New Methods for Hydraulic Characterization of Mine Waste and Cover System Materials

Jason Keller, Tzung-Mow Yao, Michael Milczarek, Dale Hammermeister and Robert Rice

With special thanks to Dirk van Zyl, Barrick Gold, Freeport McMoRan and BHP Billiton Base Metals

GSA GeoSystems Analysis, Inc.
Arizona • Nevada • Oregon

Overview

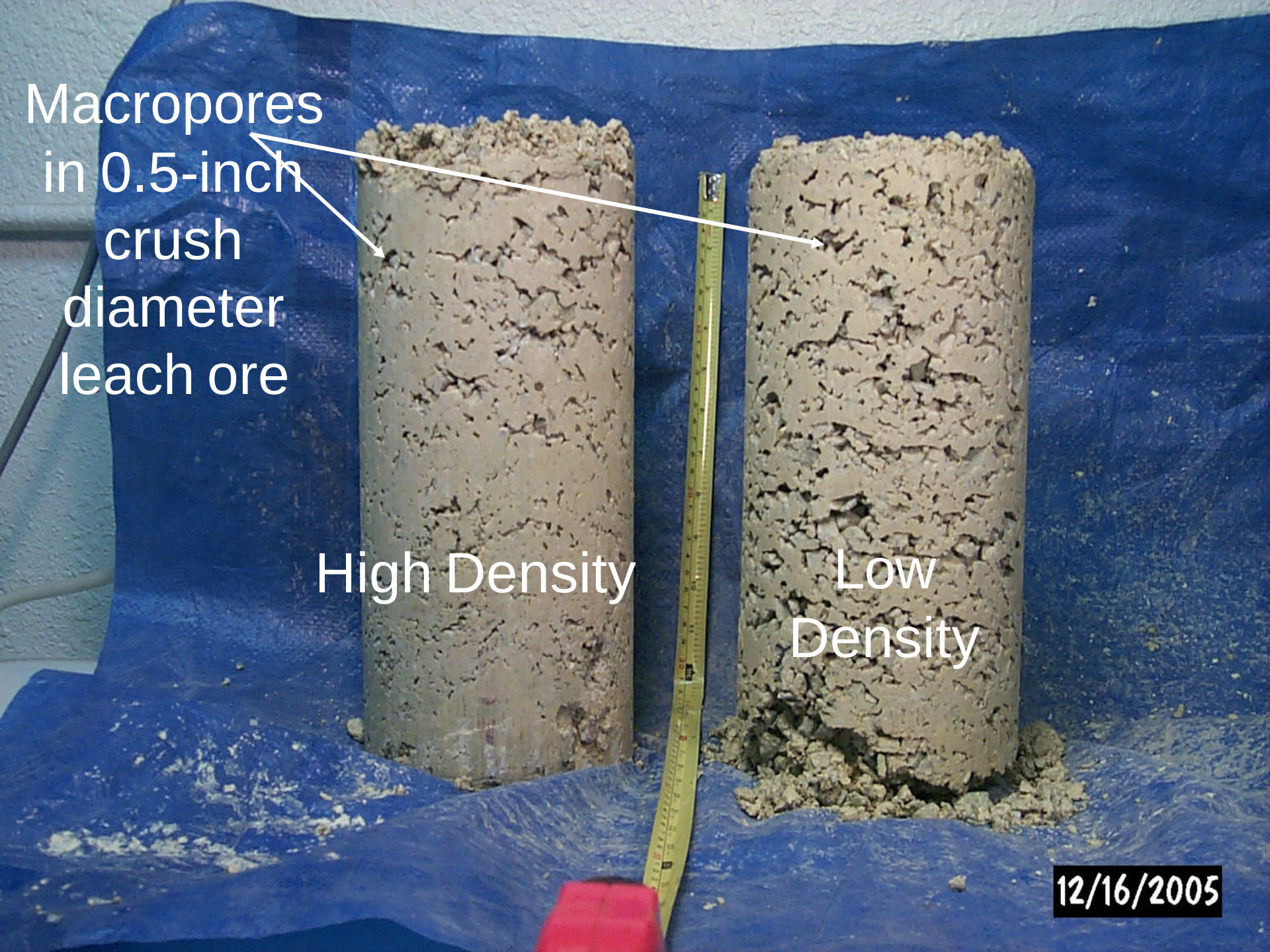
- Background review on hydraulic testing
- Review of new hydraulic tests
- Experiment with leach ore sample:
- Results
  - Data from 30 cm (12-inch) diameter core with new test methods vs 5 cm (2-inch) core traditional test method
  - Model predictions
    - HYDRUS 1D
    - MACRO 5.0 (includes macroporosity)

