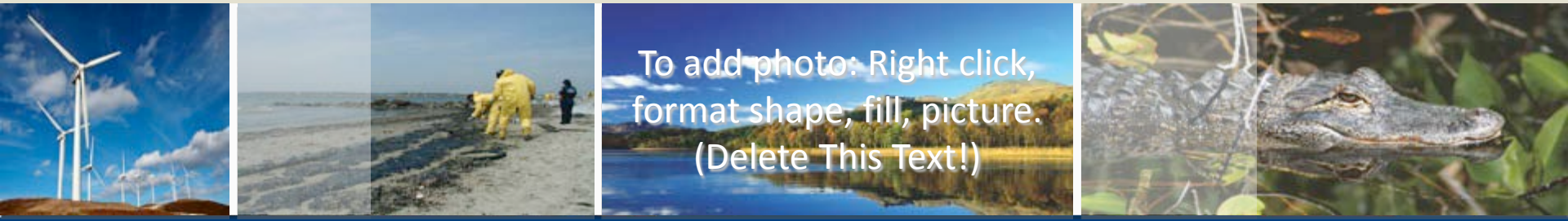
Cardno ENTRIX
Shaping the Future



People | Clients | Growth | Quality | Performance

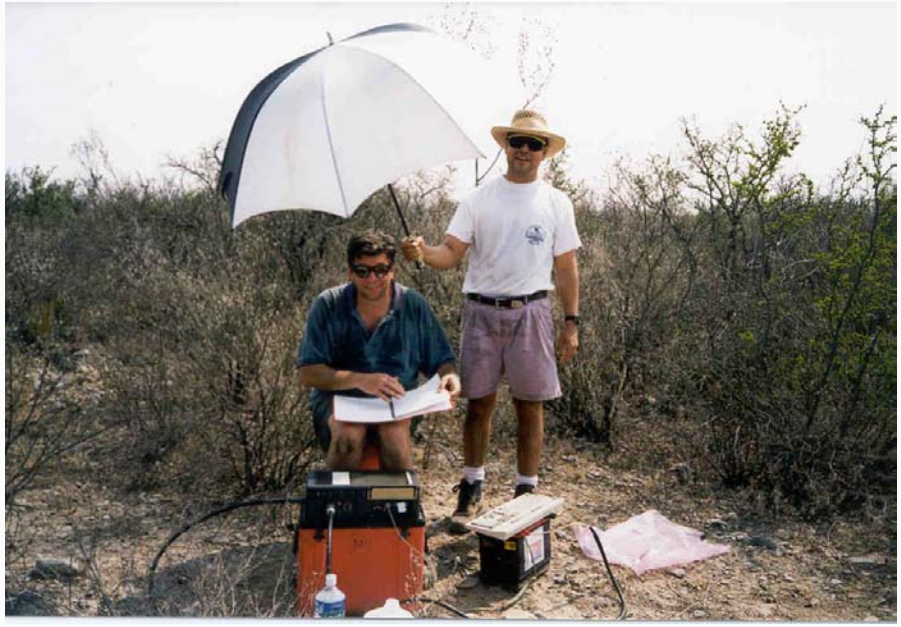
Geophysics for Ground Water Resource Investigations

or, How to find where you really want to drill.

John Jansen, Ph.D, R.Gp., P.G.

What is Geophysics?

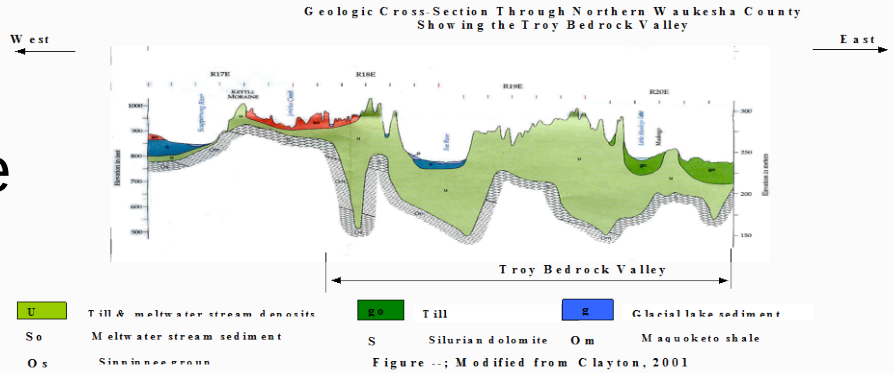
- Remote sensing of physical properties as a means to infer subsurface geology
- Surface and borehole methods
- A means to see through dirt



It is not proper to call it black magic.
We prefer the term *Mojo*!

Why bother?

- When sampling density inadequate to constrain the problem
- When the cost to get enough direct data is prohibitive
- When site access or site impact are important

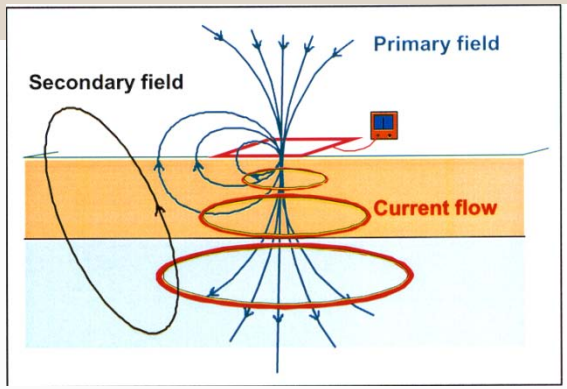


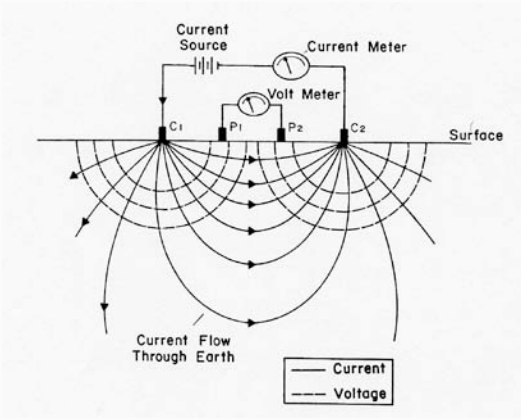
What can you expect to accomplish?

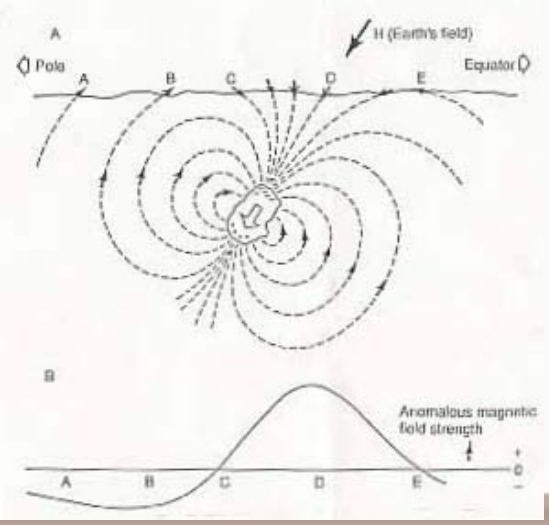
- Map significant hydrogeologic controls
  - ✓ Depth to bedrock
  - ✓ Saturated zone
  - ✓ Sand and gravel bodies
  - ✓ Confining units
  - ✓ Fracture zones
  - ✓ Faults
- Map changes in water quality at the 100s of ppm level
- Map anything else with a significant physical contrast
  - ✓ Density
  - ✓ Sound velocity
  - ✓ Electrical conductivity
  - ✓ Magnetic susceptibility
  - ✓ Dielectric constant
  - ✓ Hydrogen ion content
  - ✓ Almost any physical contrast

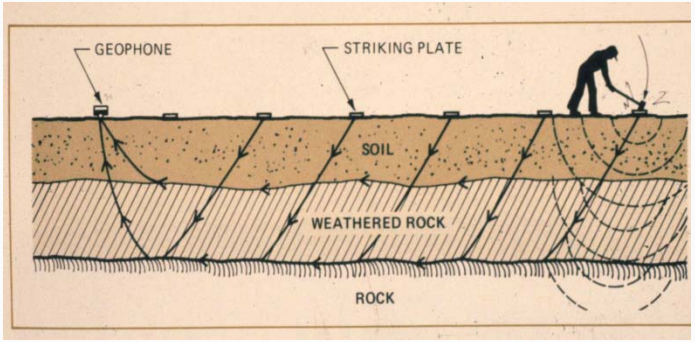
Common Geophysical Methods

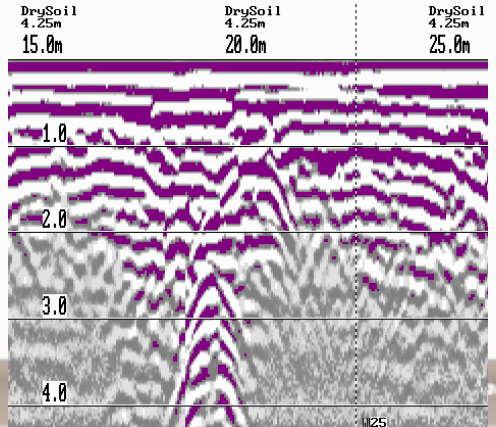
- Electromagnetics (EM)
- Seismic (Refraction or Reflection)
- Electrical Resistivity (ER)
- Magnetometry
- Gravity Surveys
- Ground Penetrating Radar (GPR)



