Avenida del Partenon, 10
28042 Madrid, Spain

Mississippi Aquifer Mapping, USA

Source: Burke et al., 2021. https://doi.org/10.1038/s43247-021-00200-z

The Mississippi Alluvial Plain (MAP) contains extensive shallow aquifers systems in USA but have been faced chronic groundwater decline.

From 2018 through early 2020, Xcalibur acquired more than 43,000 flight-line-kilometers of airborne electromagnetic, magnetic, and radiometric data for the USGS, covering >140,000 km2 within the MAP region, with the aim of improving the understanding of the shallow subsurface architecture and characterizing the geological formations, which are of critical importance not only for effective water resource management in the region but also have significant implications for infrastructure and hazards studies.

Airborne geophysical data were acquired in three phases, using two different AEM platforms that also included magnetic and radiometric sensors:

- Phase 1: A high-resolution grid with flight-line spacing between 0.25 and 1 km covered an area of ~1000 km2 just northwest of Shellmound, Mississippi.
- Phase 2: A regional grid covered over 95,000 km2 with 6–12 km between flight lines over most of the area, plus an area of higher density (1.5 km line spacing) over part of southern Crowleys Ridge in Arkansas. This regional survey also included ~2000 line-km of data acquired directly along several streams and rivers to characterize their potential for enhancing connectivity between surface water and groundwater.
- Phase 3: A second regional survey extended coverage to an area of ~140,000 km2 with 6 km between flight lines, interwoven with the first regional grid such that the combined line spacing was 3 km over most of the study area. An additional 1400 line-km were acquired streamwise along the entire Mississippi River within the study area, as well as the Arkansas River from Little Rock, Arkansas, to its confluence with the Mississippi River.

The first two phases of data collection were acquired with the helicopter-based Resolve frequency-domain AEM system, while the third phase was acquired with the fixed-wing time-domain TEMPEST® AEM system.

Data collection included a high-resolution survey over ~1000 km2 near Shellmound, Mississippi, regional surveys with 3–6 km line spacing across the entire study area, and over 3000 line-km of data acquired along streams and rivers to characterize potential surface water–groundwater connections beneath these important recharge pathways. Radiometric (Fig. 1b), magnetic (Fig. 1c), and inverted resistivity grids at multiple depth intervals (Fig. 1d–h) summarize the combined results from both regional survey phases. Together, this represents the first initiative to acquire system-scale airborne geophysical data over an entire US aquifer.

At the regional scale, radiometric data (Fig. 1b) correlate with mapped surficial geology and sediment age, with Holocene deposits clearly delineated as strong returns of multiple elements (light-colored areas in Fig. 1b) compared with Pleistocene sediments. Magnetic data gridded at this scale largely corroborated previously mapped structures, such as the line of southwest–northeast-trending magnetic highs (Fig. 1c) associated with mapped intrusive plutons along the Commerce geophysical lineament (CGL) adjacent to the RR in northeast Arkansas and southeast Missouri.

