SYNOPSIS

Title: Integrated geophysical mapping of a Mississippi Flood Plain Aquifer (0-30 m): 3D seismic and 2D resistivity imaging

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Other PIs:

Primary Findings

Flood-induced seepage under the Mississippi River levees poses an economic risk to the Louisiana industrial corridor, its agricultural economy, state infrastructure and public safety. In order to characterize the soil types and the possible geometries of the pathways for shallow groundwater flow under the man-made levees across the adjacent floodplain, we collected four electrical resistivity transects 1 km in total length, two (2) adjacent to the LSU School of Veterinary Medicine Building, Baton Rouge and two (2) at a public park (Farr Park), approximately 3.3 km south of the first site. Also at the LSU site, we collected six (6) parallel, seismic, surface-wave profiles, each 9 m apart, with 600 m in total length. Electrical profiles have a vertical resolution of 1.5 and extend to a maximum depth of 40 m. Seismic profiles have a similar resolution but only penetrate to 10 m depth. Both types of data are relatively fast to collect: 250 m – 500 m per day for electrical resistivity data and 100 m/day for seismic surface-wave data.

From nearby geotechnical sediment boring descriptions and overlapping seismic and electrical resistivity profiles we correlate the following physical properties and their values: sand, ~> 30 Ohm.m; silt ~20-30 Ohm.m; clay ~< 20 Ohm.m. Coincident and nearby seismic profiles also suggest the following shear wave velocity values (+/- 20%): sand, ~> 220 m/s; silt and clay < 180 m/s. As future work, we recommend ongoing quantitative integration of multiple data types to generate hydraulic flow permeability models.

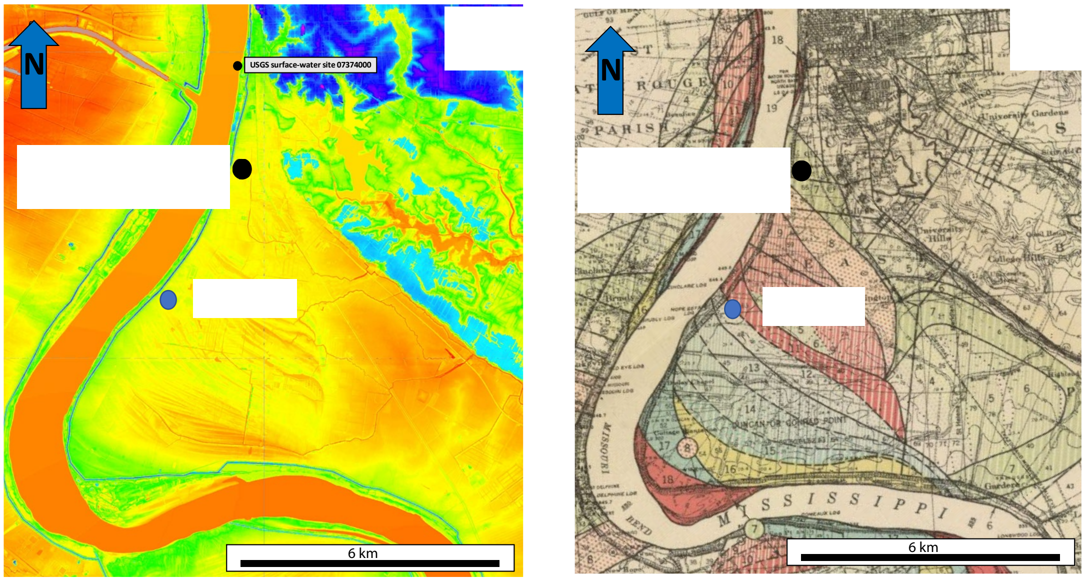

Figure 1. Location of two study areas within the Duncan Point Bar complex: northern LSU School of Veterinary Medicine (UTM 15R 673520.62 m E, 3366012.34 m N) and southern Farr Park (Table 1 for geographic coordinates). Both sites are chosen because they are publicly accessible for investigation, surrounded by residential neighborhoods, and are historically prone to under-the-levee seepage and accompanying flooding. **(a)** LiDAR-based topography shows a relatively flat surface (yellow) with occasional ridges and swale-depressions (orange) **(b)** In the subsurface these slight topographic features are created by amalgamations of previous river sedimentary bodies (point bars) generated by natural lateral migration of the

Electrical and Seismic Methods

Electrical resistivity profiles are the result of inversion of the raw field data (Figure 4). A geophysical inversion process is applied, in order to take into account vertical and lateral changes in the subsurface to which the acquisition geometry is matched. The purpose of the inversion is to find a model that gives an earth response that is similar to the actual measured values in an idealized mathematical representation of the surveyed section. The mathematical link between the model parameters and the model response for the 2D resistivity models is provided by finite-difference (Dey and Morrison 1979a) or finite-element methods (Silvester and Ferrari 1990).

