Groundwater Depletion Across the U.S. and How We Measure It

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Editor's Note: The following paper represents a transcription of the speaker's remarks made at the conference. Remarks were edited for publication by the editor. The speaker did not review this version of his presentation and the editor is responsible for any transcription and editing errors.

I'd like to thank Sam Fernald for the invitation to come and talk with you today. It's been a spectacular day for me filled with interesting information, especially for a groundwater person. Sam suggested that I could talk about what we should do about aquifer over-exploitation. At the end of the presentation, I'll have a couple of slides about that.

We have heard several other speakers today talk about a global or U.S. crisis in groundwater depletion. I have gathered some headlines and quotes from journal articles: "Global Groundwater Crisis: Groundwater Depletion during Drought Threatens Future Water Security," "Earth's Major Aquifers in Trouble," and "Aquifer Exploitation Could Significantly Impact Crop Production in the U.S.," because 60% of it relies on irrigation from groundwater. In preparation for this talk, I decided to take a look at a couple of the books on my shelf in the Office of Groundwater and came across this quote: "A survey of areas where water is pumped from underground supplies as the principal source for irrigation use shows a generally constant lowering of the water table. The situation is naturally more serious in some localities than others; and, on the other hand, some have less favorable recharging possibilities, and consequently respond more slowly to recharging, either natural or artificial." This document comes from a publication in 1937. It is the Department of Agriculture Technical Bulletin number 587. This is not a new problem. This is a problem that we have already dealt with in many parts of the country for many years. I like to think that we have overcome some of these issues in some places and we will continue to do that. However, we do have an issue on our hands, and I'll go through some slides to show you groundwater depletion in the U.S. over time.

In 1951, a map was created that showed groundwater reservoirs with perennial overdraft (Figure 1). There are some areas in the central U.S., but most are in the Southwest. At that same time, there were maps of serious cones of depression that have been developed from pumping wells (Figure 2). These areas are all over the country in 1951. In 1984, the USGS produced the National Water Summary map (Figure 3). This is showing areas of water table decline or confined aquifer decline in excess of 40 feet in at least one aquifer since pre-development. There are some large areas of the country that show up on that map.

In 2008, we produced a circular that tried to update that information, and you can see some similar patterns in the upper Midwest for instance (Figure 4). You can also see some additional areas in the High Plains that had some across the

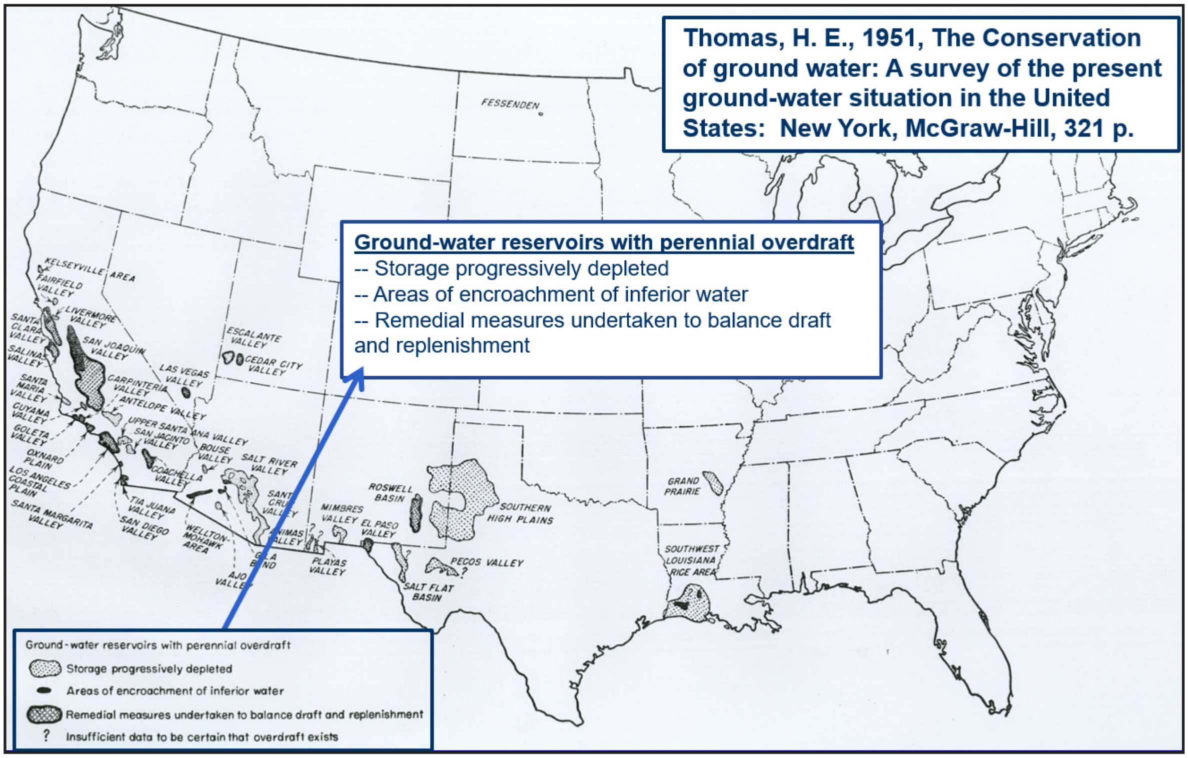

Figure 1. Previous compilations of GW depletion: groundwater reservoirs with perennial overdraft (1951).

