Using Controlled Source-Audio Frequency Domain Magnetics for Contaminated Groundwater Site Characterization: A Minimally Invasive Approach

P. Rollins, Willowstick Technologies

Challenges of Ground Water Characterization

- Groundwater is hidden from view
- Complex, dynamic system that is three dimensional in nature
- Ground water can follow multiple channels
- Monitoring wells and other methods can give conflicting or insufficient data
- Drilling enough wells can be cost prohibitive and impractical
  - Needle in a haystack syndrome

Cost of Ground Water Characterization Fractured Rock Sites

- Civilian and government agencies can individually spend millions of dollars a year on characterization and remediation
- Installing enough monitoring wells can cost hundreds of thousands of dollars
- Given the difficulties of ground water characterization, some of this money is wasted in superfluous or poorly placed wells
- Traditional ground water characterization methods generally lack ability to tell the whole story
  - There is still much “guess-work” in the process
  - Inability to effectively target remediation

History of Geophysics and Ground Water

- Most geophysical applications have been developed by oil and gas and mining companies to delineate geologic structure
- Billions of dollars have been poured into R & D for these technologies
  - Seismic
  - Electromagnetics
- Geophysical techniques often applied incorrectly
- A good ground water focused tool is needed for ground water investigations at karst sites

Introduction

- Willowstick specializes in mapping, modeling and characterizing subsurface water and ground water-related systems.

- Through Controlled Source - Audio Frequency Domain Magnetics (CS-AFDM), or AquaTrack™ Willowstick maps water and subsurface structure influencing ground water flow much deeper and with much greater accuracy than any other available technologies.

Characteristics of CS-AFDM

- Technology built expressly for ground water exploration and characterization
- A direct induction of electrical current results in measurement of strong, reliable signal
- No electromagnetic coupling, which limits signal penetration due to skin depth
- Based upon sound, easy-to-understand physical principles
- Good applicability to fractured rock sites:
  - Channelized ground water flow
  - Ground water in a resistive medium (limestone)
- Gathers hundreds of readings quickly and efficiently

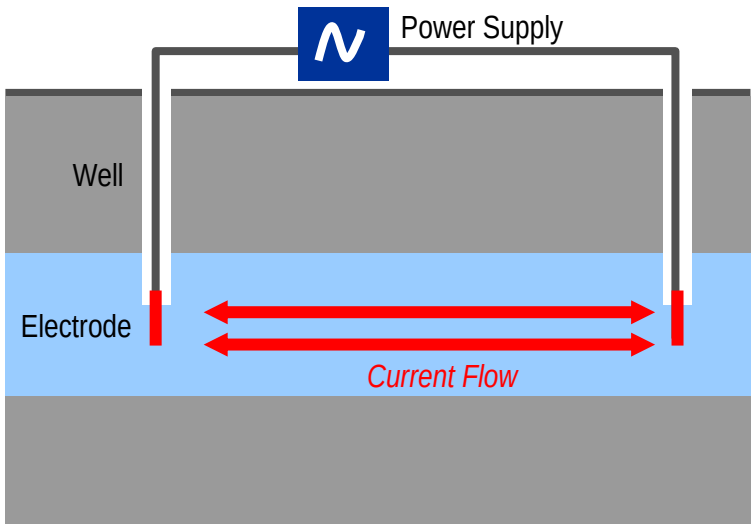
CS-AFDM Has Many Applications

- Dam leak detection and location
- Aquifer and ground water mapping
- Municipal / culinary well site placement
- Mine infiltration, control and remediation,
- Heap leach solution mapping
- Contaminant plume and reaction front mapping
- Landfill seepage mapping
- Geothermal Resource Characterization
- Oil production steam and water flood injection plume mapping

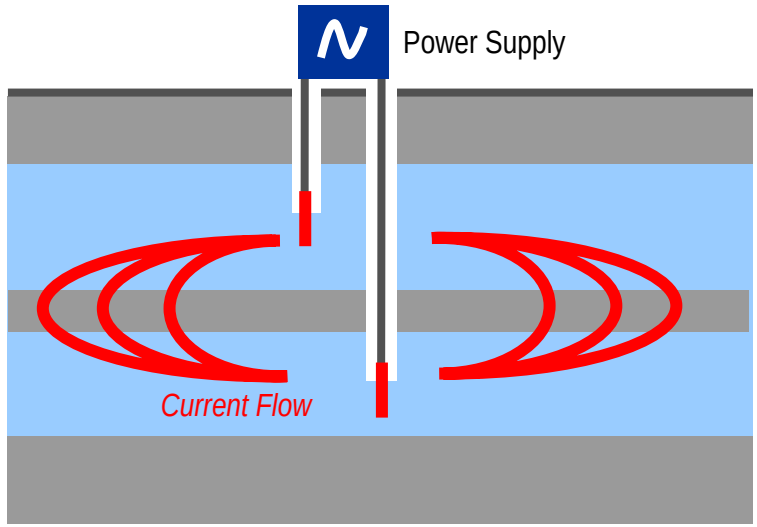
CS-AFDM: How It Works...

- Energize water-bearing zone using AC current (harmless to environment)
- Electrical current gathers in areas with high water concentration and follows preferential flow paths

Horizontal Dipole Configuration

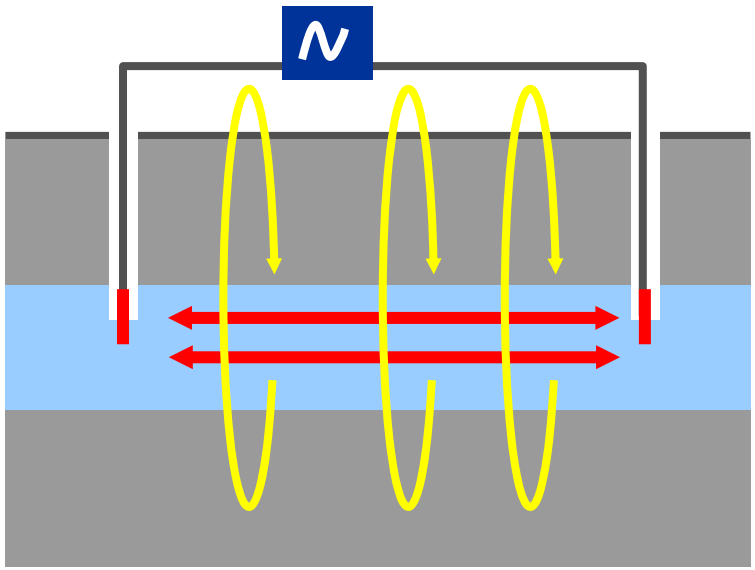


Vertical Dipole Configuration



CS-AFDM: How It Works…

- Electrical current flow generates magnetic field
- Magnetic field is measured on surface at points across survey area



CS-AFDM: How It Works…

CS-AFDM: How It Works...