GSA GeoSystems Analysis, Inc.
Arizona • Nevada • Oregon

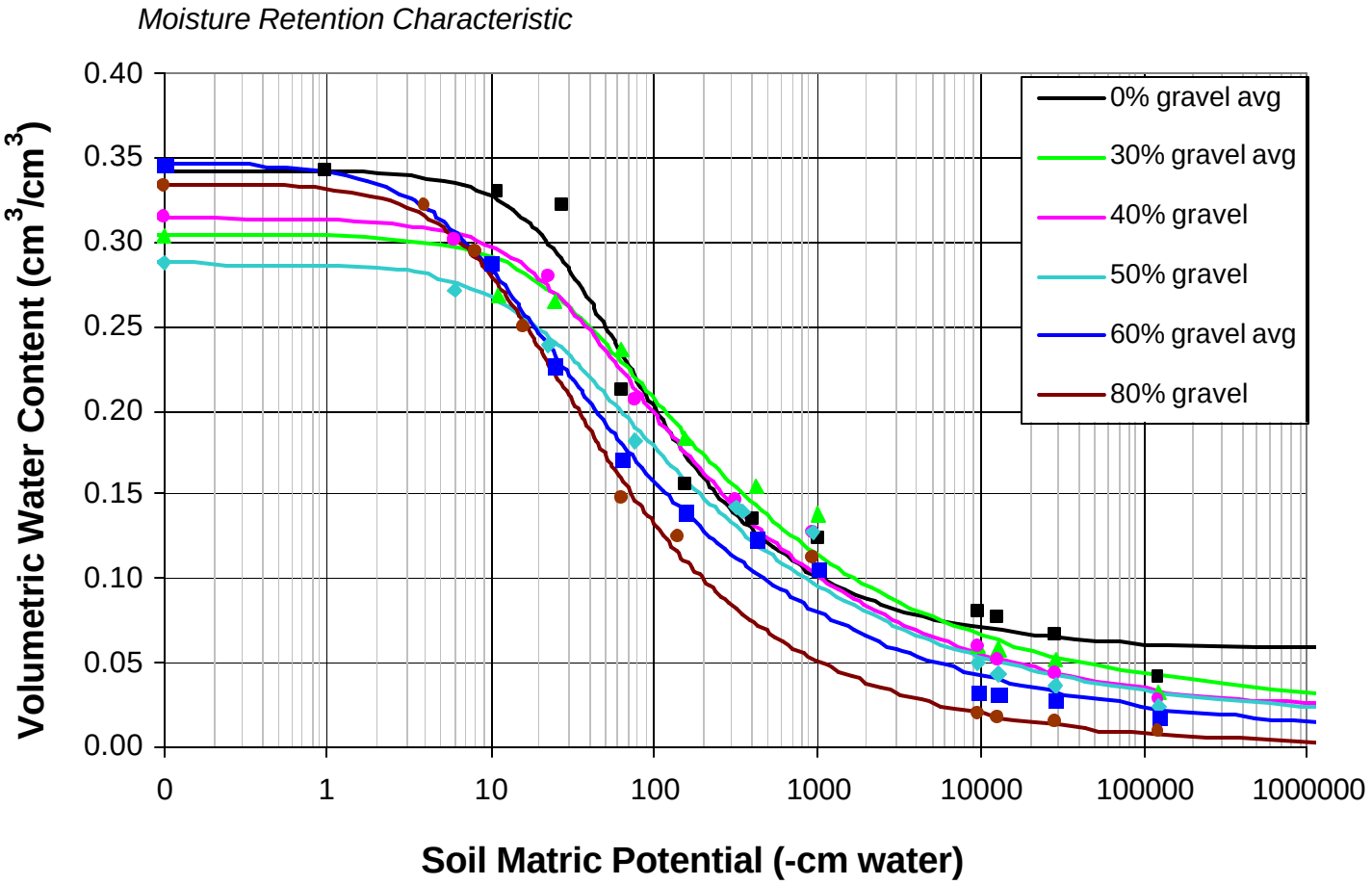
Background

- Mine materials have lots of rocks…….
- Presence of rock/gravel affects flow properties
  - Small amounts act as barriers to flow
  - Large amounts can create macropores = preferential flow
- Current laboratory methods were not designed for gravelly materials
  - Based on agricultural or well engineered soils
  - Remove rocks from sample, use correction factors
  - Theoretical assumptions for data analysis can be invalid
  - Macropore flow has been observed even in agricultural soils (>-4 cm)