Multi-channel analysis of surface waves is a seismic field technique to derive 1D estimates of shear-wave velocity versus depth (Park et al., 1999). Multiple adjacent inversion results are juxtaposed and linearly interpolated to generate "pseudo-2D" profiles. In conventional seismic imaging of the ground, surface waves normally are general treated as noise because they subdue underlying reflected seismic returns. However, surface-wave analysis can also be used to complement traditional seismic reflection profiles (herein, < 10 m) in the shallow portions of the subsurface where normally reflection profiles are of poor quality. Using this technique, we can cover a 100-m line per day, if we fix geophones at 3-m intervals (Figure 2-bottom) while we advance shotpoint locations, 9 m each time. We use a repeatable, hydraulically activated, accelerated weight drop source (80 lb) as a seismic source. In order to improve lateral resolution from 9 m to 1.5 m, we pre-process seismic data using a Common-MidPoint Cross Correlation (CMPCC) workflow (Hayashi and Suzuki, 2004) We generate dispersion curves, manually picked along the maxima for only the fundamental mode and then inverted for a shear wave velocity profile using a nearest neighbor algorithm (Wathelet, 2008).

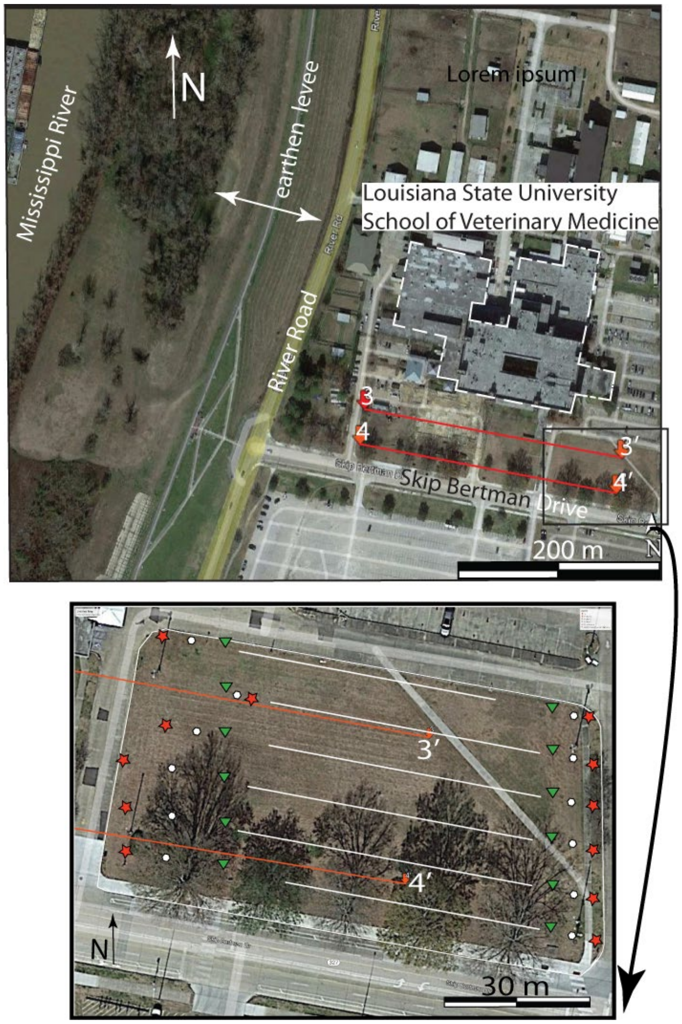

Figure 2. Top: Two lines (3-3′ and 4-4′-- red) mark extent of the ERT profiles (shown in Figure 4). **Bottom Inset:** Six (6) lines (white) indicate extent of the usable portion of the seismic profiles (Figure 5). Red asterisks represent shotpoint locations green triangles geophones and white circles midpoints. Only first and last shotpoint, geophones and midpoints (white circles) are shown.

