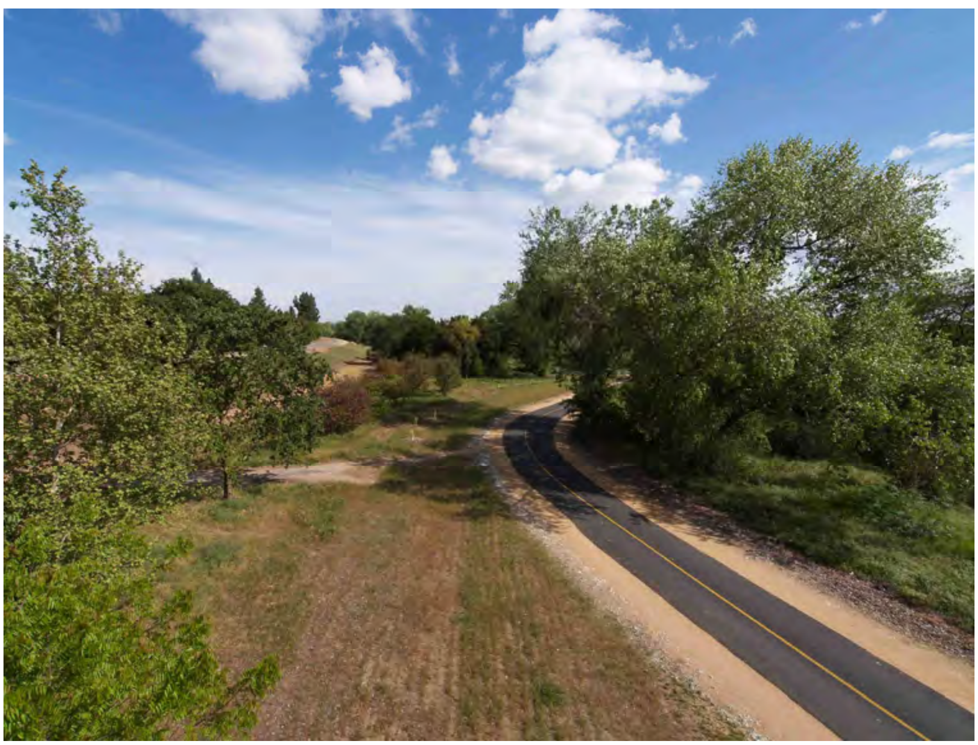
Geophysical Characterization of the American River Levees, Sacramento, California, using Electromagnetics, Capacitively Coupled Resistivity, and DC Resistivity

By Theodore H. Asch, Maria Deszcz-Pan, Bethany L. Burton, Lyndsay B. Ball



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Executive Summary

A geophysical characterization of a portion of American River levees in Sacramento, California, was conducted in May 2007. Targets of interest included the distribution and thickness of sand lenses that underlie the levees and the depth to a clay unit that underlies the sand. The concern is that the erosion of these sand lenses can lead to levee failure in highly populated areas of Sacramento. Resistivity (Geometric's OhmMapper and Advanced Geosciences, Inc.'s SuperSting R8 systems) and electromagnetic surveys (Geophex's GEM-2) were conducted over a 6-mile length of the levee on roads and bicycle and horse trails. Two-dimensional inversions were conducted on all the geophysical data.

The OhmMapper and SuperSting surveys produced consistent inversion results that delineated potential sand and clay units. GEM-2 apparent resistivity data were consistent with the DC inversion results. However, the GEM-2 data could not be inverted due to low electromagnetic response levels, high ambient electromagnetic noise, and large system drifts. While this would not be as large a problem in conductive terrains, it is a problem for a small induction number electromagnetic profiling system such as the GEM-2 in a resistive terrain (the sand lenses).

An integrated interpretation of the geophysical data acquired in this investigation is presented in this report, which includes delineation of those areas consisting predominantly of sand and those areas consisting predominantly of clay. In general, along most of this part of the American River levee system, sand lenses are located closest to the river, and clay deposits are located further away from the river. The interpreted thicknesses of the detected sand deposits are variable and range from 10 feet to 60 feet.