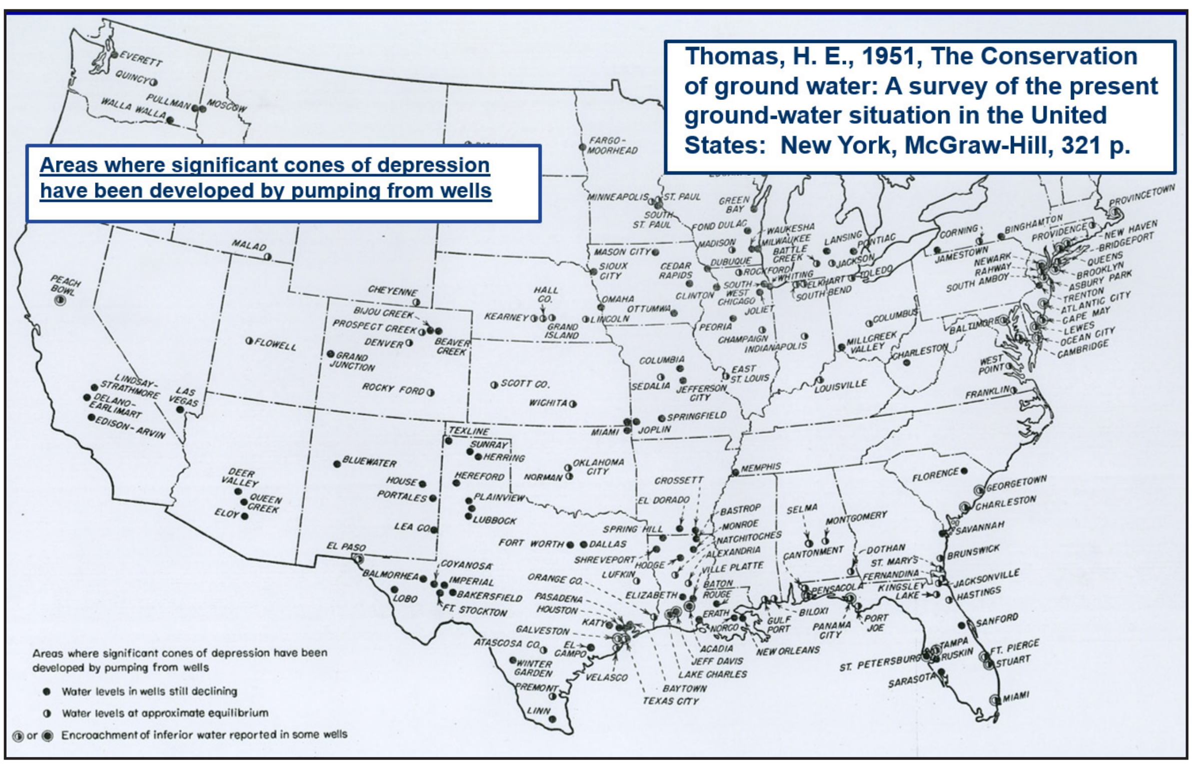

Figure 2. Previous compilations of GW depletion: areas where significant cones of depression have been developed by pumping wells (1951).

Mississippi River Valley. The blue dots indicate wells with water level declines in excess of 40 feet. These areas were also divided into areas of water table decline in excess of 25 feet and confined aquifers with declines in excess of 40 feet.

That was a water table approach to looking at groundwater decline. Another approach is to look at volumetric depletion. A report came out in 2013 that was produced by Lenny Konikow (USGS), and it shows areas of the country where there has been significant volumetric groundwater depletion (Figure 5). That is a different approach than just looking at water levels, and I will talk about that more in subsequent slides.

The last example in Figure 6 is ongoing compilations. These are weekly drought indicators. We have heard about GRACE today in several presentations. They downscale some of that GRACE data to look at groundwater drought indicators across the country. Just earlier this month, November 10th, is when this compilation occurred. We heard during lunch that some groundwater is always mined. Theis told us this in 1940 (Figure 7). When water flows to a well, mining occurs. This is not a surprise since there is going to be groundwater depletion when we use it. If we value it, however, we measure it. That is what these water level programs we have heard about today do, and it is very important that we continue to do that.