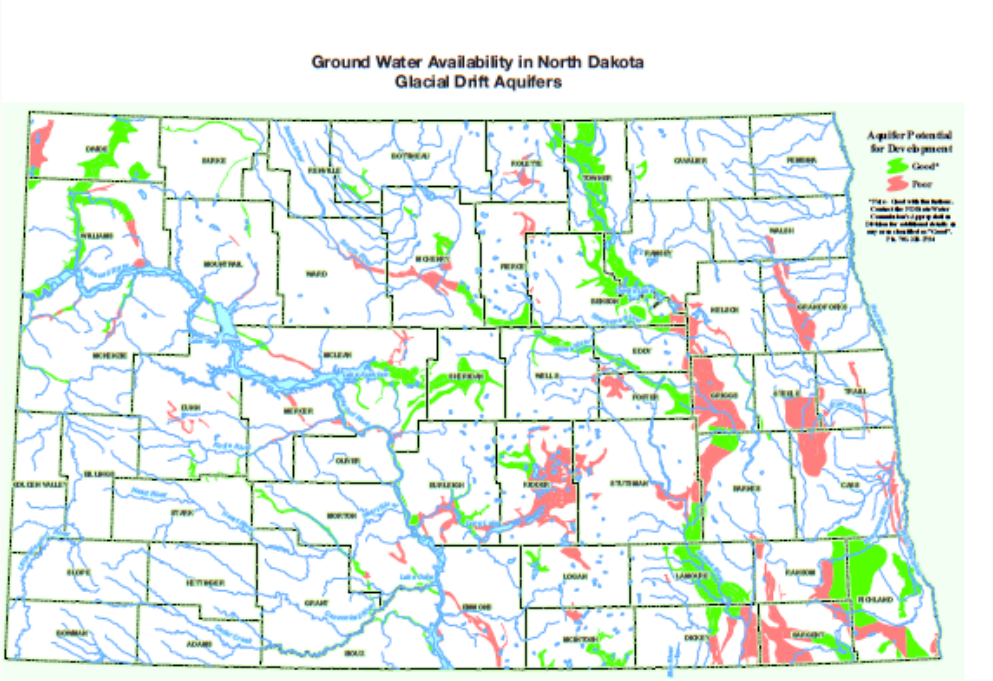








Glacial Aquifers of North Dakota



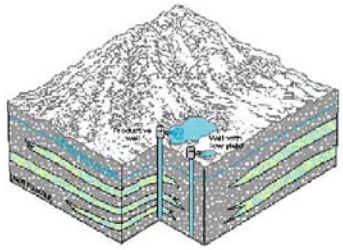
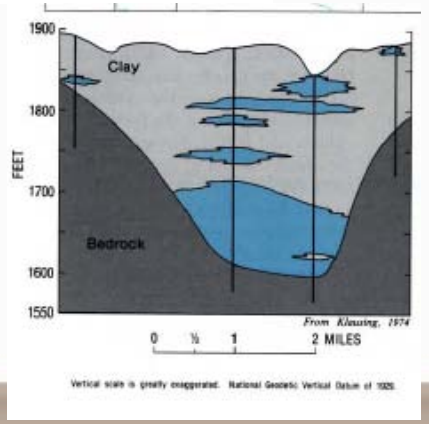


Figure 28. Discontinuous lenses of sand and gravel in deposits of till can be aquifers, especially if several lenses are penetrated by wells. Wells completed in till yield little or no water.

EXPLANATION

Sand and gravel

Till



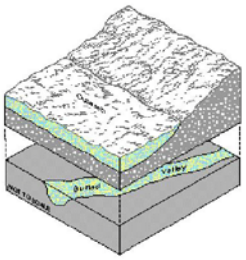


Figure 27. Sand and gravel aquifers in glacial outwash deposits can fill valleys incised into bedrock by preglacial erosion or the erosional action of the advancing ice. These buried valley deposits commonly are separated from overlying sheetlike, coarse-grained deposits of glacial outwash by low-permeability till.

EXPLANATION

Sand and gravel—Productive aquifer

Till—Confining unit

Bedrock—Can be either an aquifer or a confining unit

Bedrock Aquifers of North Dakota

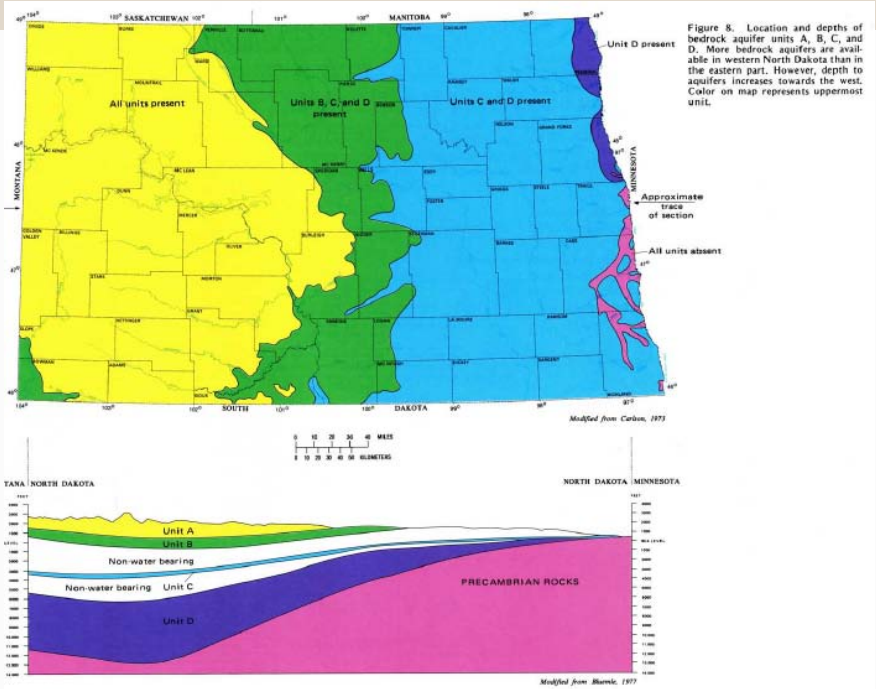


Figure 8. Location and depths of bedrock aquifer units A, B, C, and D. More bedrock aquifers are available in western North Dakota than in the eastern part. However, depth to aquifers increases towards the west. Color on map represents uppermost unit.

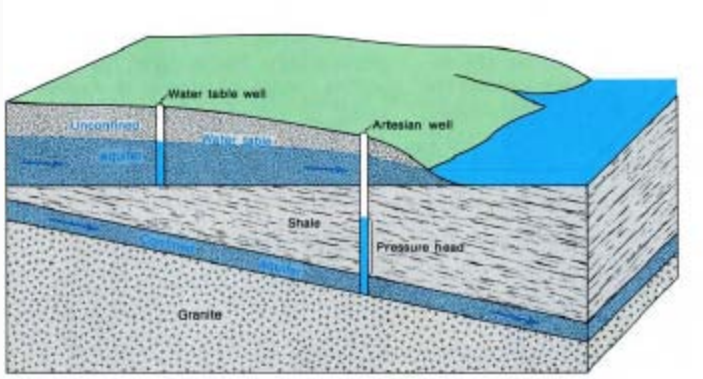


Figure 4. Confined and unconfined aquifers.

Figure 3. Bedrock exposures in western North Dakota. These rocks are part of the Fort Union Formation. Sandstone and lignite beds in this formation yield water to wells and springs throughout most of western North Dakota. Photograph by D. G. Emerson.

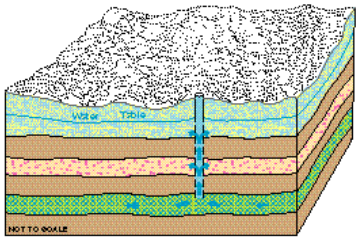


Figure 90. Uncased wells can provide conduits through which saline water in a deep aquifer with a high hydraulic head can move upward to contaminate shallower freshwater aquifers with smaller hydraulic heads.