GSA GeoSystems Analysis, Inc.
Arizona • Nevada • Oregon

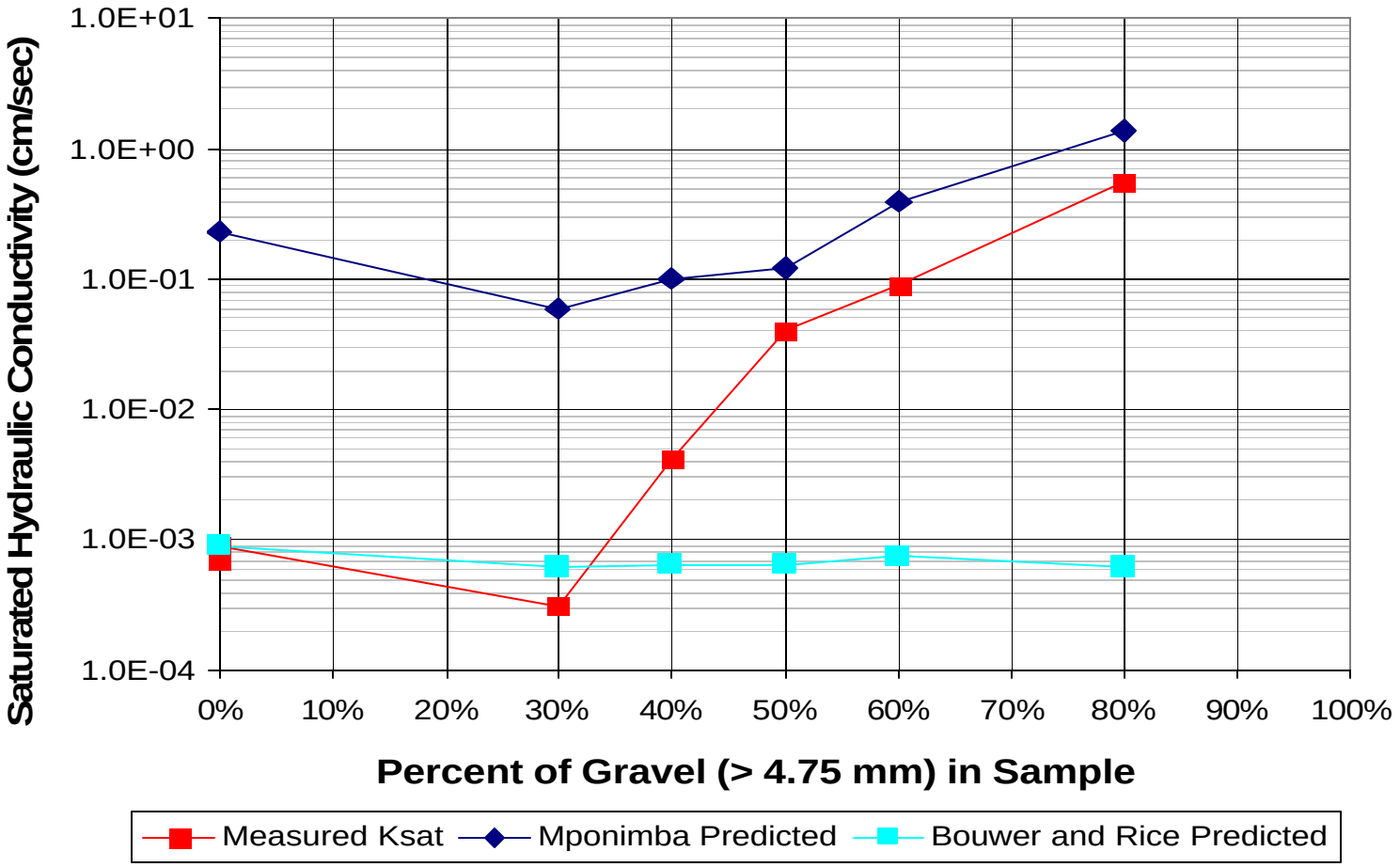

Macropores in 0.5-inch crush diameter leach ore
High Density
Low Density
12/16/2005

Removing Gravel from Samples Can Give Very Different Results



GSA GeoSystems Analysis, Inc.
Arizona • Nevada • Oregon

Correction Factors?



GSA GeoSystems Analysis, Inc.
Arizona • Nevada • Oregon

Why is This Important?

- We build models to design for closure:
  - Estimate heap leach draindown
  - Estimate cover performance
  - Estimate water balances
- Consequences can be costly
  - Oversize/undersize water treatment
  - Excess infiltration/deep percolation
  - Underpredict water holding capacity of waste
  - Underpredict drainage response to storm events
- Need to develop cost-effective methods that will:
  - Be representative
  - Truly define Unsaturated flow characteristics

Obstacles

- Accurate soil water retention measurements in gravelly samples are difficult
  - Near saturation, moderate and dry tensions need different measurement methods
  - Big changes in flow with small changes in water content at wet range
  - Impossibly slow water movement in moderate tension to dry range (test could last for months to years)
- Cost and robustness
  - Large sample sizes needed for representativeness
  - Large columns (i.e. heap leach) columns are very expensive
  - Scaling of columns to larger systems

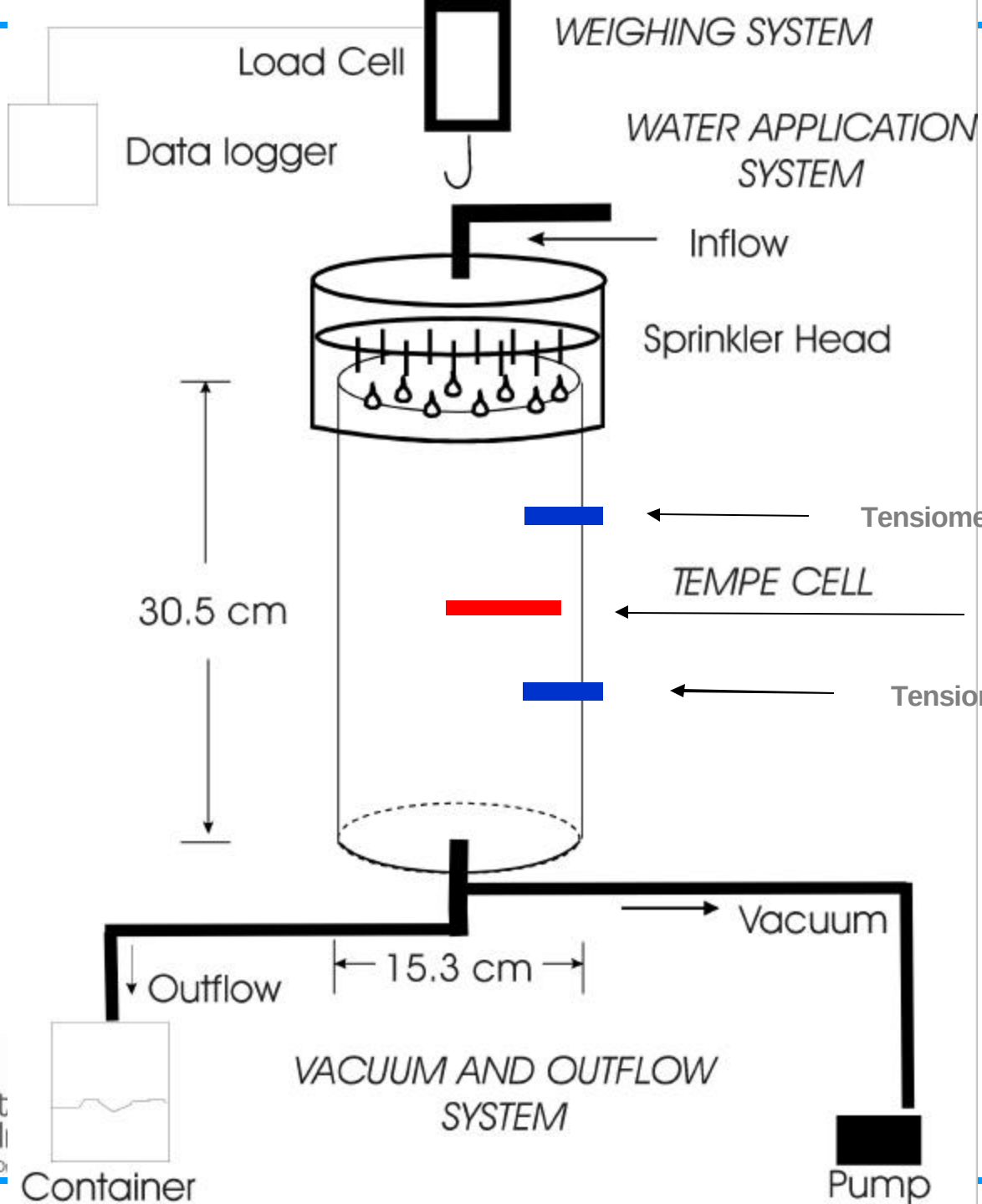
New Hydraulic Testing Methods

1. Review PSD data to determine the core diameter needed
   - Do not remove more than 20% of sample
   - 19 mm (0.75 inch) max particle diameter for 15 cm (6-inch) diameter core (8X)
   - 38 mm (1.5 inch) max particle diameter for 30 cm (12-inch) core (8X)
2. Pack and instrument large diameter cores with water content (ECH_2O) and tensiometer sensors
3. Conduct laboratory measurements for:
   a. Unsaturated irrigation at 10^{-3}, 10^{-4} and 10^{-5} cm/sec
   b. Allow 3 to 5 day drainage periods between irrigation cycles
   c. Saturated hydraulic conductivity
   d. Measure soil water retention characteristics
      i. Hanging column and Tempe cell for wet and moderate tensions
      ii. Chilled mirror for dry points