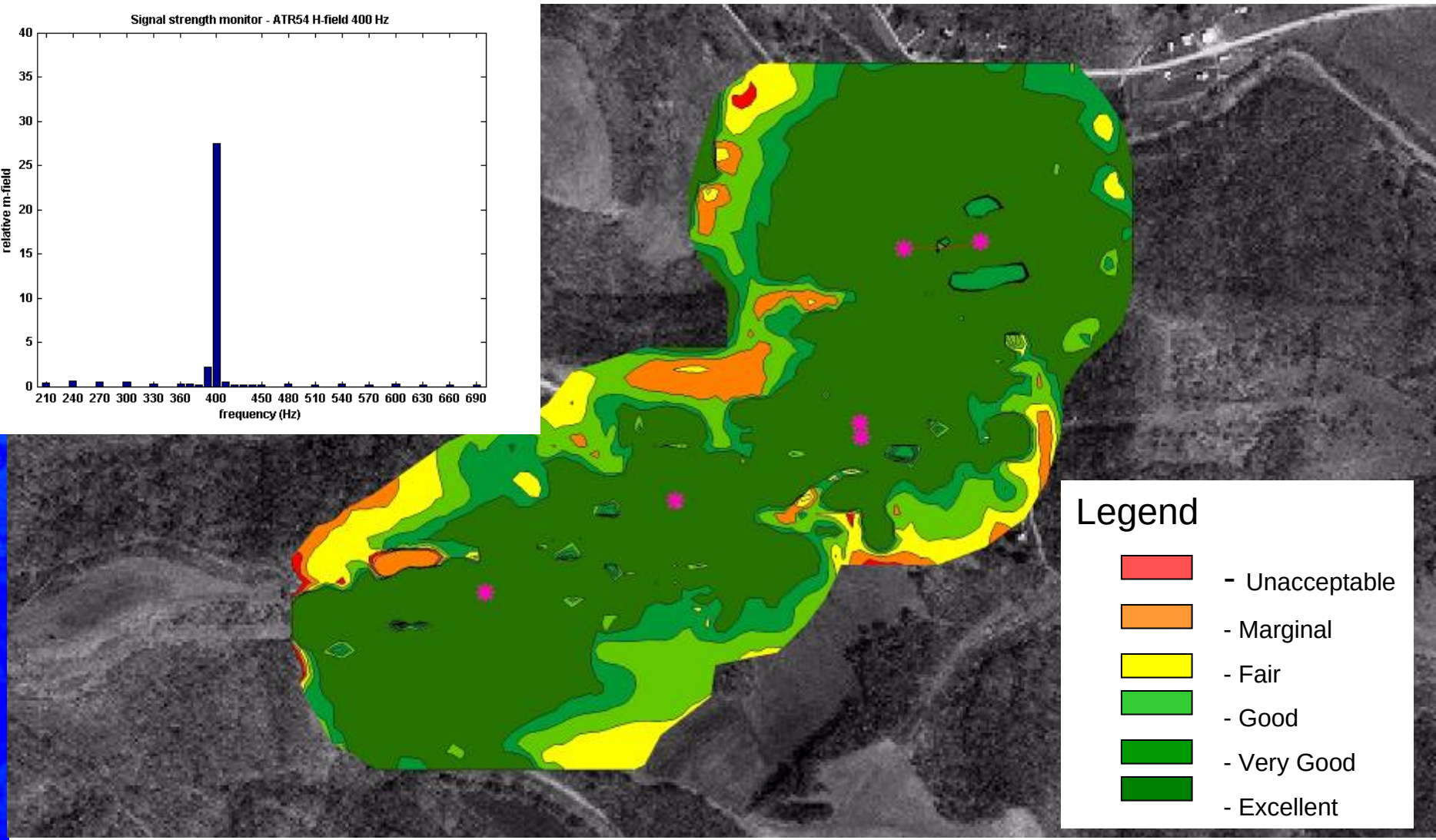
- Data is digitally gathered and processed
- Several sets of 16 readings are taken on three axes during a two minute period, monitoring frequencies from < 30 Hz to 720 Hz
- FFT and data stacking are used to eliminate interference from non-400 Hz fields and to improve signal-to-noise ratio
- Base station readings at reference locations are taken at several times during the day to provide quality and to remove diurnal effects

Trimble sub-meter accurate GPS

Computer stores positions & measurements in ArcView

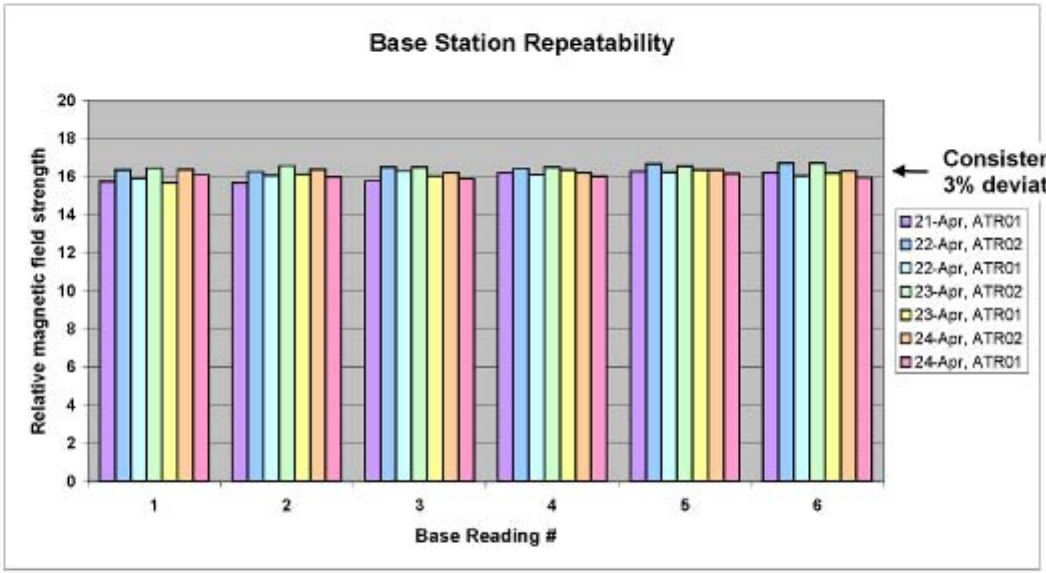
Sensitive sensors in X, Y, and Z are read by a Campbell CR1000.