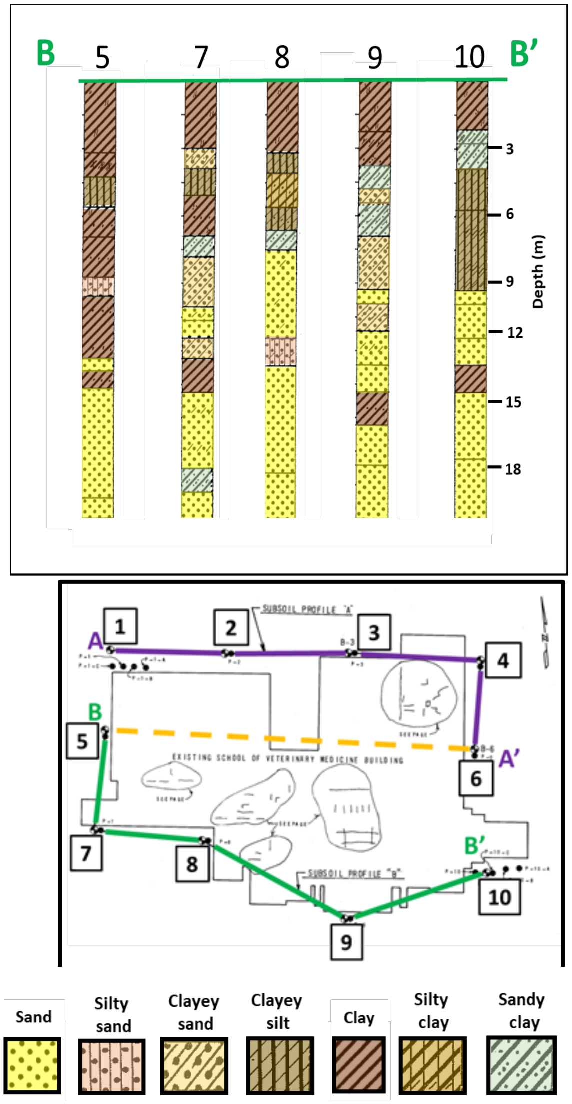

Figure 3. Top: Geotechnical engineering descriptions from relief wells (5 through 10) which surround the Veterinary Building **bottom** and dashed white line in Figure 2, top.

Results: Northern site at LSU campus

A preliminary interpretation of the electrical resistivity profiles (Figure 4) shows large differences in the soil response and hence different potential pathways for groundwater. Although only separated by ~30 m in a north-to-south direction, the southernmost electrical resistivity profile (4-4') displays overall lower resistivities (< 20 Ohm.m) within the upper 35 m of the subsurface. At greater depths, the resistivity becomes locally high (80 Ohm.m – red region). In contrast, the northernmost electrical resistivity profile (Figure 4) displays thicker and potentially more continuous groundwater pathways at depths shallower than 35 m. That is, the lower resistivity values in the southern profile represent sediment changes and not differences in saturation levels. One unlikely possibility is that the general distribution in the observed resistivity values are different because the southernmost profile was collected during a time of low river level (13 ft versus 29 feet). However, and as a result, if the sediment types were similar across both profiles, the resistivity values along the southernmost profile (4'4') would increase (e.g., Mojica et al, 2013) which is not observed.