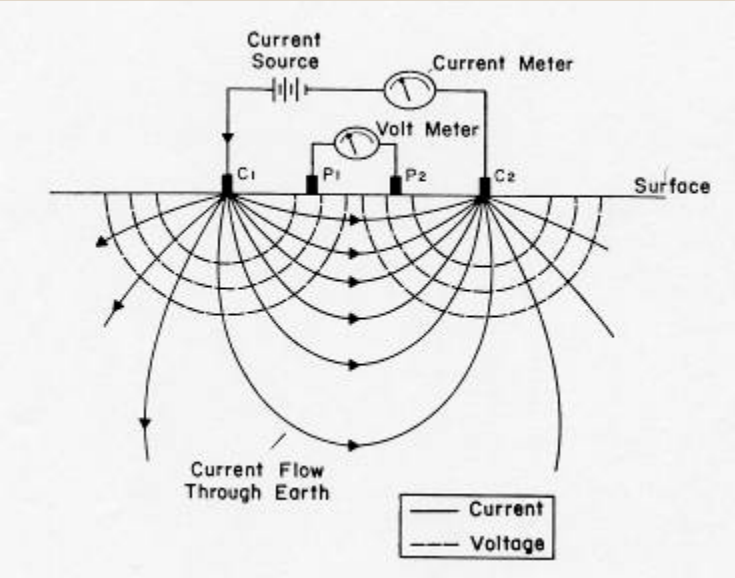
EXPLANATION

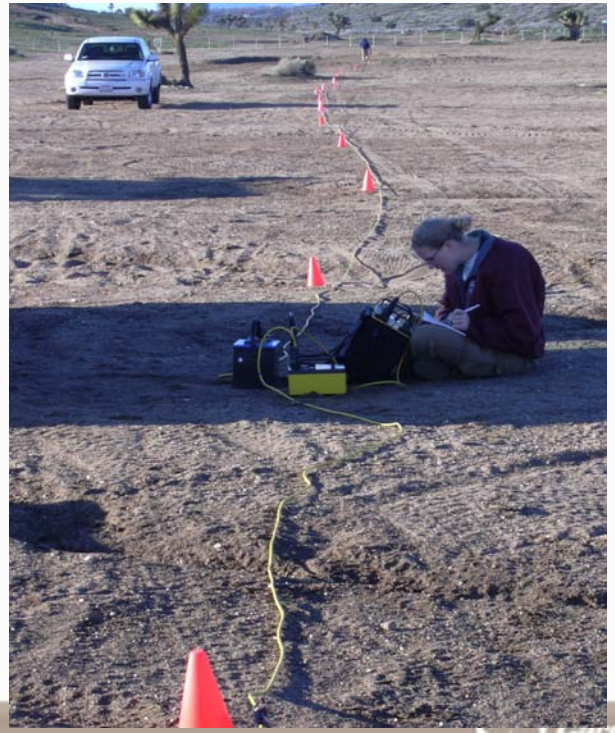
- **Aquifer A**—Water contains small concentrations of dissolved solids
- **Aquifer B**—Water contains small concentrations of dissolved solids
- **Aquifer C**—Water contains large concentrations of dissolved solids
- **Confining unit**
- **Direction of ground-water movement**
- **Uncased drillhole**

USGS Water Supply paper 2236

Electrical Resistivity (ER)

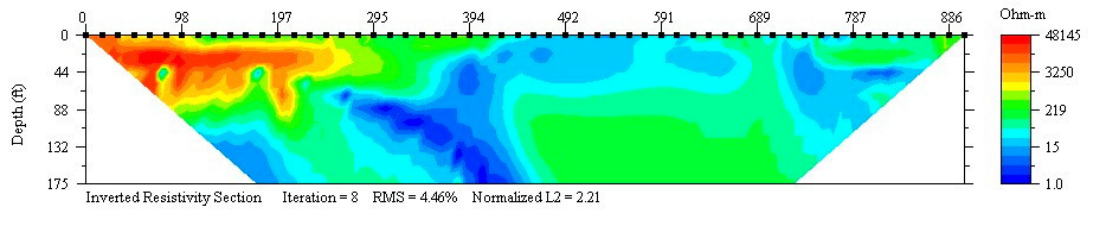
- Electrical Current is induced into the ground through two current electrodes.
- Voltage drop is measured across potential electrodes.
- Electrode array is expanded to increase depth of penetration.
- Depth of investigation about 1/3 spread length
- Resistivity of formation/fluids measured in ohm-meters.
- Modern systems use 42 to 112 (or more) electrodes with automated switching.





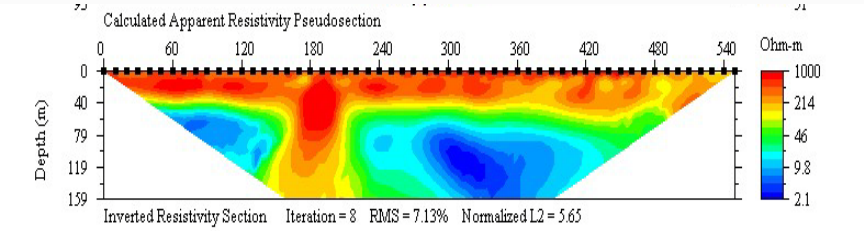
Resistivity line on Nevares Spring Mound, Death Valley National Park

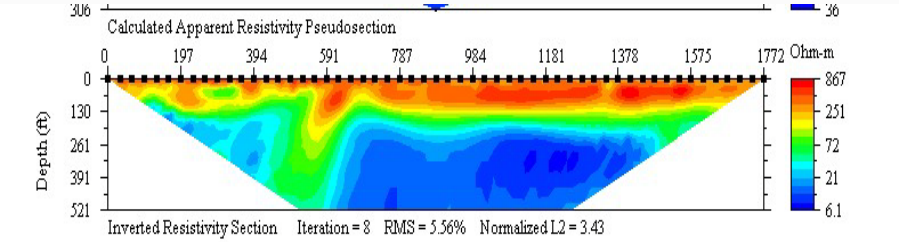
- 56 channel, 5 meter spacing (900 foot spread length)
- Shallow zone relatively conductive
- Mapped conductive feature related to spring mound

