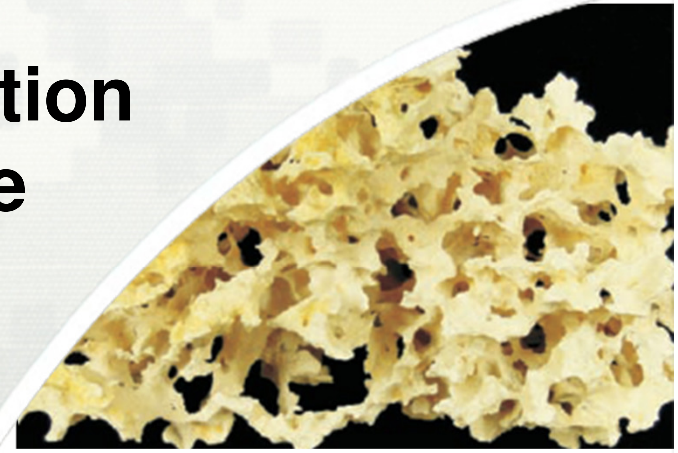
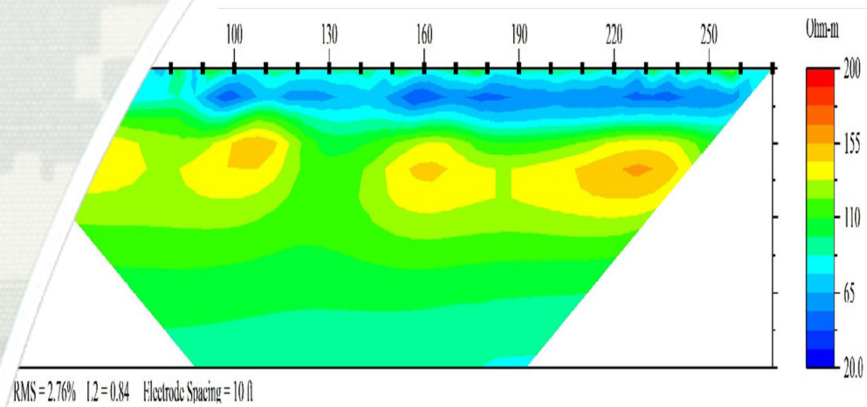
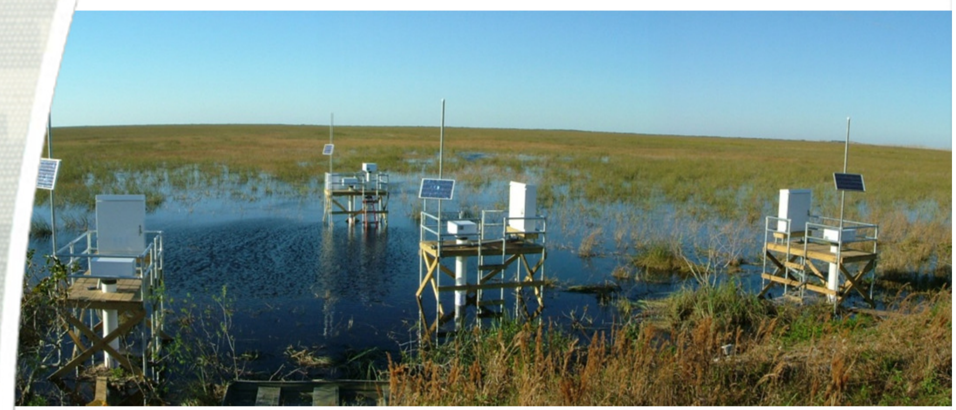
Tracer Tests with Resistivity Detection to Estimate Seepage Velocity in the Biscayne Aquifer, Florida







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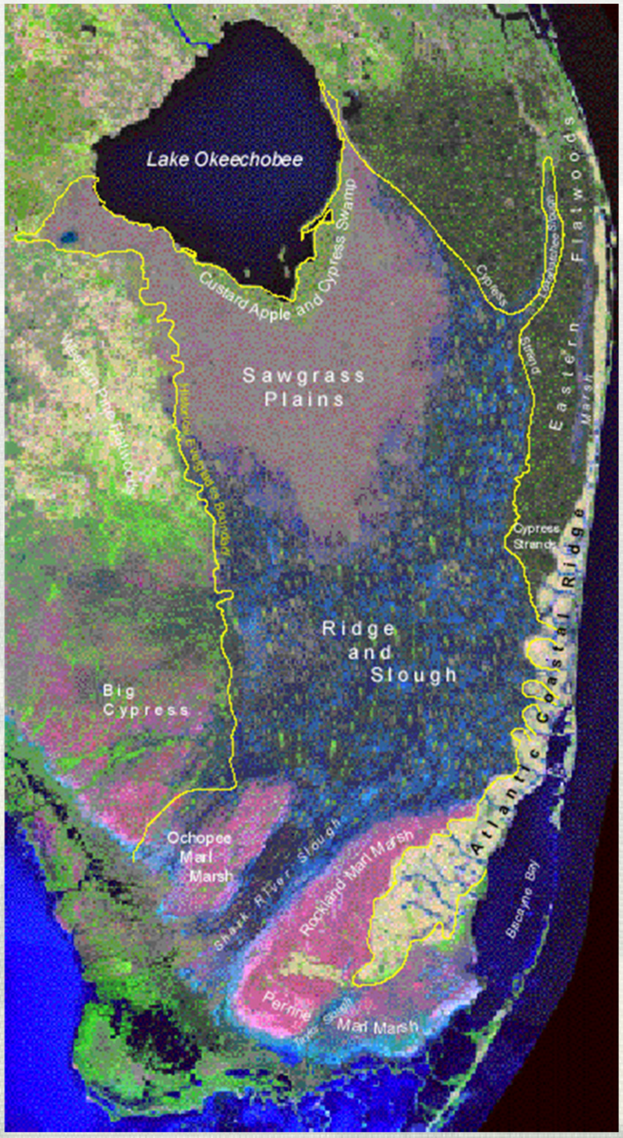
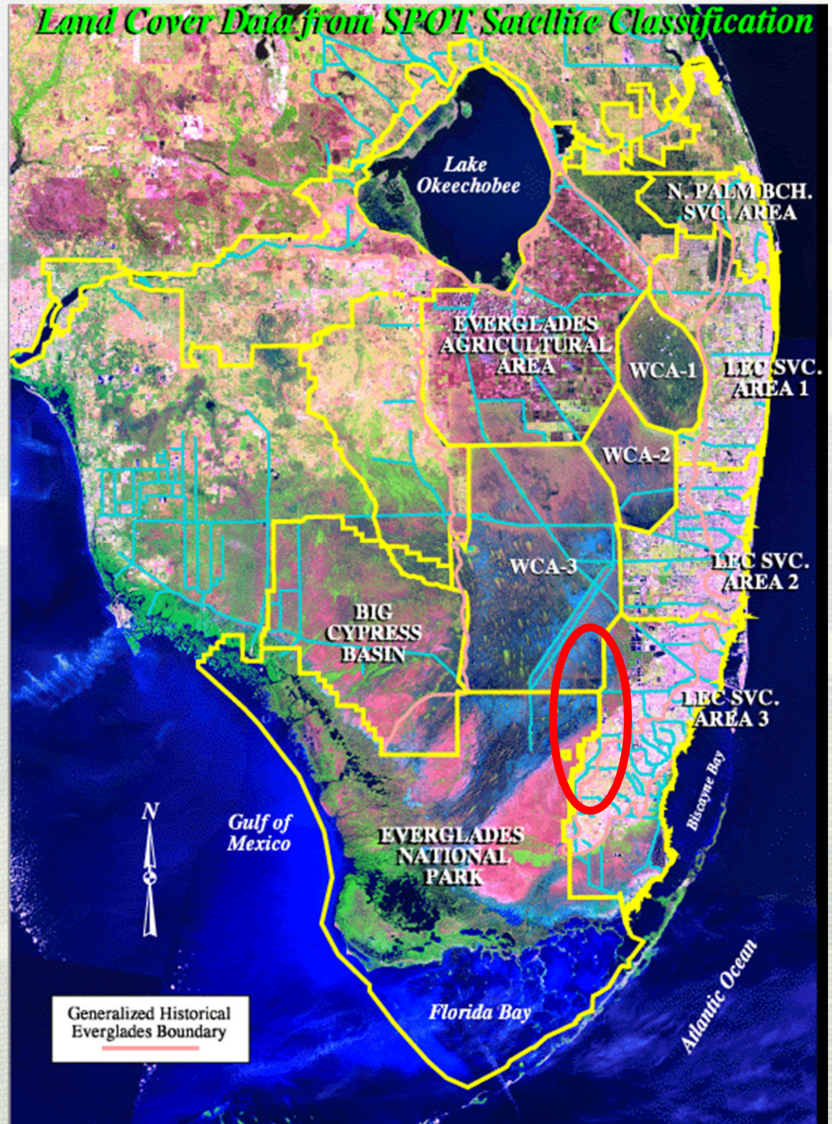
Cardno ENTRIX, Fort Myers, FL