Six areas are suggested as possible trench locations to verify the interpretation presented here. These six locations were selected because they either overlie thick sand lenses or thick clay deposits or a mixture of both. Trenching in these locations should provide greater confidence in the interpretations presented for the rest of the area investigated. The six areas suggested include:

1. The thick sand deposit just downstream of Watt Avenue
2. The thick silt and clay deposit just upstream of Watt Avenue
3. The thick clay unit located midway between Howe Avenue and Watt Avenue
4. The thick sand deposit across from the water treatment plant
5. The clay unit just downstream of the H Street Bridge
6. The thick sand deposit underlying the golf course.

Thus, despite issues with the GEM-2 inversion, this geophysical investigation successfully delineated sand lenses and clay deposits along the American River levee system and the approximate depths to underlying clay zones. The results of this geophysical investigation should help the U.S. Army Corps of Engineers (USACE) to maintain the current levee system while also assisting the designers and planners of levee enhancements with the knowledge of what is to be expected from the near-surface geology and where zones of concern may be located.

Contents

Appendices

Figures

Tables

Plates

Conversion Factors

Multiply	By	To obtain
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)

Geophysical Characterization of the American River Levees, Sacramento, California with Electromagnetics, Capacitively Coupled Resistivity, and DC Resistivity

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1.0 Introduction

Levees along the American River are situated on complex assemblages of clay, sand, and gravel. Of particular concern are sand deposits that are locally tens of feet thick. These deposits are susceptible to preferential scour during high-water events. As such, it is important to know their distribution near levees along the American River. This report discusses a geophysical survey that was designed to detect these contrasting materials and to map their distribution along a segment of the American River in Sacramento, California.

1.1 Purpose and Scope

The purpose of this geophysical investigation was to improve the understanding of geologic conditions along a six-mile-long stretch of the American River between Rio Americano High School and the Campus Commons Golf Course just downstream from the H Street Bridge near California State University, Sacramento (CSUS). These locations are shown in figure 1.