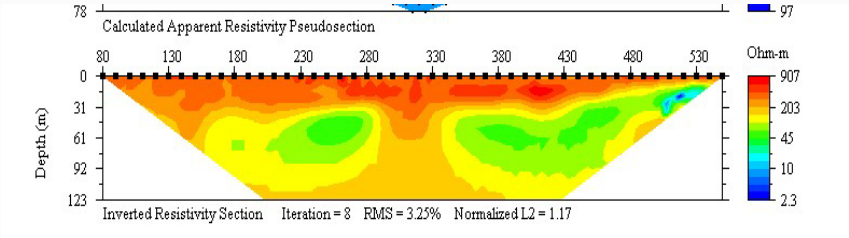


Mapping Faults, Depth to Water, and Grain Size

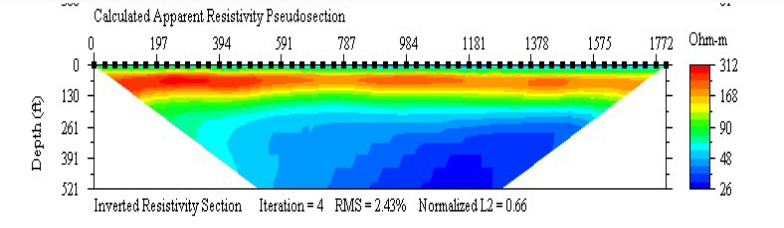
Faulted Lines

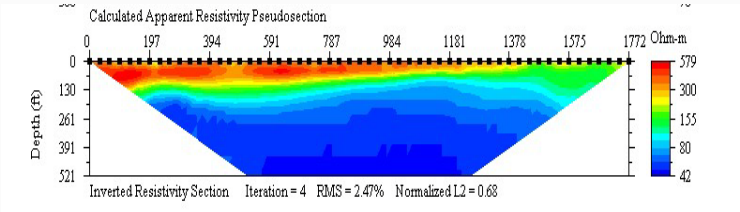






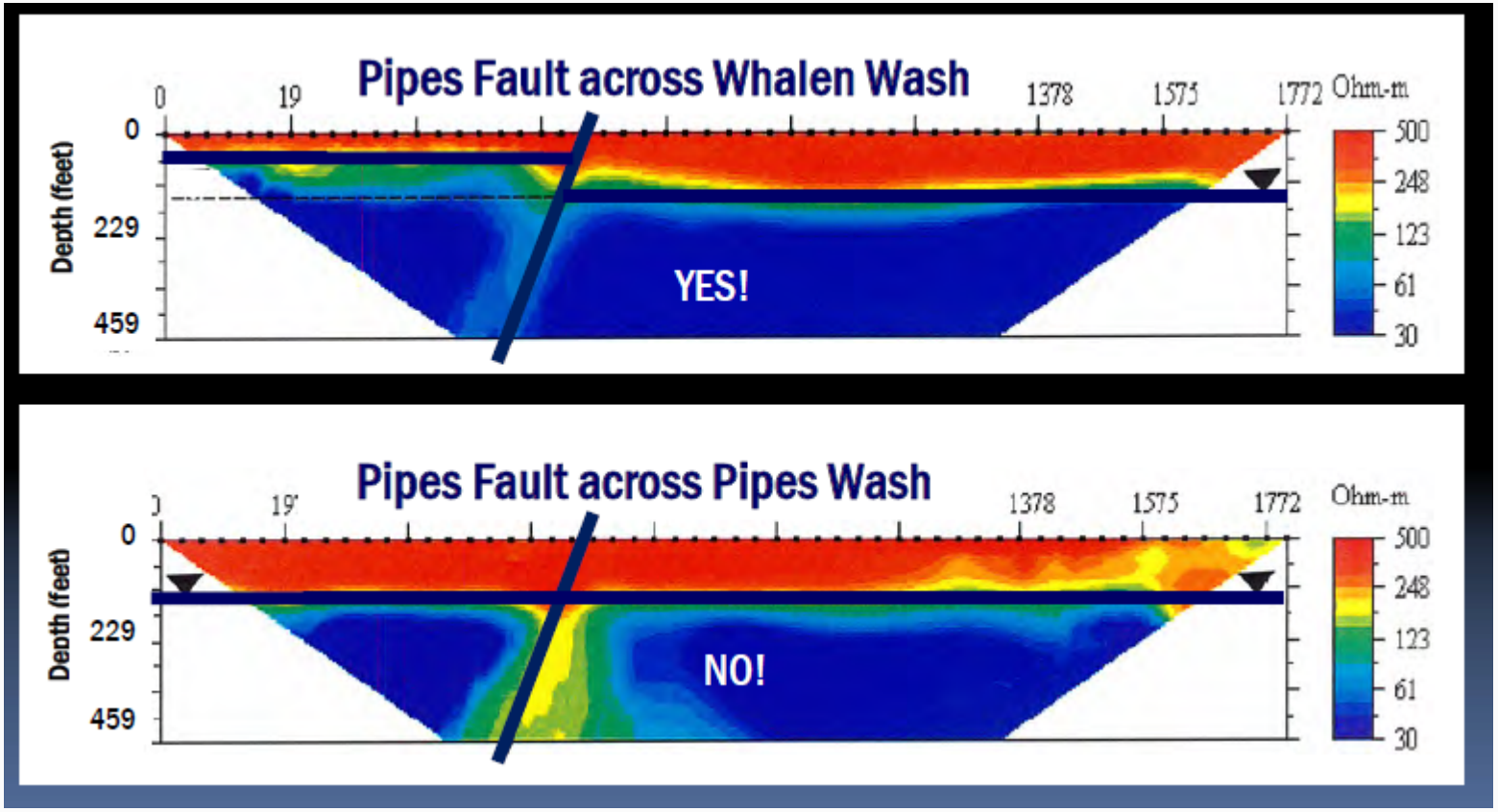
Non-faulted Lines





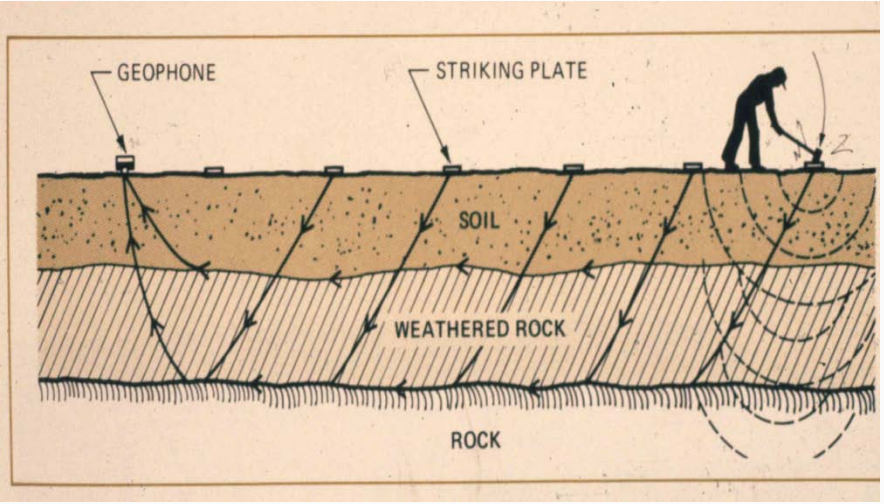
Mojave Water Agency, Ames/Means Valley, Yucca Valley, CA 2006 Survey

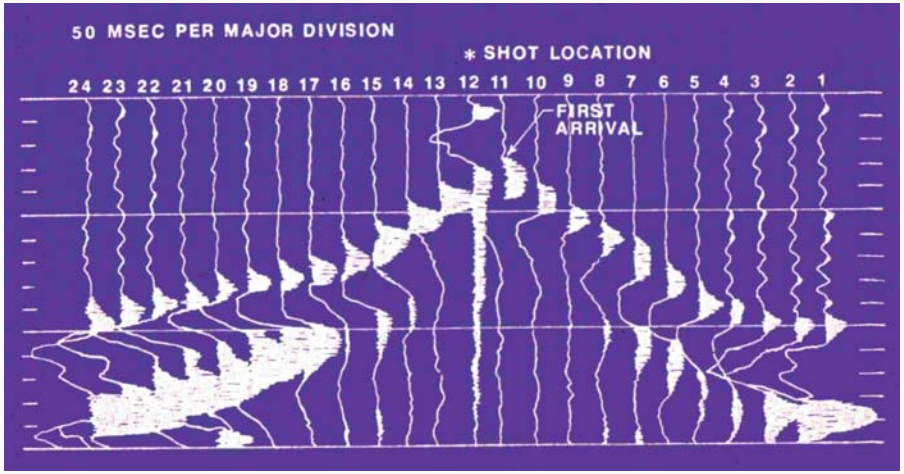
Offset on Water Table Indicated Some Faults Are Barriers



From Todd Engineers

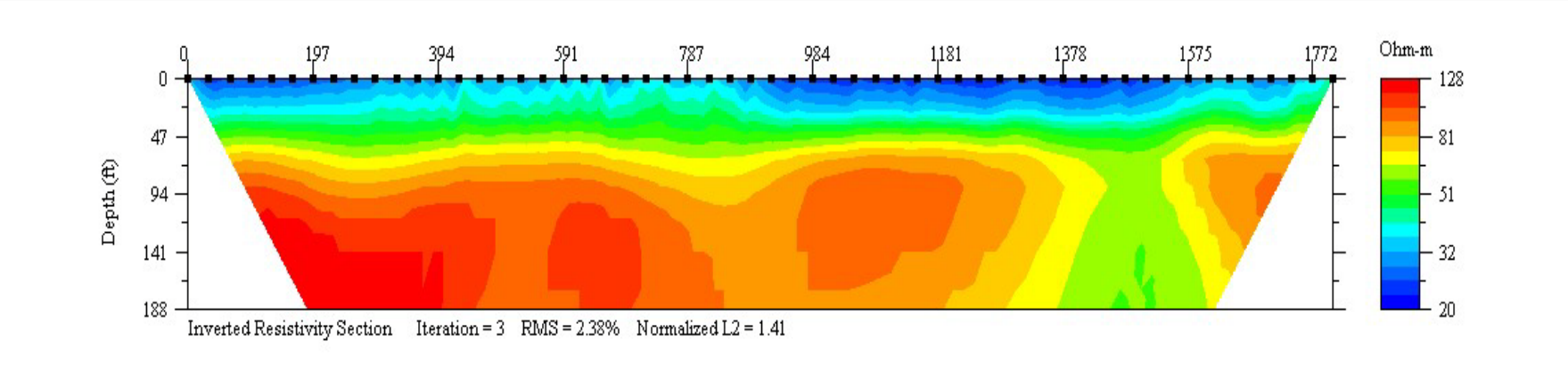
Refraction Theory

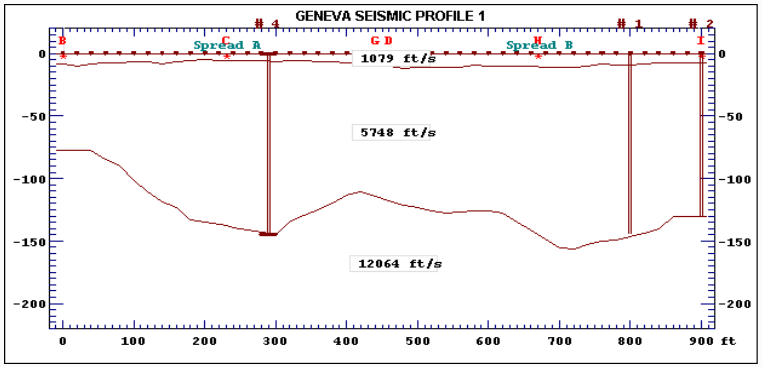




- **Measures seismic velocity of soil and rock.**
- **Function of soil & rock physical properties & density.**
- **Requires generation of sound wave into subsurface.**
- **The first arrival of the refracted wave is used for interpretation.**
- **Multiple shots are used to increase resolution and correct for dipping beds.**

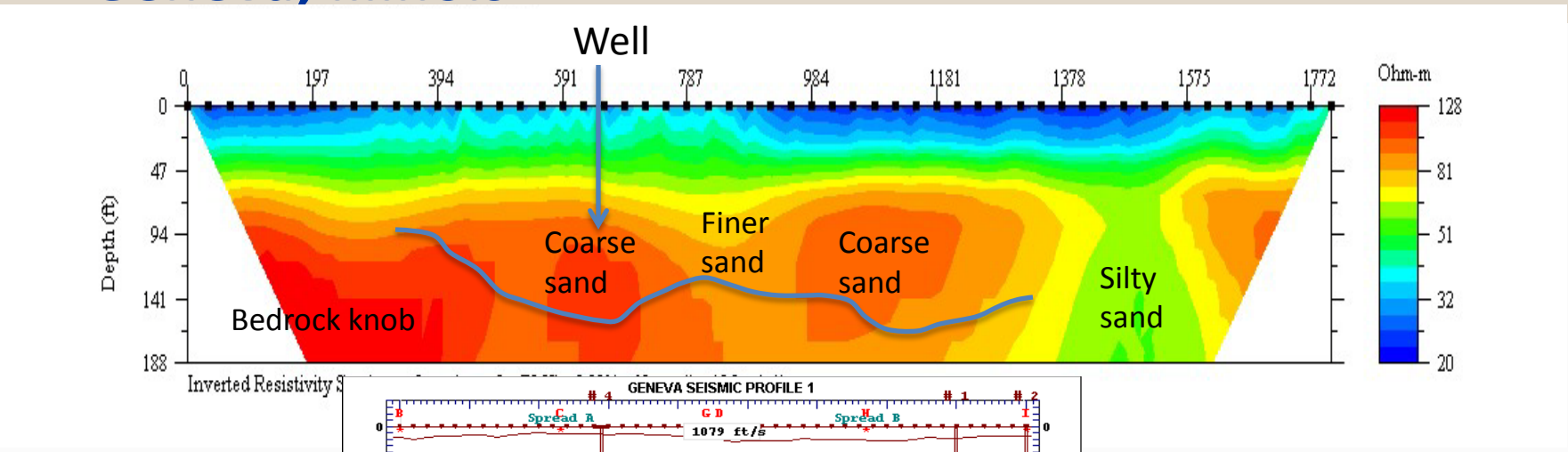
Geophysical Image of Bedrock Valley Aquifer, Geneva, IL