16 November 2011
South Florida Hydrologic Society
Ft. Lauderdale, FL

Water Management in the Everglades Restoration

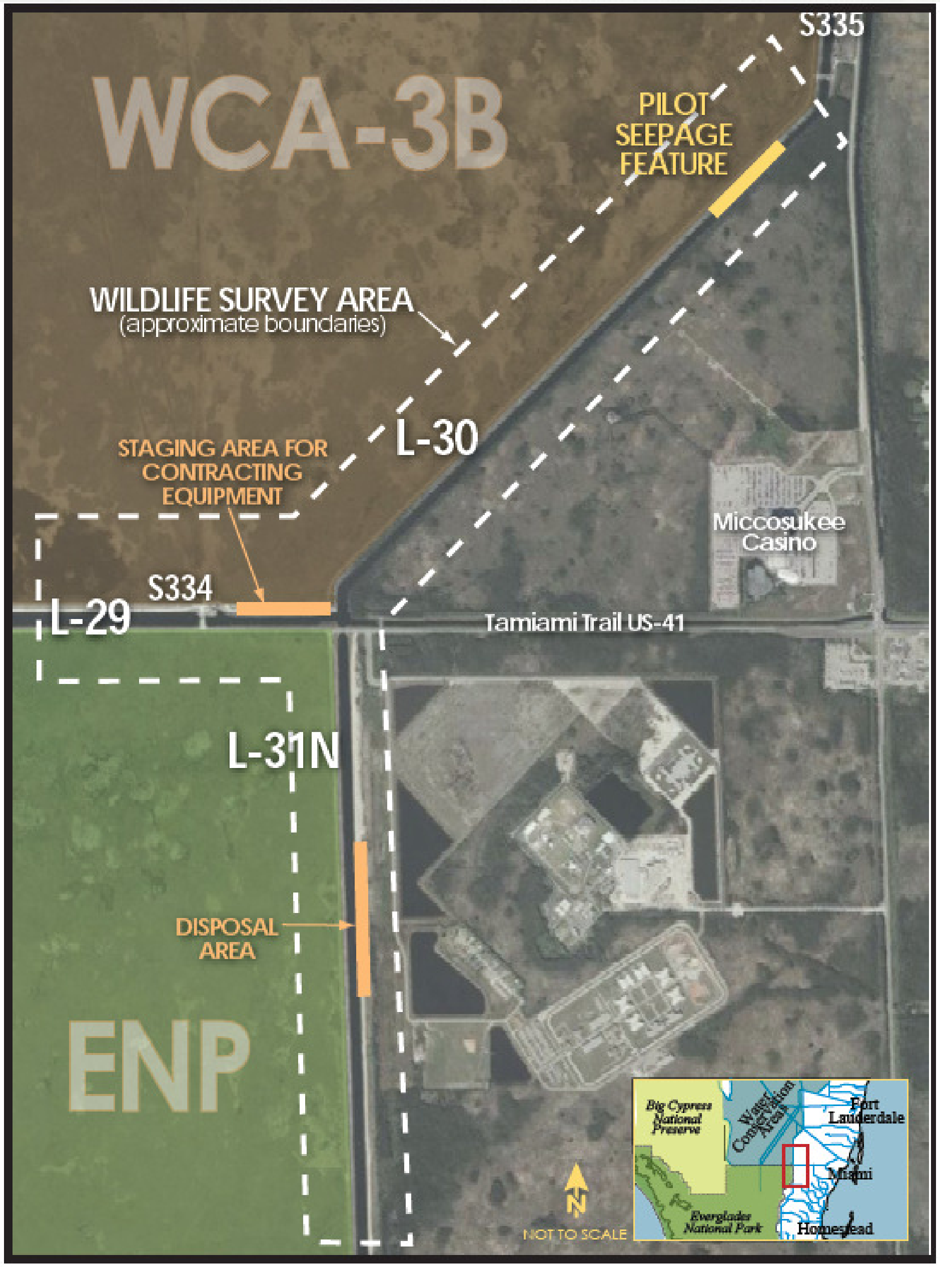


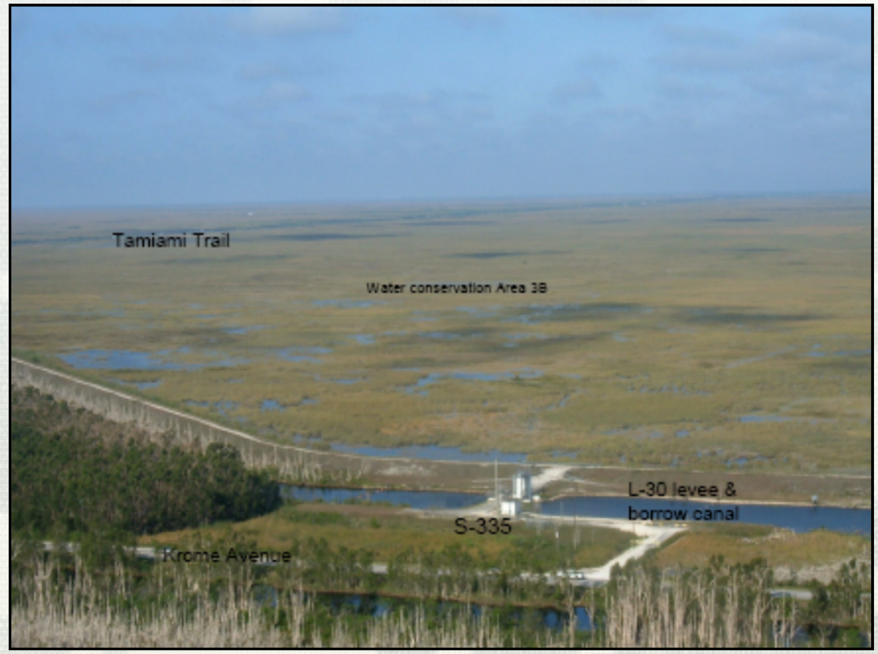
NATURAL SYSTEM (circa 1850)



MANAGED SYSTEM (1995 Landscape)