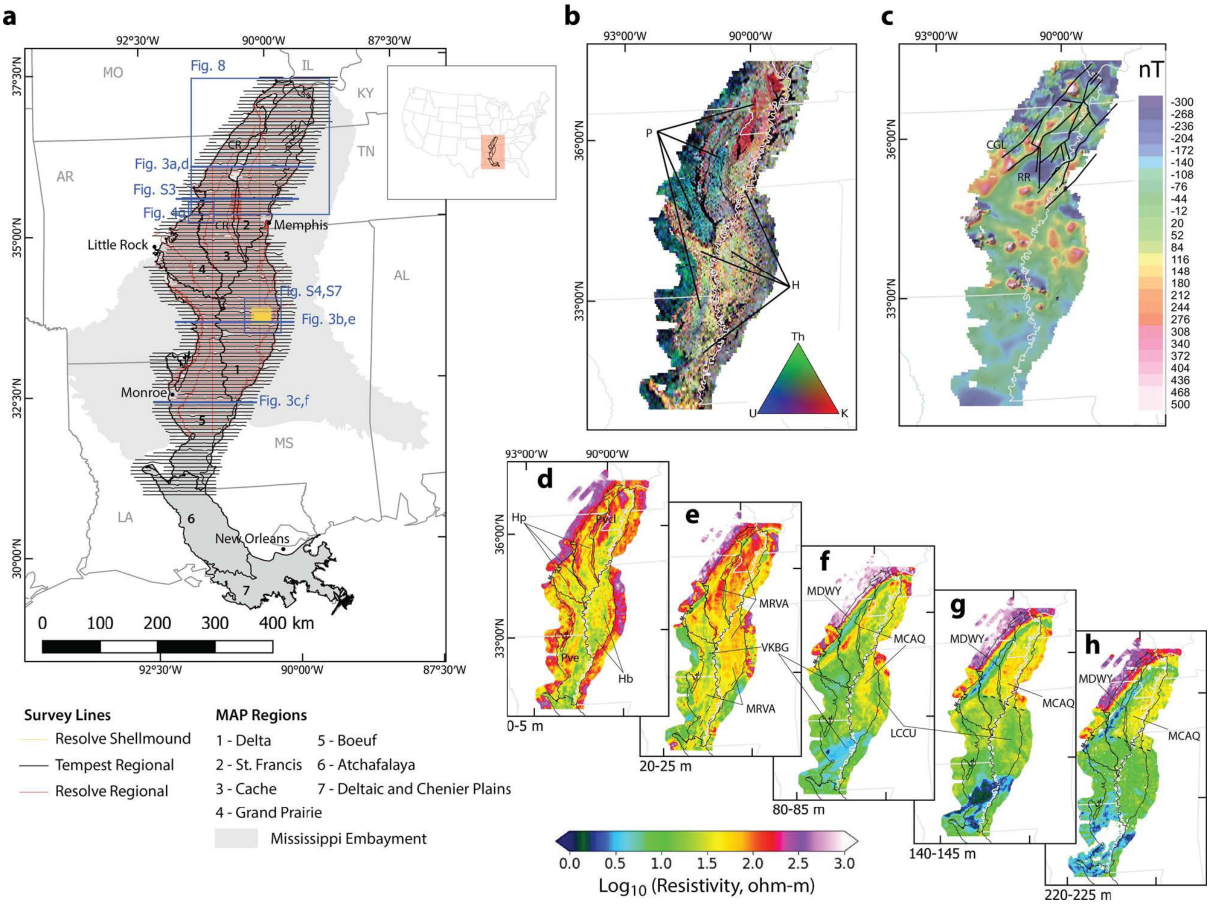

***Figure. 1. Airborne geophysical survey coverage and summary of regional datasets. a** Primary management region in the MAP study area, with flight lines for each of the three phases of data collection completed through early 2020 (CR Crowleys Ridge). Results from the combined regional surveys gridded onto the 1 km National Hydrogeologic Grid include: **b** radiometric data presented as a ternary diagram that indicates the relative abundance of K, U, and Th in surficial sediments with areas of Holocene (H)- and Pleistocene (P)-aged sediments indicated, **c** the residual magnetic intensity map (in nanoTeslas, nT) shows faults46 related to the New Madrid seismic zone (RR Reelfoot rift, CGL Commerce geophysical lineament); and **d–h)** resistivity depth slices at five depth intervals from 0 to 220m below land surface annotated with mapped surficial geologic units32 (Hb backswamp, Hp Point bar and meander belt, Pve & Pvcl Wisconsin-age valley train) and four-letter codes of distinguishable hydrogeologic units (MRVA Mississippi River Valley alluvial aquifer, VKBG Vicksburg–Jackson confining unit, MCAQ Middle Claiborne aquifer, LCCU Lower Claiborne confining unit, MDWY Midway confining unit).*

The USGS has used the acquired airborne geophysical data to develop maps of aquifer connectivity and shallow geologic structure, infer relationships between structure and groundwater age, and identify previously unseen paleochannels and shallow fault structures (Fig. 2 and 3).