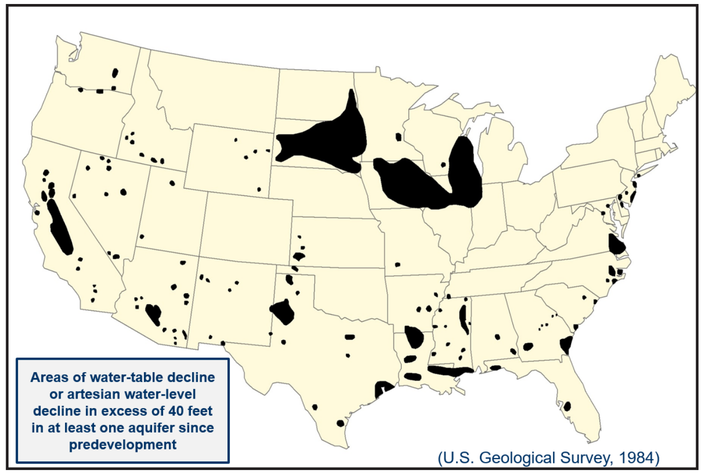

Figure 3. Previous compliations: 1984 National Water Summary.

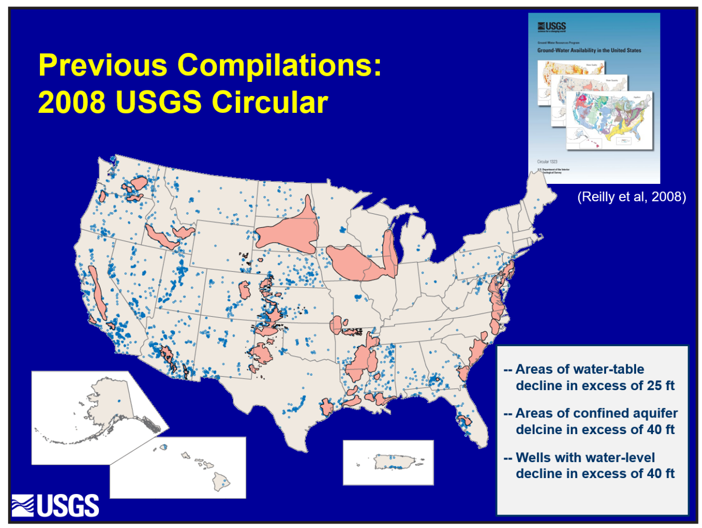

Figure 4. Previous compilations: 2008 USGS circular.

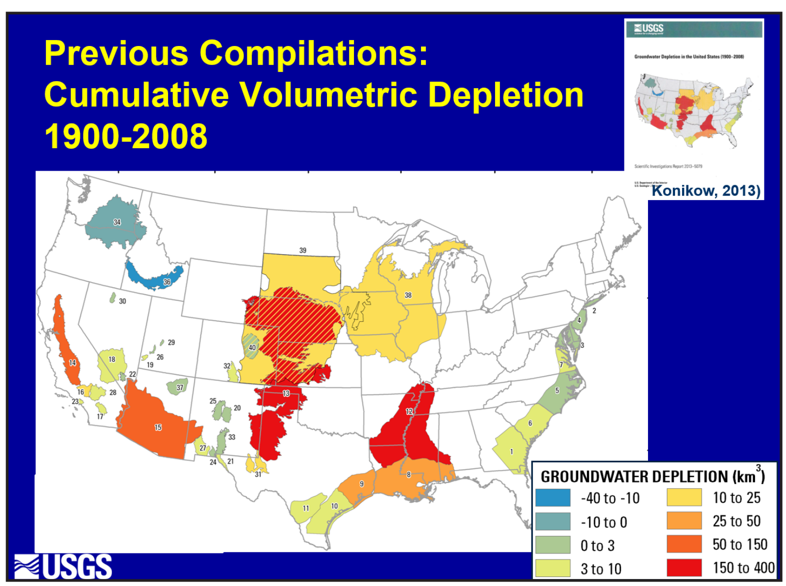

Figure 5. Previous compilations: cumulative volumetric depletion 1900-2008.

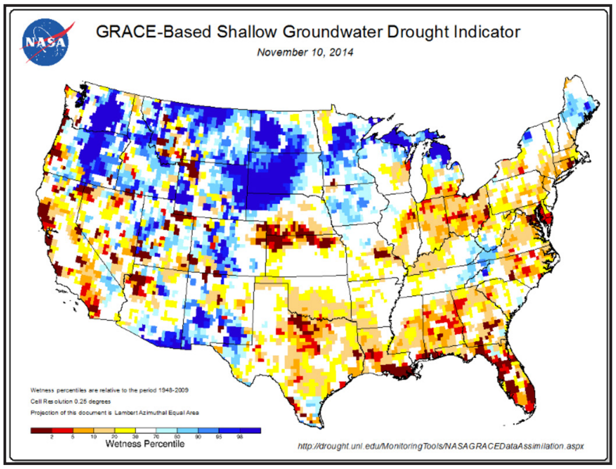

Figure 6. Ongoing compliations: weekly drought indicator (November 10, 2014).