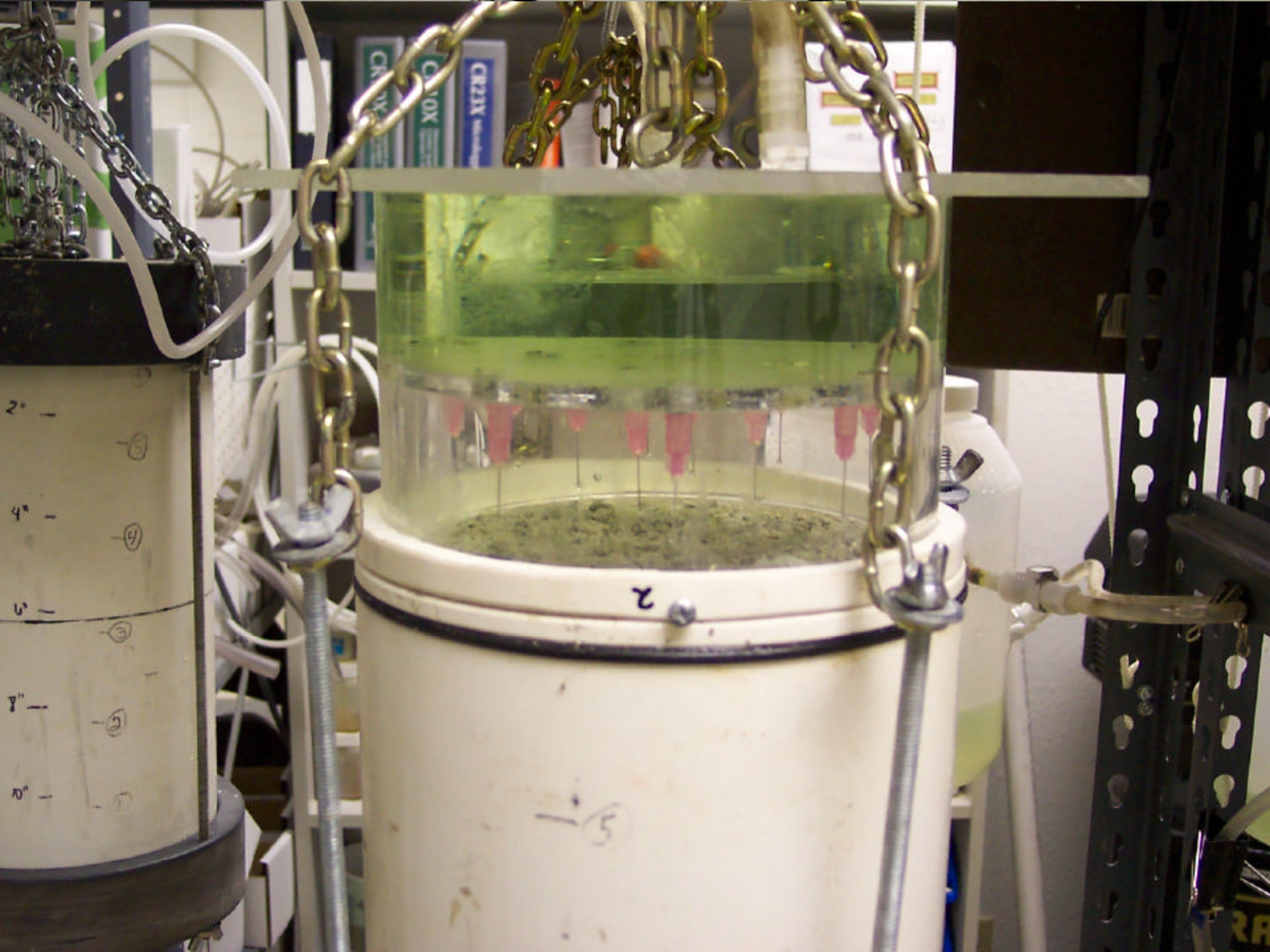
GSA GeoSystems Analysis, Inc.
Arizona • Nevada • Oregon

New Hydraulic Testing Methods

GSA GeoSystems Analysis, Inc.
Arizona • Nevada • Oregon


WEIGHING SYSTEM
Load Cell
Data logger
WATER APPLICATION SYSTEM
Inflow
Sprinkler Head
Tensiometer
TEMPE CELL
ECH20 Water Content Sensor
30.5 cm
Tensiometer
Vacuum
Outflow
15.3 cm
VACUUM AND OUTFLOW SYSTEM
Container
Pump