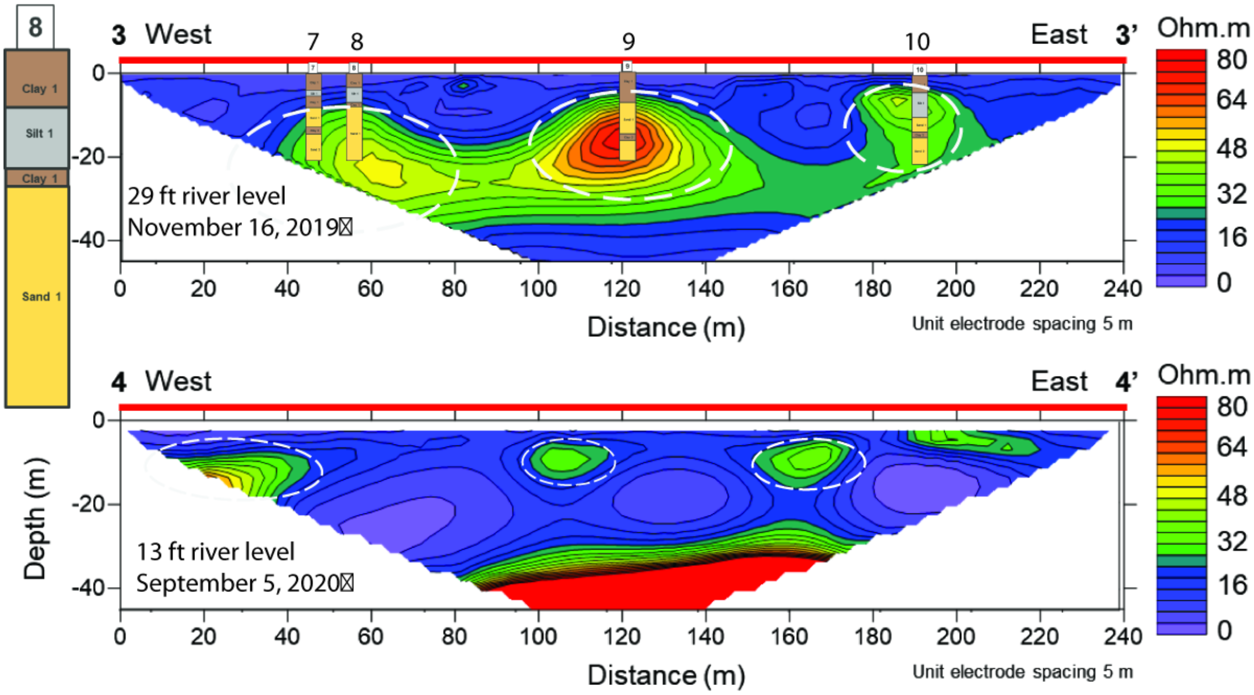

Figure 4 Two, E-to-W, parallel electrical resistivity profiles separated ~30 m in a N-to-S direction (Figure 2) developed for two different times of the year when the level of the Mississippi River is almost at either at its highest or lowest level. Within the **upper profile (3-3'**) projections of geotechnical engineering borehole descriptions suggest high (> 30 Ohm m) electrical resistivity, or low electrical conductivity, and correlate to dominantly quartz-rich, sandy/silty intervals (white, dashed ellipses). Within **profile 4-4',** the intervals of higher resistivity (i.e., sandier units) are smaller and imply (1) large lateral heterogeneity of the subsurface and (2) a possible increase of electrically conductive clay content. A possibly sandy unit (80 Ohm.m) lies at depth.

We can derive general ranges for electrical resistivity values for different geotechnical sediment descriptions via a graphical projection of engineering log descriptions from nearby locations ~30 m north. These provide the following estimates: **sand ,~> 30 Ohm.m; silt, ~20-30 Ohm.m; clay, ~< 20 Ohm.m.**