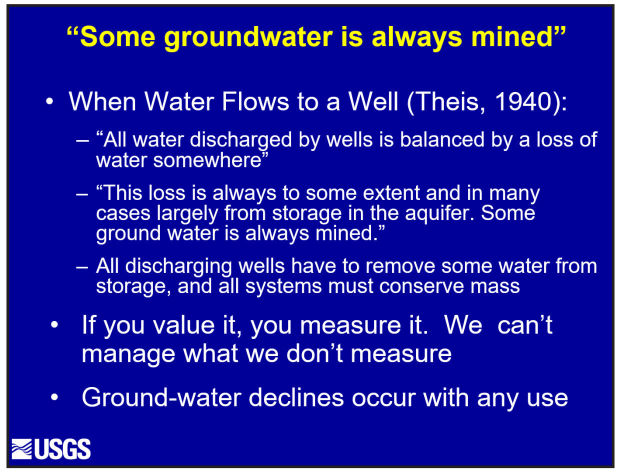

Figure 7. "Some groundwater is always mined."

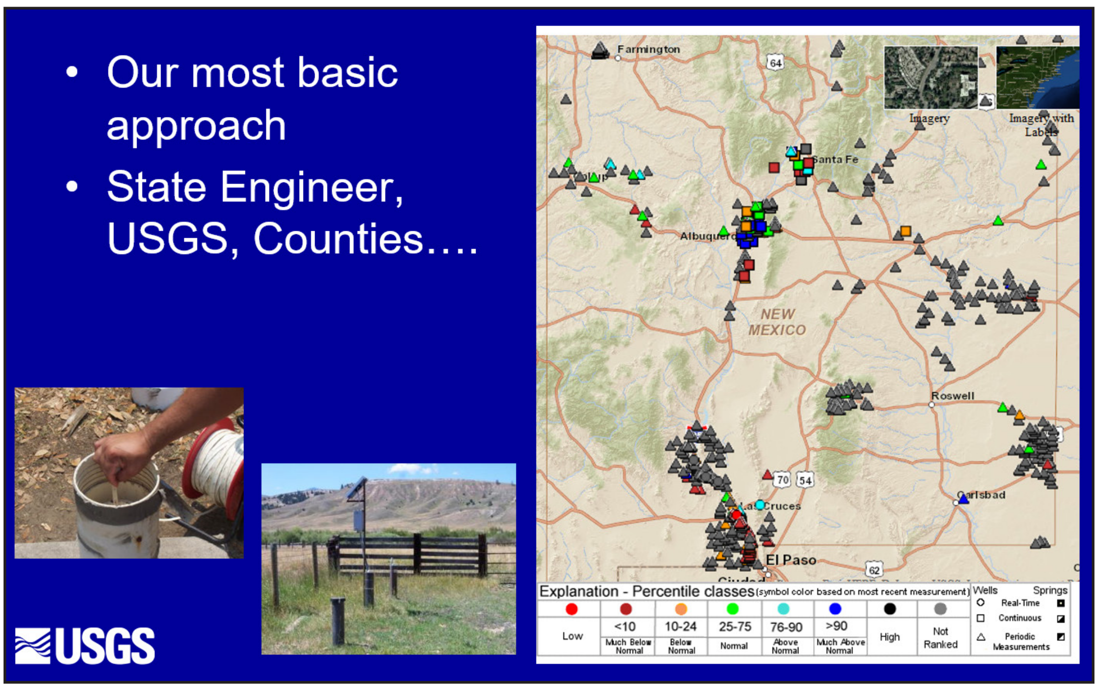

Figure 8. Measure water levels.

How do we measure water depletion now? I showed you some maps, so let's talk about how those are done. The most basic approach is not a simple one. Still, the most basic approach is to measure water levels, and we have heard that from the State Engineer's Office, the USGS, and counties. Figure 8 is a map of New Mexico from the USGS's Groundwater Watch showing the most recent measurements in these wells across the state. We measure water levels, but from a national perspective, we don't have complete coverage to do that. In 2007, the subcommittee on groundwater set out to try to remedy that, and created this concept for a National Groundwater Monitoring Network. This National Groundwater Monitoring Network was piloted in 2010 and 2011. This is a collaborative approach by which government agencies, state agencies, county agencies and any data providers that meet the necessary criteria, can participate in the National Groundwater Monitoring Network. A system was built through this pilot process with six states and six state water agencies in 2010 and 2011. This pilot program portal was built to bring in the information from federal agencies in the six states and the six state water agencies.

That plan was completed, and the associated document that was finished in 2013 is available at http://acwi.gov/sogw. This is another example of pending federal action, it is authorized but not yet appropriated. It has been in the USGS budget to help support this, but unfortunately, those budgets have not materialized and we have had continuing resolutions.