ECH2O EC-5



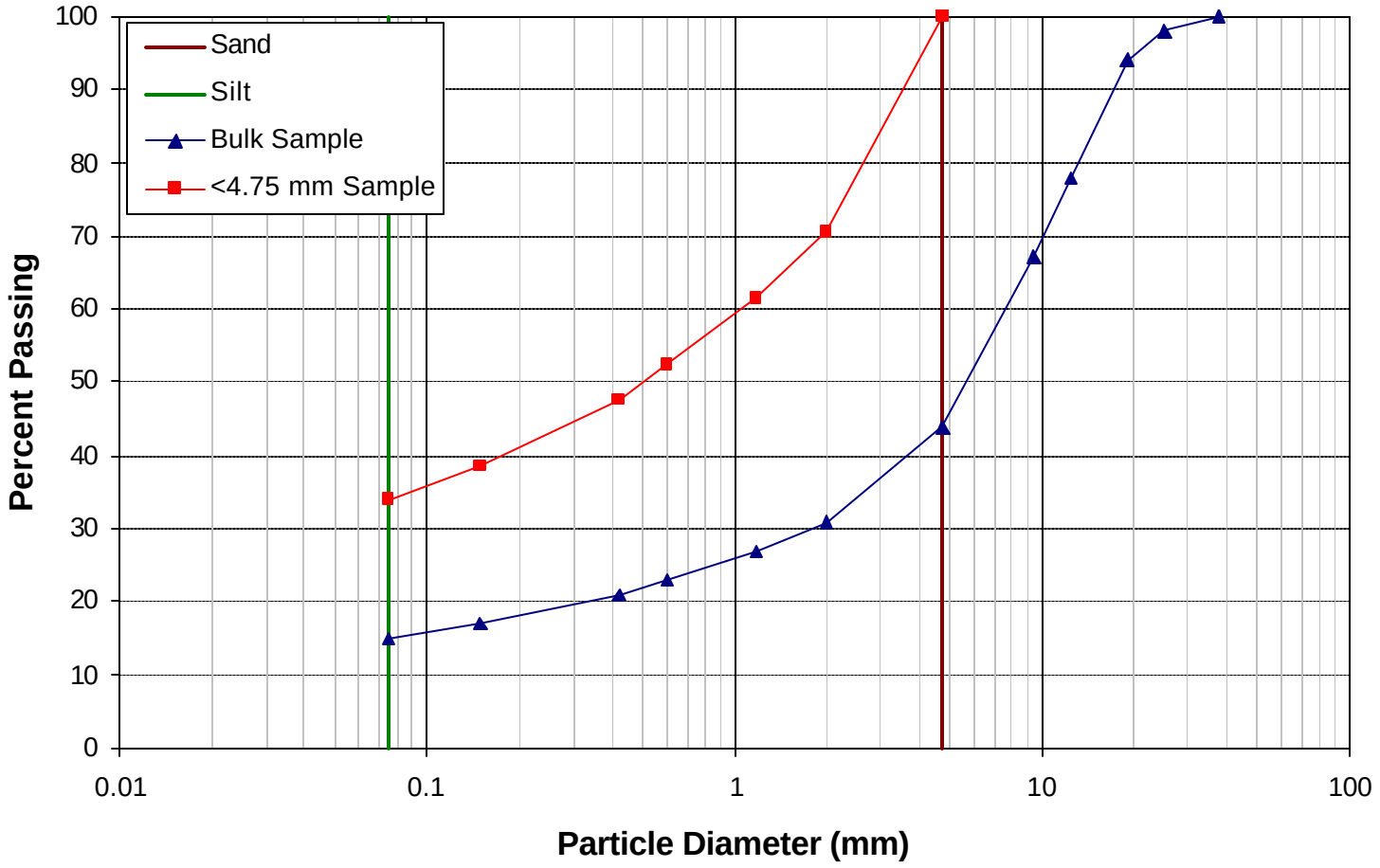
GSA GeoSy Analysis
Arizona • Nevada

Characterization Experiment

GSA GeoSystems Analysis, Inc.
Arizona • Nevada • Oregon

- Waste rock sample
  - Crushed - 80% passing 13 mm (1/2–inch)
  - 55% gravel
  - Relatively well graded below #4 mesh