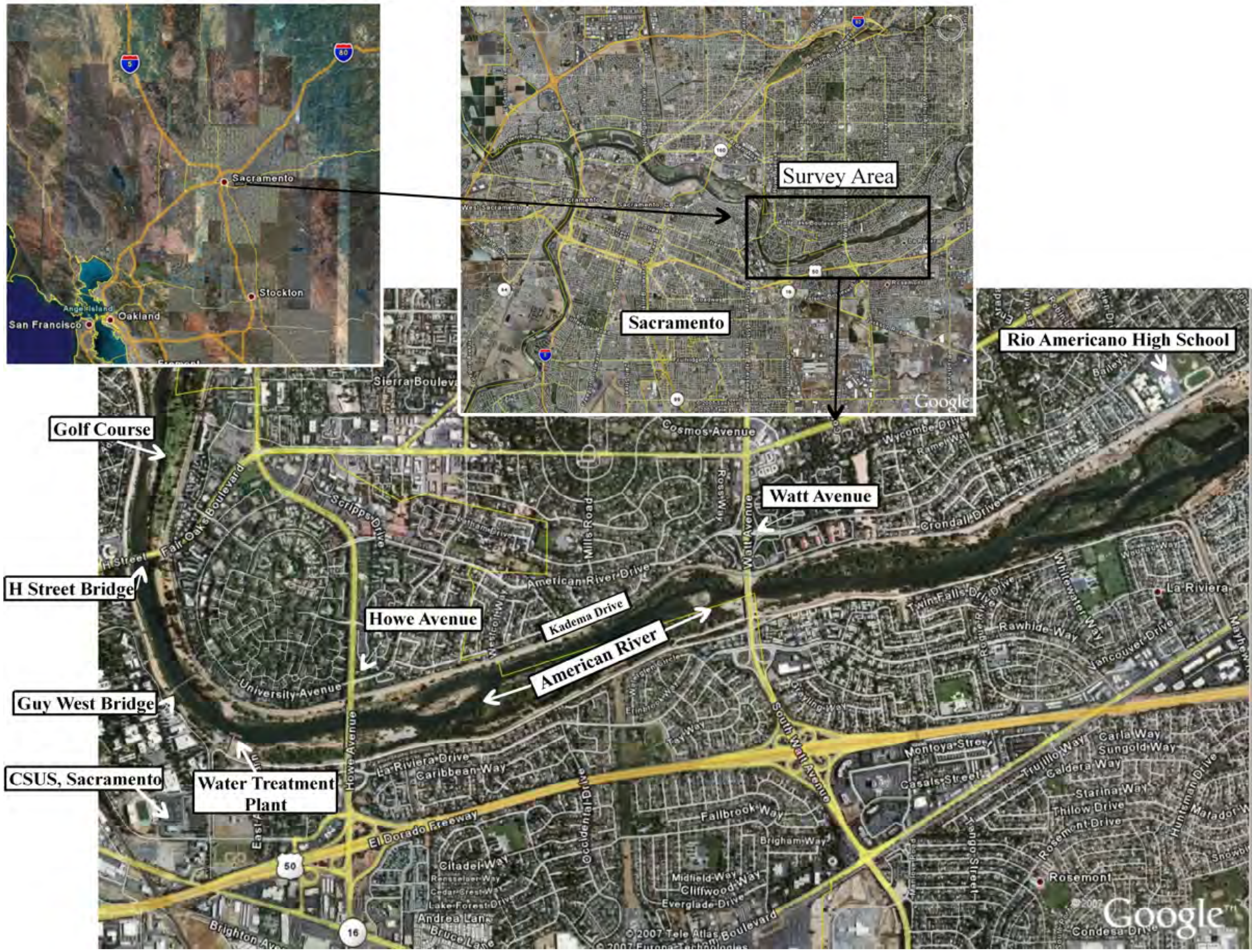

Figure 1. Location of the American River Levee surveys

The scope of this geophysical characterization is detailed in the Scope of Service in appendix A. This project included mapping the distribution and thickness of sand lenses that are underlain by a clay substrate between the levee and the river.

A phased approach using multiple and complementary geophysical techniques including capacitively coupled resistivity, frequency-domain electromagnetics (FDEM), and direct current (DC) resistivity was used in this investigation. The primary objective was to collect three transects where enough access was available, using the capacitively coupled and FDEM systems along the toe of the levee, between the toe of the levee and the river, and near the river shore. Five anomalous zones indicative of sand deposits were then investigated in detail using DC resistivity.

2.0 USGS Geophysical Investigation

2.1 Crew and Schedule of Survey Data Acquisition Activities

The USGS geophysical surveys along the American River began on May 15, 2007, and were completed on May 25, 2007. Table 1 provides a listing of the survey activities that were performed by USGS scientists.

Table 1. USGS American River Levee geophysical survey schedule

SURVEY	START DATE	FINISH DATE
OhmMapper Resistivity	05/15/07	05/22/07
GEM-2 FDEM	05/15/07	05/25/07
SuperSting DC Resistivity	05/20/07	05/24/07

2.2 Capacitively Coupled (OhmMapper) Resistivity Survey

Geometric's OhmMapper (OM in pl. 2) is a capacitively coupled resistivity system designed to measure subsurface resistivity in areas with high surface electrical resistivity, where exploration using traditional galvanically coupled resistivity systems is impractical (Geometrics, 2004). In galvanically coupled resistivity systems, electrical current is transferred into the ground from metal electrodes that are in direct contact with the wet soils in the subsurface. In capacitively coupled resistivity systems, electrical current is produced in the ground because of a capacitively coupled alternating current source operating at about 16,500 Hz.

