Chloride Mapping on the Basis of Electromagnetic Log Data

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In cooperation with The Northeastern San Joaquin Groundwater Banking Authority and the California Department of Water Resources
Scope of Presentation

- Spatial distribution of chloride
- Description of EM Induction
- Results
- Correlation of EM resistivity & Cl
- 2-D chloride mapping
- Conclusions

Chloride concentrations in water from wells

Preliminary Findings


Chloride, in mg/L
- Less than 50
- 50 to 100
- 100 to 250
- Greater than 250

1931 extent of chloride greater than 1,000 mg/L in Delta surface water (Piper and others, 1939)
Wells EM logged and sampled for chloride

- 8 multiple-well sites (28 individual wells)
- 39 EM logs (2004 - 2012)
- ~1,460 m logged well depth versus 29 screened intervals w/combined length of 165 m
- Chloride: 88 water samples (range 4 to 2,050 mg/L) and 8 core material samples (range 28 to 3,590 mg/L)
Electromagnetic Induction Logging

5 - cm diameter PVC well

Receiver coil

Transmitter coil

Volume of maximum tool sensitivity

drawworks
Electromagnetic (EM) Resistivity Results

Preliminary Findings

[Graphs showing depth, lithology, gamma units, and resistivity values for wells 1A2-6 and 11H4-7 in Sept 2007.]
Comparative Electromagnetic (EM) Logs

**Multiple-Well Site 29H1-3**
- Stable with little change in electromagnetic resistivity or chloride concentrations

**Multiple-Well Site 1A2-6**
- Changing electromagnetic resistivity and chloride concentrations

Preliminary Findings
Multiple-Well Site 1A2-6

- Highlighted depth intervals show change greater than 1 standard deviation.
- ‘+’ percent change is increase in EM resistivity i.e. improving water quality.
- ‘-’ percent change is decrease in EM resistivity i.e. poorer water quality.
Depth intervals with changing EM resistivity

<table>
<thead>
<tr>
<th>Bear Creek</th>
<th>Calaveras River</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A2-6</td>
<td>36C3-5</td>
</tr>
<tr>
<td>8N1-3</td>
<td></td>
</tr>
<tr>
<td>20E1-3</td>
<td></td>
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<tr>
<td>29H1-3</td>
<td></td>
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<tr>
<td>4J3-5</td>
<td></td>
</tr>
</tbody>
</table>

Depth Below Land Surface, in meters

Distance, in kilometers

- Depth showing increasing EM resistivity
- Depth showing decreasing EM resistivity

avg depth to water
screened interval
natural gamma
borehole depth

VERTICAL EXAGGERATION x30

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Preliminary Findings
Comparative Electromagnetic (EM) Logs

Well 1A6 (17 - 21 m depth)
- Stable with little change in electromagnetic resistivity or chloride concentrations

Well 1A5 (67 - 73 m depth)
- Changing electromagnetic resistivity and chloride concentrations
Relation between chloride and EM resistivity

$\log_{10}(\text{Cl}) = 4.36 - 2.12 \log_{10}(\text{EM})$

$R^2 = 0.52$

- **Core material**
- **Well**
Chloride estimations and associated uncertainty

2N/5E-1A2-6

2N/6E-8N1-3

- measured well water sample
- pore-water (core material)
- predicted Cl low soln (-2 sigma)
- predicted Cl high soln (+2 sigma)
- predicted Cl best soln

Depth Below Land Surface, in meters

Mesured and predicted chloride concentrations, in milligrams per liter

\[ \log_{10} \text{Cl} = 4.67 - 2.23 \log_{10} \text{EM} - 0.005 \text{ gamma} \]
Depth intervals with changing EM resistivity

Predicted Chloride Ranges
- < 100 mg/L
- 100 - 250 mg/L
- 250 - 500 mg/L
- > 500 mg/L

Depth Intervals with Changing Resistivity
- Depth showing increasing EM resistivity
- Depth showing decreasing EM resistivity

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Comparative Electromagnetic (EM) Logs, 2006-12

Depth, in meters

EM Resistivity, in ohm-m
Conclusions

- Chloride moves laterally from the Delta inland, primarily thru thin, coarse-grained zones.
- Sequential EM logging suggests degrading water quality in numerous thin zones (1-7 m thick), particularly in the northern and southern parts of the study area.
- EMI can provide a continuous profile of changes in groundwater quality within an aquifer penetrated by a PVC-cased well, thereby permitting the identification of zones of poor-quality water that may otherwise be missed by traditional water quality sampling from wells.
- Sequential EM logging may be a useful screening tool for detecting the early onset of increasing chloride concentrations as EMI logs can be used to identify brine invasion before concentrations reach levels of concern for groundwater management.