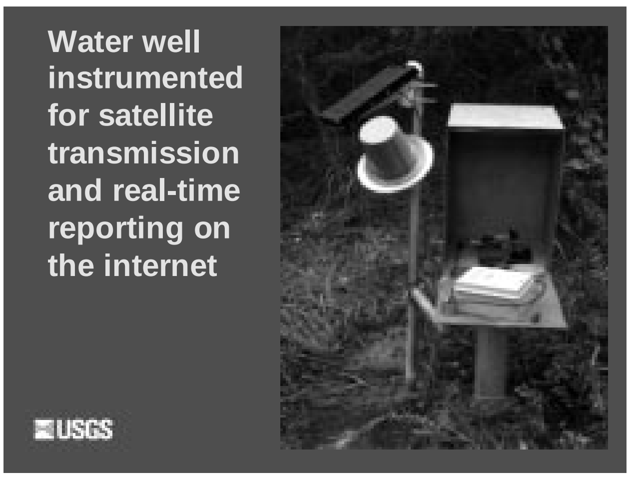


Figure 15. Water well instrumented for satellite transmission and real-time reporting on the internet.

For a few things about what we are doing in New Mexico. I want to particularly emphasize enhancements in the stream gaging network and then I want to wrap up with a couple of words about our Middle Rio Grande study.

We are really pleased that progress has been made here in New Mexico. Some of it has been with new federal money that I talked about, but there has also been excellent support from the state and local agencies, particularly the Interstate Stream Commission, which has helped enhance this network over the last couple of years. Just in the last year we have installed 10 new stream gages, replaced a cableway, installed 16 new satellite radio transmitters to make more of these gages real-time, and added seven new rain gages statewide.

We talked about the Los Alamos fire earlier. Some of you went on the field trip there. We are getting a gage in very, very quickly with financial help from the Army Corps of Engineers (Fig. 16) so that we could measure not only flow, but also, changes in chemistry after the fire.

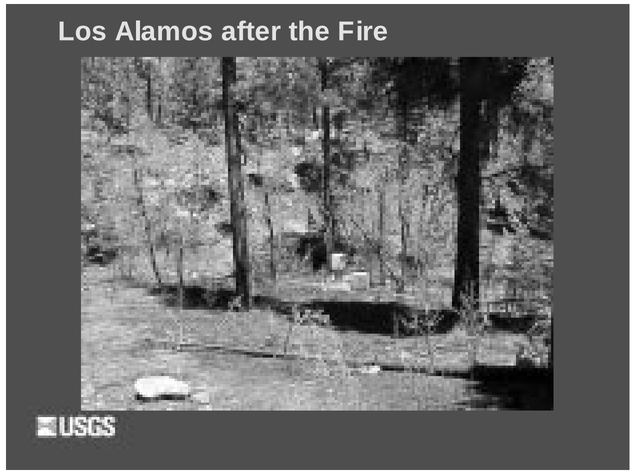


Figure 16. Los Alamos after the Cerro Grande fire.

Another example is doing some flood surveys that provide the critical kind of data we need to understand the flooding phenomenon in the state (Fig. 17).

Figure 17. Flood survey of the San Francisco River.

Now to turn finally to the Middle Rio Grande study (Fig. 18). This has been a major effort of the USGS and illustrates something I want to stress to you. While we have an excellent office here in Albuquerque with outstanding scientists, they draw on a truly national organization. The Middle Rio Grande Basin Study, now in its completion phase with reports coming out over the next several months, is really an effort involving hydrologists, geologists, and geochemists from across the entire U.S.–from our Reston office, Denver, Menlo Park and other locations. They do a lot of good work here and really advance the science in ways I think are going to be contributing to groundwater science in general for many years to come. I don't need to tell you of the importance of water resources in the Middle Rio Grande basin (Fig. 19).