What do water levels tell us about depletion? Measuring water levels in wells provides information about changes of water levels in time. But, it does not tell us how much water there is, how much is available, or if the use is sustainable. However, it does allow us to differentiate among aquifers with depth. This is important because of the next approach - microgravity measurements (Figure 9). We do this on the ground, and this is an example from Arizona. This is a map of a network in Arizona where this microgravity unit has an absolute gravimeter and a relative gravimeter that are used to make point measurements of the mass of the Earth in that location. They have been doing this for the last 20 years, and it is a measurement of the water that is in the unsaturated zone and in the aquifer as well. You can make repeated measurements and see those changes.

GRACE is an example of microgravity measurements from space (Figure 10). GRACE is a pair of satellites that were launched in 2002 by NASA. Those satellites are about 140 miles apart orbiting the Earth, and the distance between them is measured very precisely by microwaves.

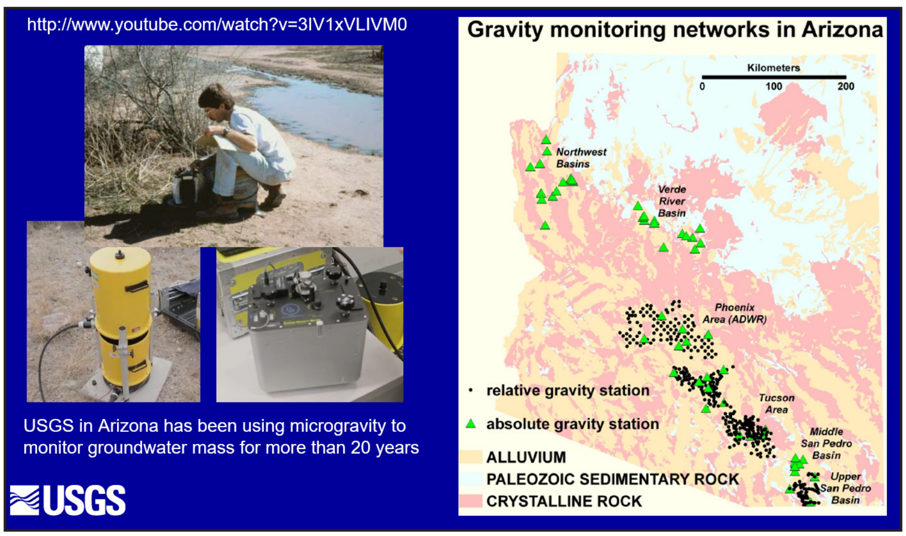

Figure 9. Microgravity measurements on the ground.

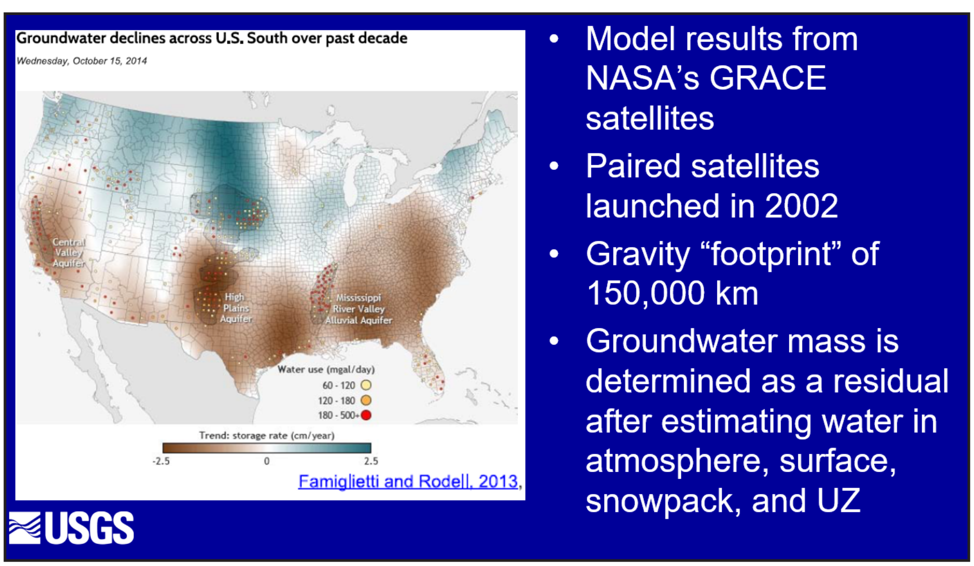

Figure 10. Microgravity measurements from space.

As one satellite approaches an area of greater gravity, it speeds up before the second satellite, and the way the distance between the two satellites changes is how they determine what the difference in the microgravity signal is. That microgravity signal has a very large footprint, which is one of the negatives of it. Also, that groundwater mass is determined as a residual after you estimate the water in the atmosphere, the water at the surface, the snowpack, and the water in the unsaturated zone. The ground-based microgravity eliminates some of those errors. The GRACE satellite approach has to account for those in their model.