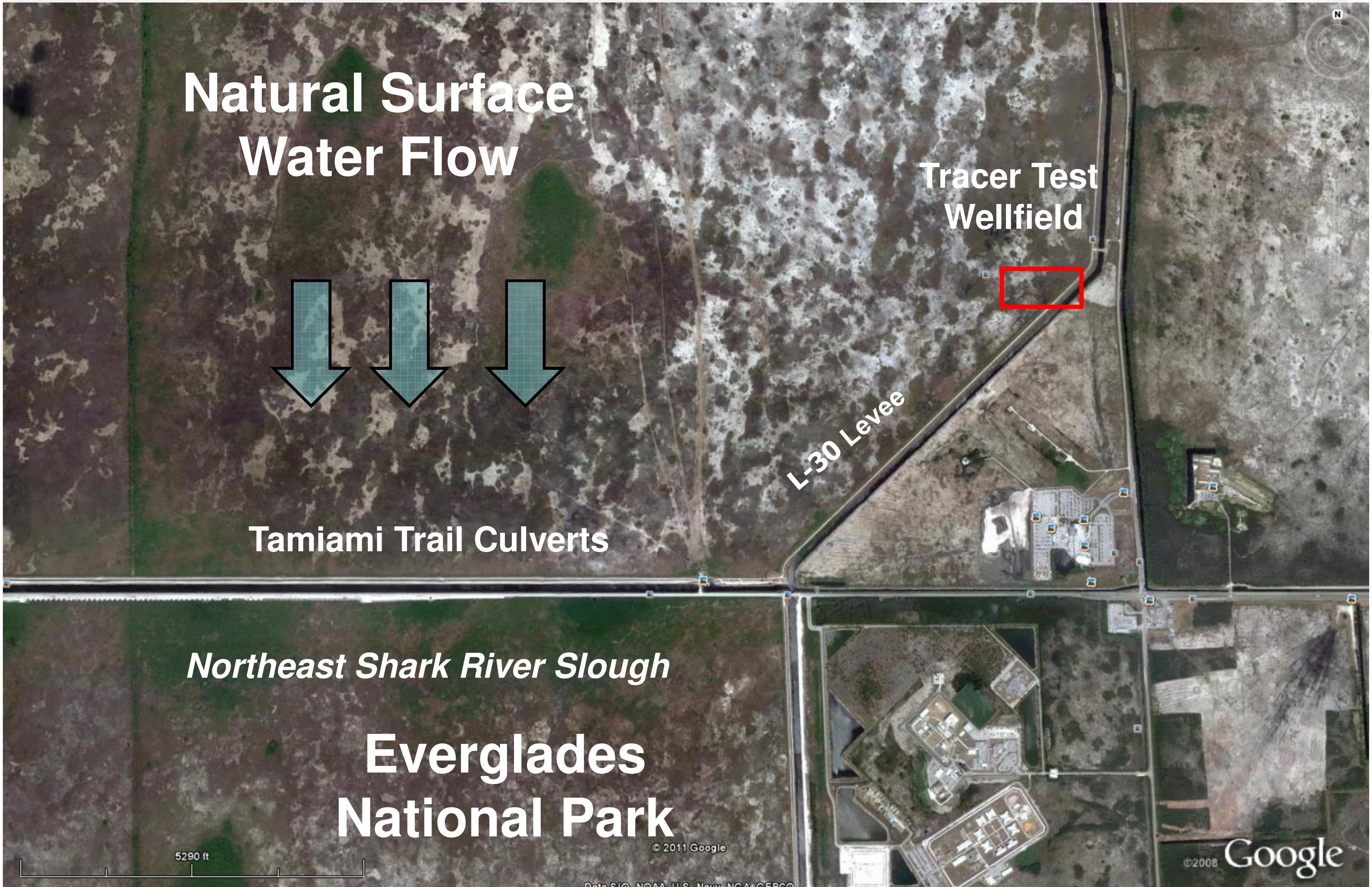
Seepage Management for Everglades Restoration





- **Maintain and increase groundwater levels to the west**
- **Improve hydroperiod in Everglades NP**
- **Keep high quality surface/ground water in ENP**
- **Maintain flood control protection as CERP projects increase surface and groundwater flows into ENP**
- **Seepage management using cut-off wall**

Hydrogeologic Conditions at the L-30 Test Site



Hydrogeologic Conditions at the L-30 Test Site

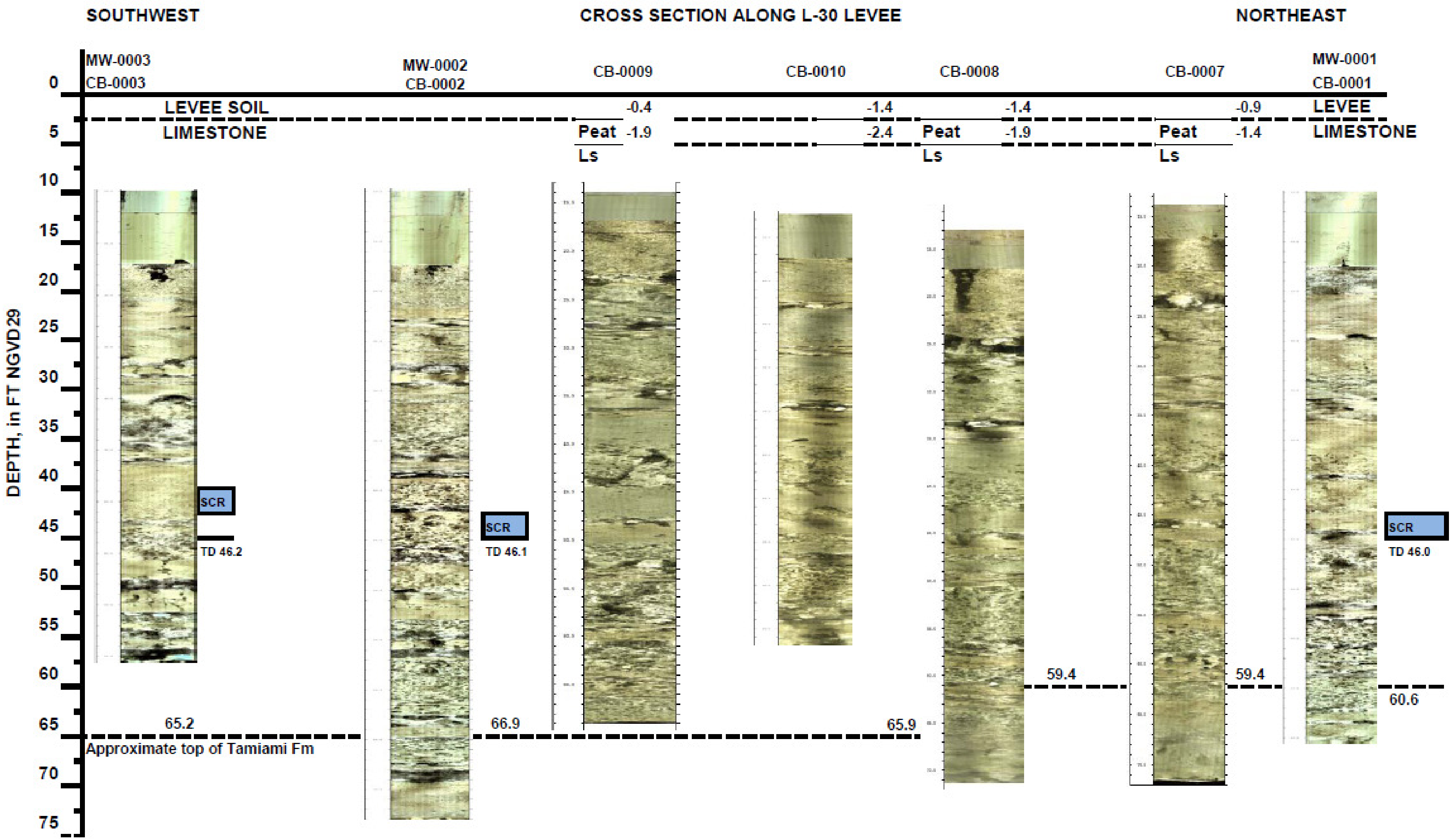
Hydrogeologic Characteristics of the Biscayne Aquifer

- Marine limestone karstic aquifer material
- Heterogeneous pore network
- Permeability values range over 13 orders of magnitude (Cunningham et al., 2011)
- Drinking water supply for 2.5M in Miami-Dade Co.