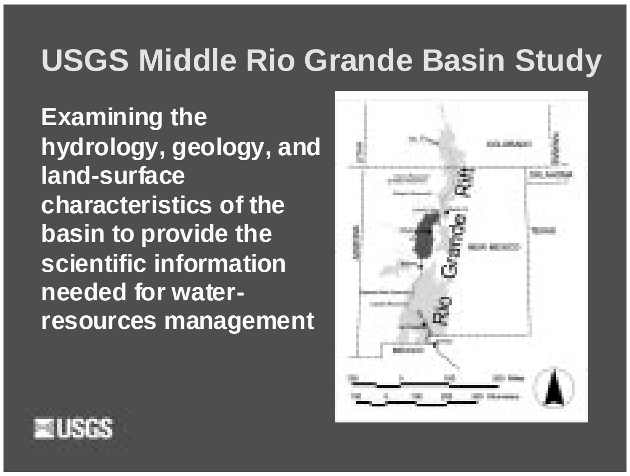


Figure 18. USGS Middle Rio Grande Basin Study.

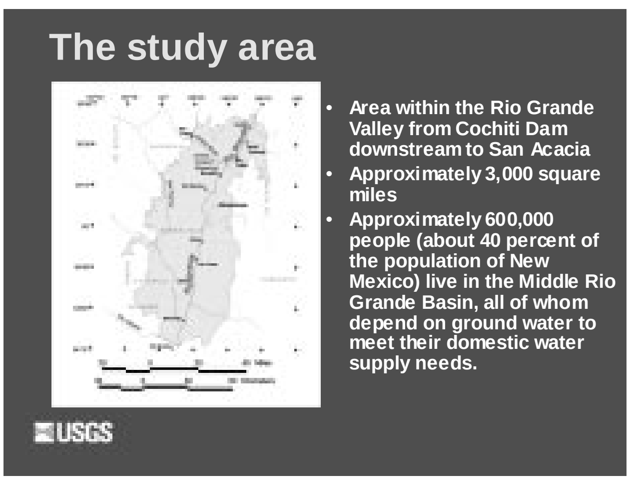


Figure 19. Middle Rio Grande Basin study area.

Recharge is something that I think most of us in the hydrologic community feel has typically been some kind of a guess and something that could be computed by subtracting out a couple of other things. We are working diligently to truly measure recharge in the aquifer systems and we have worked with a number of technologies that are bringing the science of recharge estimation forward (Fig. 20). The use of temperature profiles as a way of estimating recharge is a key new technique. Some techniques back in the laboratory are helpful–chemical tracers, chloride, bromide, hydrogen isotopes–these things and age dating techniques and then, of course, flow loss analysis in arroyos and small streams are all contributing to improving our under-standing of recharge. Understanding recharge is critical to understanding what is the available resource in any basin in New Mexico.

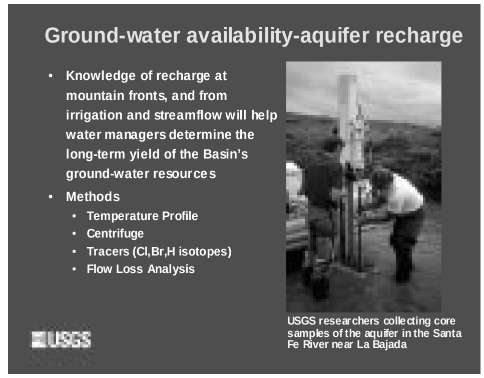


Figure 20. Ground-water availability-aquifer recharge.

Groundwater age dating has been critical to the study of the Middle Rio Grande Basin (Fig. 21). In the past, the groundwater age dating techniques were mostly centered around looking at longtime scales as one might get from carbon-14 and other techniques and some helium tritium kinds of techniques that helped us trace back to the 1950s era. We have added to that chlorofluorocarbons (CFCs) that allowed us to look at time spans over the last 50 years or so. This has helped us quantify what is the old water and what is the younger water and it helps to really verify what we are seeing in our groundwater models. Then using modeling techniques and parameter estimation techniques, we can build much improved models and transfer those models to the agencies that have the responsibility for resource management.