Avenida del Partenon, 10
28042 Madrid, Spain

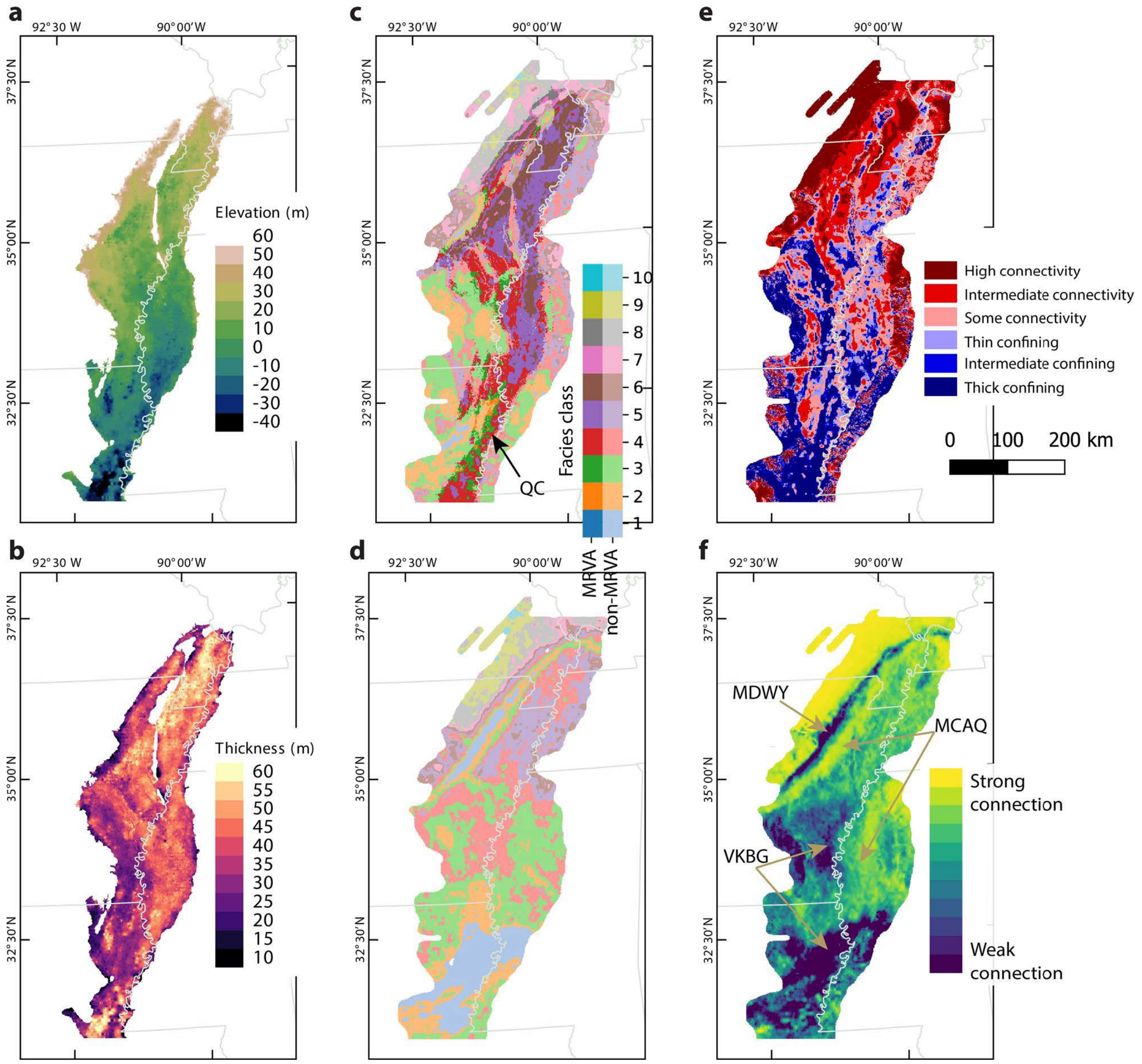

***Figure. 2. Derived hydrogeologic products from AEM data. a** Base of aquifer elevation surface determined from combined AEM and borehole data and **b** the aquifer thickness. Resistivity models grouped into facies classes at depths of 35–40m **(c)**150–155m **(d). e** Surficial confining and connectivity conditions based on the thickness and presence/absence of shallow low-resistivity facies classes. f Connectivity metric between the base of the MRVA and sub-cropping Tertiary unit defined as the vertically integrated electrical conductance within 25m of the base of aquifer elevation **(a).** QC Quaternary channel, MRVA Mississippi River Valley alluvial aquifer, VKBG Vicksburg–Jackson confining unit, MCAQ Middle Claiborne aquifer, MDWY Midway confining unit.*