The OhmMapper consists of an ungrounded (i.e., no electrodes pounded into the ground) dipole transmitter and receiver. The operating principle is relatively simple: an alternating current (AC) is capacitively coupled into the earth at a particular operating frequency by a transmitting dipole. The measured AC voltage coupled to the receiver's dipole is proportional to the resistivity of the ground between the dipoles. The transmitter and receiver are deployed in an in-line, axial dipole-dipole configuration (see figures C-1 and C-2 in appendix C) and are separated by an integer number of dipole lengths (2 or 4, for example). In this investigation the dipoles were 5 m and 10 m in length. As with a DC resistivity survey, an apparent resistivity is calculated by multiplying the appropriate geometric factor by the OhmMapper's received voltage, normalized by the transmitter current. The OhmMapper is pulled along the ground as a streamer by an ATV (figures C-1 through C-4) or is pulled by hand to collect nearly continuous apparent resistivity data. The depth of investigation for the OhmMapper in this survey was about 12 m (~40 ft).

The OhmMapper survey traverses are shown on plate 1 in various colors depicting thirteen different acquisition events and are also listed in table 2.

Table 2. OhmMapper survey traverse locations

Traverse Number	Location	Traverse Length (ft)
1	Along levee toe road from H Street Bridge towards Guy West Bridge	~1950
2A	Along levee toe road from H Street Bridge to Howe Ave	~3350
2B	Start at downstream end of the golf course on levee toe road and proceed to H Street Bridge. At H Street Bridge switch to bicycle path and end traverse at Howe Avenue	~8350
3	Begin on horse trail west of the water treatment plant and end at Howe Ave	~2250
4	Western (river) side of golf course	~2575
5	Eastern (away from river, closer to levee) side of golf course	~2475
6	Along horse trail just downstream (west) from Watt Avenue	~3425
7	Along levee toe road from Howe Avenue to Watt Avenue	~8175
8	Along gravel path just upstream (east) of Watt Avenue	~1625
9	Along gravel path further upstream (east) from Watt Avenue	~1575
10	Along bicycle path from Howe Ave to Watt Ave	~8375
11	Horse trail just upstream (east) of Watt Avenue	~1675
12	Along bicycle path and levee toe road upstream (east) of Watt Avenue	~7800
13	Along bicycle path between traverses 8 and 9	~1300

Georeferenced locations of all the geophysical data acquired in this investigation were recorded with a Leica GPS1200 global positioning system (GPS), shown in figures C-11 through C-13. Two roving receivers linked by a cell phone modem radio with a commercially available fixed Leica base station transmitter were used so that multiple geophysical surveys with the different instruments could be conducted at the same time.

Prior to two-dimensional (2-D) inversion, each of the OhmMapper data files were pre-processed with two USGS in-house programs specifically designed to process OhmMapper data. The GPS-PathTool program allows for editing of bad GPS data points recorded in the OhmMapper data files and interpolation through missing or bad data locations. The output of the GPS-PathTool program is then input to the OhmBin program, which performs data editing, binning, and averaging.

The output of the OhmBin program is then input in to Advanced Geosciences, Inc., EarthImager 2D inversion program (AGI, 2007). Parameters used in the inversion of the OhmMapper data are listed in table 3.

Table 3. Summary of OhmMapper and DC resistivity inversion parameters used in EarthImager 2D inversion program.

OhmMapper & DC INVERSION PARAMETERS	
Mesh thickness incremental factor	1.1
Depth factor	1.1
Min number mesh cells between electrodes	2
Min voltage accepted (mV)	0.2
Min abs (V/I) accepted (Ω)	0.0005
Max repeat error accepted (%)	3
Min apparent resistivity accepted (Ω-m)	1
Max apparent resistivity accepted (Ω-m)	10000
Inversion method	Robust
Max number of iterations	8
Max RMS model error (%)(Stopping Parameter)	3
Starting model (Ω-m)	Average Resistivity of Data
Min output resistivity (Ω-m)	10
Max output resistivity (Ω-m)	1000
Horiz./Vert. Roughness Ratio	0.5
Stabilizing factor (Lagrange multiplier)	100
Damping factor	100
Model parameter width (horiz. smoothing)	1
Model parameter height (vert. smoothing)	1
Resolution factor (rough conditioner)	0.2
Robust data conditioner (ε_D)	1
Robust model conditioner (ε_M)	1

During inversion of each section of edited OhmMapper data, the sections are subdivided into smaller intervals and then spliced together at the end of the inversion. Each of the individual inversion subsets for the thirteen acquired OhmMapper sections is included in appendix B.

