Measuring the High Plains Aquifer From the Air

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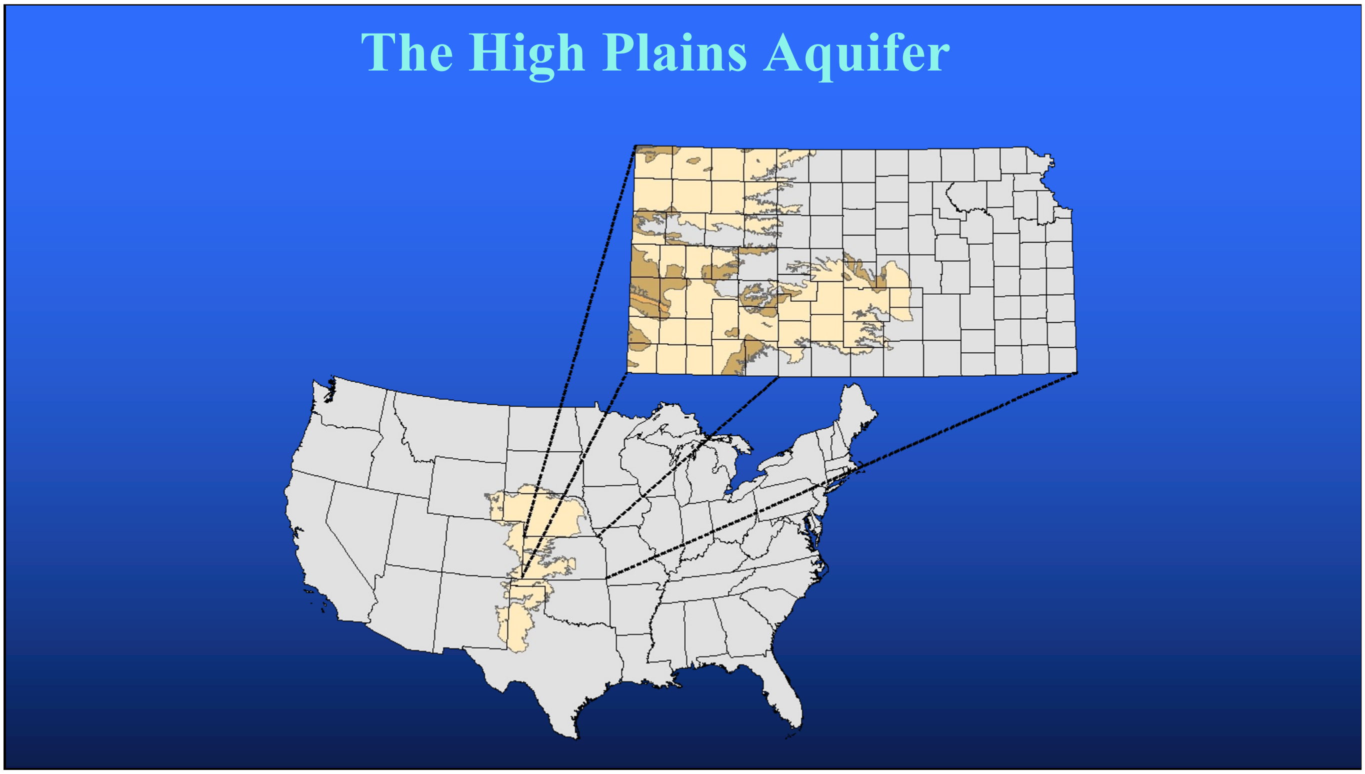
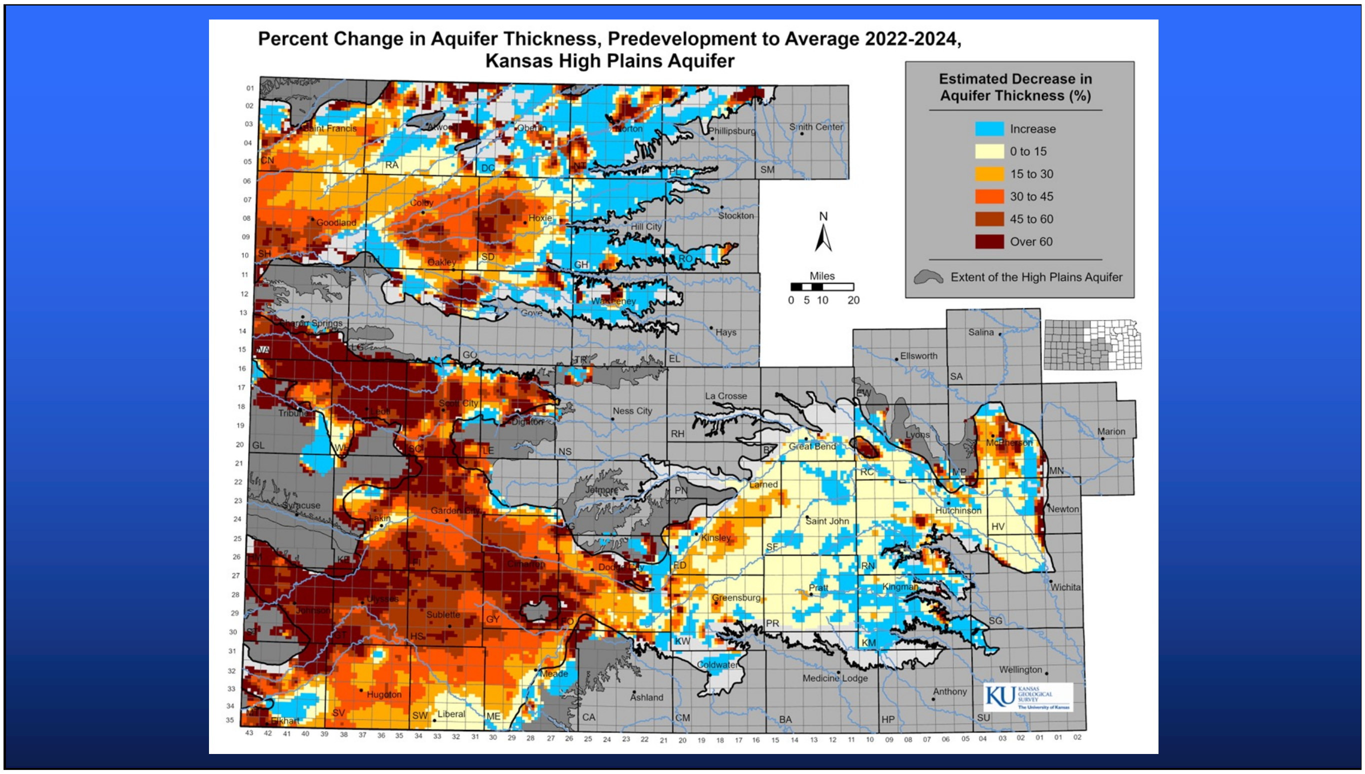
The Kansas Geological Survey (KGS) is a research and service unit of the University of Kansas. This presentation is given by Jim Butler (jbutler@ku.edu) and prepared with the assistance of colleagues listed as coauthors. Please contact Jim if you have further questions.

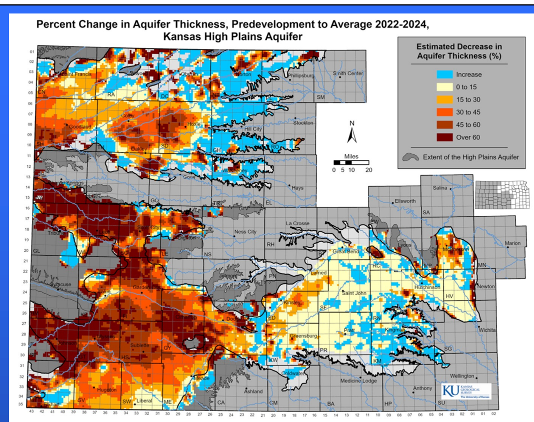


The High Plains aquifer (HPA) is one of the worlds largest and most important regional aquifers – it extends over portions of eight states in the central U.S. We're extracting the portion of the aquifer in Kansas – the tan is the aquifer while the brown is similar geological material but little water. In Kansas, the HPA has been heavily pumped for decades in support of irrigated agriculture. That intensive use has come at a price in terms of aquifer conditions as illustrated in the next slide.



This map is the percent change in aquifer thickness from predevelopment (the period prior to the onset of widespread pumping for irrigated agriculture – mid-1950s and earlier) to present (average of 2022-2024 conditions). The semi-arid Ogallala portion of the HPA in western Kansas has experienced the greatest decreases in aquifer thickness. These decreases threaten the continued viability of irrigated agriculture; in some areas, more than 60% of the aquifer has been lost since predevelopment. The Great Bend Prairie and Equus Bed aquifers in south-central Kansas have had relatively small changes in aquifer thickness over the same period. The blue areas in western Kansas are areas of thin aquifer and of little practical significance.