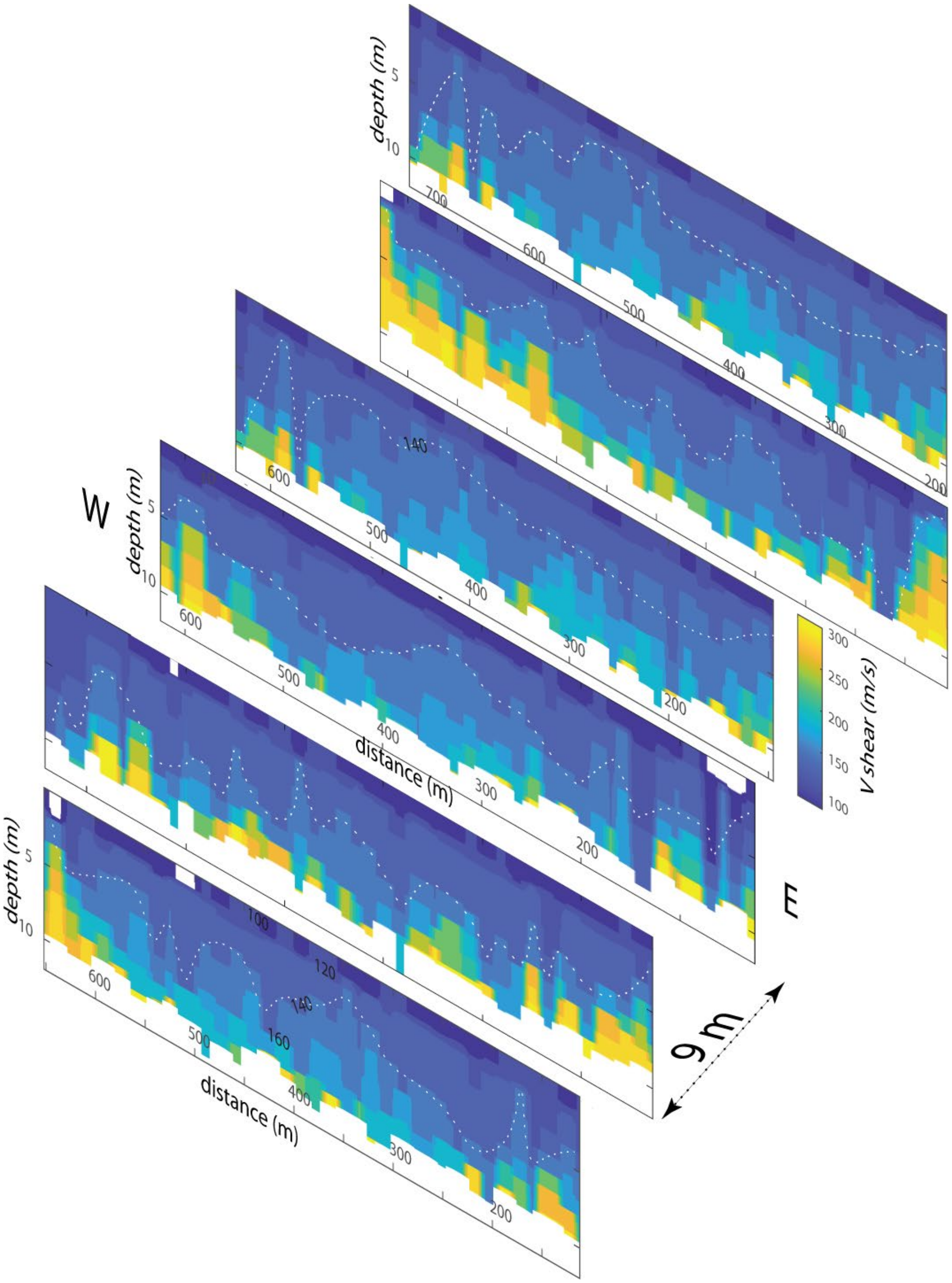

Figure 5. Six (6) **"**pseudo-2D", shear-wave (Vs)-depth profiles each assembled from surface-wave inversions. One resultant Vs-depth inversion is calculated each 1.5 m horizontal distance. Lateral and vertical interpolations are strictly linear. Vertical resolution is nominally, ~ 1,5 m. In general, from N to S, there is a noted increase in the average depth to the 140 m/s contour line of ~ 2 m, suggestive that shallower, and softer materials also thicken ~ 2 m. Color bar shows shear-wave velocity (V shear) ranges between 100 and 300 m/s. All profiles are parallel to each other and separated by 9 m. The 140 m/s contour is highlighted for reference (dashed white line).

A 30-m overlap along the eastern edge of the two electrical resistivity profiles and two sheare wave (Vs) velocity profiles (Figures 2 and 4) suggest a usable relationship exists between seismic velocity values and geotechnical sediment types: Vs values (+/- 20%): **sand, ~> 220 m/s**; **silt and clay < 180 m/s**. We note that the sediment types are inferred from geotechnical boring descriptions which are closer to the electrical resistivity profiles.

Overlapping electrical resistivity profiles and seismic profiles describe similar observable general trends. In both there is an increase in the abundance of "clay-rich" material toward the south within the upper section of the profiles (< 10 m). Electrical profiles show a decrease in the electrical resistivity whereas seismic profiles indicate that the shallower, low-velocity material (~< 140 m/s) thickens toward the south.

Greater seismic coverage is limited by new building construction (Figure 2, west half of line 3-3') which has reduced the amount of available open ground to conduct geophysical surveys. For the same reason, the electrical resistivity line 4-4'was forcibly displaced 30 m to the south of the original line 3-3'.