CS-AFDM: How it Works...



CS-AFDM: How it Works...

MAGNETIC FIELD READINGS AT BASE STATION		
DATE	Receiver ID	AquaTrack signal
21-Apr	ATR01	15.77
21-Apr	ATR01	15.69
21-Apr	ATR01	15.79
21-Apr	ATR01	16.21
21-Apr	ATR01	16.28
21-Apr	ATR01	16.23
22-Apr	ATR02	16.36
22-Apr	ATR02	16.27
22-Apr	ATR02	16.52
22-Apr	ATR02	16.44
22-Apr	ATR02	16.68
22-Apr	ATR02	16.74
22-Apr	ATR01	15.93
22-Apr	ATR01	16.08
22-Apr	ATR01	16.30
22-Apr	ATR01	16.11
22-Apr	ATR01	16.25
22-Apr	ATR01	16.06
23-Apr	ATR02	16.47
23-Apr	ATR02	16.58
23-Apr	ATR02	16.52
23-Apr	ATR02	16.61
23-Apr	ATR02	16.56
23-Apr	ATR02	16.75
23-Apr	ATR01	15.68
23-Apr	ATR01	16.14
23-Apr	ATR01	16.04
23-Apr	ATR01	16.37
23-Apr	ATR01	16.37
23-Apr	ATR01	16.20
24-Apr	ATR01	16.10
24-Apr	ATR01	16.00
24-Apr	ATR01	15.90
24-Apr	ATR01	16.04
24-Apr	ATR01	16.16
24-Apr	ATR01	15.97
24-Apr	ATR02	16.40
24-Apr	ATR02	16.40
24-Apr	ATR02	16.23
24-Apr	ATR02	16.22
24-Apr	ATR02	16.37
24-Apr	ATR02	16.32



WILLOWSTICK TECHNOLOGIES, LLC.
Groundwater Mapping Services
11814 Election Road, Suite 100
Draper, Utah 84020
TEL: (801) 984-9850 FAX: (801) 984-9851

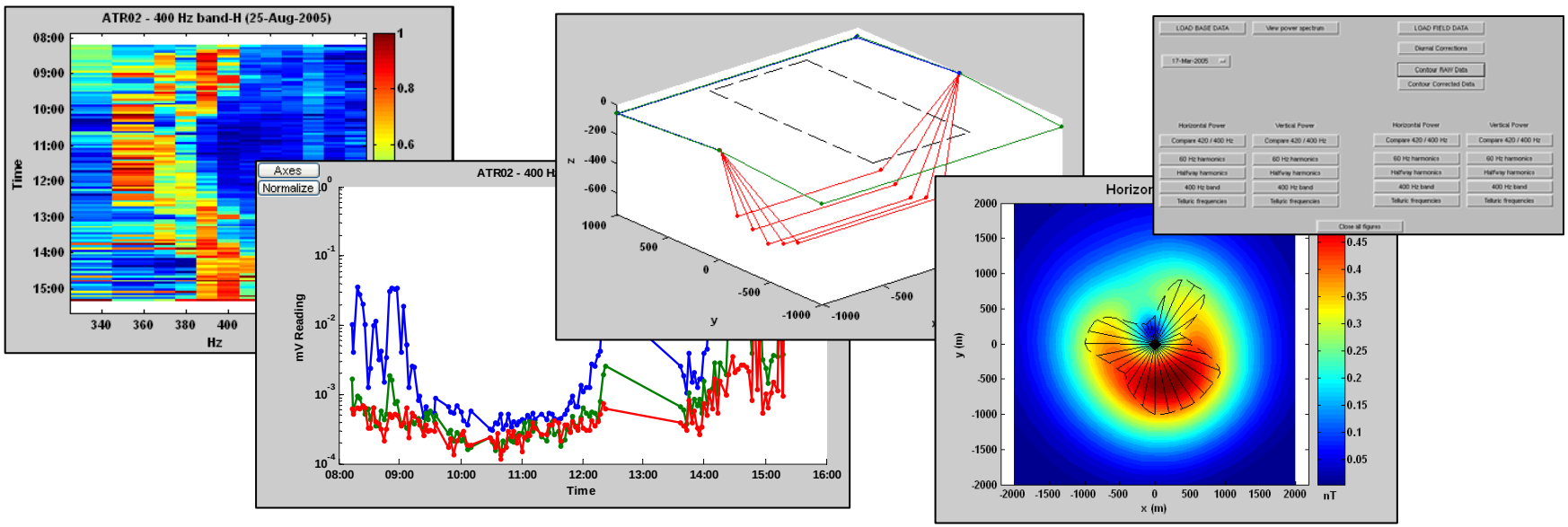
willowstick

AquaTrack Geophysical Investigation
Beacon Lake Dam, TX
Bluegreen Corporation
Figure 12 - Measurement Repeatability Analysis

PROJECT NO.: 06033
DESIGNED JRM | CHECKED VDK | DRAWN MLJ
DATE 17-May-2006 | SHEET NO. 12 of 16
SCALE N.T.S.