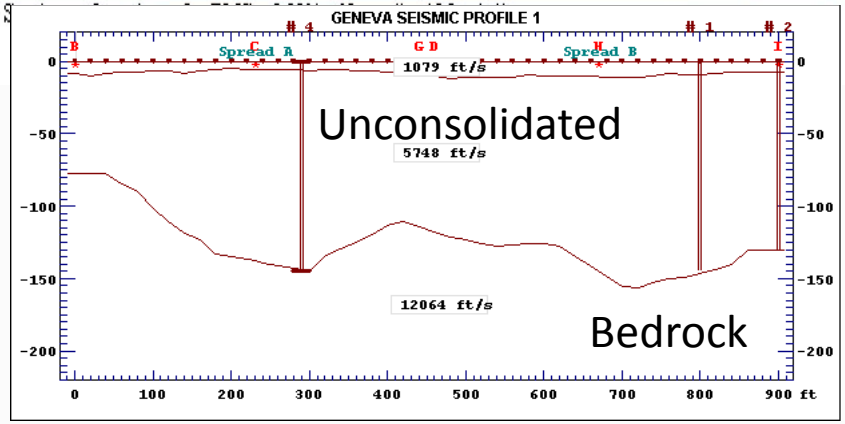


- Resistivity and refraction survey to site municipal well

Geophysical Image of Bedrock Valley Aquifer Geneva, Illinois



Refraction line

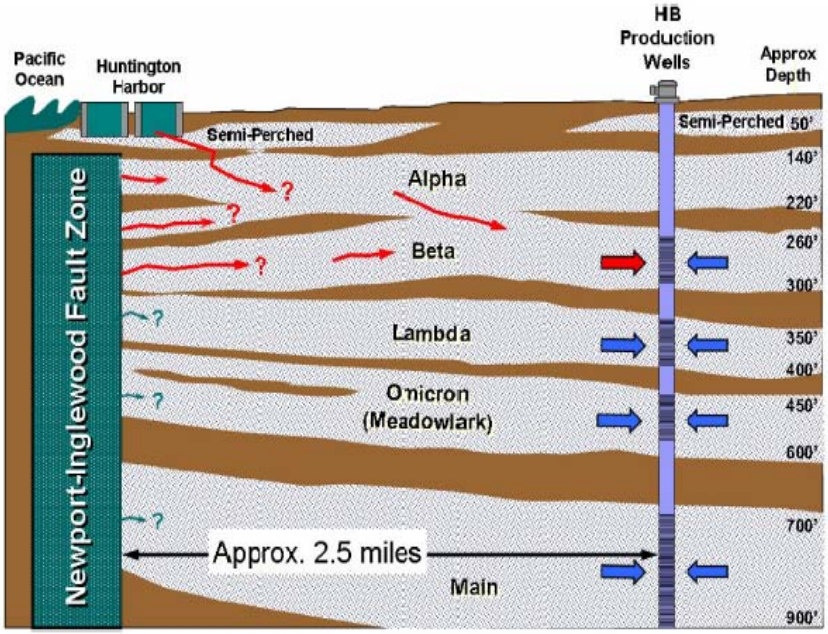


- Mapped two bedrock lows with sand bodies
- Drilled two test borings and one test well
- Well now on line at 1,400 gpm (one of the best in area)

Orange County California Saltwater Intrusion

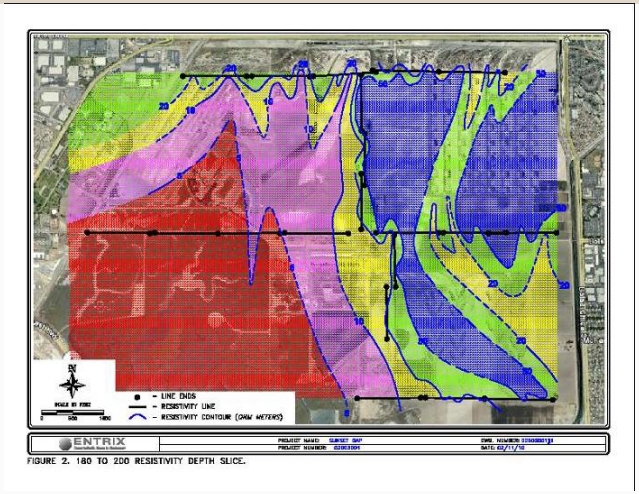
ENTRIX
PROJECT NAME: SUNSET GAP
PROJECT NUMBER: 02603001
DWG. NUMBER: 02603001132
DATE: 08/10/10

FIGURE 1. SUNSET GAP LOCATION MAP.

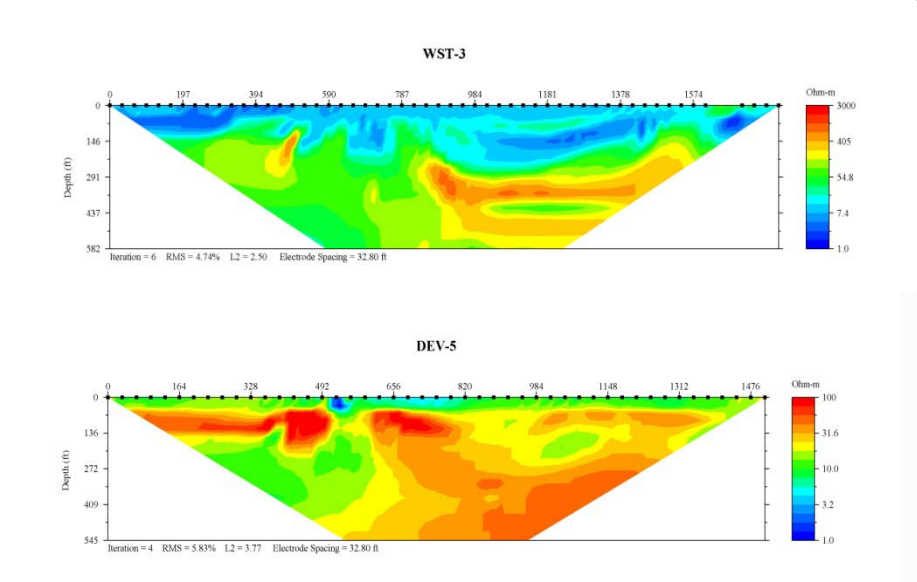


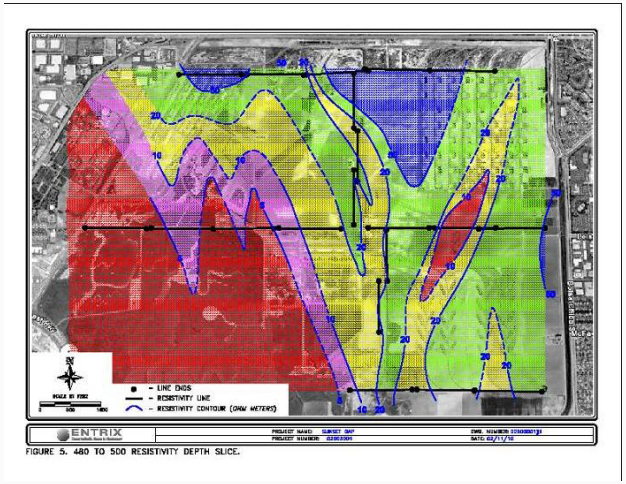
- Saltwater intrusion from pumping
- Intrusion in upper aquifers at gaps in coastal bedrock ridges
- Vertical migration through faults
- Limited access on Naval Base

Resistivity Survey Results



180 to 200 feet

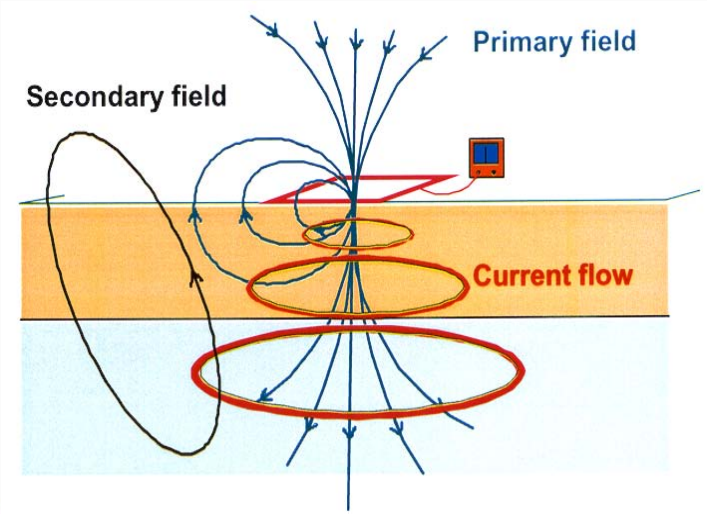




480 to 500 feet

- **Resistivity mapped saline plumes to 500 feet**
- **Mapped faults and breaches in confining units**
- **Mapped aquifers and confining units**