The final inverted OhmMapper data sections are displayed on plates 2 and 3. Plate 2 is a 3-dimensional (3-D) map view of the inversion results showing their location along the river. Plate 3 is a detailed sectional view of the OhmMapper data. Locations of potential sand deposits are shown in blue colors and the underlying substrate clay units are indicated in orange to red colors. This color assignment is based on observations in the field by the survey crew of the near-surface material (sand) just downstream of Watt Avenue along DC Section 3.

An examination of the OhmMapper inversion results beginning from the downstream end of the investigation near the golf course and progressing upstream towards Rio Americano High School (plate 3 from top to bottom) shows:

1) The near surface under the Campus Commons Golf Course is predominantly sand up to 60 feet thick near the river (plate 3, panel A, Section 4) and a mixture of sand (up to 40 feet thick) and clay (mineralogical – not grain size) away from the river (Section 5).
2) The near surface along the levee toe road (panel A, Section 2B) from the golf course past the H Street Bridge contains mostly clay with some pockets of sand (up to 10 feet thick).
3) Between the H Street Bridge and the Howe Avenue Bridge overpass, the levee toe road (panel A, Section 1 and Section 2A) overlies mostly clay with some sand lenses up to 20 feet thick. However, the near surface under the bicycle path, which is closer to the river, from the H Street Bridge to Howe Avenue is underlain by sand (up to 50 feet thick near traverse distance 4,700 ft on Section 2B) interspersed with some shallow clay zones.
4) The near surface under the horse trail (closest to the river) between the water treatment plant and Howe Avenue (panel A, Section 3) is mostly sand up to 50 feet thick.
5) The levee road between Howe Avenue and Watt Avenue (panel B, Section 7) overlies mostly clay until it approaches Watt Avenue (traverse distance 6,400 feet).
6) However, along the bicycle path between Howe Avenue and Watt Avenue (panel B, Section 10) there are indications of two large, subsurface sand lenses. One sand

lens begins at Howe Avenue and continues until approximately traverse distance 1,200 feet. The second begins at traverse distance 6,400 feet and continues to the end of the traverse at Watt Avenue. There is a third sand lens with variable thickness (10 to 30 feet) between 4,100 to 6,000 feet along the traverse.

7) There are sand lenses of variable thickness (10 to 60 feet) along the horse trail (closest to the river) just west of Watt Avenue (panel B, Section 6), which is consistent with the results at the upstream ends of Sections 7 and 10.
8) The near surface along the bicycle path and levee toe road upstream from Watt Avenue (panel C, Section 12) consists primarily of clay zones with interspersed sand lenses of variable thickness (5 to 40 feet).
9) However, closer to the river along the horse trails, bicycle, and gravel paths (panel C, Sections 8, 9, 11, and 13), much more sand is present in variable thicknesses (20 to 60 feet).

2.3 Frequency Domain Electromagnetic (GEM-2) Survey

The Geophex GEM-2 (Geophex, 2004) consists of a transmitter coil and a coplanar receiver coil set about 5.5 ft away on a fiberglass ski (figures C-5 and C-6). The GEM-2 simultaneously transmits up to ten user-selected frequencies between 300 Hz and 48 kHz, and the receiving coil measures the induced secondary fields. In low-conductivity soils (such as dry sands) the lower-frequency electromagnetic (EM) fields penetrate several meters into the subsurface, while at higher frequencies the instrument investigates shallower depths. The system operates by transmitting a composite waveform of electromagnetic energy into the ground. The advantage of the GEM-2 over either the OhmMapper or the SuperSting is that its ski design, held by a shoulder strap, provides greater flexibility for investigating anomalies in dense vegetation and often allows more rapid data acquisition. A disadvantage is its lower resolution compared to the other systems. GEM-2 data were acquired over most of the traverse lines as the OhmMapper data (plate 1). Although the depth of investigation for the GEM-2 in this survey cannot be determined precisely, it is estimated that the GEM-2 sampled between 2 to 10 m (~6 to 30 feet) depths. As with the OhmMapper, GEM-2 data positions were located with a Leica GPS1200 GPS.