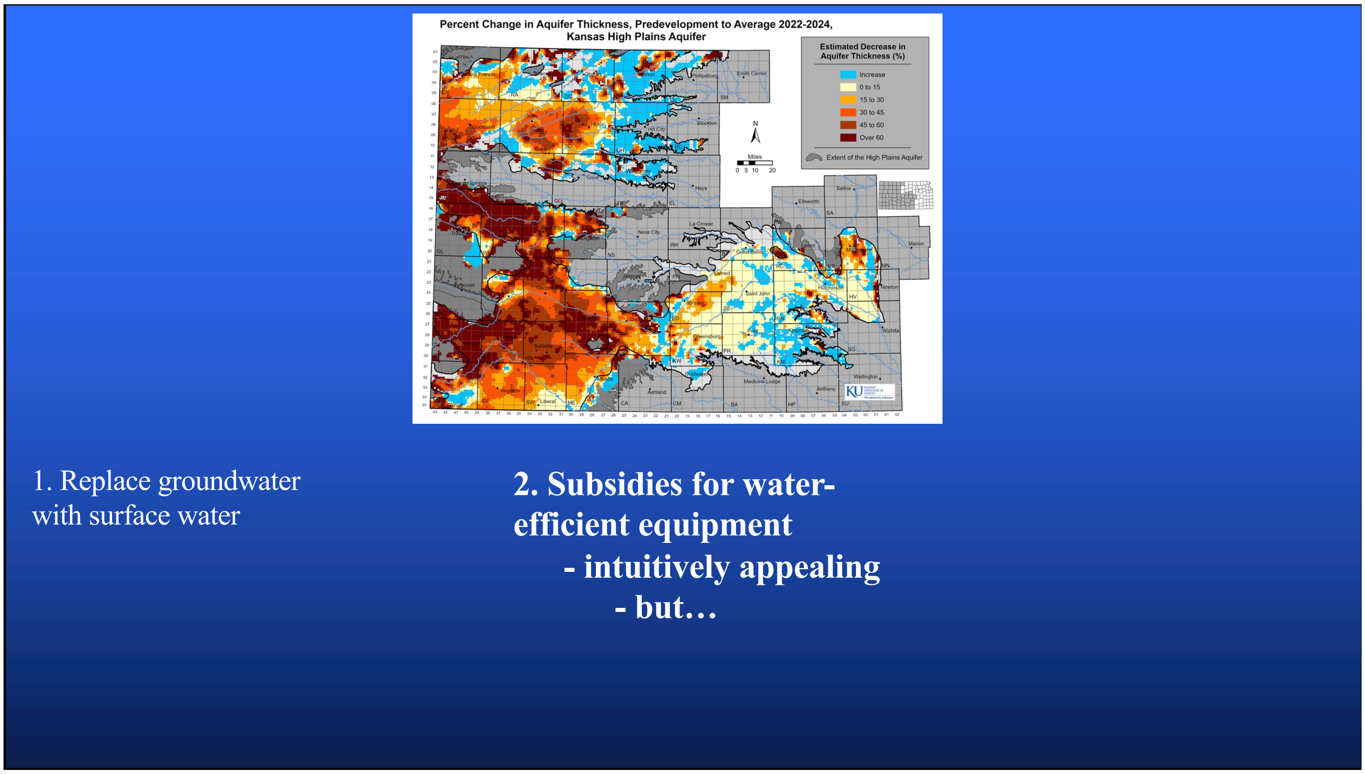
It doesn't take a great leap of imagination to see that continuation of past practices into the future is not going to end well for irrigated agriculture in many areas in western Kansas. The question is what can be done to change this narrative. We have three options as shown in the next few slides.



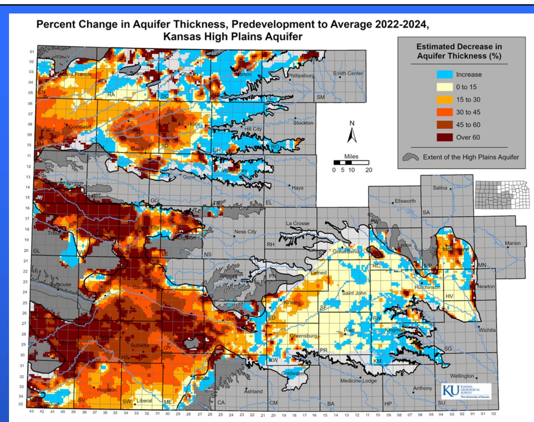
1. Replace groundwater with surface water

- **no local source**
- **long-distance transfers**

The three options are 1. Replace the groundwater with surface water – the problem is that there is no excess surface water to be had in western Kansas and long-distance transfer projects aren't coming online anytime soon.



2. Provide subsidies of water efficient irrigation equipment. This is intuitively appealing but natural resources economists have known for more than 150 years that efficiency improvements don't lead to less use of a natural resource (Jevon's Paradox). The Kansas irrigation data certainly support that. The only way subsidies will lead to reductions in water use is if they are coupled to a legally binding agreement to reduce water use.

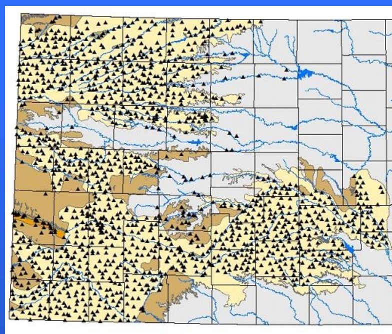


1. Replace groundwater with surface water

2. Subsidies for water-efficient equipment

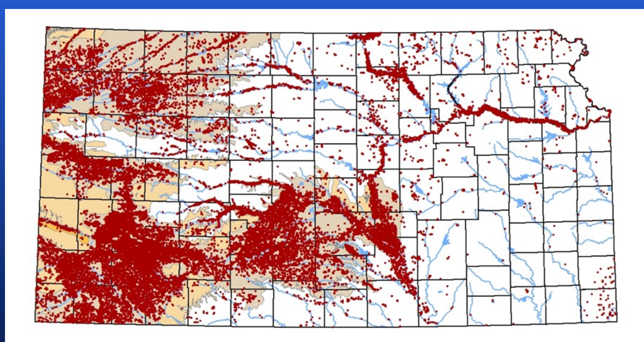
3. Pumping reductions with modifications of agricultural practices

That leads us to the third option. 3. This is the path being blazed by producers in northwest and west-central Kansas. The question we get asked at the KGS is how much does pumping need to be reduced to have a significant impact on water-level decline rates. To get at that, we need data. Fortunately, Kansas is among the world leaders in terms of water quantity data. Two key datasets are discussed in the next slide.



Annual Water Level Data

≈1400 wells measured in the Kansas High Plains aquifer in 2025

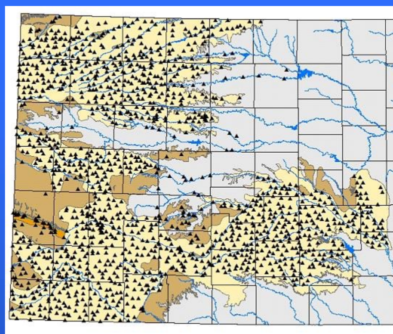


Annual Groundwater Pumping Data

As of 2022, 99+% of the non-domestic pumping wells in the High Plains aquifer in Kansas had totalizing flowmeters.

The triangles in the top figure represent wells included in the Kansas Cooperative Water-Level Measurement Network. Each winter, the KGS and the Division of Water Resources (Kansas Department of Agriculture) measure roughly 1,400 wells to assess regional trends and conditions in the High Plains aquifer region. The wells are measured in winter, three to four months after cessation of irrigation pumping, to minimize the year-to-year variations in the timing of the end of the irrigation season and the possibility of pumps running when wells are being measured.

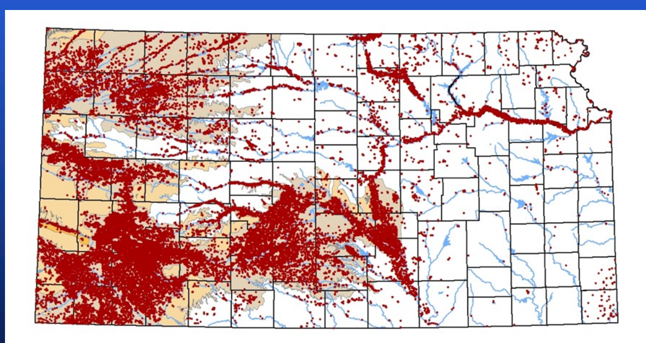
Annual water-level changes are calculated from these data. Those changes are a response to an excitation or stress to the aquifer. In the Kansas HPA, the major stress is pumping. The lower map shows all the wells with the right to pump groundwater. This map also reveals where the aquifers are in Kansas. In the Kansas High Plains aquifer, all non-domestic pumping wells have totalizing flowmeters and the annual pumping volumes are reported each year and subject to regulatory verification.