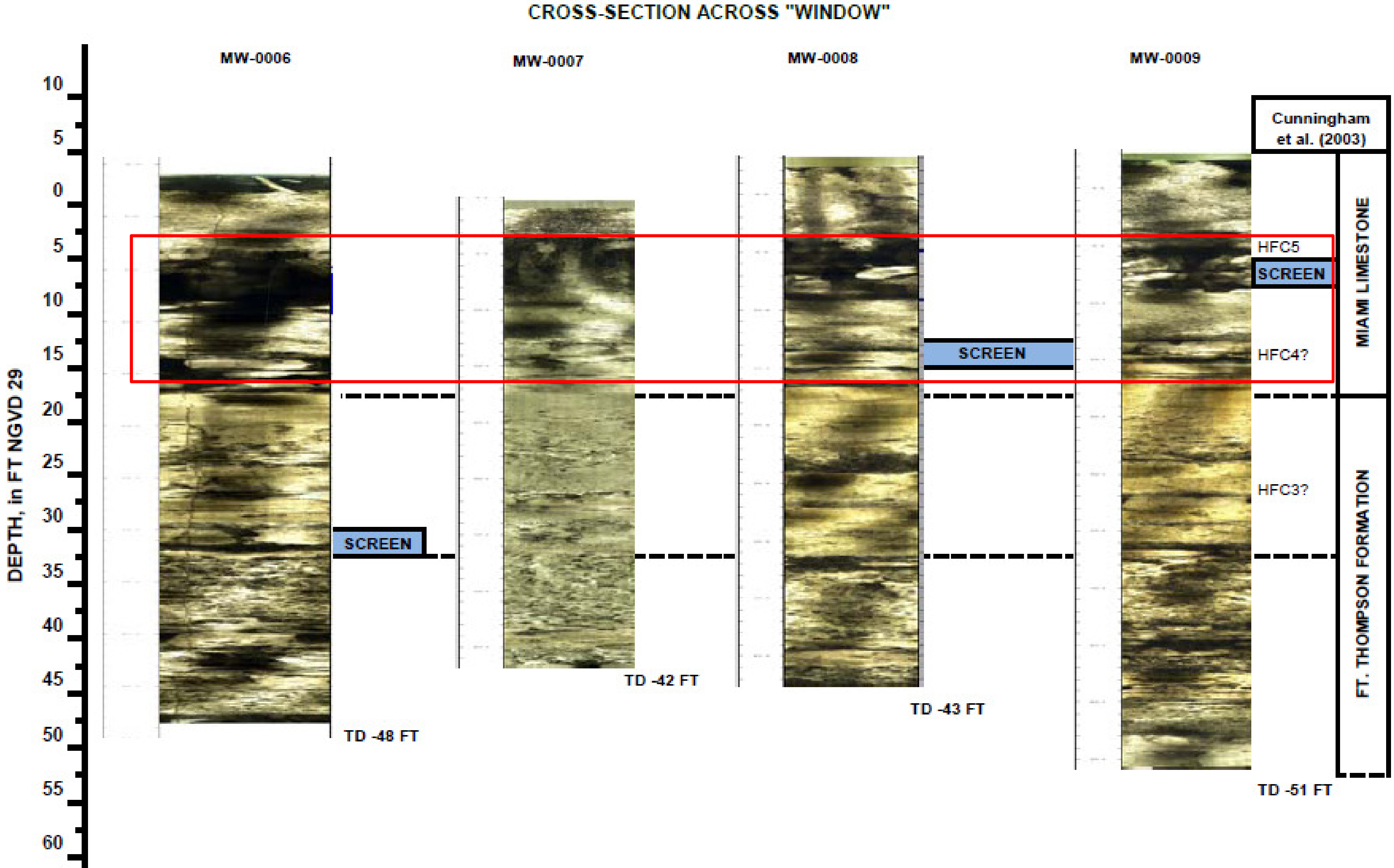
Photos from Cunningham and Sukop (2011) USGS OFR-1037

Hydrogeologic Conditions at the L-30 Test Site

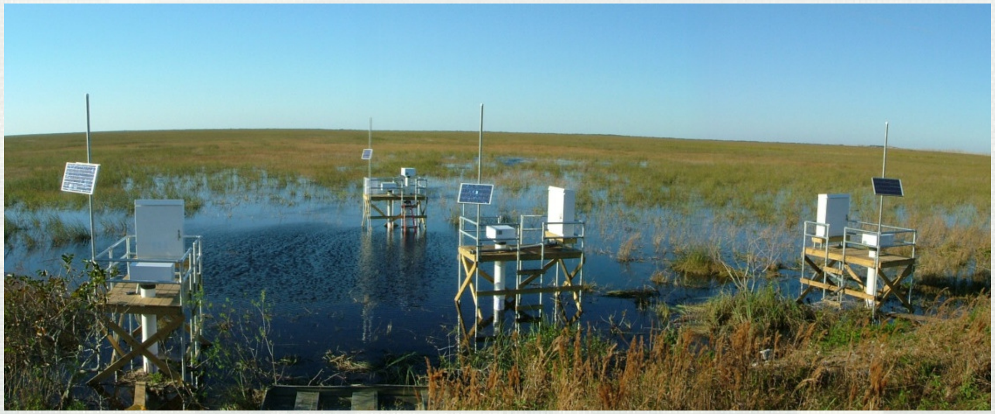
Fort Thompson Formation includes the Biscayne Aquifer



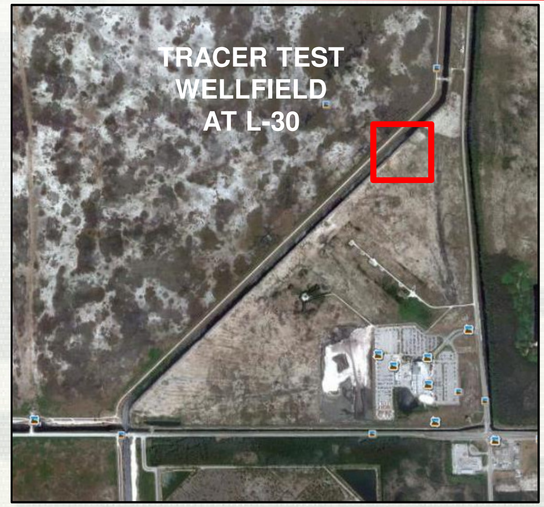
Optical Borehole Images in Wellfield Boreholes