The GEM-2 survey results are presented in plates 4-9. Five frequencies were used in this investigation: 44 kHz, 36 kHz, 29 kHz, 20 kHz, and 10 kHz. Plate 4 is a stacked composite representation of the data for these five frequencies. The highest frequency data (shallowest depth of investigation) are at the top, and the lowest frequency data (deepest depth of investigation) are at the bottom. Plates 5-9 present the individual data maps for each of the frequencies shown in plate 4. The color scale ranges from 50 to 1,000 ohm-m.

The GEM-2 results presented in plates 4-9 are somewhat consistent with the OhmMapper results in plates 2-3. As with the OhmMapper, blue colors in the maps are interpreted to represent predominantly sand units and red colors show the underlying clay units. The GEM-2 data exhibit a clear progression from sand to clay in the area just downstream of Watt Avenue in the vicinity of DC Line 3, with a change in color with decreasing frequency. The 44-kHz data (plate 5) begins the progression with an indication of sand (large blue area) and then, as lower frequencies are used (plate 6), the color changes from blue through greens (plate 8) and toward yellow and orange (plate 9), which is an indication of the electrically conductive clay substrate at depth. Similar progressions from sand to clay (blue to red/orange colors) are located elsewhere, including beneath the golf course near the river at the downstream end of the survey, just upstream from Howe Avenue, the area already noted just downstream from Watt Ave, and the area near DC Section 4.

2.3.1 GEM-2 Inversion

Many attempts were made to invert the GEM-2 data and create conductivity-depth images. Industry-standard programs including EM1DFM (UBC, 2000) and EMIGMA (PetRos Eikon, 2006) were used extensively. However, none of the inversions were successful. This is primarily because of the physics of the problem – i.e., a low induction number in a noisy environment. This phenomenon is discussed in detail in Huang and others (2008) and is summarized below.

Electrically resistive ground, a small separation distance between the EM transmitter and receiver, and a band-limited frequency range can result in the GEM-2 operating in what is called the “low induction number” range. Within this low induction number range, the sensor response is linearly dependent on frequency and not on variations in the ground resistivity. The result of this is that electrically conductive and resistive anomalies can be detected and then located, but conductivity depth images (i.e., thicknesses of anomalous zones) cannot be developed by numerical inversion.

A smaller EM sensor set (transmitter/receiver combination) may be used as a tool for determining depth of anomalies in electrically conductive areas where frequency-dependent EM data can be reliably obtained because of the higher induction number, $\theta=(\omega\sigma\mu/2)^{1/2}s$, where ω is the angular frequency, σ is the conductivity, μ is the magnetic permeability and s is the coil separation. However, the small coil separation in the GEM-2, coupled with a limited operational frequency bandwidth, results in a low induction number response on electrically resistive terrain, where a given bandwidth may not produce sufficient frequency dependence for determining depths to targets.

The low induction number range for a half-space is defined as $\theta \leq 0.02$ (Spies and Frischknecht, 1991). For the GEM-2 geometry assuming non magnetic ground, a low induction number corresponds to a σf *(conductivity*frequency)* product of less than about 36. The EM response in this range is small (with the EM in-phase component being significantly smaller than the quadrature component), so that resistivity changes at a given investigation frequency may not produce large enough variations in the measured data. Also, the observed response of the GEM-2 at multiple investigation frequencies will be almost linearly correlated and so will depend on the measured frequency and not on the electrical resistivity of the ground. Furthermore, the low degree of EM signal attenuation observed over resistive ground results in large skin depths that exceed practical depths of exploration. All the resistivity depth variations would be lumped into a single equivalent layer. Thus, no additional information is gained by employing multiple frequencies during the investigation.