Key Question - How much does pumping need to be reduced?

We can obtain reliable predictions of the pumping that will stabilize water levels (Q_{stable}) from these data.

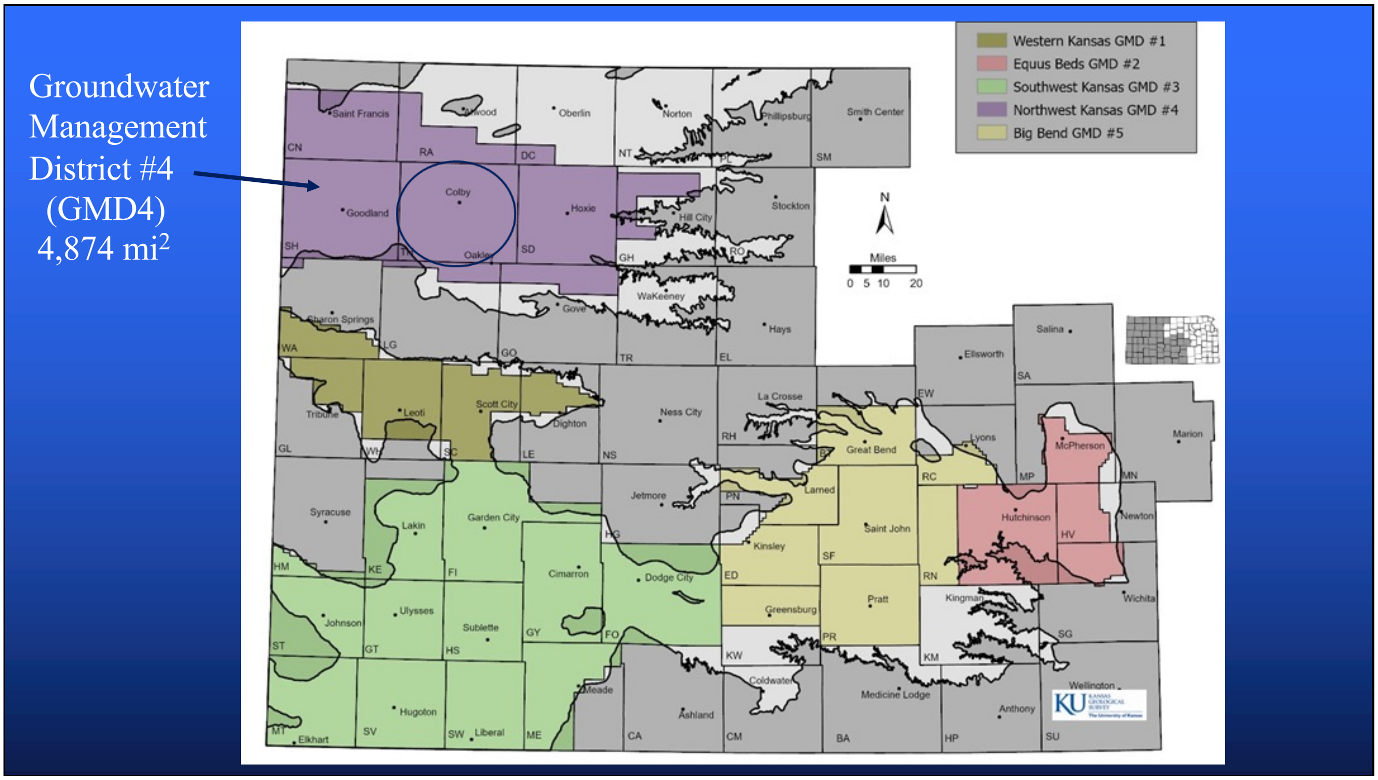
- **GMD to sub-county scale (> 100 mi^2)**
- **several years to a few decades**



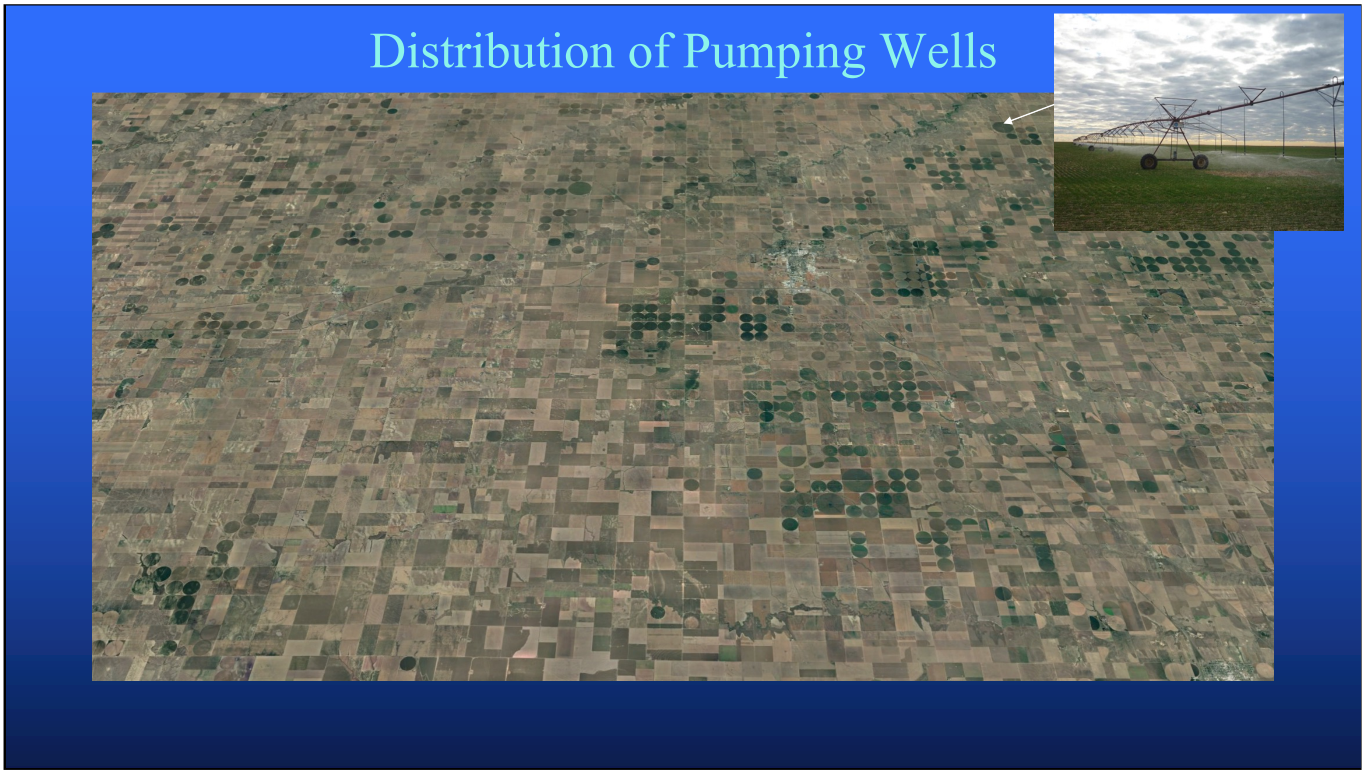
Need better information on aquifer conditions (the hydrostratigraphic framework) to go finer and longer.

- **How do we get that?**

The hydrostratigraphic framework describes the manner in which intervals that readily yield water to wells and those that don't are arranged in the subsurface.



Kansas has five groundwater management districts, all of which overlie the HPA. We've circled Thomas County in GMD4 – we'll get an aerial view of a portion of that county in the next slide.