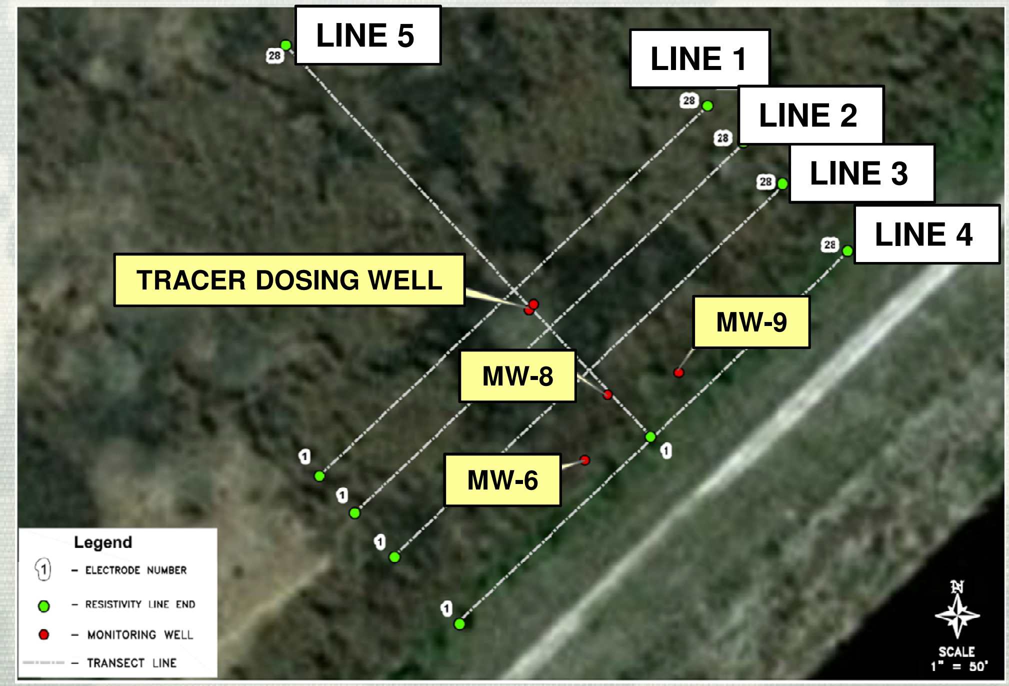


Instrumented Wellfield at the L-30 Test Site



Photograph courtesy Jim Brock, Rapid Creek Research





- Wells have 2-ft screen intervals at upper flow zones
- Hourly measurement of temperature, specific conductance, water level, flow velocity and flow direction
- Monitoring effort will compare wet and dry season conditions
- Resistivity transects superposed on the well field for test

Quantifying Groundwater Flow Velocity

Approaches

- **Numerical Groundwater Flow Model**

  Calculate Darcian (non-Darcian?) flow velocity

- **Heat-Pulse Borehole Flow Meters**

  Do FM velocities represent aquifer flows?

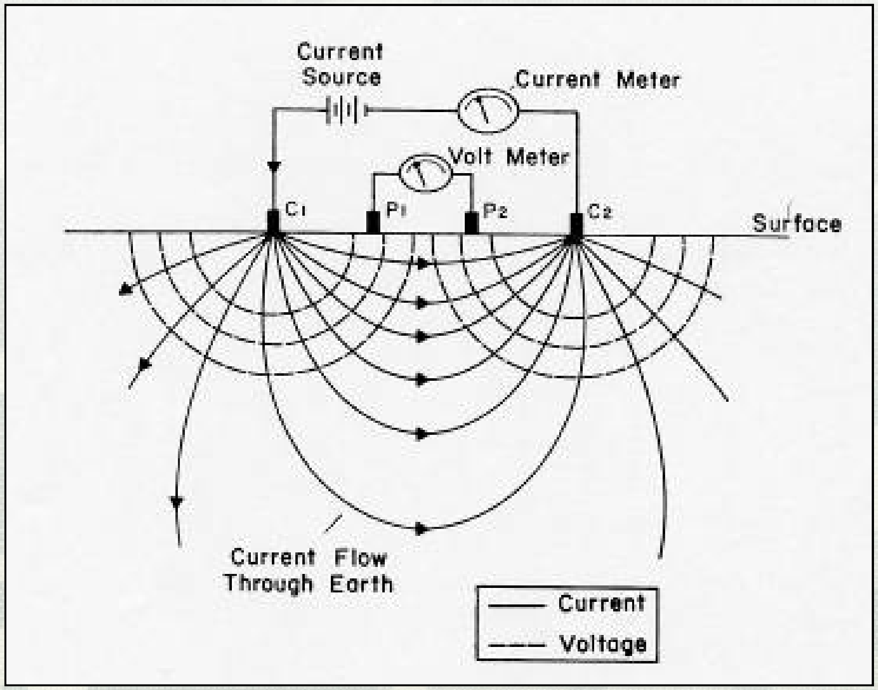
- **Tracer Tests using Bromide Tracer**

  Detecting breakthrough in down-gradient wells. Needle in a haystack?

  Resistivity survey provides better spatial resolution of ionic tracer transport

  Flow induced from dense saline tracer?

Electrical Resistivity



- Electrical Current injected through two current electrodes.
- Voltage drop is measured across potential electrodes.
- Electrode array is expanded to increase depth of penetration.
- Resistivity of formation/fluids measured in ohm-meters (Ω-m).
- Modern systems use many electrodes with automated switching.

Resistivity Survey Methods and Advantages

- Ionic Tracer (KBr) to provide resistivity contrast with fresh groundwater.
- Resistivity survey consists of 4 lines parallel to L-30, 1 line perpendicular. Tracer detected in X-Y-Z axes
- Each line is 270 ft long with electrodes every 10 ft.
- Resistivity contrast detected at full depth of Biscayne Aquifer (65 ft below land surface)
- Can be conducted in wet or dry conditions
- Rapid data collection: 4 lines surveyed in 1 hour
- Results can be viewed in field, so tracer detection frequency can be evaluated and modified

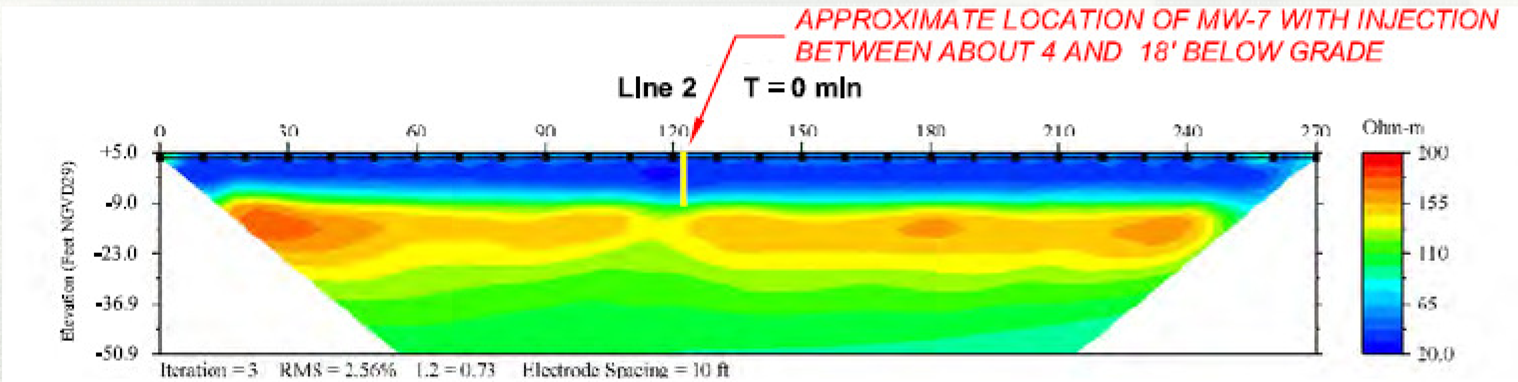
Field Work: May 2010 (wet) and April 2011 (dry)