The data listed in table 3 are the calculated standard deviations of the EM noise observed in the GEM-2 data acquired at one of the two GEM-2 calibration sites that were located along the survey traverse (pl. 5). The In-Phase values are all greater than 1,000 ppm (parts per million), and the Quadrature data are well over 100 ppm. A low EM-noise environment would be characterized by In-Phase values in the range of 20 to 30 ppm and Quadrature values in the range of 7 to 14 ppm. The data in table 4 show that the electromagnetic environment along the sections of the American River levees that were investigated is quite noisy.

Table 4. Standard deviation of observed noise values at one GEM-2 calibration site.

Frequency (Hz)	In-phase/Quadrature Noise (ppm)
10 650	1002.99/153.98
20 190	1038.95/138.55
29 190	1055.38/125.42
36 570	1060.58/119.60
44 910	1065.01/111.82

This is further illustrated by the data presented in plate 10. The GEM-2 has the ability of monitoring and recording the ambient electromagnetic noise caused by 60-Hz power lines. Plate

10 shows the noise recorded along the GEM-2 traverses. The red colors show areas of higher noise, and the blue colors show areas of lower noise. High electromagnetic noise was observed near the golf course and continued upstream to a location directly across from the water treatment plant (fig. 1). This noise is possibly caused by some form of electromagnetic protection of the pipe running under the levee toe road that crosses the river at the treatment plant.

Other areas with high electromagnetic noise are under the power lines just upstream from Howe Avenue and in the vicinity of Kadema Drive, about halfway between Watt and Howe Avenues (fig. 1).

At higher induction numbers the potential EM signal level would be high, and changes in the electrical resistivity of the ground would result in large changes in the measured GEM-2 data. The depth of exploration at the different investigation frequencies would also vary.

Thus, because (a) the GEM-2 data had very low EM signal levels (on the order of 150 to 300 ppm in the Quadrature) over the resistive dry sand zones that were the target of this investigation; (b) the ambient electromagnetic noise in the investigation areas was quite high (over 112 to 154 ppm in the Quadrature); and (c) the GEM-2 had data tears or jumps on the order of 100 to 200 ppm when it was started or restarted at the beginning and end of lines and during calibration measurements, the GEM-2 system response could not be properly calibrated using the DC and OhmMapper resistivity data following the procedure outlined in Abraham and others (2006). Note that whereas the GEM-2 data acquired at the sites discussed in Abraham and others (2006) had similar tears and jumps (~200 ppm Quadrature) as observed in our survey, their survey was over conductive targets (high induction numbers), and the acquired data signal levels were on the order of 3,000 to 3,500 ppm in the Quadrature. Consequently, a data tear of 200 ppm did not have as much of an effect on their interpretation process.

2.4 DC Resistivity (SuperSting) Survey

DC resistivity data for this American River levee survey were acquired with an Inverse Schlumberger array using 100 electrodes per initial data acquisition run. Stainless steel electrodes were set in straight lines and were separated by no more than about 5 feet (1 to 1.5 meters) as listed in table 5 (figures C-7 and C-8). Each electrode was watered with a dilute saline solution in order to reduce the electrical contact resistance with the ground. For a single apparent resistivity measurement, the SuperSting console (AGI, 2003), shown in figures C-9 and C-10, simultaneously measures voltages from electrodes spaced evenly on either side of a central measurement point. Two inner electrodes transmit current into the earth, and two outer electrodes measure the electrical potential difference in the earth. The instrument sequentially switches the transmitter and receiver electrodes along the survey line following instructions in a user-defined command file. When the equipment finished collecting data from the given setup of 100 electrodes, a section of 20 electrodes was moved from the beginning of the line to the end. This “roll-along” technique extended the data coverage and allowed for the collection of very long profiles without sacrificing resolution.

Table 5. Summary of DC resistivity acquisition parameters.