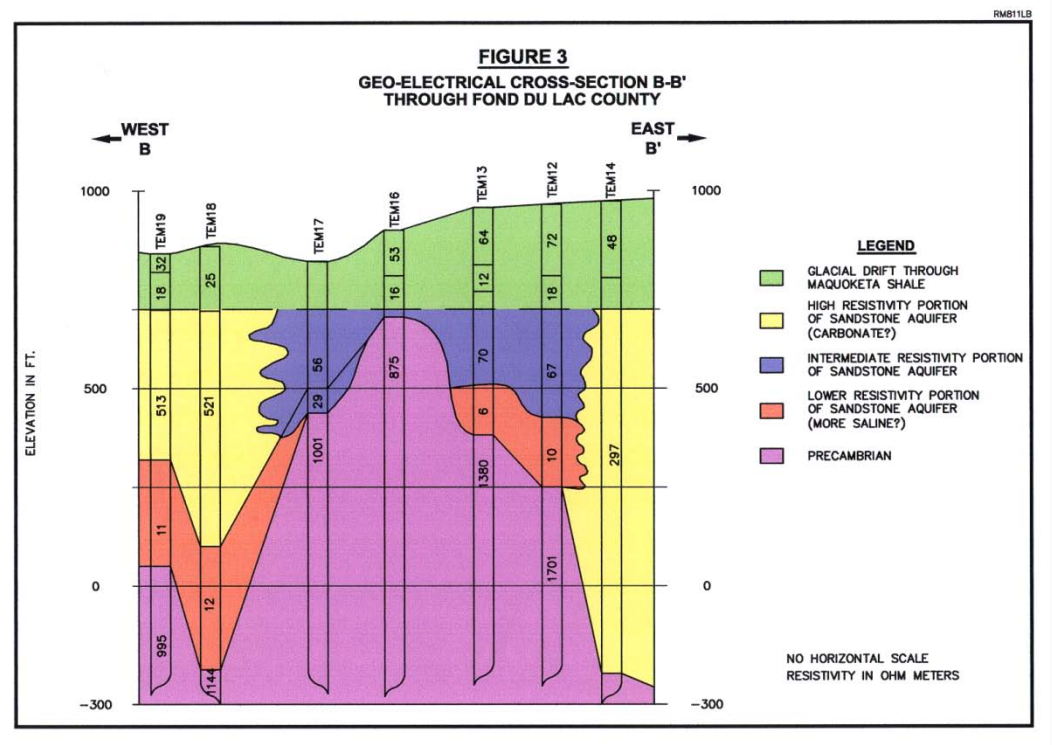
Physical Principles of TEM Soundings



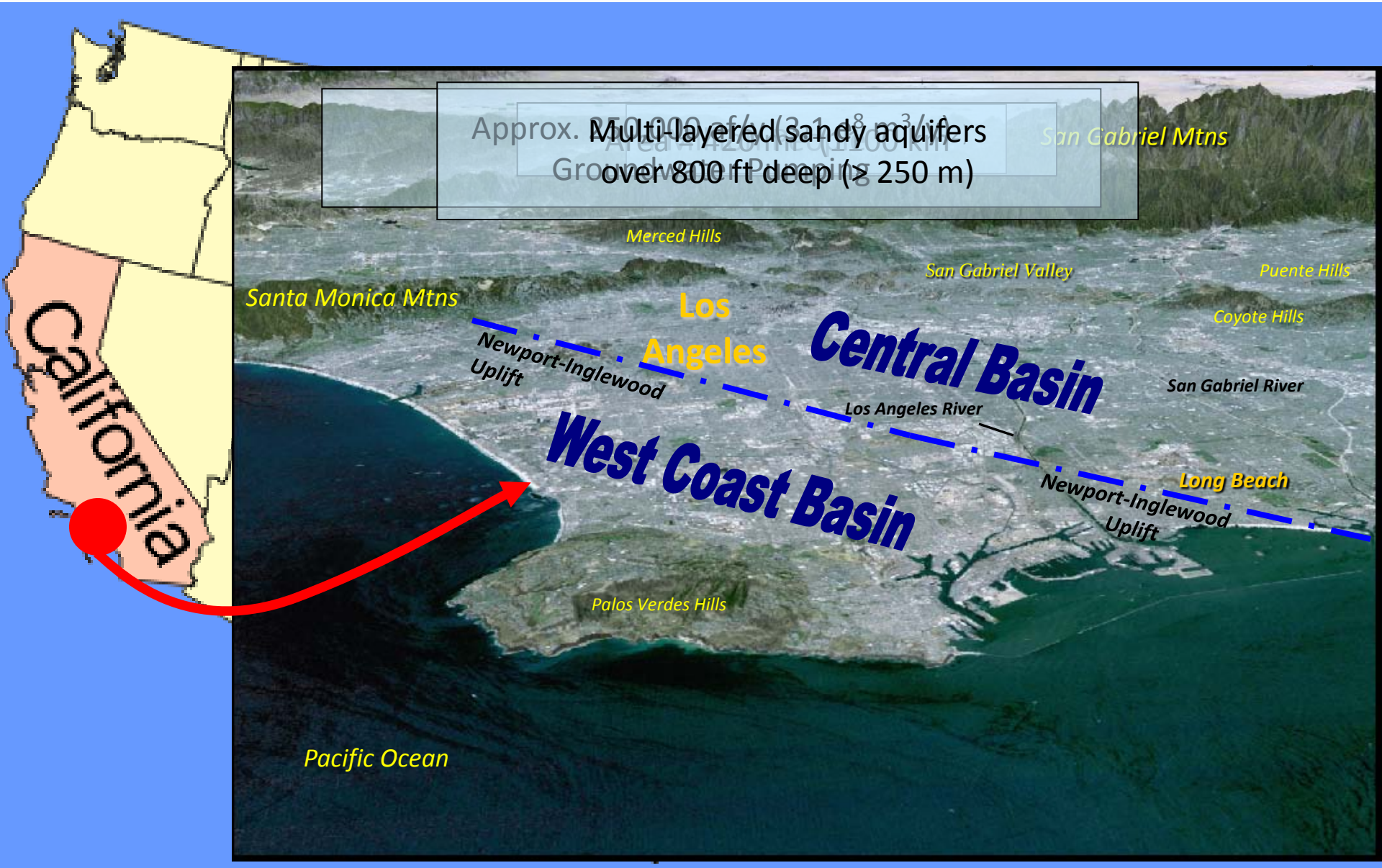
- Square transmitter loop of 5 to 500 meters on a side laid out on surface
- Current of several amps cut off nearly instantaneously
- Creates broad frequency EM pulse
- Nearly vertical propagation of pulse induces eddy currents in conductive units
- Receiver measures magnetic field from eddy current over time
- Data is modeled into layered system

TEM Profile of Brackish Zone in Deep Aquifer

- Apparent mound on Precambrian surface in center of proposed well field expansion area for Fond du Lac, Wisconsin
- Apparent zone of elevated TDS associated with zone
- Indicates well yield and water quality will be significantly lower than projected