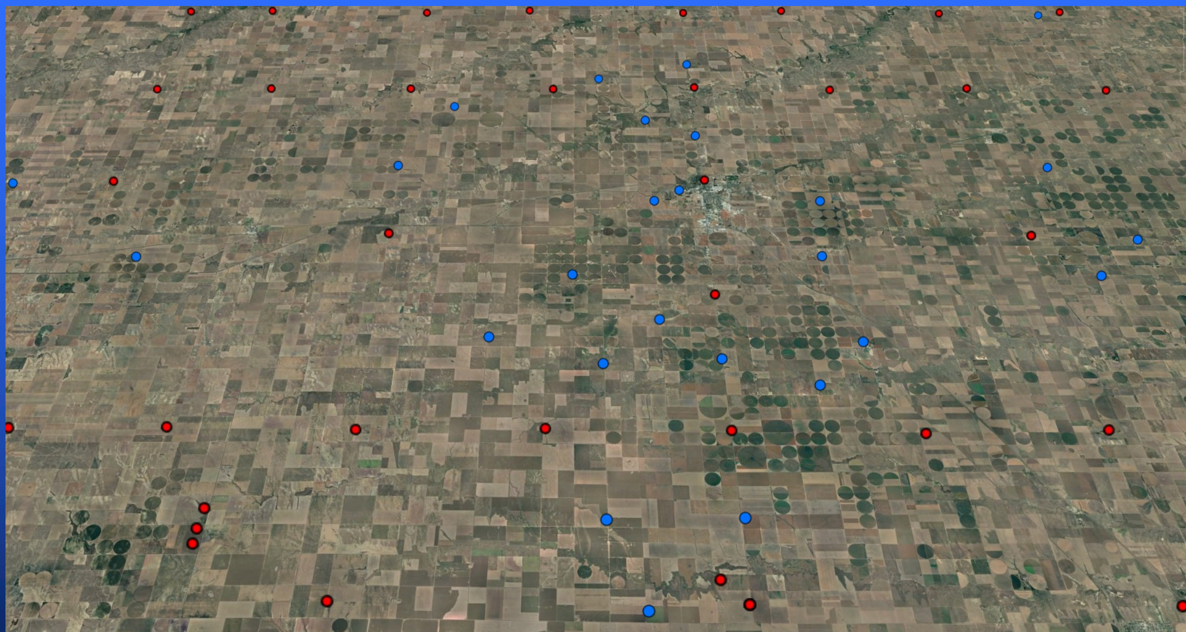


The green circles are created by central pivot irrigation systems. Note that there are large swaths of areas without central pivots. This indicates a discontinuity of transmissive zones (intervals that readily yield water to wells) and is a reflection of aquifer heterogeneity at the regional scale.

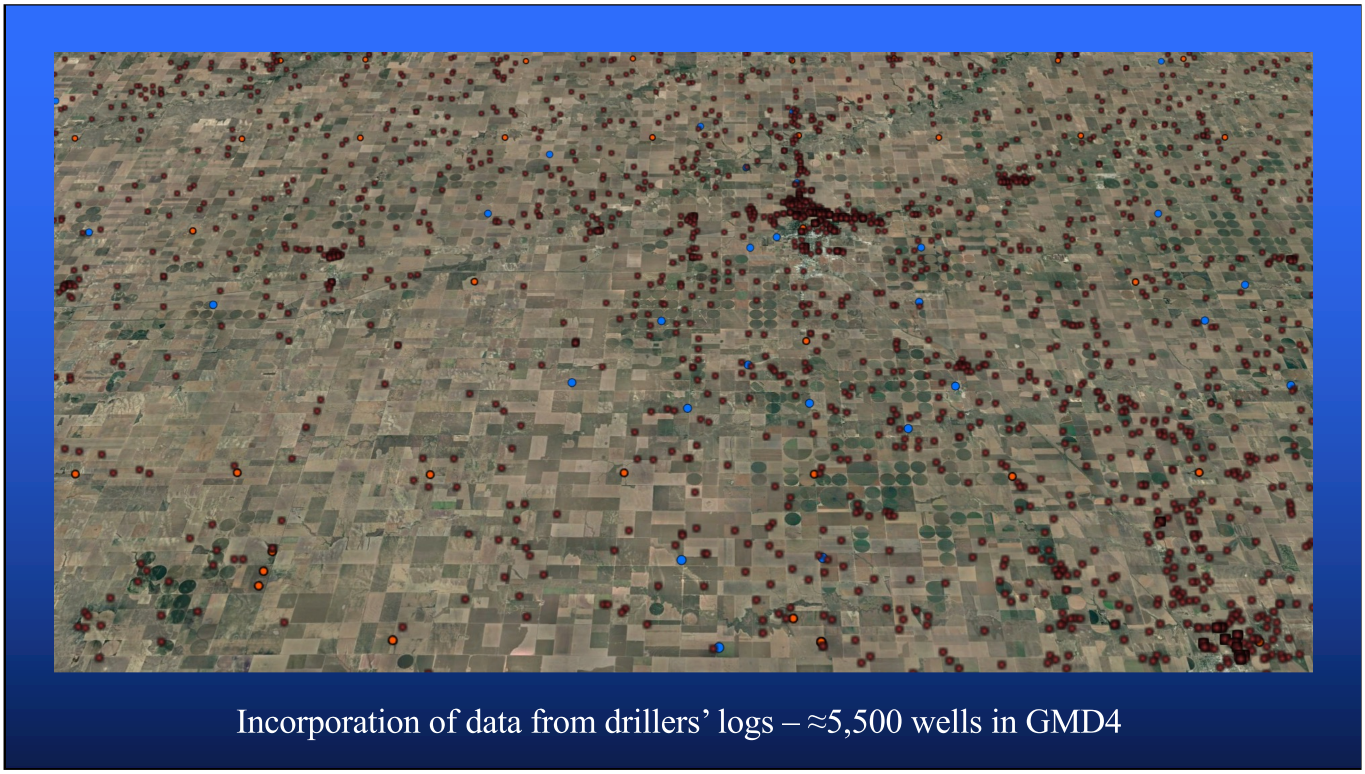
Aquifer Heterogeneity on the Regional Scale

Discontinuity of transmissive zones

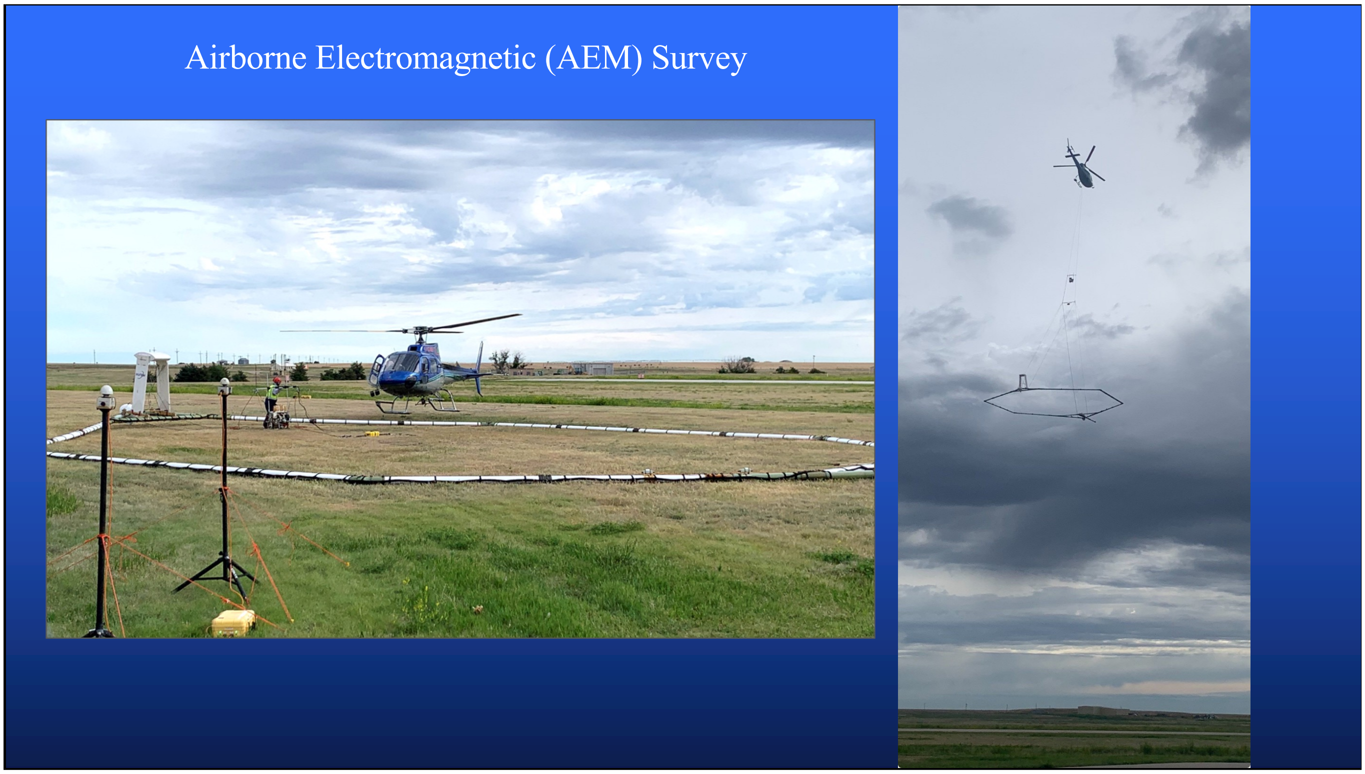
Hydrogeologic Framework – KGS and USGS Test Holes



We do have information about the subsurface hydrogeology (hydrostratigraphic framework) at a finer scale than the distribution of central pivots. From the 1940s to 1970s, geoscientists from the KGS and the USGS put in test holes across the area (blue and red circles). These provide very high quality information on the geology.



We can supplement that high-quality information with the information from drillers' logs. Since the mid-1970s, drillers have been required to turn in a record of the material through which they passed during the drilling process. This is a voluminous dataset but highly variable in quality (reddish-brown squares). These datasets still leave us with many questions. How can we do better?