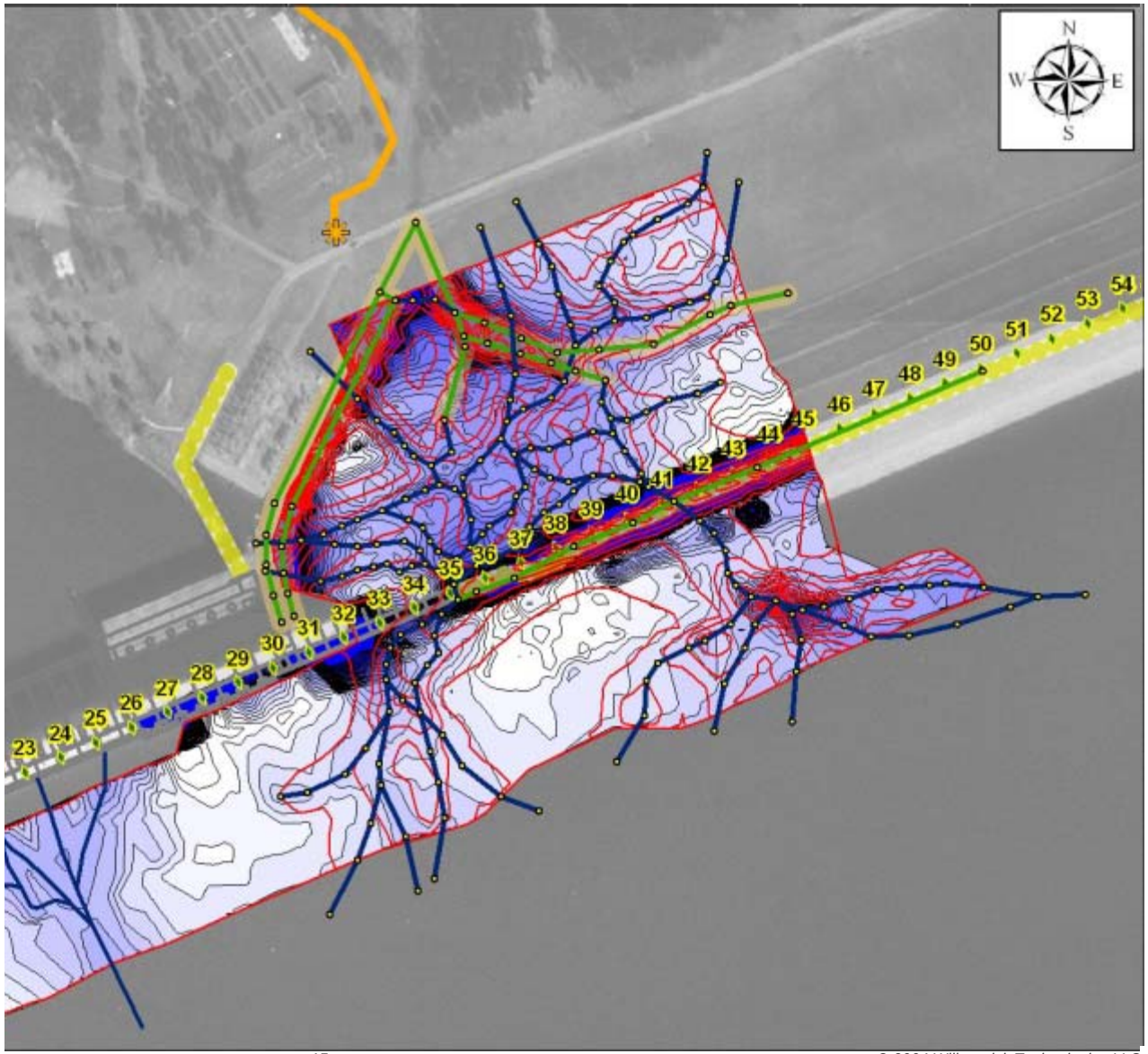
CS-AFDM: Data Interpretation

- Surfer, Excel, ArcGIS and MATLAB-based analysis tools:
  - Assess data quality
  - Normalize and process data
  - Analyze and visualize interpretative results
  - Build conceptual maps and models of ground water concentrations and flow.



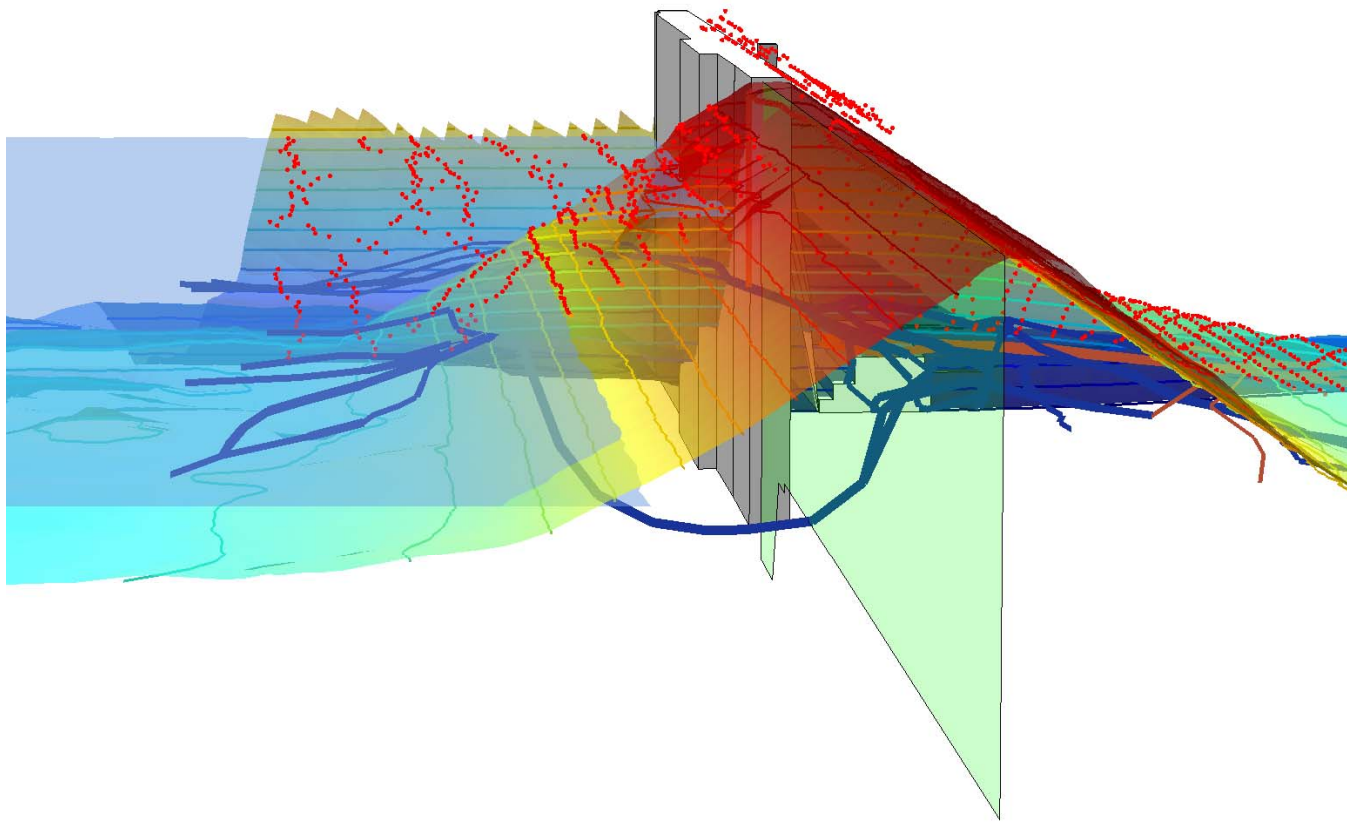
CS-AFDM: Deliverables – Ground Water Maps

- Data is correlated with other hydrogeologic data
- Magnetic field contour maps and profiles highlight areas of water concentration and flow paths.