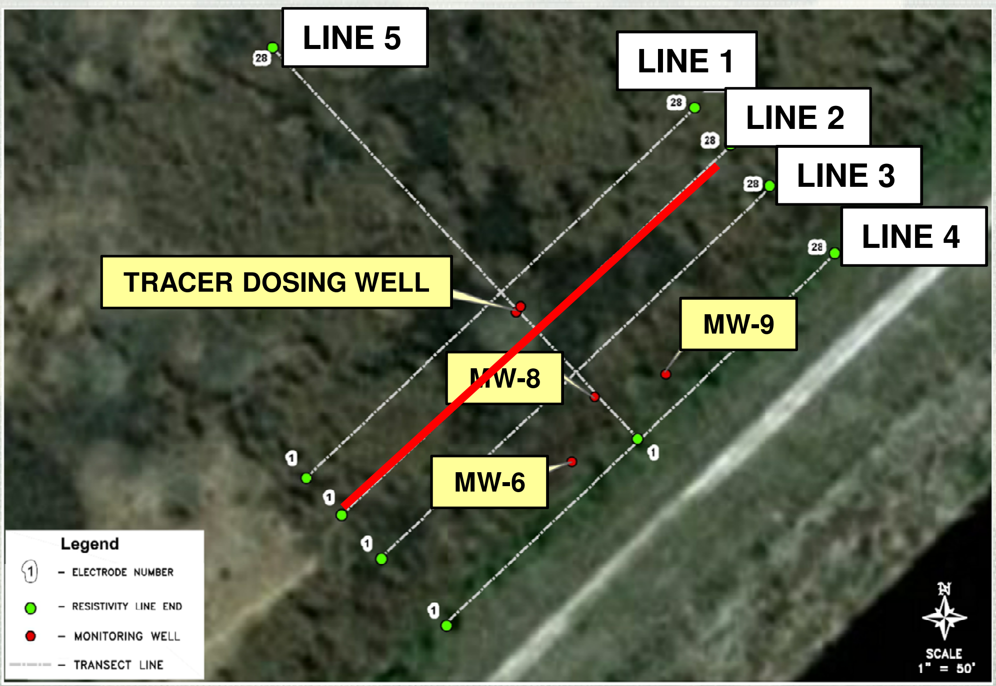
May 2010 Test: 50 lbs KBr in 100 gal potable water with 100 gal potable water chaser

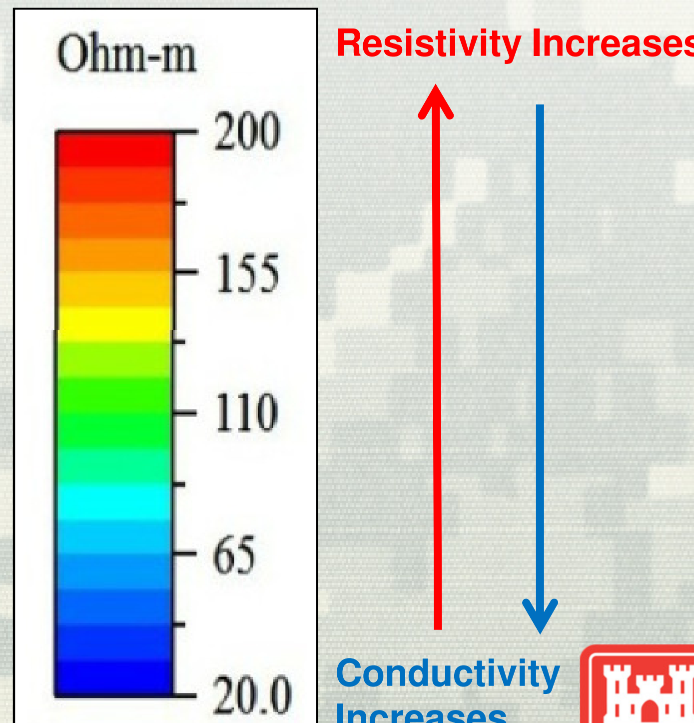
April 2011 Test: 500 lbs KBr in 500 gal potable water, with 500 gal potable water chaser

Dosing well open interval restricted with packer. Open interval at -0.89 to -12.09 ft NGVD

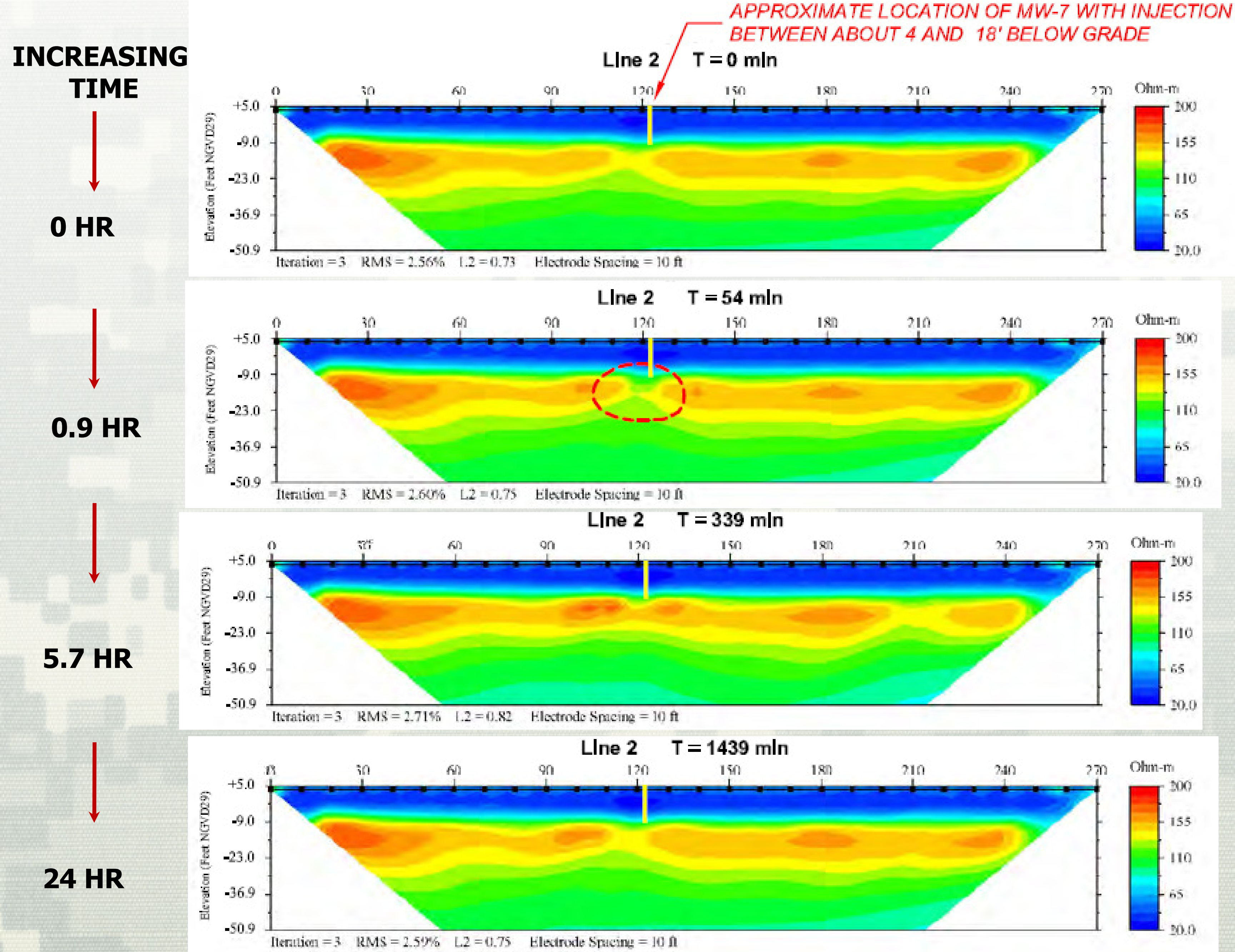
May 2010 Tracer Test Background Conditions: Line 2, Time 0 Before Tracer Dosing







INCREASING TIME



Results of the “Wet” Season Test (May 2010)