Sample Particle Size Distribution



GSA GeoSystems Analysis, Inc.
Arizona • Nevada • Oregon

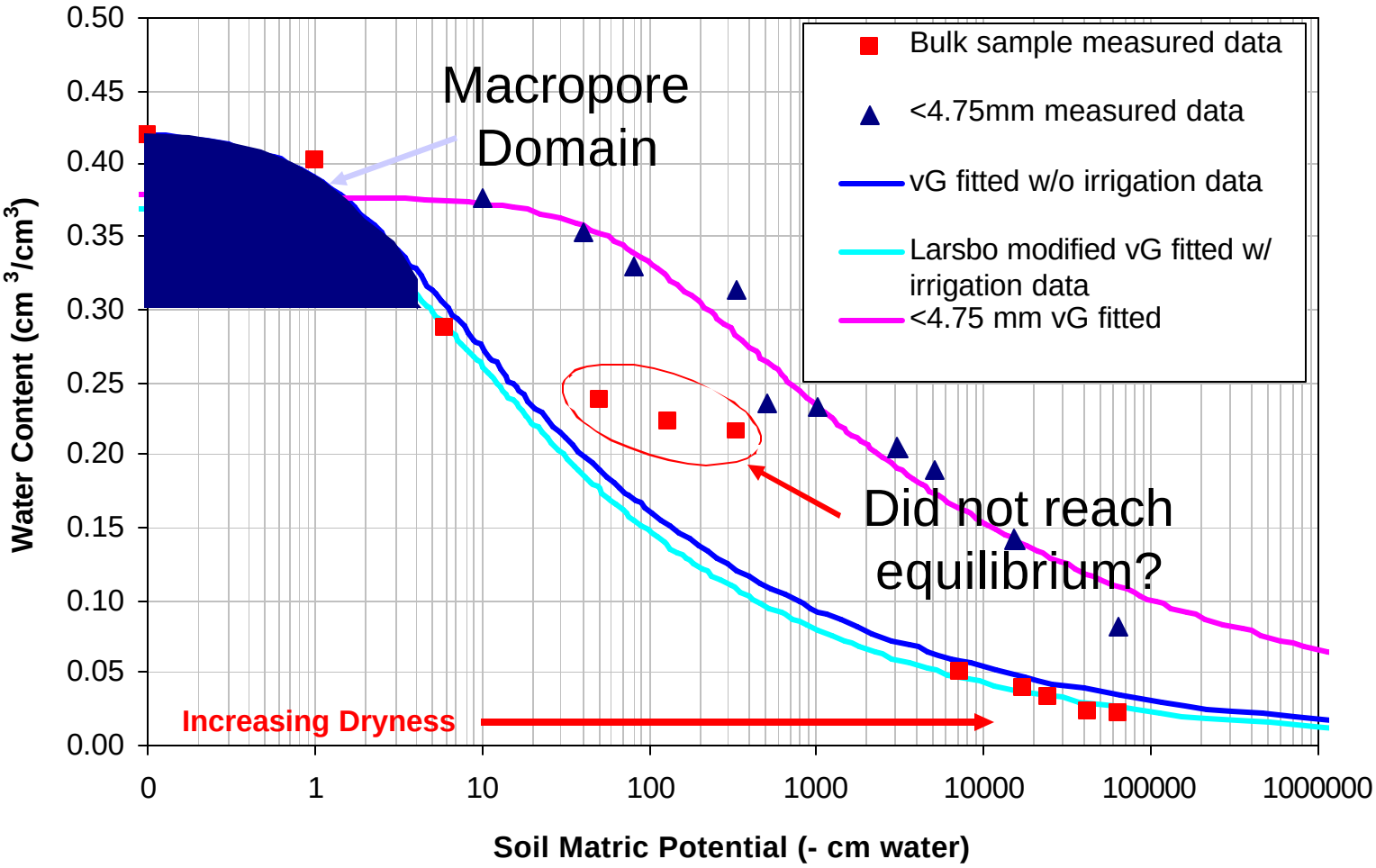
Experimental Design

- 12-inch diameter column, measure:
  - Saturated hydraulic conductivity
  - Water content and tension at known hydraulic conductivity (irrigation experiments)
  - Soil water retention characteristics (water content vs tension)
  - Chilled mirror for dry points
- Outside laboratory
  - Measure saturated hydraulic conductivity in 8-inch diameter cores
  - Soil water retention characteristics in 2-inch diameter cores (screen samples)
- Model results using:
  - HYDRUS-1D (van Genuchten)
  - MACRO 5.0 (Larsbo)
    - Assumes matrix flow follows van Genuchten
    - Macropore flow is kinematic wave
    - Define macropores as region between saturation and -4 cm

Experimental Results

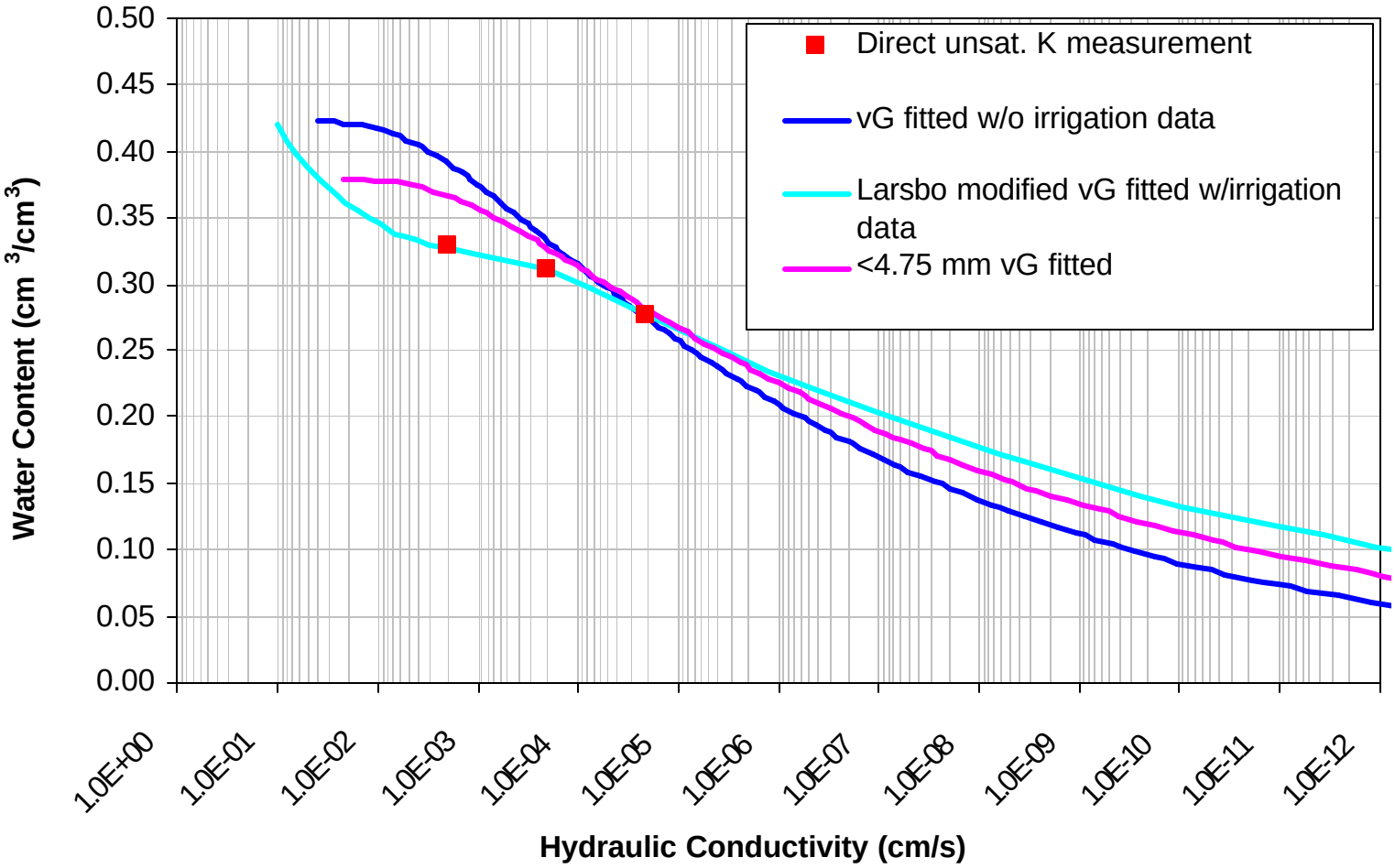
GSA GeoSystems Analysis, Inc.
Arizona • Nevada • Oregon