These photos are from the Goodland Airport on May 31, 2024. This was the first AEM survey ever done in Kansas. Note that the helicopter is just taking off in the left photo. The technician will hook a cable underneath the helicopter and it will lift the hexagonal frame up until it is 100-150 ft above land surface. The helicopter will then fly at 50-55 mph gathering information about subsurface conditions. $700K in funding was provided by the Governor's Office for this project. We were able to combine with a project in Nebraska to reduce the cost.

How AEM works is described in the next slide.

How AEM works:

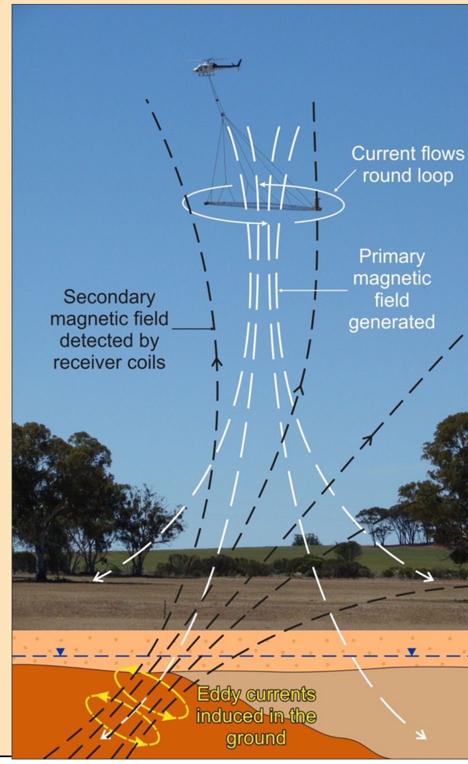
The transmitter fires discrete electromagnetic pulses that generate a primary magnetic field.

The pulses induce eddy currents in the subsurface that generate a secondary magnetic field.

We are measuring this secondary magnetic field.

This measurement provides information on electrical resistivities in the subsurface.

We are taking a measurement every ≈85 ft as we are flying at 50-55 mph.



Typically, sands and gravels have high electrical conductivities, and shales and clays have low. However, silts and cemented sands and gravels also can have relatively high electrical conductivities, which complicates things.

Each measurement is called a “sounding,” and the depth of investigation is about 600 ft below land surface.

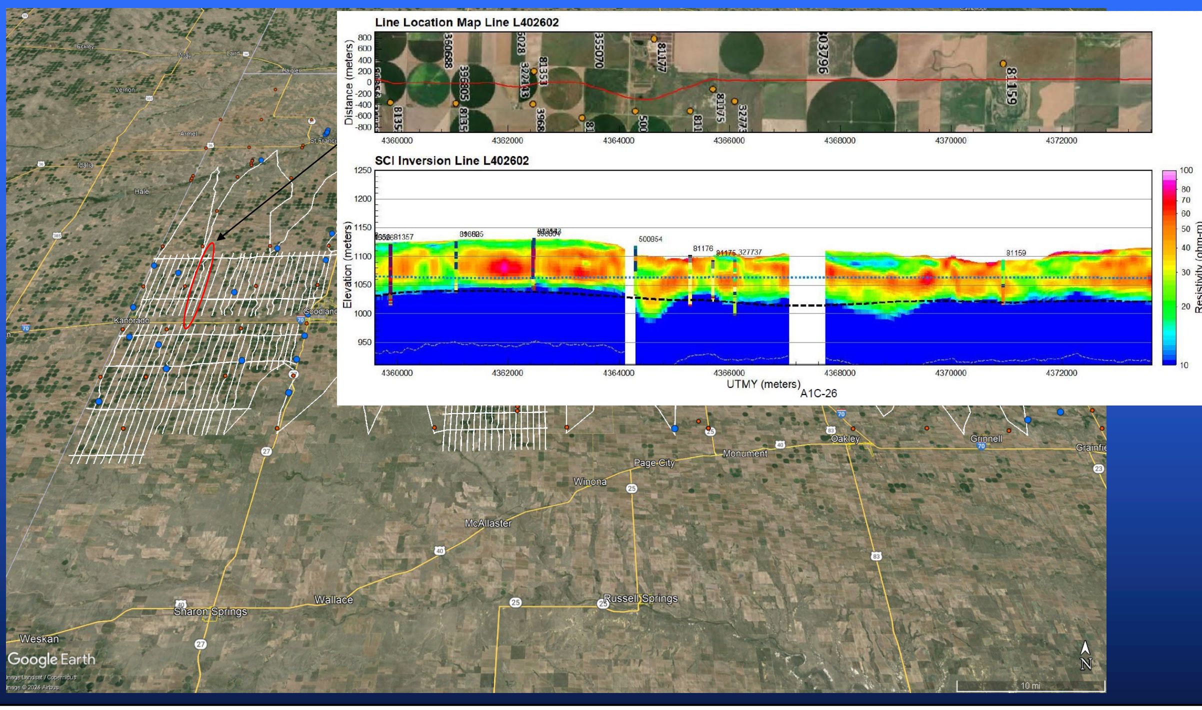
GMD4 Flights Lines – 2,486 miles – May 28-June 16, 2024

This figure shows the lines that were flown in GMD4 – some are closely spaced and some are more reconnaissance-mode lines. The lines were decided upon in cooperation with Shannon Kenyon, GMD4 manager, and her board. Note that the hexagonal frame and associated equipment weighs about 1,700 lbs, so we could not fly over any buildings or confined feeding operations, and we could not get close to wind farms. We also had to be very careful about flying over major highways.

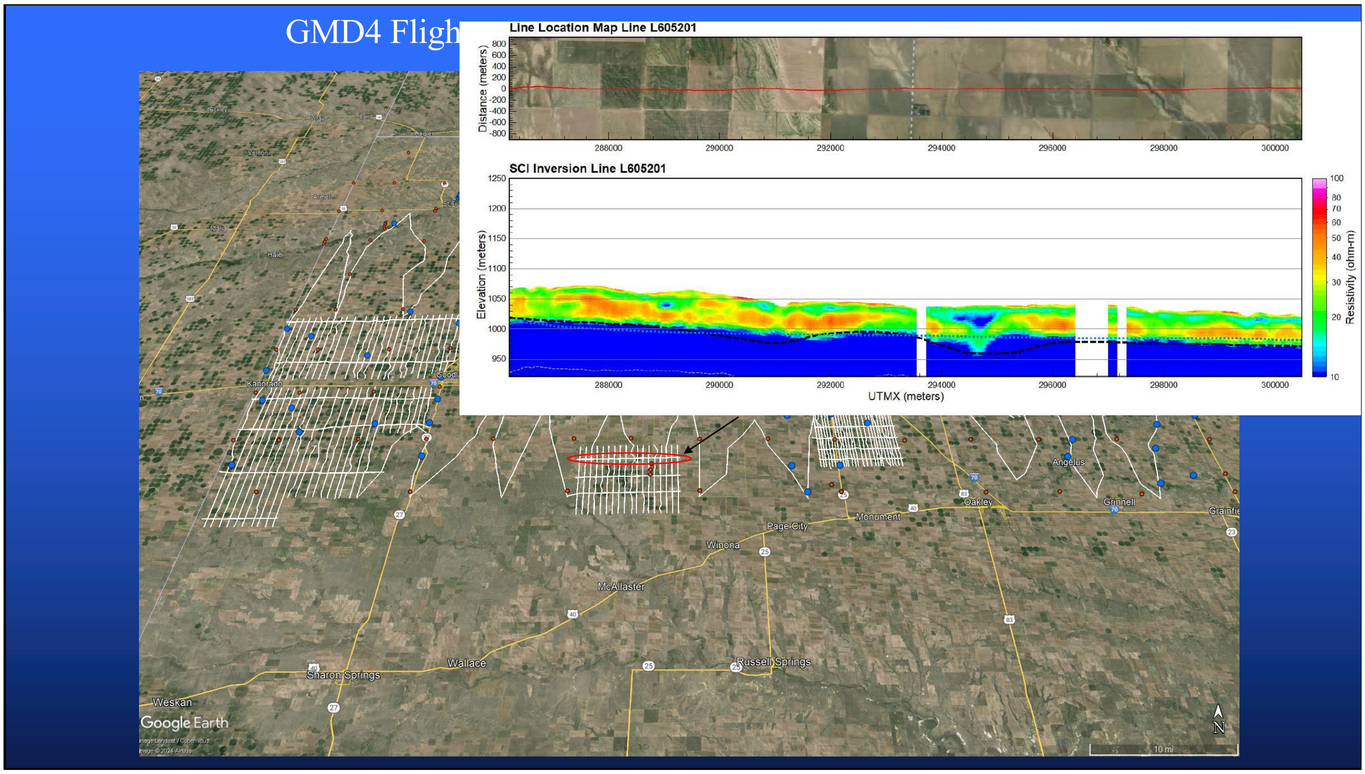
GMD4 Flights Lines – 2,486 miles – May 28-June 16, 2024

We now will look at a 9.3 mi N-S line in Sherman County (red oval).