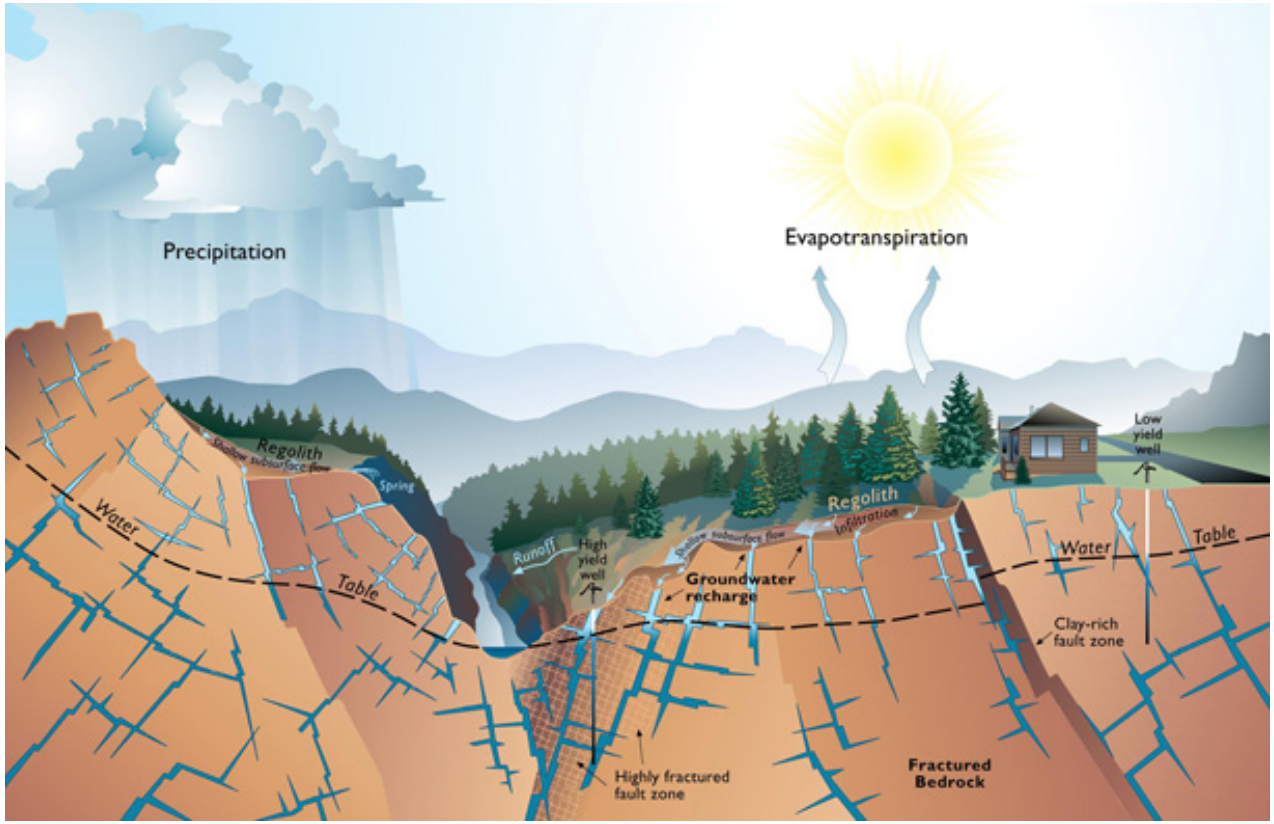
CS-AFDM: Deliverables - 3D Models

- A 3D model of the subsurface study area is prepared for subsurface visualization, presentation and further analysis