What does microgravity readings tell us about depletion? It provides a change of the mass over time from which change in volume can be obtained. However, it does not tell us how much water there is, how much is available, whether the use is sustainable, and it does not allow us to differentiate among aquifers with depth. If you have a layer system and you have a lot of production from one aquifer but not another, you cannot differentiate between those.

What about hydrogeological studies? We tend to put a lot more weight in that. We heard Stacy Timmons talk earlier today and we heard several discussions of hydrogeological studies that are taking this approach. In hydrogeological studies, we compile all of the hydrogeological information, develop that hydrogeological framework, determine conceptual models of the flow system, and most importantly, develop numerical flow models. The report that I mentioned earlier by Lenny Konikow is on groundwater depletion in the United States from 1900-2008 (published in 2013), and is an example of information coming from these hydrogeological studies.

Figure 11 is from the Konikow report. This is cumulative volumetric groundwater depletion from 1900-2008 in cubic kilometers. Regional aquifers in the United States were evaluated, and you can actually see that there are some with negative depletions, which results in a gain. You can see the range of depletions in cubic kilometers from aquifers across the country. There are some very significant changes. The red represents 150-400 cubic kilometers of groundwater depletion since 1900. The most significant change is in the High Plains Aquifer (Figure 12). The figure has a plot from the High Plains Aquifer since 1950 with a dot at the top left that nearly gets lost.

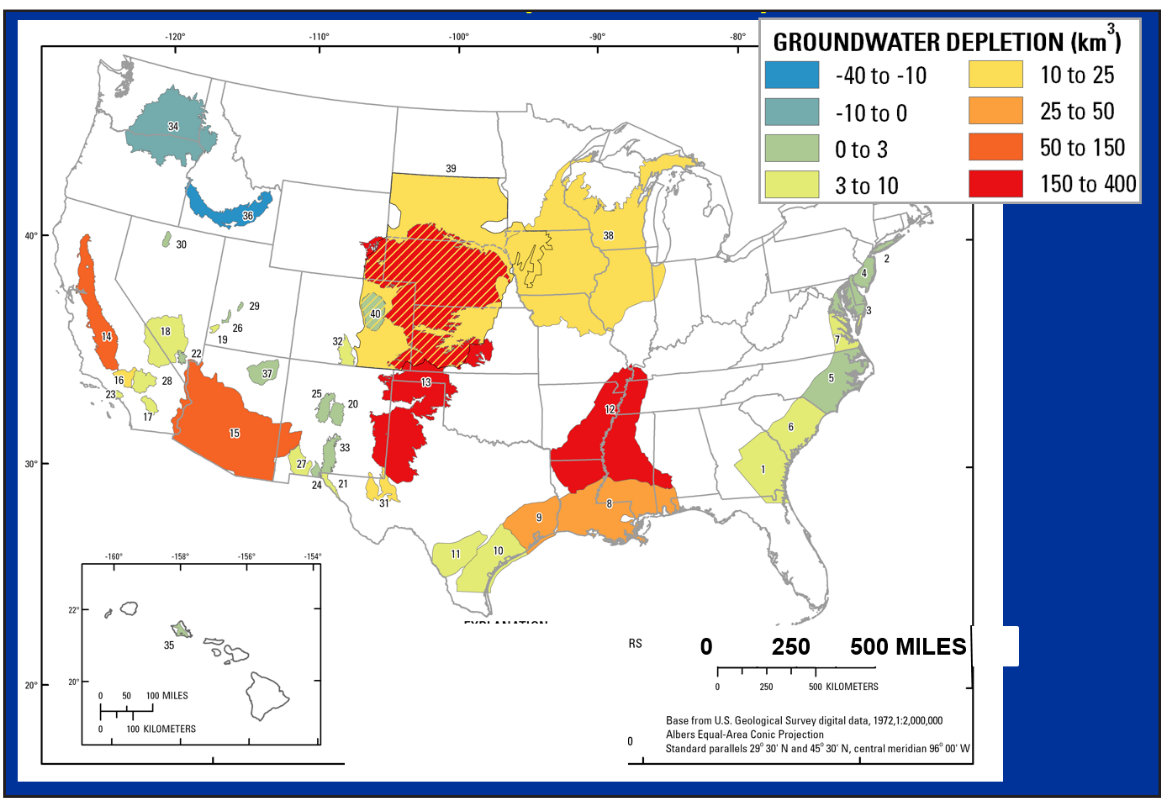

Figure 11. Cumulative volumetric groundwater depletion (1900 - 2008) in km³.

You see the cumulative change in groundwater storage since 1950 in millions of acre-feet. You can also see the total available water in the aquifer on the right-hand side. It is the most significant drop in groundwater seen across the United States.