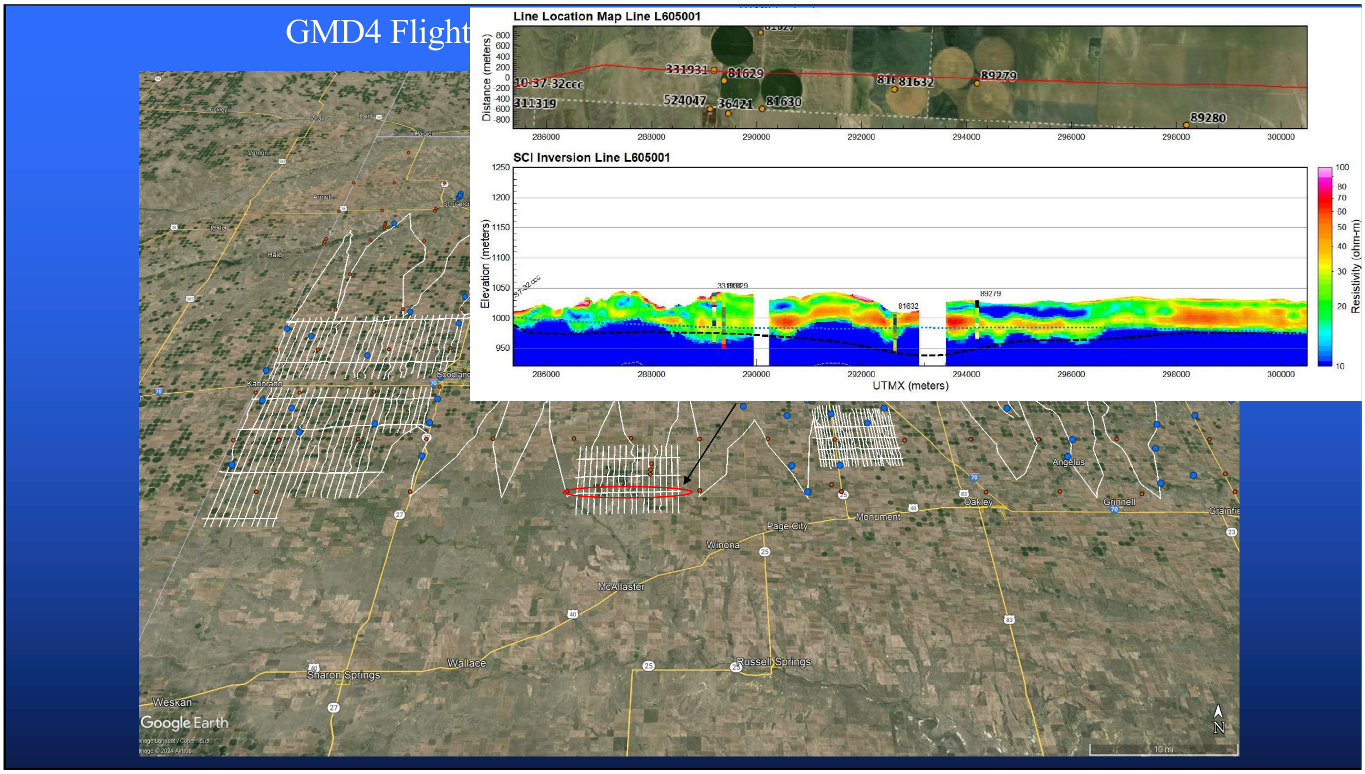
GMD4 Flights Lines – 2,486 miles – May 28-June 16, 2024



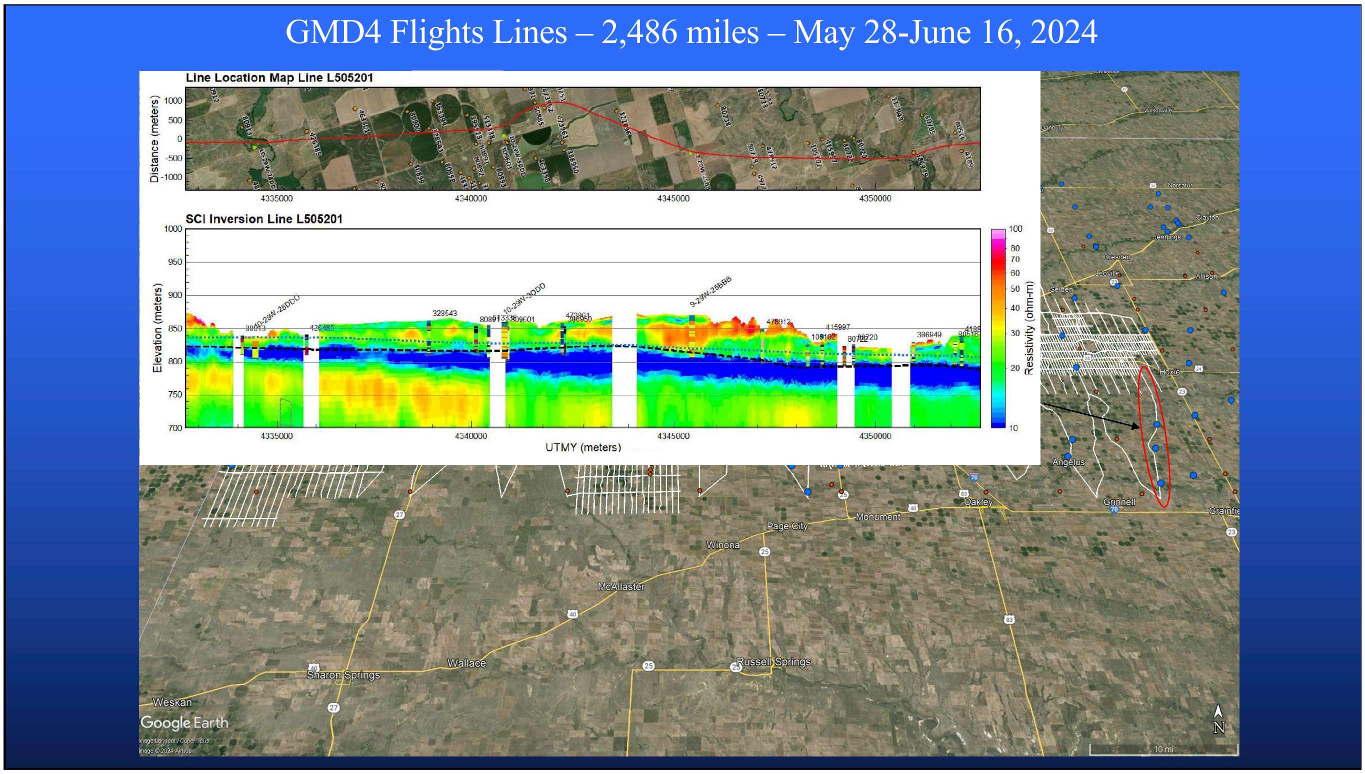
The red line on the aerial photo is the flight line (N-S, left-right). The cross-section image below that shows the electrical resistivity determined from the AEM survey. There are two geologic units – the blue is the Pierre Shale, the bedrock unit that is basically impermeable. Above it lies the material that composes the HPA. The dashed black line is the interpolated bedrock surface before the AEM survey, the dotted blue line is the interpolated water-level surface from the annual measurement program, the dashed grey line near the bottom is the depth of investigation, and the blank areas are areas where pipelines, high-voltage transmission lines, etc. introduced so much noise into the AEM data that we had to remove those areas. The key point to note is that there is much more topography on the bedrock surface than we had previously known – there are clear practical ramifications of that finding.



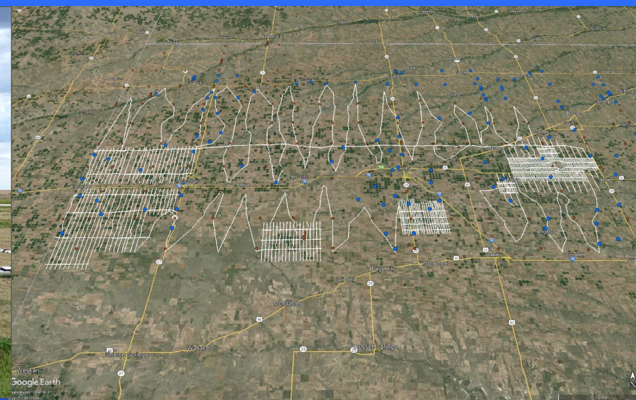
Here is a line where there are no central pivots because there is no groundwater to be had (the dotted blue line is at or very close to the bedrock surface in most areas).