Soil Water Retention Characteristics



GSA GeoSystems Analysis, Inc.
Arizona • Nevada • Oregon

Hydraulic Conductivity

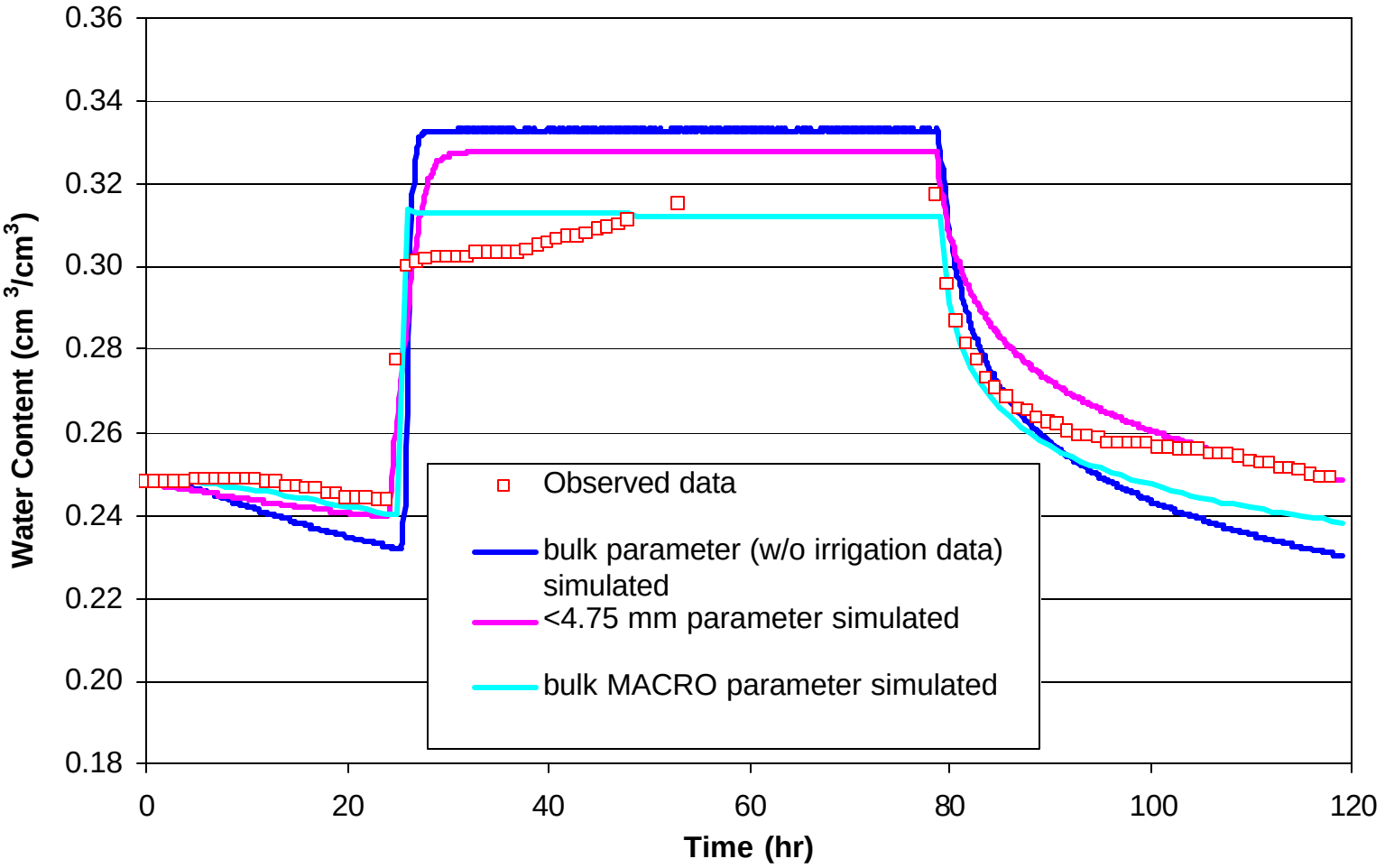


GSA GeoSystems Analysis, Inc.
Arizona • Nevada • Oregon

Modeled Results

GSA GeoSystems Analysis, Inc.
Arizona • Nevada • Oregon

Simulated Water Content

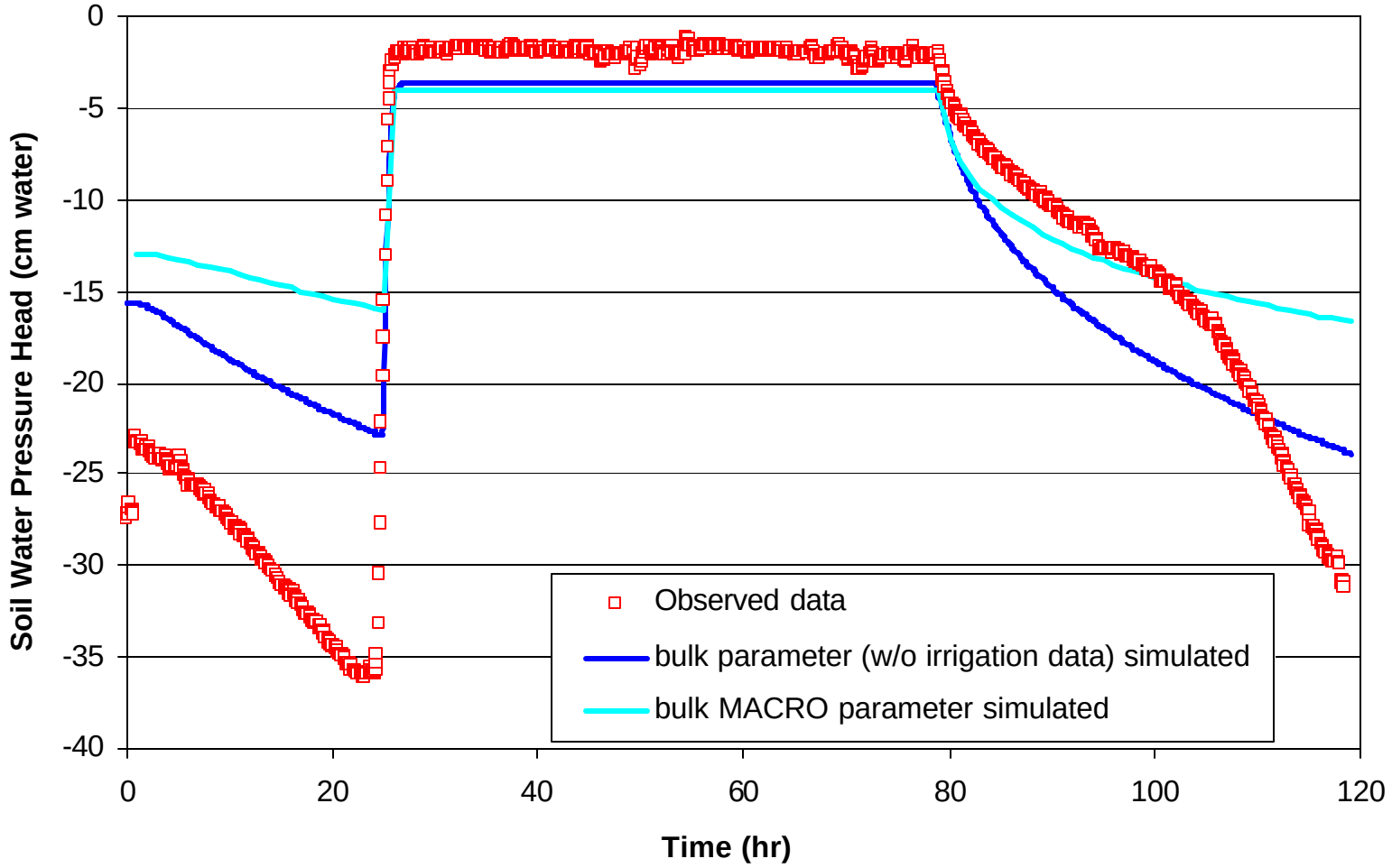


GSA GeoSystems Analysis, Inc.