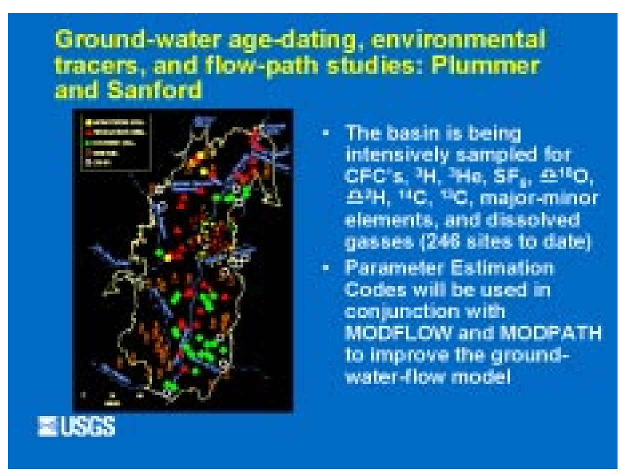


Figure 21. Ground-water age-dating, environmental tracers, and flow-path studies.

Subsidence is a key issue in the Middle Rio Grande Basin (Fig. 22). I talked with city officials yesterday and they are just beginning to see the issue of subsidence due to groundwater withdrawals and are trying to prevent it from becoming a crisis situation by managing the resource appropriately. We are using satellite techniques, interferometry techniques where we can literally measure these few centimeter type changes that occur on an annual basis. We are measuring from space and getting an idea of the depression and some of the rebounding that is occurring in the Middle Rio Grande Basin. Also, high resolution gravity measurements are helping to detect mass changes of water in the unsaturated zone and saturated zone. I think it is yet another advance that is going to help with our understanding of water in a critical basin like the Middle Rio Grande.

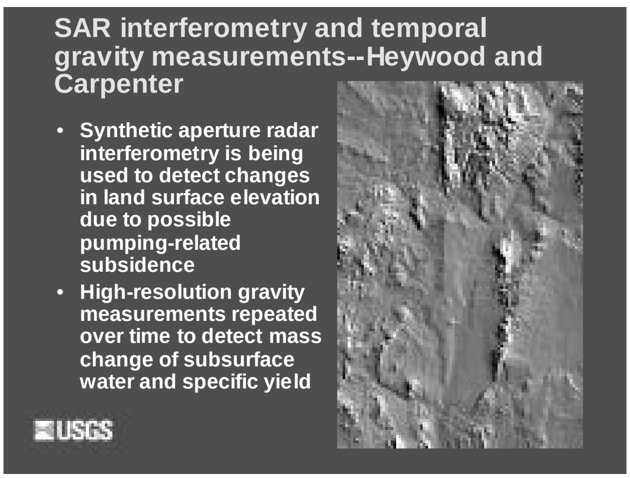


Figure 22. SAR interferometry and temporal gravity measurements.

And finally, the groundwater flow model that Doug McAda and others have worked on, is one of the best implementations of groundwater flow modeling that I have ever seen (Fig. 23). It contains tremendous geologic detail and the role that faults play as boundaries in this system, some of them highly transmissive boundaries and some of them as boundaries that impede the flow of water. This is critical to being able to understand exchanges between the Rio Grande and the aquifer itself. Our hope is that this will be a tool that will be continually of use to those with the responsibility of managing the water in the Middle Rio Grande area.

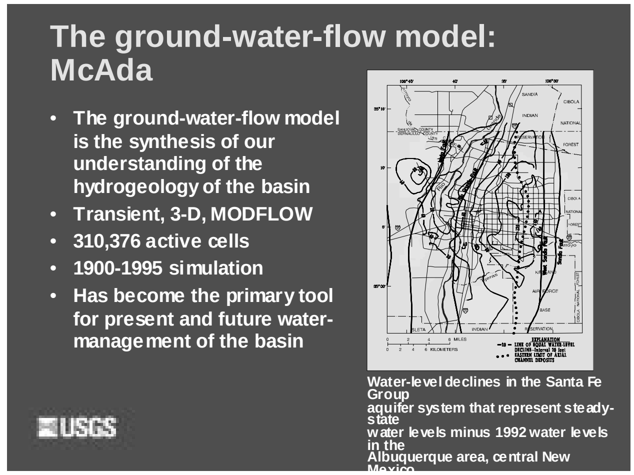


Figure 23. Ground-water-flow model, Middle Rio Grande Basin.

Let me just finish with this picture (Fig. 24) of one of our folks out in the field doing what we do best, in what is truly our bread and butter, which is making the measurements that help everyone to understand the precious water resources on which we all so much depend.

Figure 24. Taking measurements.