- **Resistivity changes are subtle from this tracer test**

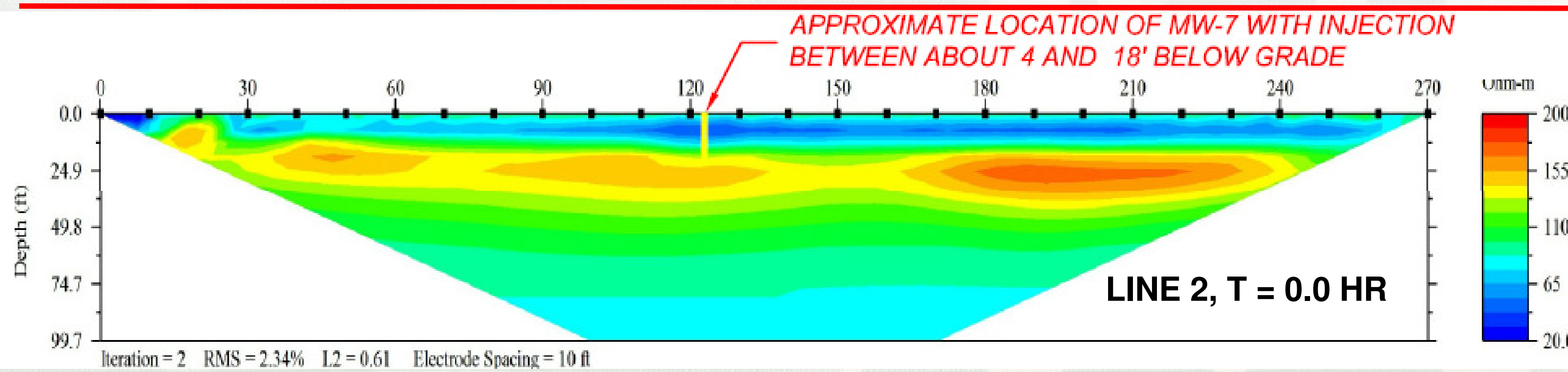
- **Resistivity reduction was observed only in Line 2 (10 ft from dosing well), 54 min after dosing.**

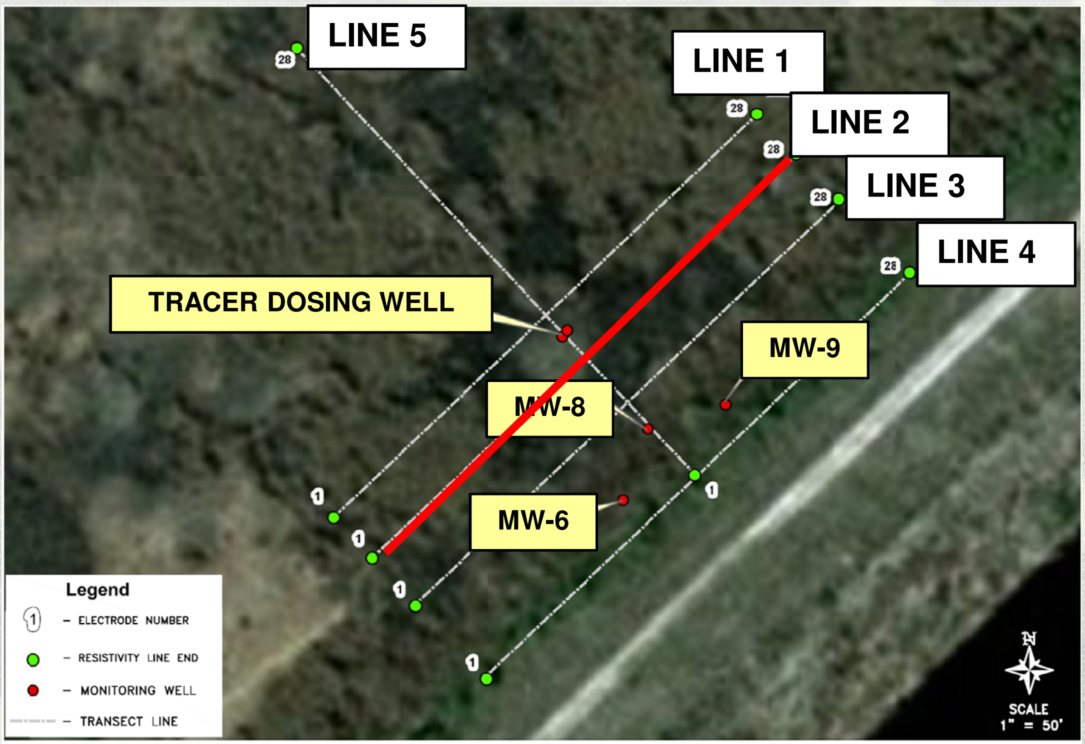
  Groundwater flow rate: 10 ft/0.9 hr = 266 ft/day

- **More subtle response appeared in Line 3 (35 ft from dosing well), 365 min after dosing.**

  Groundwater flow rate: 35 ft/6.1 hr = 138 ft/day
- **Test results suggest that the next experiment should have a larger volume dose of KBr tracer**

April 2011 Tracer Test Background Conditions: Line 2, Time 0 Before Tracer Dosing





- Experiment conducted under dry conditions (no surface water in WCA3B)
- Tracer dose increased in volume and concentration: 500 lbs KBr dissolved in 500 gal potable water, with a 500 gal potable water chaser