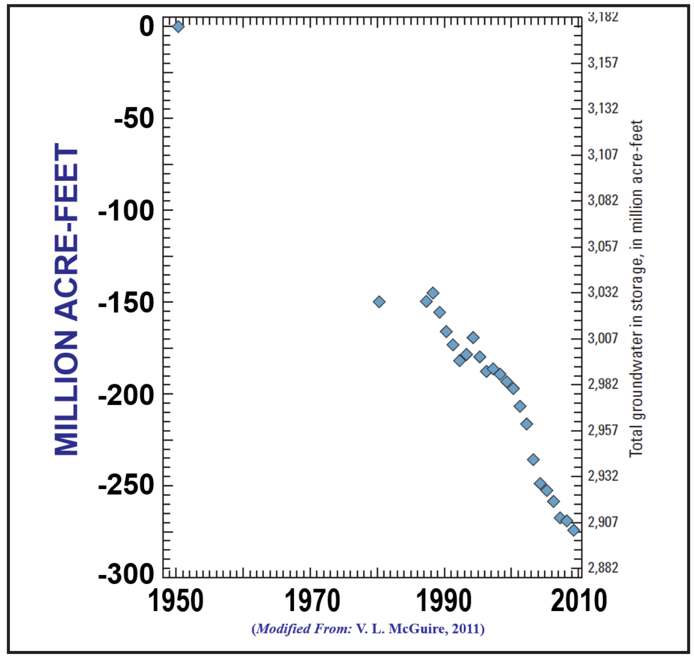

Figure 12. Cumulative change in GW storage, High Plains, since 1950.

Konikow created a concept called depletion intensity. Figure 13 is a map that shows the depletion intensity from 2000-2008. This is depletion in the aquifer divided by the aerial extent of the aquifer, which is a benefit in that it normalizes the aquifer depletion data in a way. When you look at the High Plains Aquifer, because it has such a large extent, its relative color becomes cooler. The Central Valley of California, on the other hand, stands out much more drastically with depletion intensity. The plot summarizes the report of groundwater depletion in the United States. You can see the principal aquifers here with significant groundwater depletions: the High Plains Aquifer, the Mississippi Embayment, the Central California Valley, and the Arizona alluvial basins. The plots on the bottom describe these. The grey line represents total U.S. groundwater depletion from 1900 to 2008. In 2008, total depletions in the U.S. were approximately 1,000 cubic kilometers. In acre-feet this would be approximately 800 billion acre-feet of depletion, which I think would be somewhere around 20,000 times what Albuquerque has. That is a significant amount of groundwater depletion in the U.S. What is perhaps most alarming is that in the year 2000, depletions were about 800 cubic kilometers and eight years later depletions were 1000 cubic kilometers.

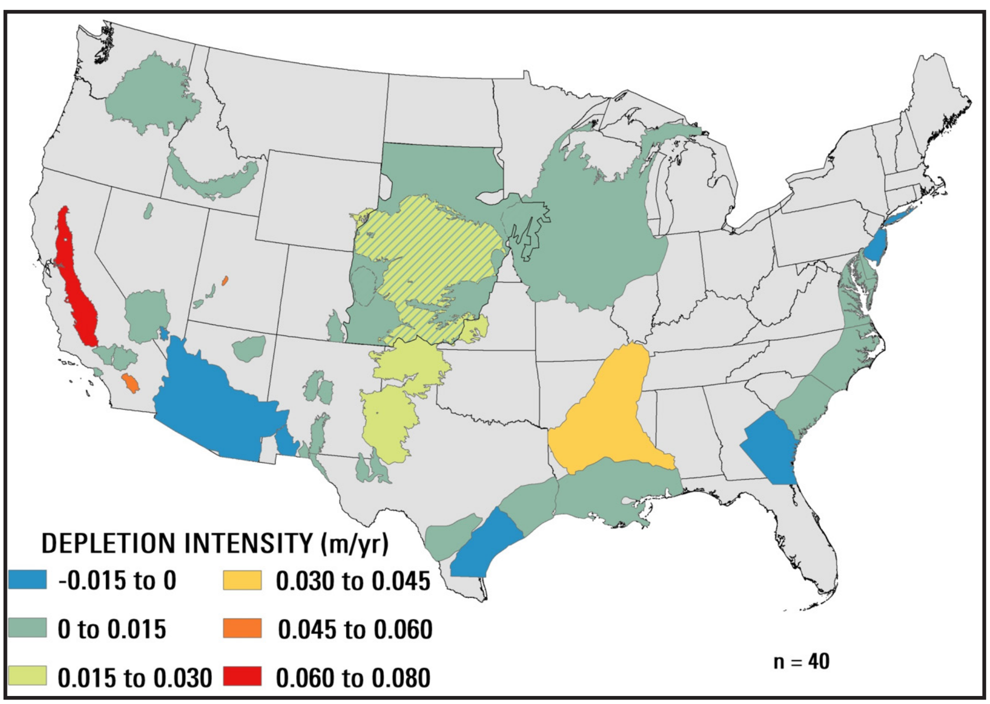

Figure 13. Depletion intensity (2000-2008).