CS-AFDM in Fractured Rock and Karst

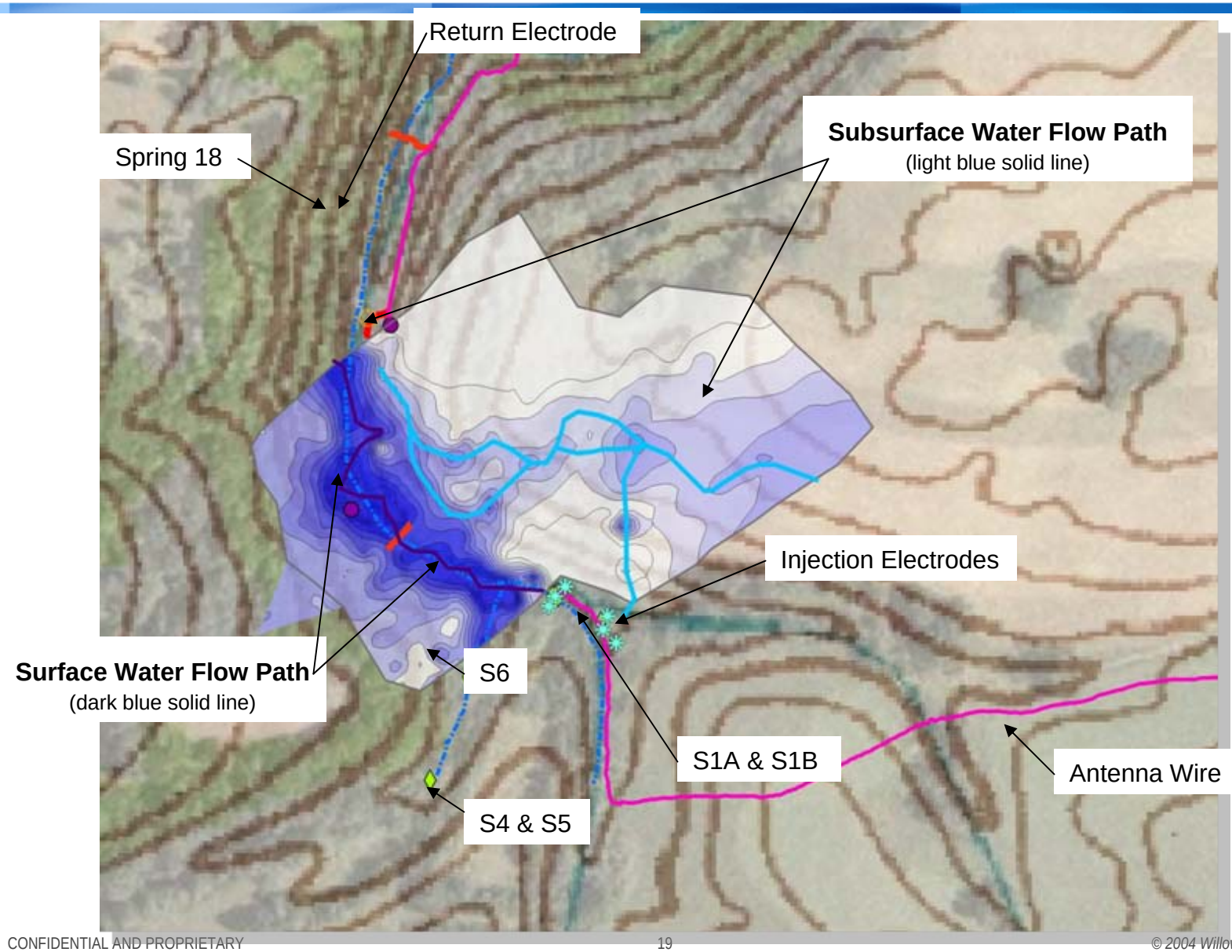
- Fractured rock systems consist of channelized groundwater (electrically conductive) in a resistive medium (rock).
- Electricity must follow groundwater flow paths.



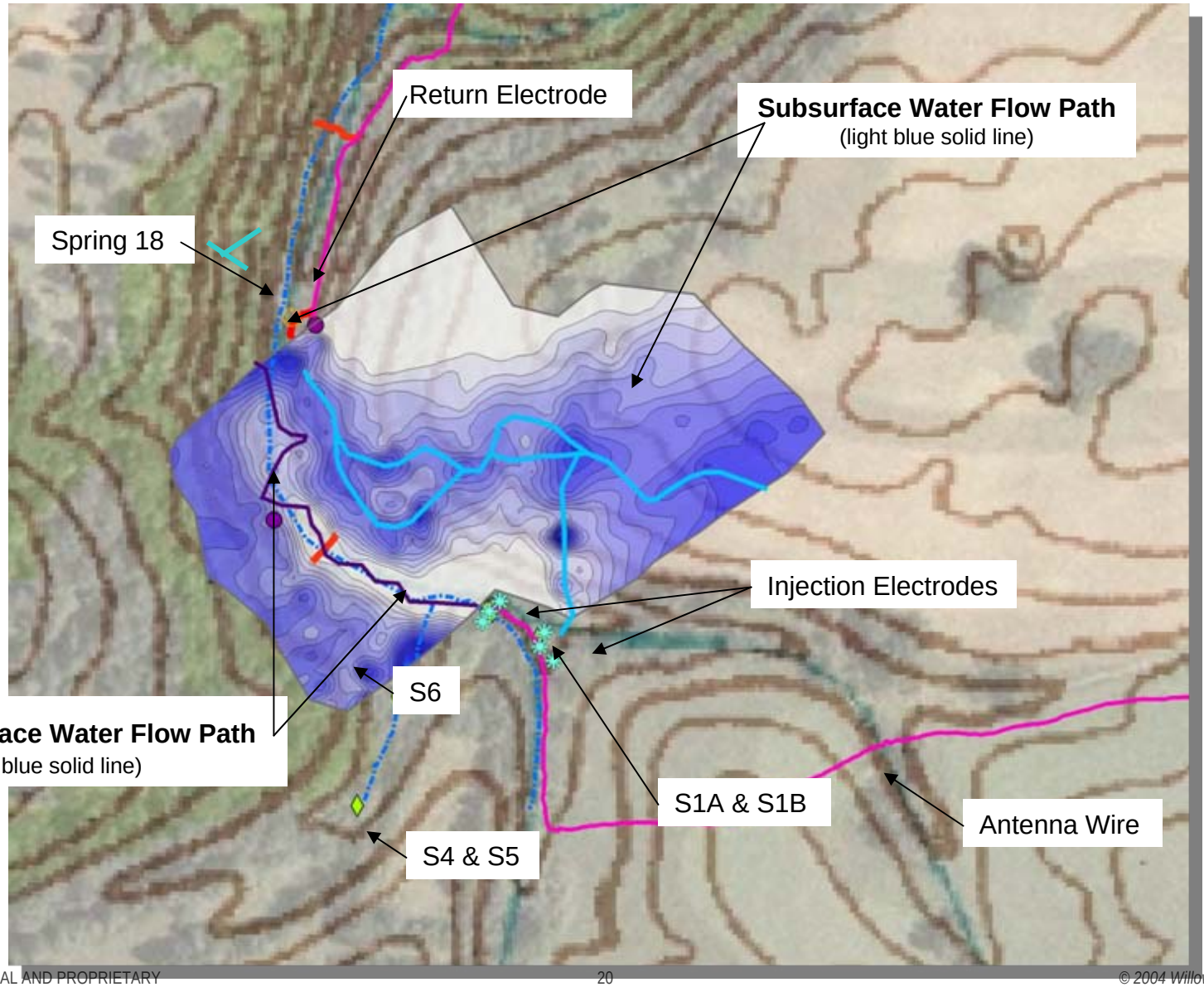
geosurvey.state.co.us/.../ chapter7_5page2.asp