Here is a line to the south of the previous one where the topography on the bedrock surface greatly increases. This explains the clump of irrigation circles we see in that area. Note that on the east side of the line, there is little bedrock topography and no irrigation circles (dotted blue line is on the bedrock surface). Likely, the isolated pivots that one sees from aerial photos are located in bedrock troughs like these.



Virtually the entire flown area of GMD4 is underlain by the Pierre Shale, which has a strong resistivity contract with the aquifer material. However, other bedrock units, such as the Niobrara Chalk, don't have such a strong contrast. In this line (S-N, left to right), you can see that the Pierre Shale is thinning and the Niobrara (yellow and green below the Pierre) has a resistivity that could make the bedrock boundary more difficult to determine outside of GMD4.



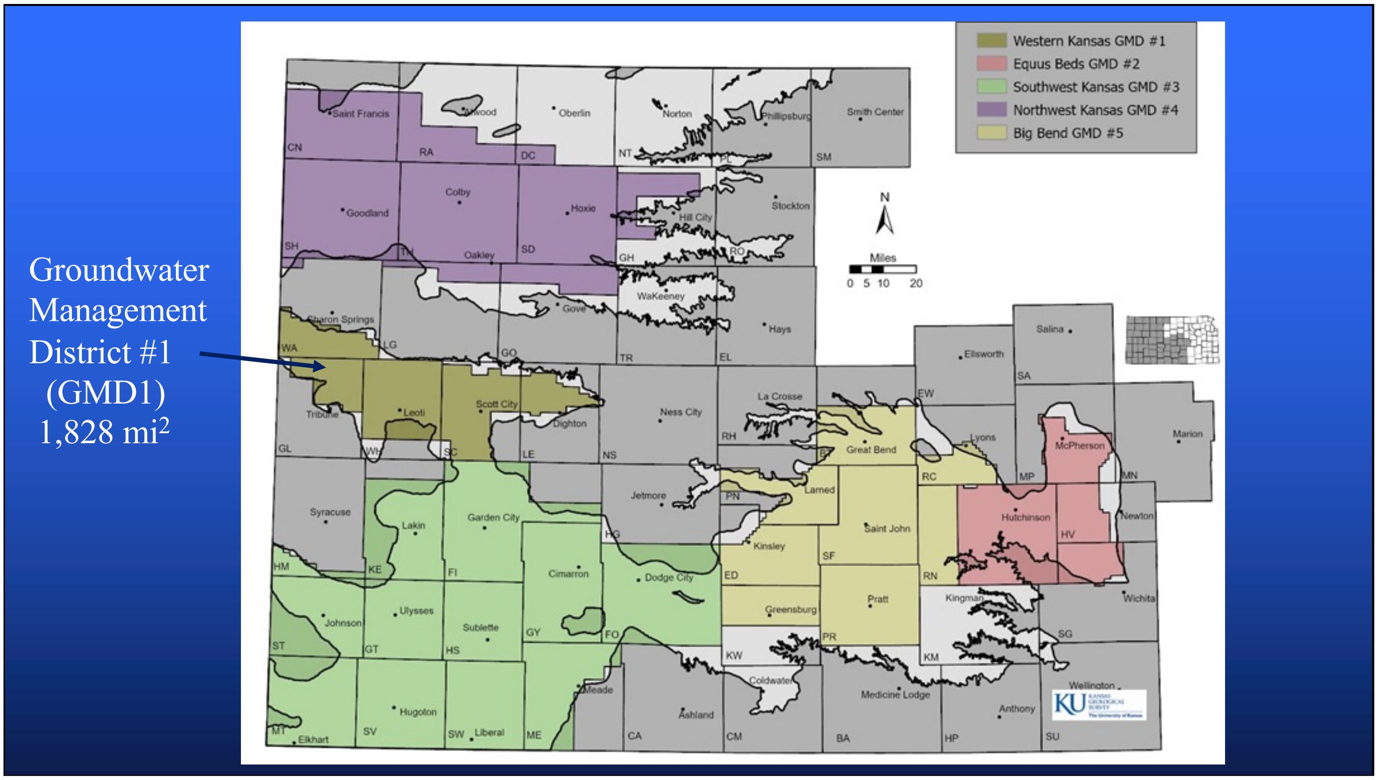
Strengths of Airborne Electromagnetic Surveys:

- Near-continuous record (≈85 ft separation) of electrical resistivity in the subsurface.
  - 155,294 AEM soundings collected and 138,000 used (≈11% not usable)
- Provides important insights into the distribution of pumping wells in GMD4.
- Enhances the design of groundwater conservation areas.

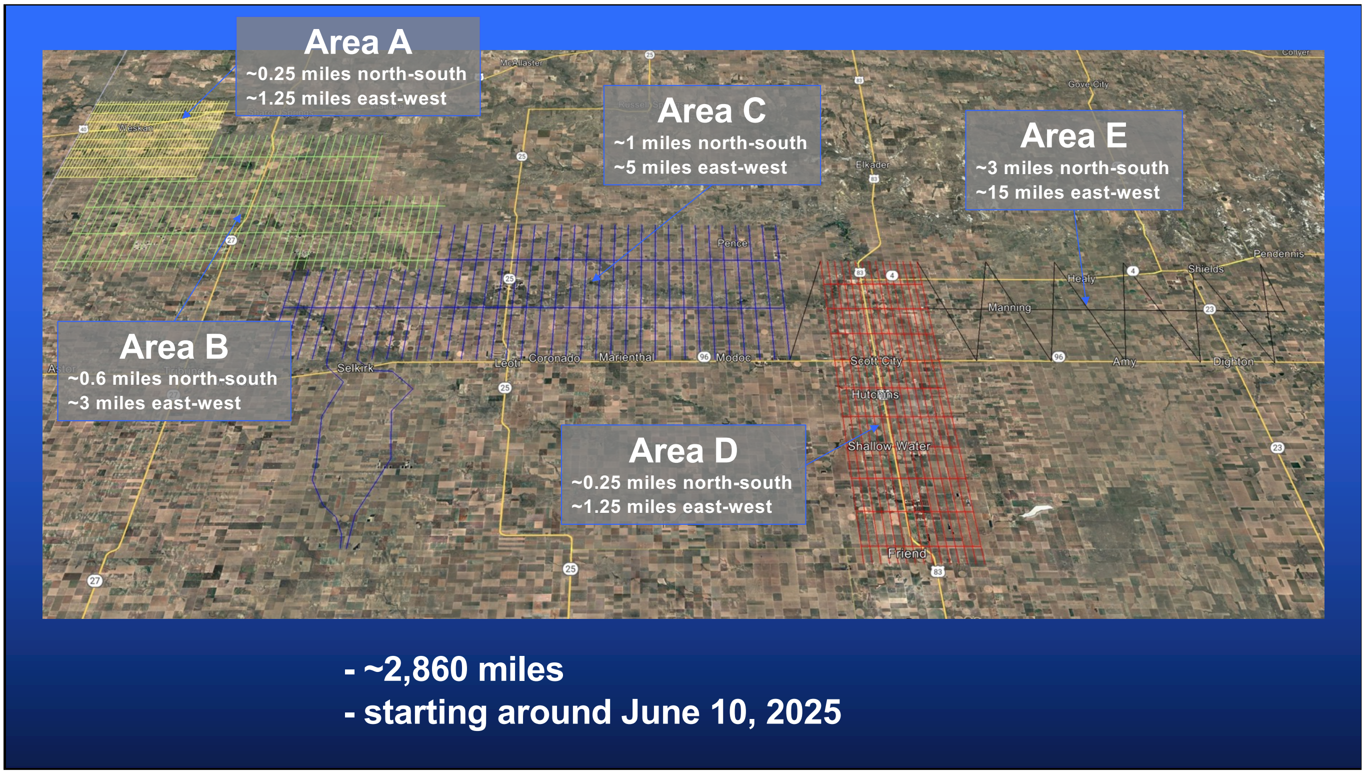
Major Challenge – Transformation of electrical resistivity to lithologic type.

11% of the soundings could not be used because of the level of electrical noise produced by power lines, pipelines, etc.