April 2011 Tracer Test:
Line 2, time 0 to 6 hours

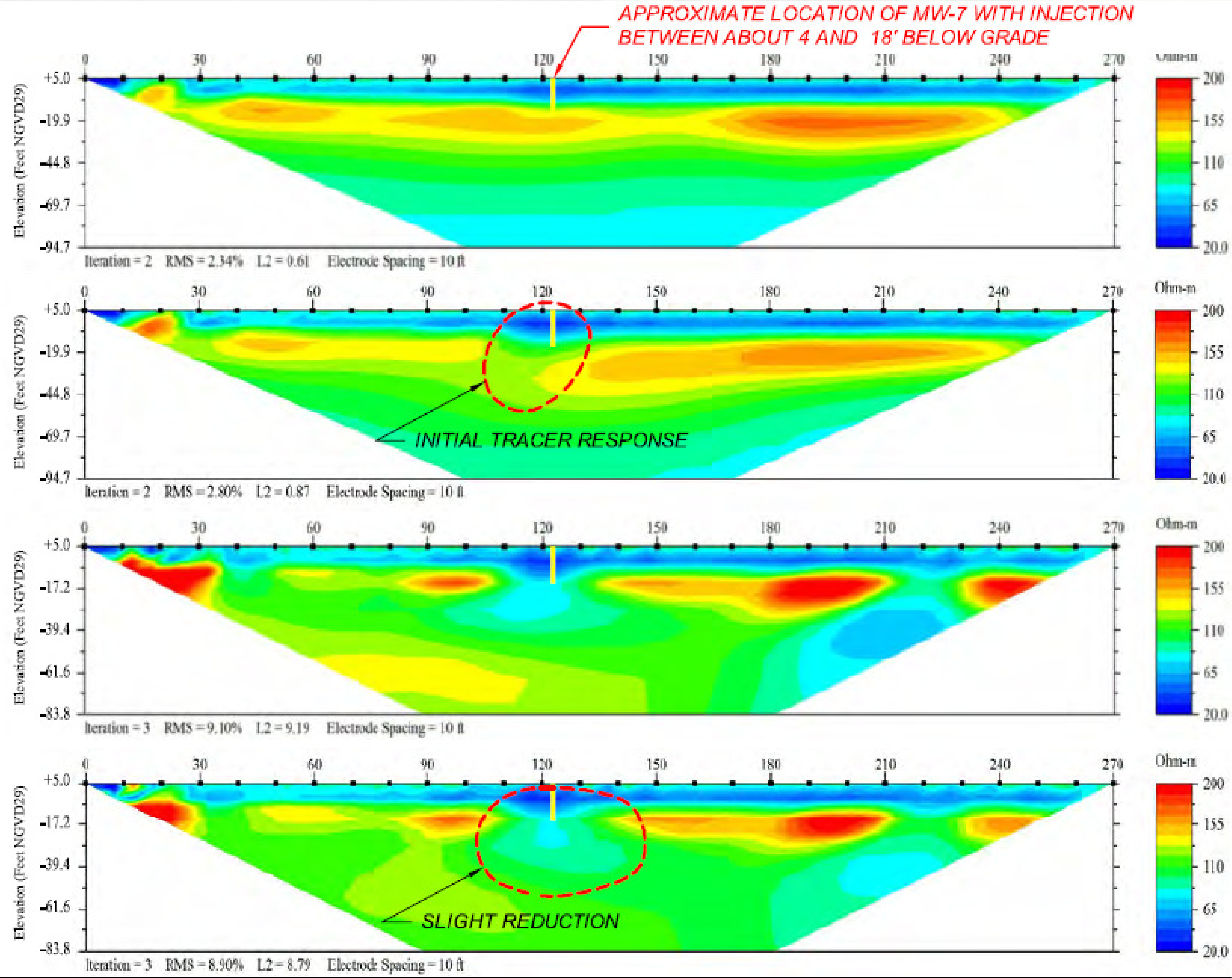
INCREASING TIME

0 HR

3.1 HR

5.1 HR

6.0 HR



April 2011 Tracer Test:
Line 3, time 0 to 8 hours

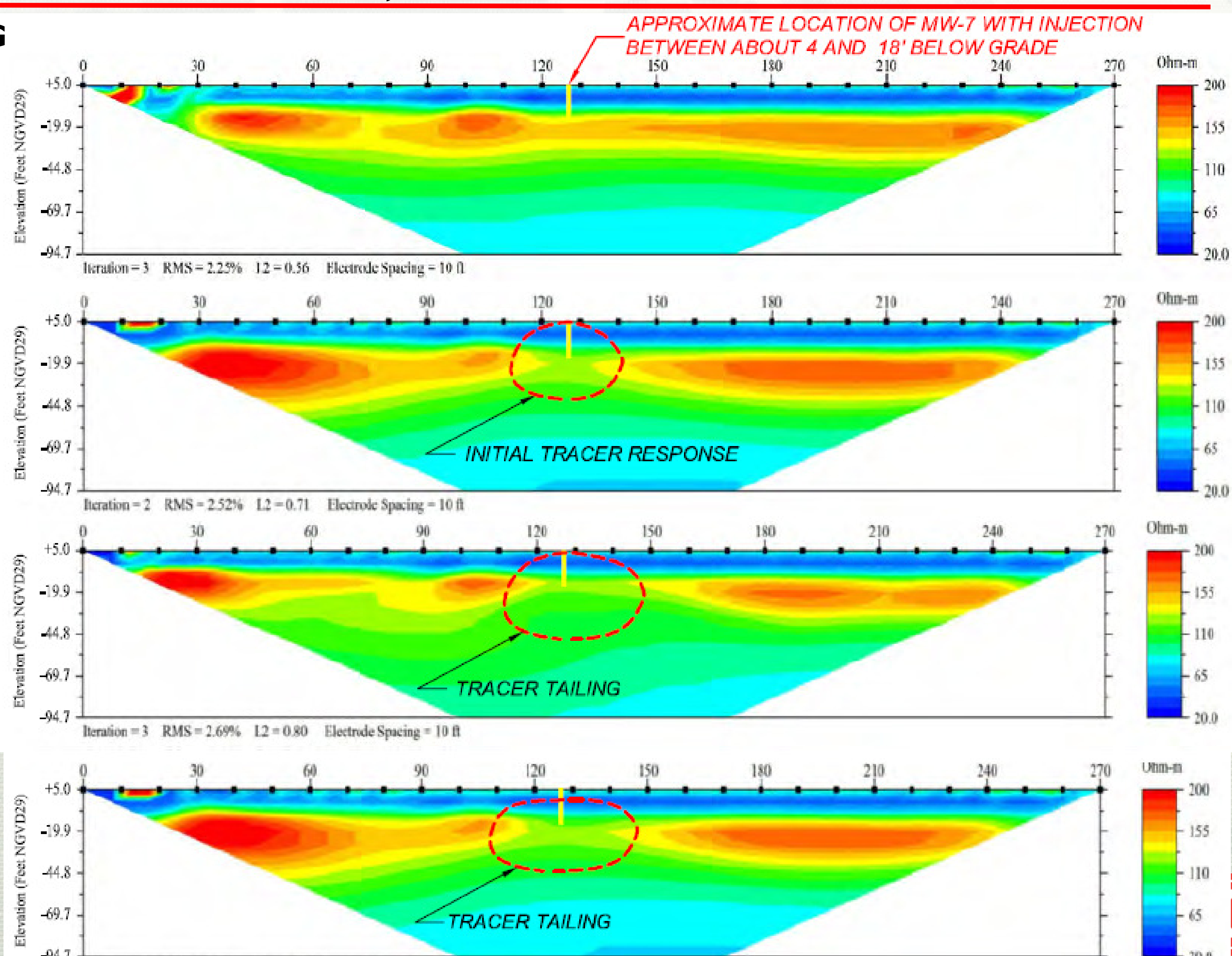
INCREASING TIME

0 HR

3.3 HR

6.2 HR

8.1 HR



Results of the "Dry" Season Test (April 2011)

- Resistivity changes are clearer in this tracer test due to increased frequency of resistivity measurements
- Maximum resistivity reduction was observed in Line 2 (10 ft from dosing well), 5.1 hr after dosing.

  Groundwater flow rate: 10 ft/5.1 hr = 47 ft/day
- More subtle response appeared in Line 3 (35 ft from dosing well), 5.3 hr after dosing.

  Groundwater flow rate: 35 ft/5.1 hr = 158 ft/day
- Some density effects observed. Tracer detected at 2.9 hours in upgradient Line 1.

How significant are density effects?

Archie's Equation relates electrical resistivity to porosity and brine saturation

Archie's Equator: $R_W = ø^M R_O$ $R_W = .3^2 R_O$ $R_W = .09 R_O$

Ø = porosity = 20 – 70% use 0.3 for Biscayne

M = cementation factor ≈ 2 Ranges from ≈ 1.3 to 2.0

R_O = Saturated Formation Resistivity

Line	$R_{O\ (min)}$	R_W (Ωm)	S.C. (µS/cm)	ppm**	K_3/M^3*** Density at 25°C
1	65	5.9	1,700	830	997.7
2	80	7.2	1,400	690	997.6
3	105	9.5	1,100	540	997.5
5	112	10	1,000	490	997.4
MW-8	720 µS/cm	14	720	350	997.3
MW-6	580 µS/cm	17	580	280	997.3
Seawater				30,000	1,019.6

1 µS/cm = 10,000 Ωm = 0.0001 mho/m

Results and Interpretations

- April 2011 test data is interpreted as the best representation of solute flow through the Biscayne Aquifer. Groundwater flow rates are estimated as:

  Line 2 is 48 ft/day

  Line 3 is 158 ft/day
- Multiple 2-D resistivity transects enable 3-D definition of tracer distribution and transport
- Maximum depth of tracer approximately -35 ft NGVD29

Questions ?

For more information see
http://www.evergladesplan.org

With Thanks

David Hire and Joshua Epting, Cardno ENTRIX

Jim Brock, Rapid Creek Research, Inc.

Steve Krupa, South Florida Water Management District