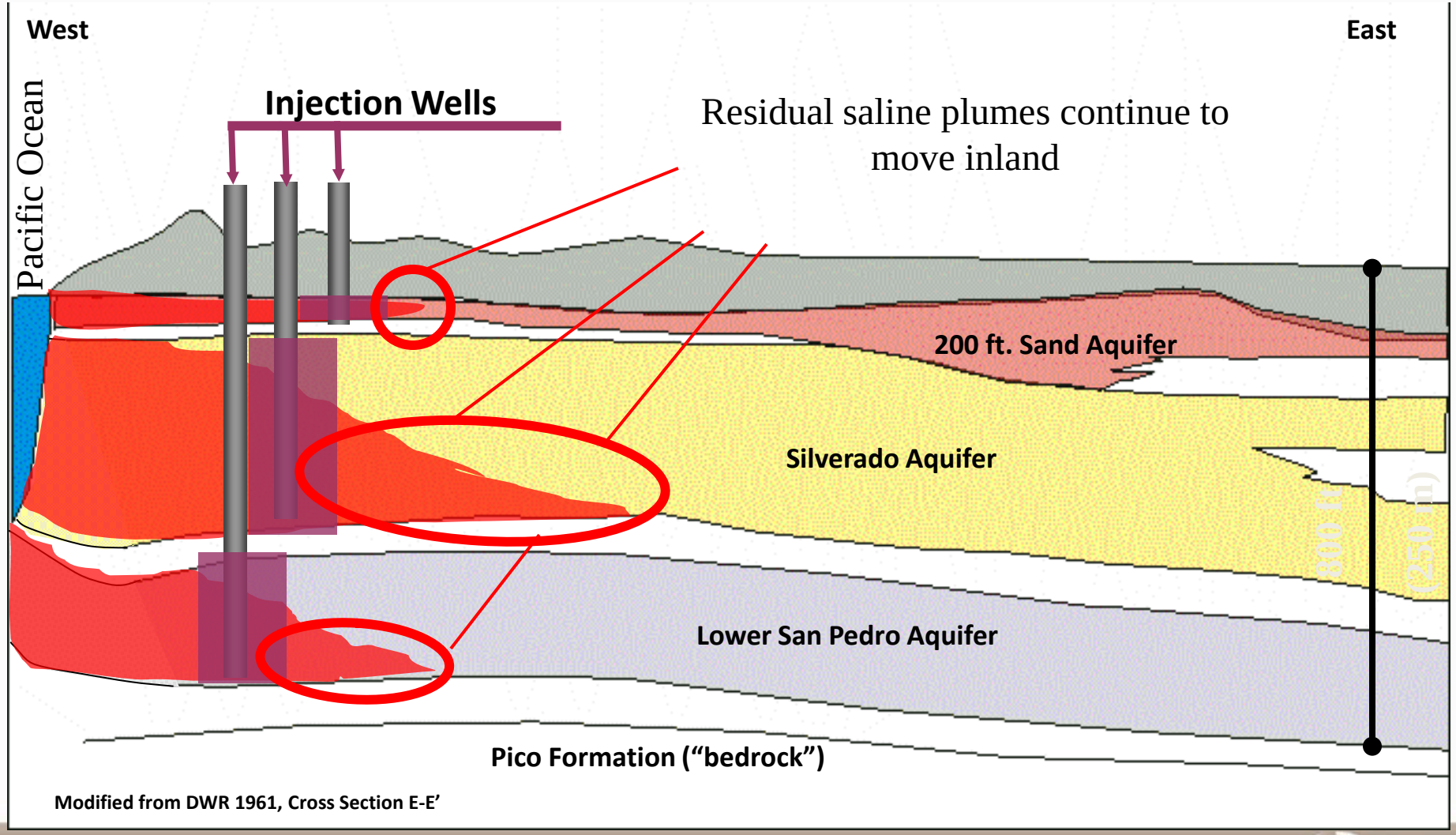


Setting


California
Multi-layered sandy aquifers
over 800 ft deep (≥ 250 m)
San Gabriel Mtns
Merced Hills
San Gabriel Valley
Puente Hills
Santa Monica Mtns
Los Angeles
Coyote Hills
Newport-Inglewood Uplift
Central Basin
San Gabriel River
Los Angeles River
West Coast Basin
Long Beach
Newport-Inglewood Uplift
Palos Verdes Hills
Pacific Ocean

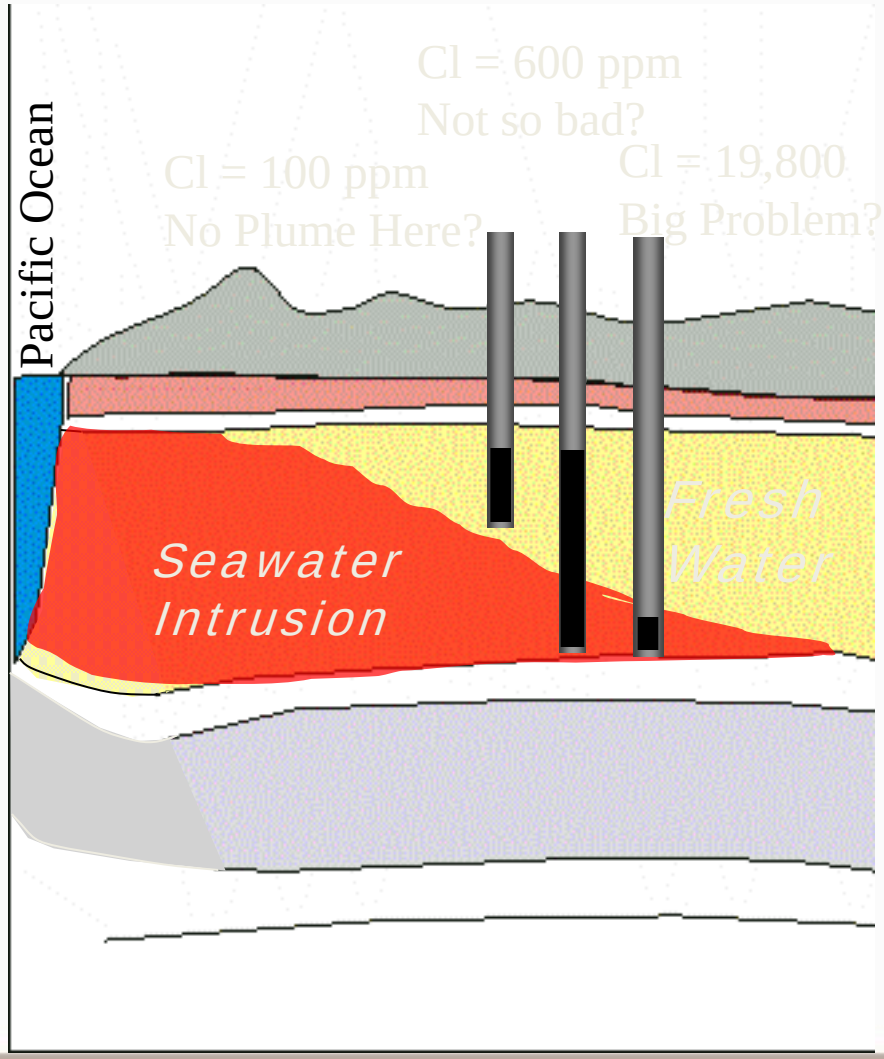
Barrier Wells & Saline Plumes

Saline Plume in multiple aquifers to different extents up to 800 feet deep (250 m).



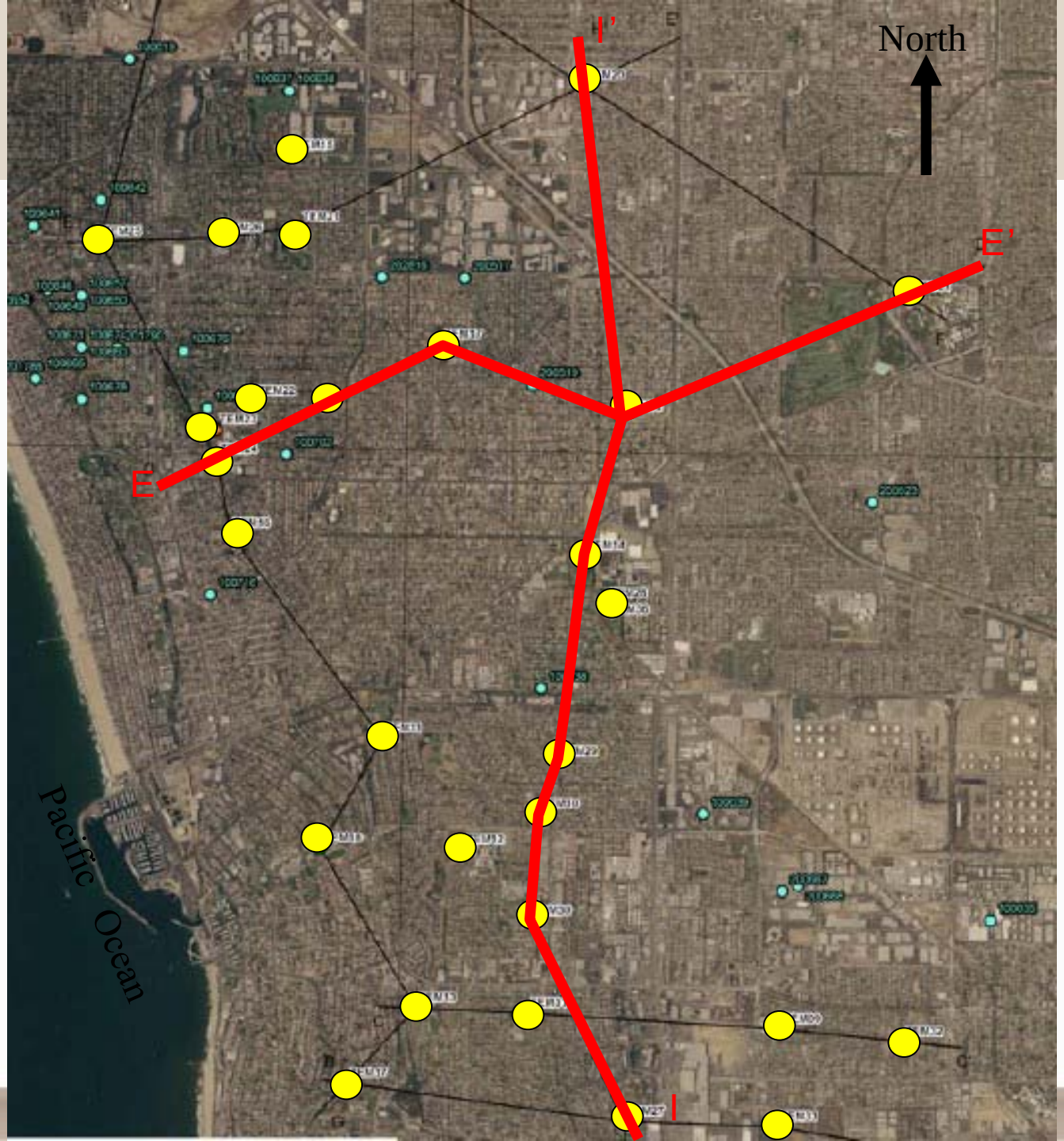
Modified from DWR 1961, Cross Section E-E'

Saline Plume Definition



- Intrusion Maps biased based on well locations and screen intervals
- Shallow wells may miss salt
- Production wells with long screens and high Q may average/dilute salt
- Short screen wells identify salt at that discrete depth
- Many wells needed to identify 3D nature of intrusion $$$$, or…

Time Domain Electromagnetic Induction (TEM)