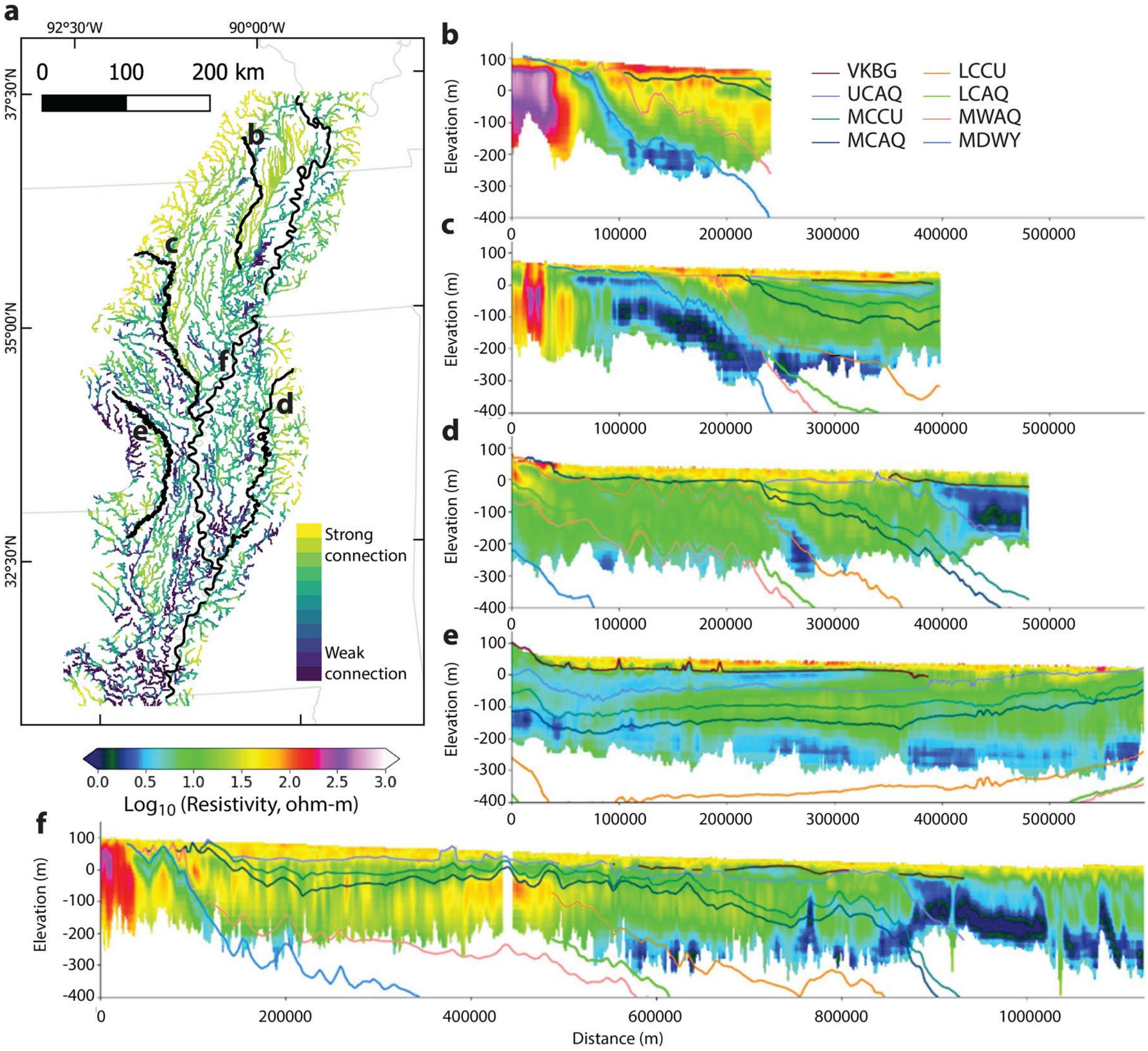

***Figure. 3. Characterizing rivers and surface water-groundwater connections**. **a)** River connectivity metric defined along all NHDPlus segments in the study area identifies areas for high or low potential for surface water-groundwater connectivity based on streambed resistivity values. Resistivity cross-sections (from north to south) extracted from gridded data along the St. Francis River; **b)** White River; **c)** Yazoo-Tallahatchie River; **d)** Bayou Bartholomew; **e)** Mississippi River (f). The top elevation of Tertiary MERAS model layers43 is indicated as solid lines on top of resistivity cross-sections.*