Contaminated Ground Water in Karst

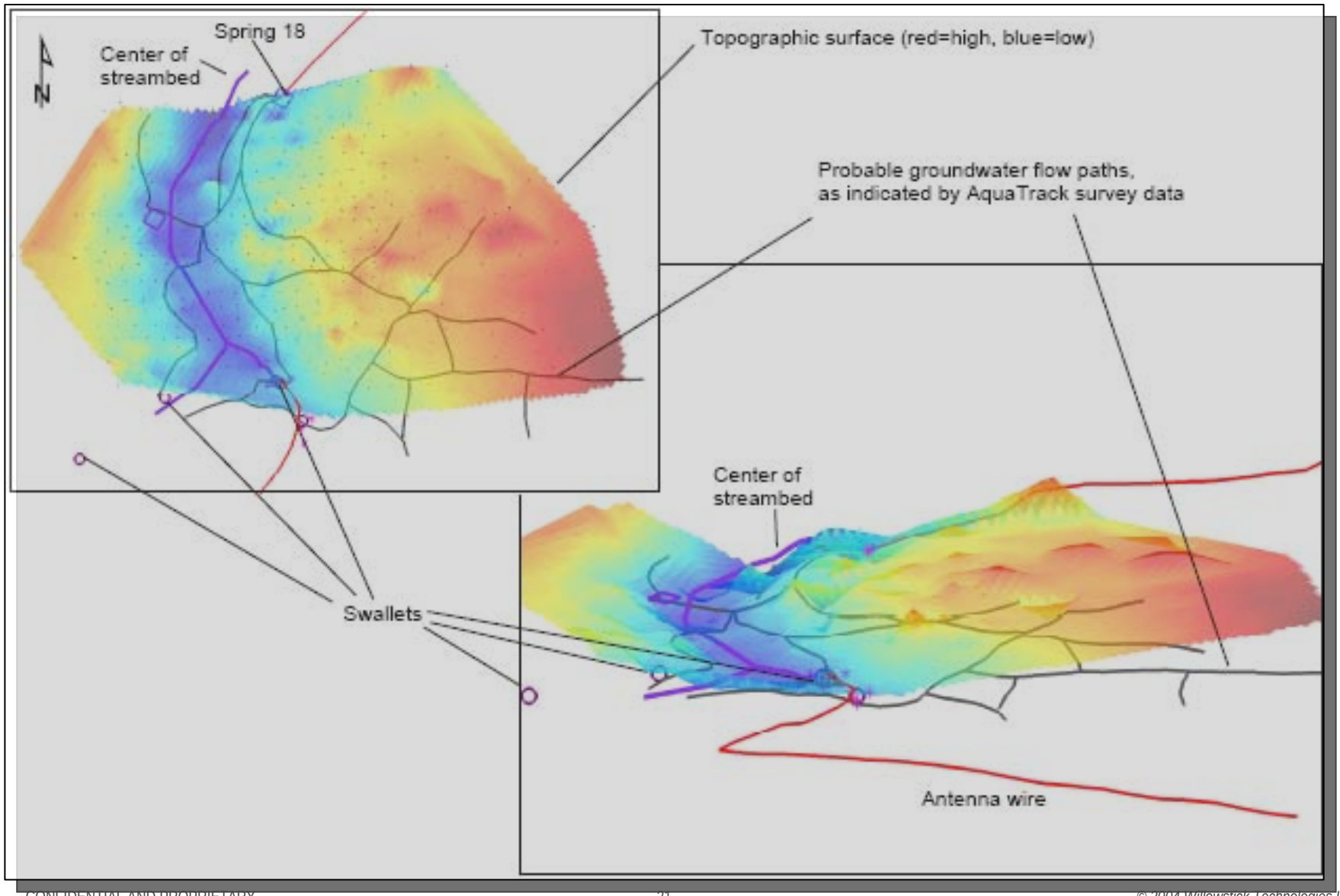
Contaminated Ground Water in Karst



Contaminated Ground Water in Karst



Contaminated Ground Water in Karst

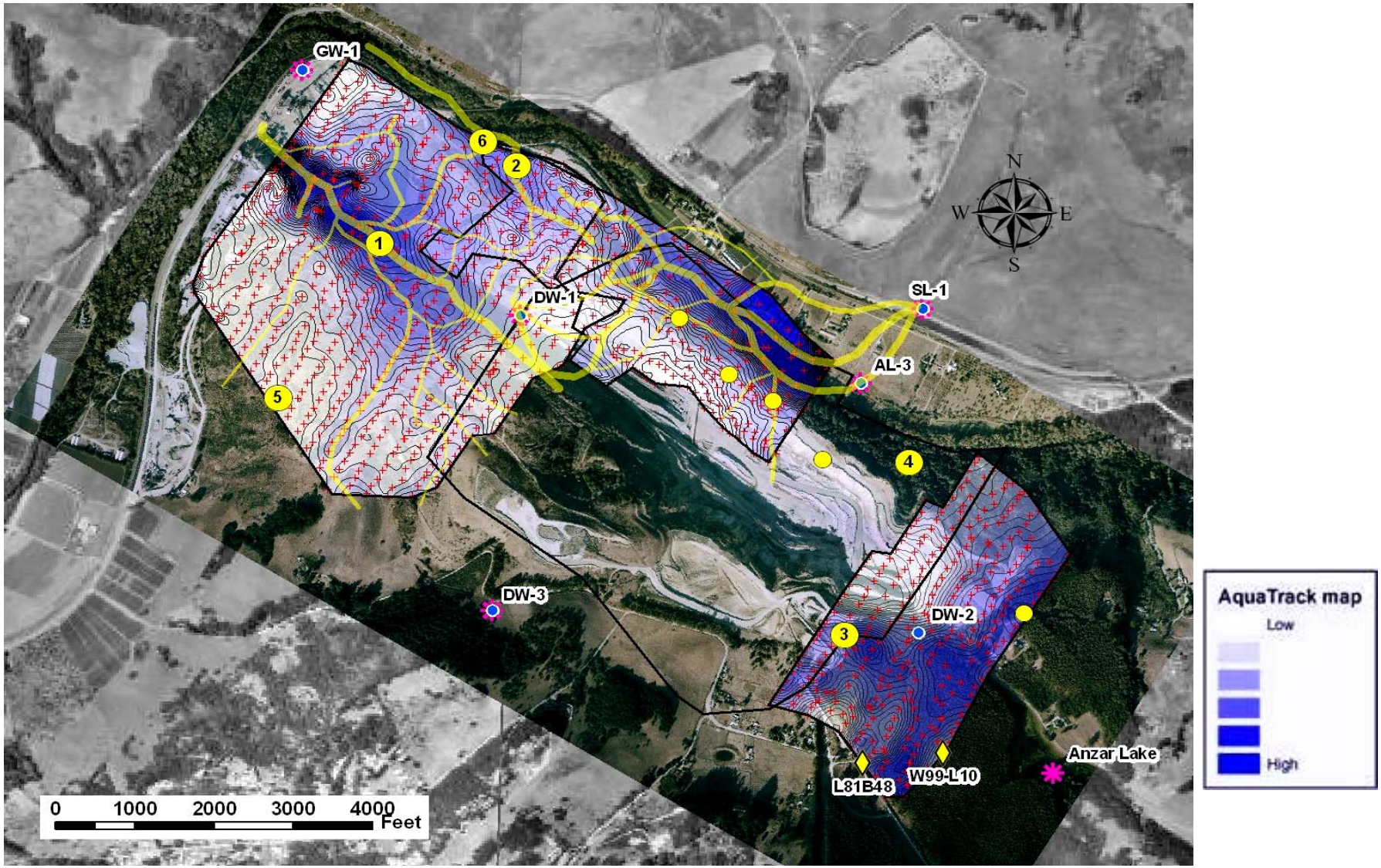


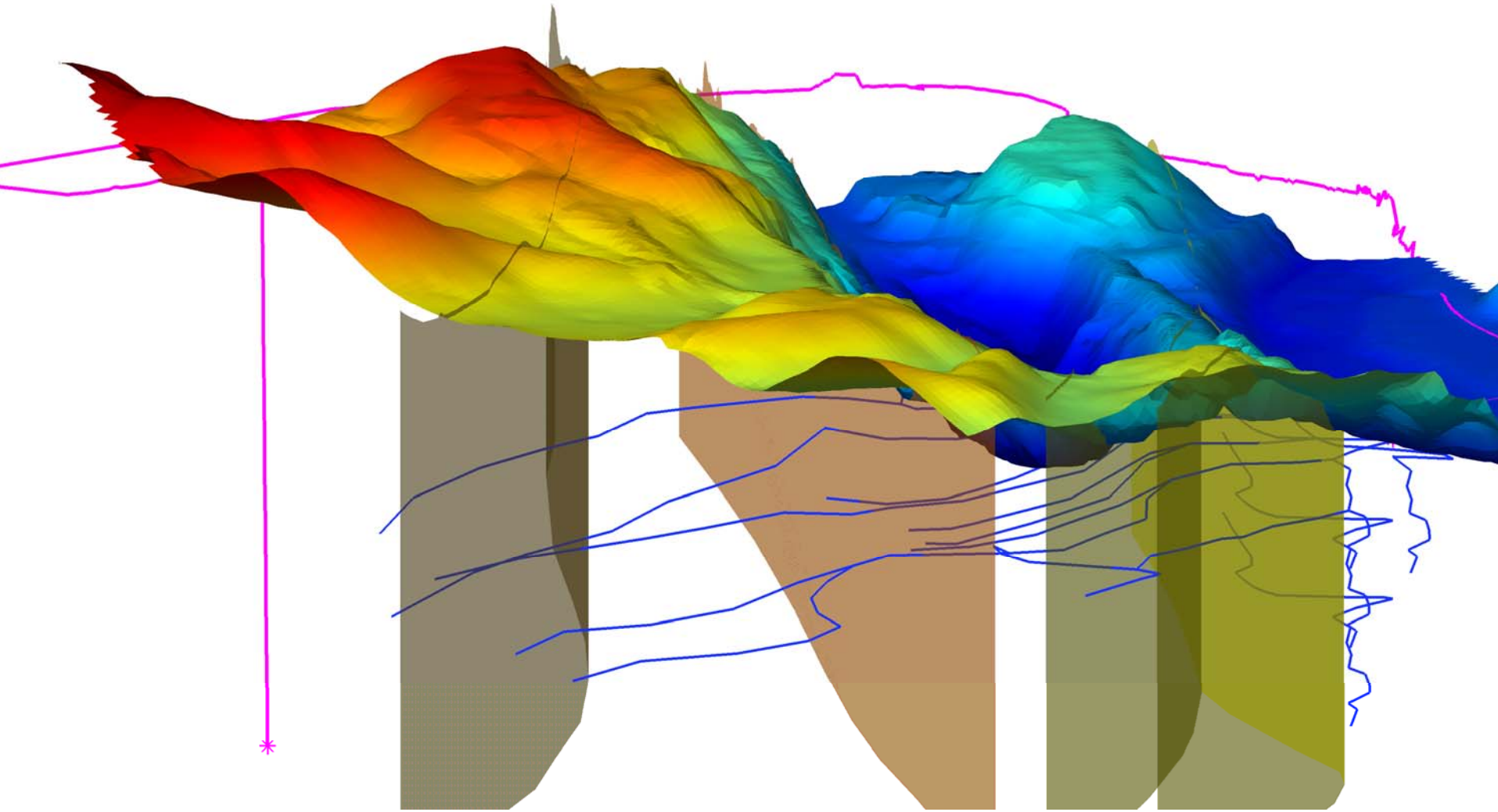
Fractured Rock Investigation

- The Client
  - Large Gravel Company
  - Producing aggregate in Southern California.
  - One of the largest producers in continental USA.

- Challenges
  - Permitting requirements for expansion
  - Traditional investigatory methods are expensive and did not yield enough data
  - Lack of confidence in choice of remediation decisions

Final Interpretation: Subsurface Structure and Groundwater Characterization for Large Gravel Pit





Vertical Exaggeration = 2.0

Value of Groundwater Investigation

- **Learned of concerns without drilling more holes**
  - Extended life of mine
  - Obtained necessary intelligence on where to drill and grout
- **Able to target remediation**
  - No more “blanket”, “hunt and peck” approach
  - Savings of over a million dollars in drilling/grout
- **Other Value**
  - Enables client to prioritize problems effectively
  - Helps confirm or deny theories related to groundwater flow
  - Shows preferential flow paths within the subsurface
  - Helps with permitting issues

Back

Summary

- CS-AFDM has potential to significantly improve ground water characterization even in challenging geology
- A direct induction of electricity into ground water of interest yields a strong, reliable signal
- Maps and models show ground water concentrations and preferential flow paths
- CS-AFDM results can be correlated to existing data and other geophysical surveys to greatly enhance hydrogeologic understanding of site
- Excellent tool for detailing karst flow paths