Southern site--Farr Park

Farr Park is a suitable location to investigate because it is most prone to under-levee seepage (Jafari et al., 2019) and so readily serves as end-member example for highly permeable soils.

Geometry (UTM 15R N)	Line 1	Line 2
Azimuth	N53°E	N56°W
Start (electrode 1)	671,819 m E; 3,363,180 m N	671,819 m E; 3,363,180 m N
End (electrode 48)	671,657 m E; 3,363,012 m N	671,986 m E; 3,363,008 m N
Electrode spacing	5 m	5 m

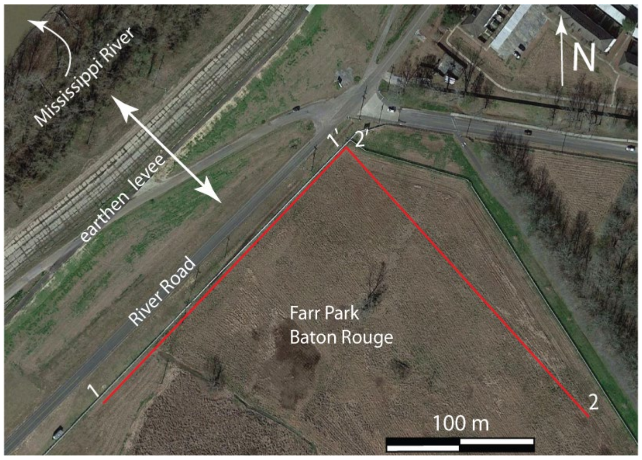

Figure 6. Location of electrical resistivity profiles along two orthogonal lines in the Farr Park study area. Data along both lines were collected on 12.9.20 during a low stage of the Mississippi river (18 ft above sea level) when the ground surface was completely dry and accessible.

At the southern study area (Figures 1, 6), two electrical resistivity profiles, collected on the same day, also suggest heterogeneous, sub-surface, sedimentary units**.** Based on sediment type-electrical resistivity relations taken from the northern study site, the profile closer to the river (Line 1-1'), appears to contain two disconnected, sand-rich units that extend from depths of a few meters to the maximum sampled. Along the orthogonal profile (Line 2-2') the sand-rich unit becomes more laterally extensive and occupies most of the section. The more sand-rich units, which are more resistive electrically (or less electrically conductive), are also more likely to be more hydraulically conductive. Of all the four electrical resistivity profiles created across the Duncan Point bar, the southern area contains the greatest amount volume of permeable sand-rich sediments.

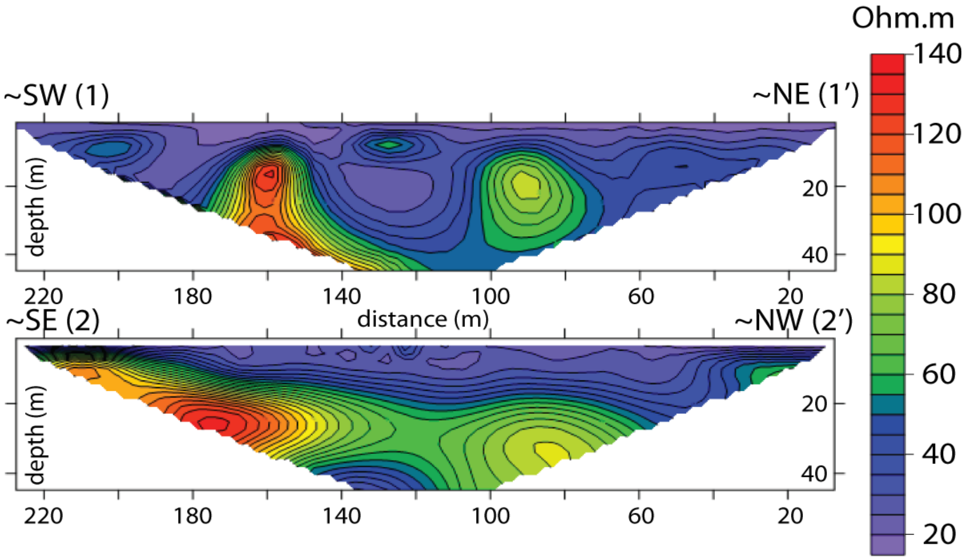

Figure 7 Two inverted electrical-resistivity profiles from the Farr Park area of the Duncan Point Bar. Areas of higher (orange) and lower (green) resistivity which appear in both two profiles, may be connected. Based on conclusions taken from the other study site ~3.3 km to the north, the upper profile (Line 1-1′) comprises more clay-rich material that displays lower electrical resistivity values (or higher electrical conductivity). By comparison, the lower profile (Line 2-2′) shows only half of its area comprises the same electrically conductive material. In the lower profile, the more electrically resistive units (or less electrically conductive), are rich in sand and possible also more hydraulically conductive. Line locations are shown in Figure 6 and Table 1. Contours appear every 5 Ohm.m.