35 TEM Locations

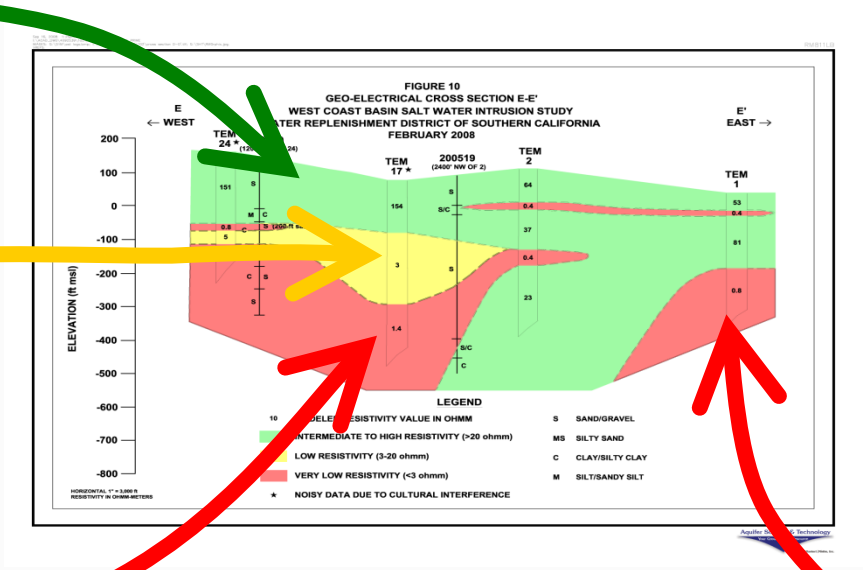
Cross Section Line

Comparison to Chloride Concentration Data From Wells

Fresh water in 200 ft. sand

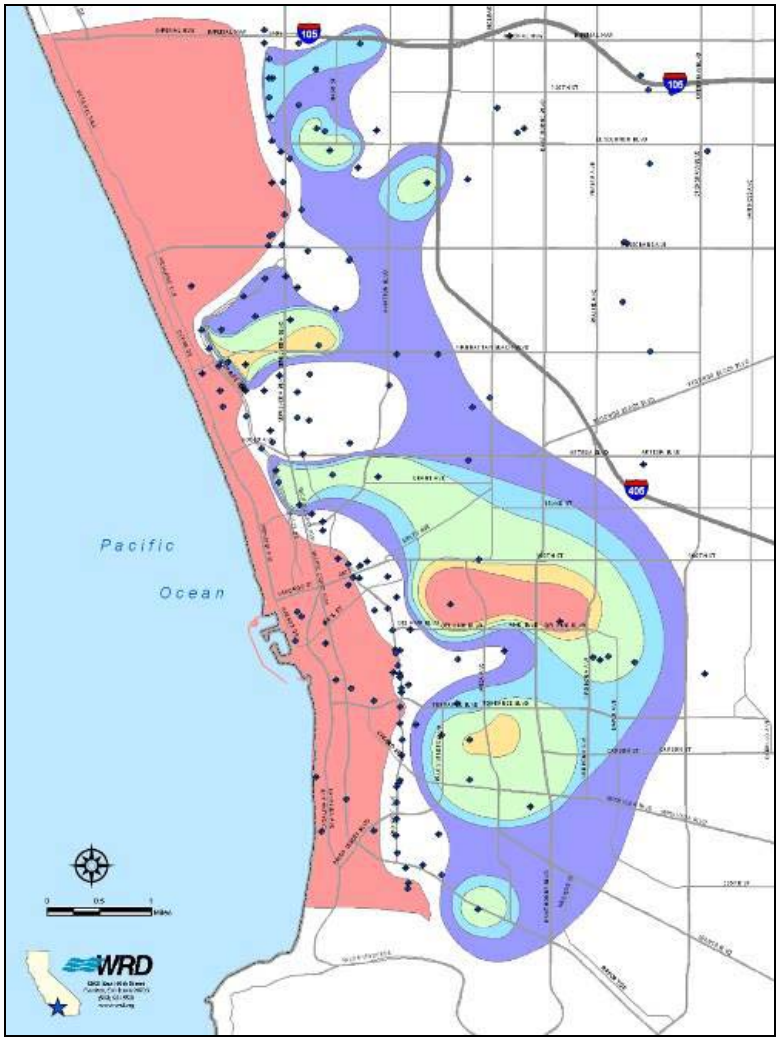
Saline to brackish water in Silverado

Saline to brackish water in San Pedro

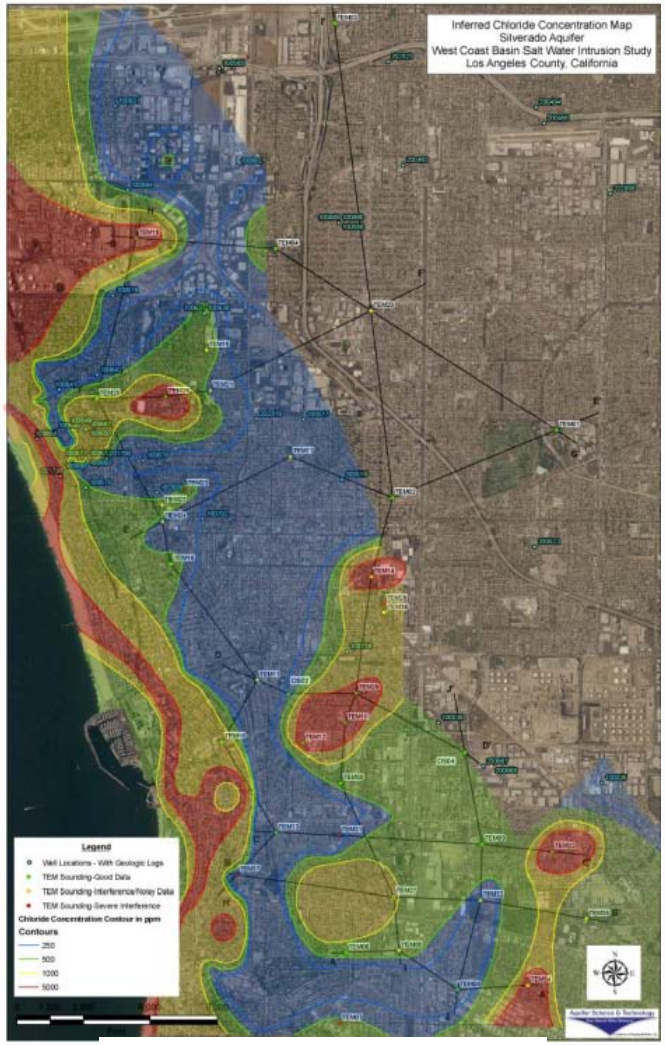


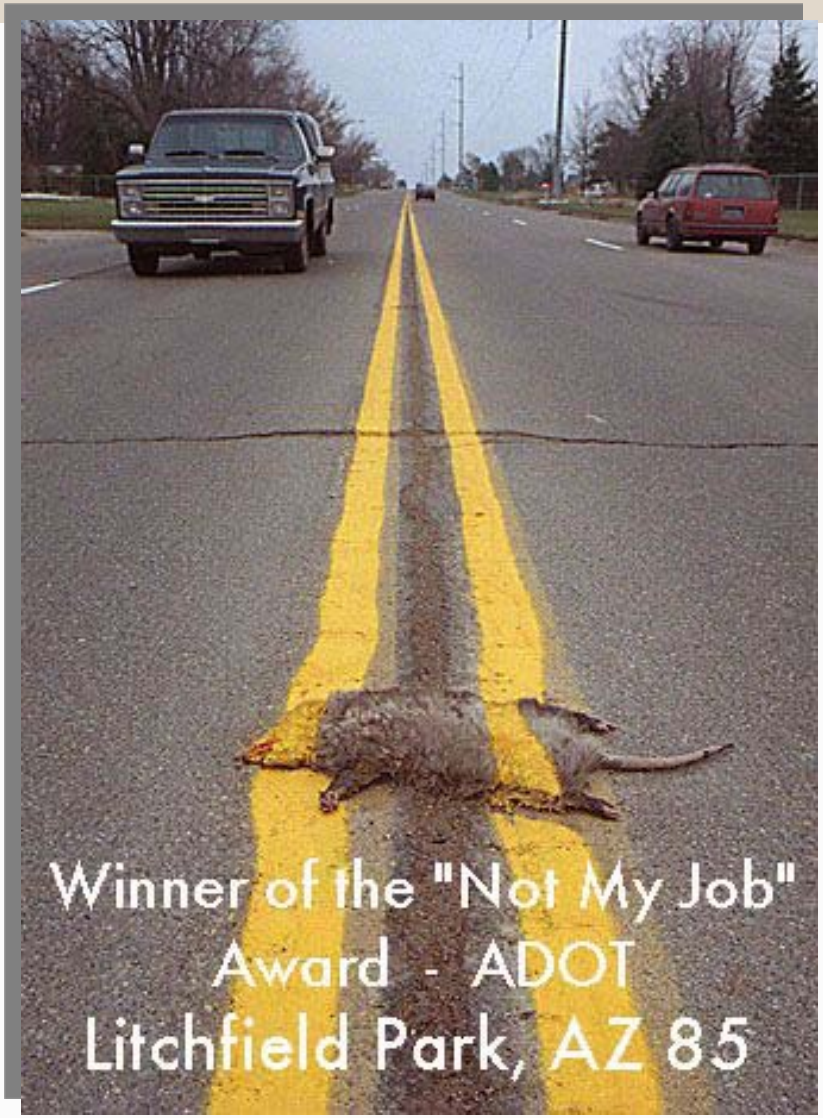
Unknown saline to brackish water in San Pedro

Comparison of Water Quality Maps



Well Data Map



TEM Data Map

The End