The multiple phases of AEM mapping (Fig. 1a), along with targeted ground-based and waterborne geophysical data collection, provide an excellent case study in the value of subsurface mapping over multiple scales. From regional surveys aggregated to 3 km line spacing with 1 km grid cells to high-resolution AEM data in the Shellmound area with 0.25–1 km line spacing with 100 m grid cells, USGS were able to illustrate the value of an order of magnitude increase in flightline spacing (Fig. 4).

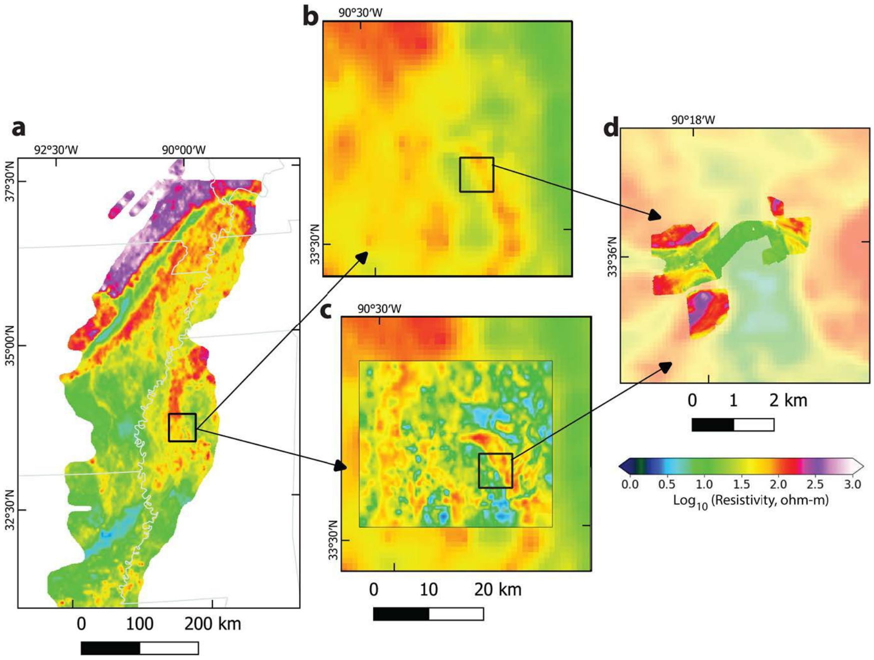

Figure. 4. ***Multi-scale mapping with airborne and ground-based methods.*** *a Regional-scale structure mapped on 1 km grid cells interpolated from ~3 to 6 km spaced flight-line data over the entire MAP region. b Regional-scale structure enlarged to the ~30 × 30 km Shellmound study area, compared with high-resolution structure mapped on 100m grid cells interpolated from 0.25 to 1 km-spaced flight-line data from the Shellmound study area (c) shows the ability to resolve detailed buried channel structure. d Comparison of near-surface high-resolution Shellmound AEM data (background) with very high-resolution ground-based electromagnetic data66 acquired with a sensor towed over ~4 km2 on survey lines spaced by 25 m.*

When allocating resources for data collection, a balance should be sought between the optimality of data collection to address a narrow decision-space (such as a single, focused question) and robustness of the investment to address future questions that expand the decision-space. The variety of applications demonstrated in this study highlights the robustness of large-scale AEM data in this respect. Although AEM surveys can involve high absolute cost, at large scales they may be 3–4 orders of magnitude less expensive on a per-datapoint or per-square-kilometer basis compared with traditional ground-based surveys or drilling. Because large surveys can cover parts of multiple counties and states and support the interests of multiple scientific disciplines or stakeholder interests, a community-driven approach to the acquisition of these foundational geoscientific datasets is advantageous.