Recommendations

In the future, as more data become available, surface-based geophysical data types (e.g., electrical resistivity and surface wave velocities) should be integrated with geo-engineering data to provide more confident estimations of derivable properties such as hydraulic conductivity. The latter is an eminently useful parameter for predicting groundwater flow and pressures. Electrical resistivity profiling and MASW should be viewed as quick (cheap), complementary geophysical techniques.

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1.Articles in Refereed Scientific Journals

Locci,D. 2022. Students use geophysics to investigate flooding on campus, The Leading Edge, Society of Exploration Geophysicists, https://doi.org/10.1190/tle41030892.1

2. Book Chapters

3. Theses and Dissertations

Locci, Daniel, (in prep, est. 2022) Seismic and electrical detection of shallow groundwater flow in response to changes in the Lower Mississippi River Flood Plain, Baton Rouge, LA (in prep)

Ali, Tamer (in prep, est. 2025): Quantitative integration of well log, seismic and geological facies for the prediction of groundwater flow across point bars in the Lower Mississippi River Flood Plain, Baton Rouge, LA.

4. Water Resources Research Institute Reports

5. Conference Proceedings

Locci-Lopez, D., Lorenzo, J., and, Zhou, X. Soil Type Data Analytics Prediction Using Electrical Resistivity and S-wave Velocities for Shallow (<20 m) Unconsolidated Sediments 2020 **Conference paper and presentation**. SEG Annual Convention, 2020. **https://doi.org/10.1190/segam2020-3428165.1**

Locci-Lopez, D., Lorenzo J., Tsai F., and Elgettafi M. 2019. Shear Wave and Resistivity Surveys to Evaluate Seepage Flow Under a Levee in the Lower Mississippi River Valley. **Conference paper and poster presentation.** SAGEEP Annual Convention, OR, USA, 2019. **https://doi.org/10.4133/sageep.32-065**

Locci-Lopez, D., 2020.Underseepage Pressure Detection in the Landside of an Artificial Levee Using Non-invasive Geophysical Methods. **Professional talk. Baton Rouge Geological Society**, LA, USA.

Locci Lopez, D.E., Lorenzo, J.M. Tsai, F. T.-C. and Elgettafi M., 2019. Shear Wave and Resistivity Surveys to Evaluate Seepage Flow under a Levee in the Lower Mississippi River Valley. **Poster presentation.** Louisiana Geological Survey Louisiana State University Agricultural Center & Louisiana Water Resources Research Institute Proceedings of the 13th Annual Louisiana Water Conference (LAWater 2019). April 15 & 16, 2019 Dalton Woods Auditorium Energy, Coast, & Environmental Building Louisiana State University Baton Rouge, Louisiana.

Locci-Lopez, D. Underseepage Pressure Detection in the Landside of an Artificial Levee Using Non-invasive Geophysical Methods. **Professional talk. Department of Civil and Environmental Engineering, LSU**, LA, USA, 2021.

Locci-Lopez, D. Underseepage Pressure Detection in the Landside of an Artificial Levee Using Non-invasive Geophysical Methods. Professional talk. Thesis Day: **An International**

Workshop for Doctoral Students. The Multidisciplinary Faculty of Nador, Morocco, 2021.

6. Other Publications

Information Transfer

Student and Postdoc Support:

Ph.D. graduate students: Daniel Locci-Lopez, Tamer Ali

Notable Awards and Achievements

The grant was used completely for the support two graduate students who helped complete the work during the summer. As a result of the grant, Daniel Locci-Lopez was able to receive supplementary recognition for his research through the following awards from professional societies:

- 2021 AAPG Foundation Grants-in-Aid Program Grant.
- 2020 SEG Near-Surface Research Award.