Line name	1	2A	2B	3	4
No. electrodes	100	100	100	100	100
Electrode spacing	1.5 m / 5 ft	1.5 m / 5 ft	1.5 m / 5 ft	1.5 m / 5 ft	3 m / 9.84 ft
Line length	240 m / 787 ft	100 m / 328 ft	100 m / 328 ft	210 m / 689 ft	100 m / 328 ft
No. roll-alongs	3	0	0	2	0
Array type	Inverse Schlumberger				
Measurement time (ms)	800				
Maximum input current (mA)	1000				

Each DC resistivity electrode location was georeferenced with the Leica GPS1200 system. Five DC resistivity profiles were acquired using the AGI SuperSting with an Inverse Schlumberger array, with the 100 available electrodes at various spacings. The acquisition parameters are summarized in table 5.

Processing of the DC resistivity consisted of editing out noisy and bad data followed by 2-D inversion using AGI's Earth Imager 2-D program. The inversion parameters are listed in table 3 and the models compiled in appendix C. The data were checked for abnormal outliers and a determination was made as to why the outliers exist. The data were then either retained or deleted from the interpretation process. The resistivity data were collated with the GPS station location and elevation data. The 2-D inversion process was monitored for unusual results caused by inclusion of bad data and for the inversion program's proclivity to include non-existent conductors that were solely used to reduce the statistical error. Field processing included preliminary 2-D inversions. Final deliverables include topographically-corrected 2-D inversions.

In total, approximately 750 meters (2,460 feet) of DC resistivity data were acquired along the levee of the river on parts of the same lines as the OhmMapper survey. The 2-D DC resistivity inversion results are shown on plates 2 and 3 in their approximate locations relative to the acquired OhmMapper data lines. Electrically conductive zones (clay) are shown by orange-red colors, and less conductive zones are shown by green to blue colors (dark blue representing resistive material such as the dry sand).

The inverted DC resistivity sections are internally consistent with the OhmMapper inversion results. SuperSting sections 2A and 2B are consistent with OhmMapper Section 3, and SuperSting Sections 1 (indicating clay) and 3 (indicating sand) are consistent with the results for the same positions along OhmMapper Section 7. SuperSting Section 4, located upstream from Watt Avenue, indicates a thick sand sequence (similar to OhmMapper Section 13).

3.0 Discussion and Conclusions

The goal of this USGS multi-tool investigation of a six-mile length of levee along the American River in Sacramento was to locate zones containing predominantly sand that may be eroded during winter- and spring-time flood events and also clay units that, in some locations, underlie the sand lenses. Each of the geophysical techniques utilized contributed to delineating these zones of interest.

Plate 11 (using the base map from Plate 5) presents an integrated interpretation of the geophysical data acquired in this investigation. The interpreted locations of areas consisting predominantly of sand and clay are shown. In general, along most of this part of the American River levee system, sand lenses are located closest to the river, and clay is located further from the river. The interpreted thicknesses of the sand deposits are variable, ranging from 10 feet up to 60 feet.

Six areas are also shown on Plate 11 as possible trench locations to improve the confidence in the interpretation presented here. These six locations (listed in table 6) were selected because they either sit on thick sand lenses or thick clay deposits or a mixture of both.

Table 6. Potential locations for ground-truth trenching of USGS investigation

Trench Number	Location
1	Thick sand deposit just downstream from Watt Avenue
2	Thick silt and clay deposit just upstream from Watt Avenue
3	Clay unit midway between Howe Avenue and Watt Avenue
4	Thick sand unit across from the water treatment plant
5	Thick clay unit with pockets of sand just downstream of the H Street Bridge
6	Thick sand unit on river side of golf course

Thus, despite issues with the GEM-2 inversion, this geophysical investigation successfully delineated sand lenses and clay deposits along the American River levee system and the approximate depths to underlying clay zones. The results of this geophysical investigation should help the USACE to maintain the current levee system while also assisting the designers and planners of levee enhancements with the knowledge of what is to be expected from the near-surface geology and where zones of concern may be located.

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