Figure 14 is a decadal scale of depletion in the U.S. The rate of depletion from 2000 to 2008 has gone up dramatically according to Konikow's report. What do these hydrogeological studies tell us about depletions? They provide us with a volume change over time. Those studies give us information about how much water there is, but they do not tell us how much of that water is available. That is a societal decision. They do allow us to forecast the effects of use, which is very important from the modeling point of view. They also allow us to differentiate among aquifers with depth.

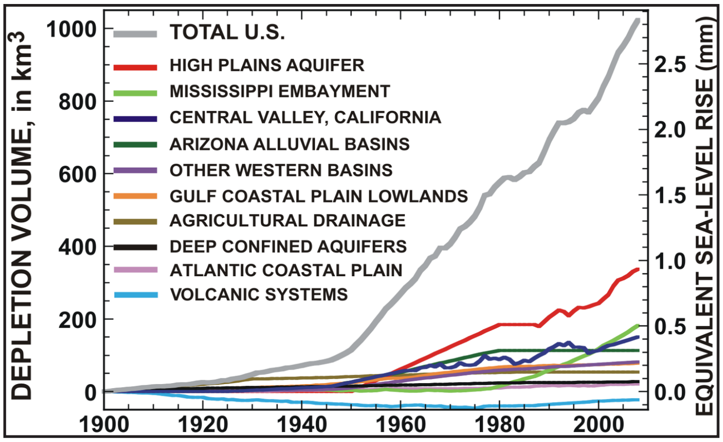

Figure 14. Long-term groundwater depletion in the U.S.

How do we stop the overexploitation of our groundwater resources? I was on a group associated with the Council of Canadian Academies in 2009 that evaluated what Canada should do for sustainable groundwater use. They have almost no problems in Canada compared to us, frankly, but they are still concerned about the sustainable use of their groundwater resources. Our report created a pyramid and it is incumbent upon us to provide the baseline information to this pyramid: a strong foundation with ongoing data collection; a solid geologic model; building conceptual models of the hydrogeological system, which they call hydrological regimes north of the border; and building numerical models to test hypotheses and forecast future conditions (Figure 15).

It is incumbent upon us scientists to provide that information and a good foundation for the decision making part of that pyramid that is at the top. We use that solid knowledge foundation to educate decision makers and to determine how to address the overexploitation of groundwater resources.

My closing message is that our groundwater supplies have limits, depletion is a growing issue in the U.S., and the best way for scientists to address depletion is a full understanding of the hydrologic system. The last message I have is that depletion decisions are societal. Decision making is the top of the pyramid and if we address them, solutions do exist. I think we have heard many of them today.

Thank you.

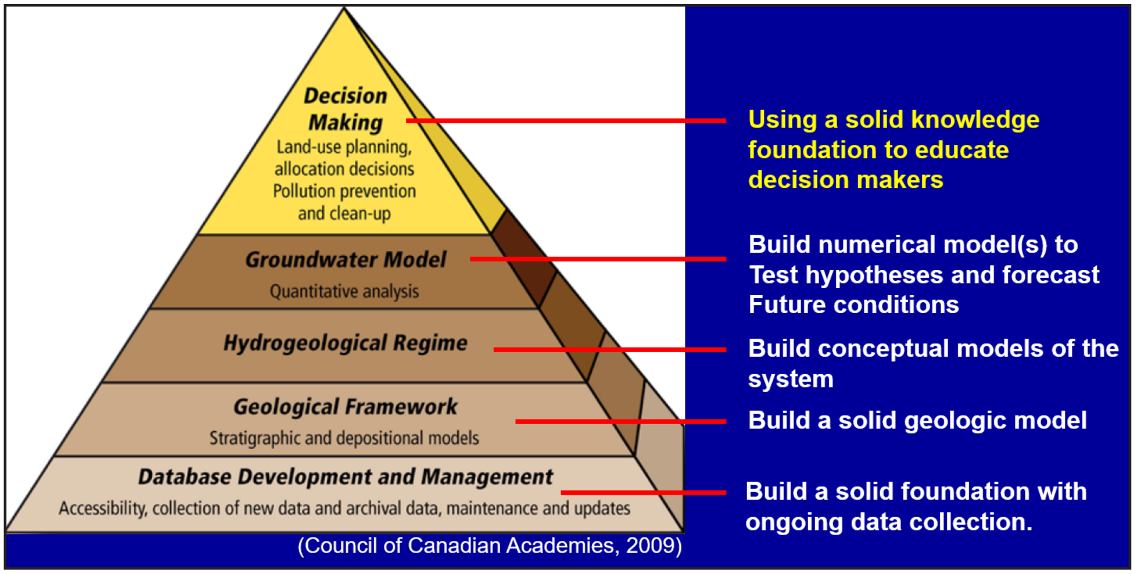

Figure 15. How do we stop 'over-exploiting' our groundwater resources?