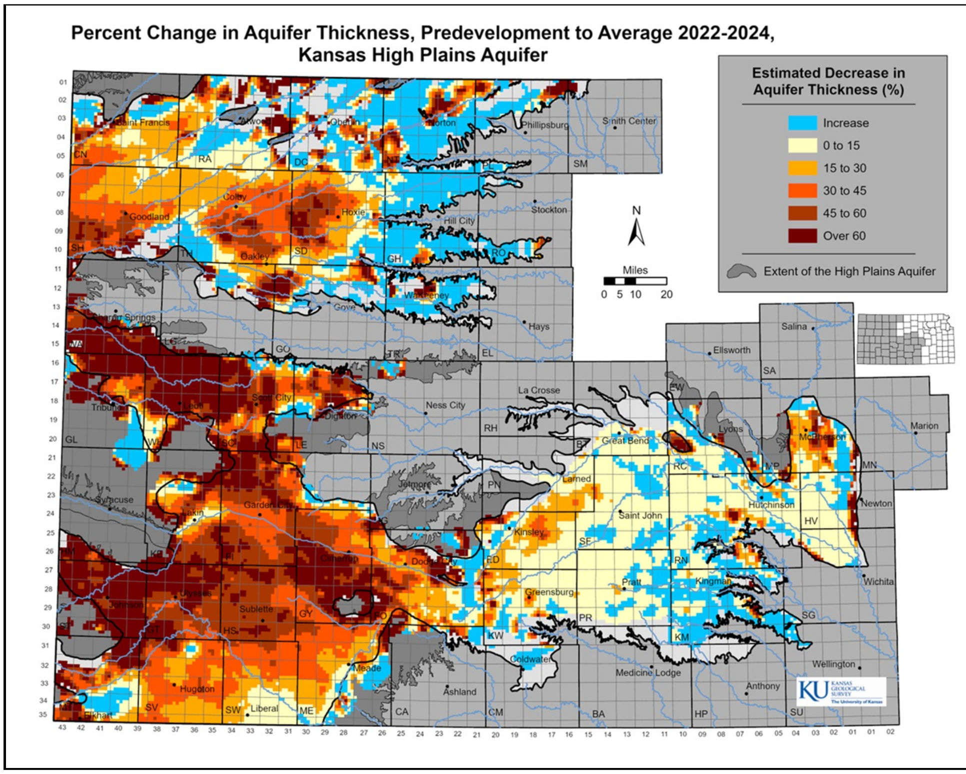
The AEM survey has already given us an unprecedented view of the bedrock-aquifer boundary. Our next step is to move from electrical resistivity to lithology (e.g., sand, silt, clay, and gravel). We are still figuring out the best way forward for that step.

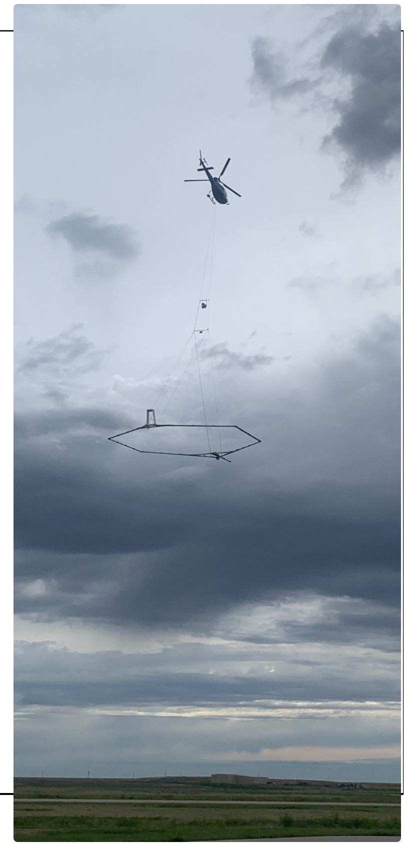


This summer, we will be carrying out an AEM survey of GMD1. Details of that survey are given in the next slide.



GMD1 flight lines.

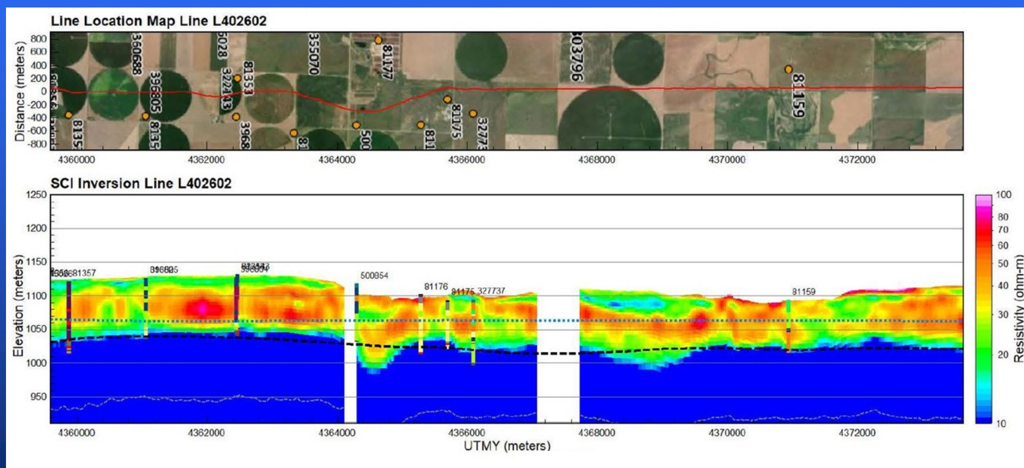


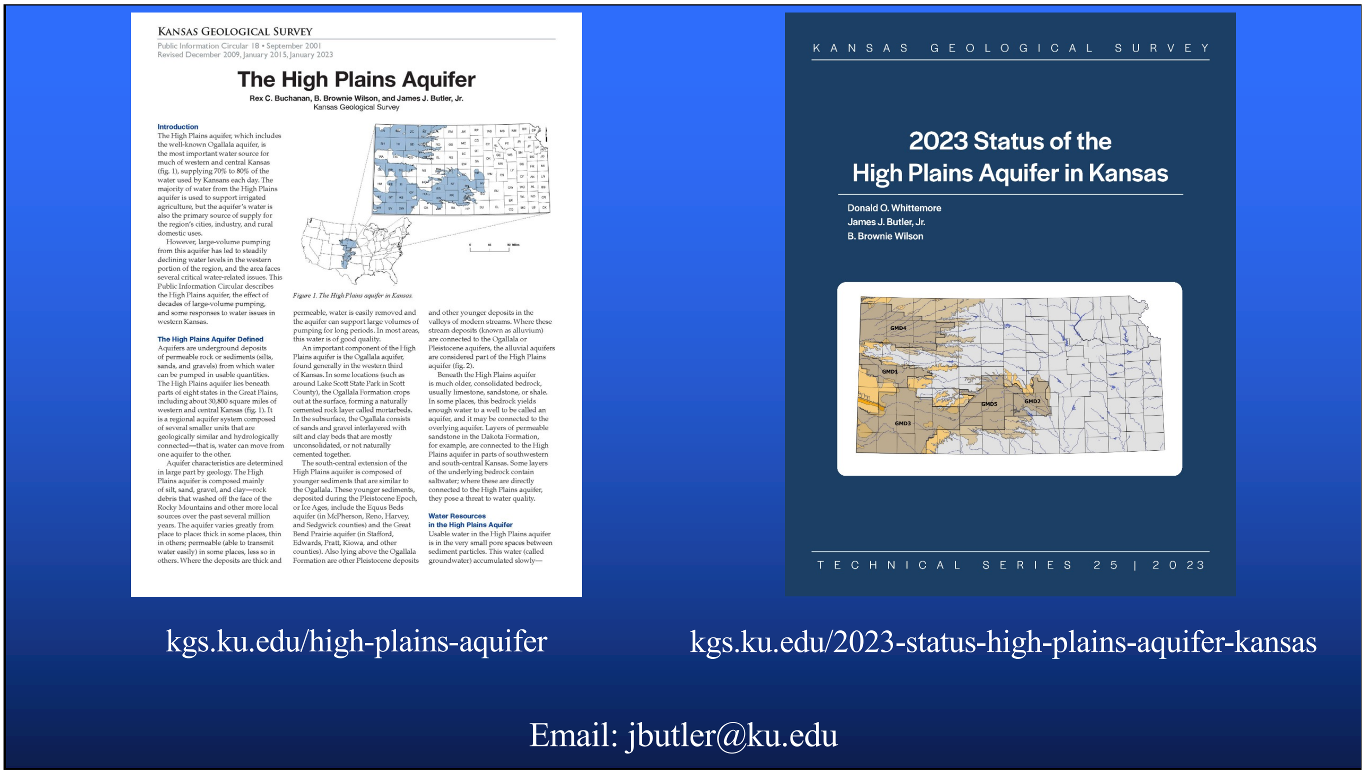


In summary, the AEM survey is improving our understanding of aquifer conditions at a level of detail that we previously did not have.

ACKNOWLEDGMENTS

This work was primarily supported by funding from the Kansas Water Office. Additional support was provided by the Kansas Water Plan (Ogallala Technical Support Program of the KGS) and the U.S. National Science Foundation.





Further information about the High Plains aquifer can be found in these documents that can be freely downloaded from the KGS website: Public Information Circular 18: The High Plains Aquifer (https://kgs.ku.edu/high-plains-aquifer and Technical Series 25: 2023 Status of the High Plains Aquifer (https://kgs.ku.edu/2023-status-high-plains-aquifer-kansas).

Please email me if you have questions. My email is jbutler@ku.edu.