Arizona • Nevada • Oregon

Is the 2-inch Core Data Really That Good?

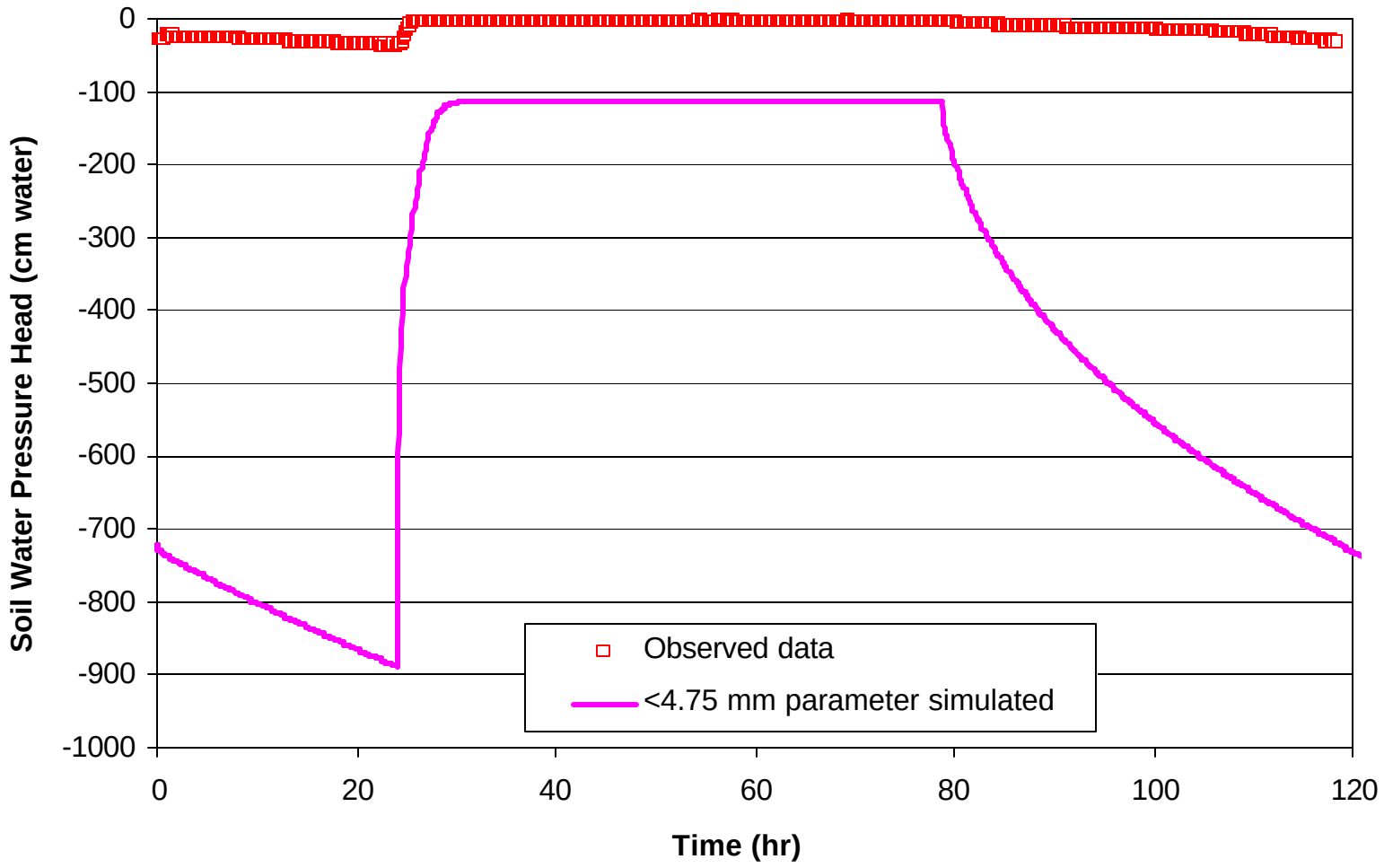
GSA GeoSystems Analysis, Inc.
Arizona • Nevada • Oregon

Bulk Parameter Simulated Pressure Head



GSA GeoSystems Analysis, Inc.
Arizona • Nevada • Oregon

<4.75 mm Parameter Simulated Pressure Head



GSA GeoSystems Analysis, Inc.
Arizona • Nevada • Oregon

Dual Wall Ksat and Kunsat

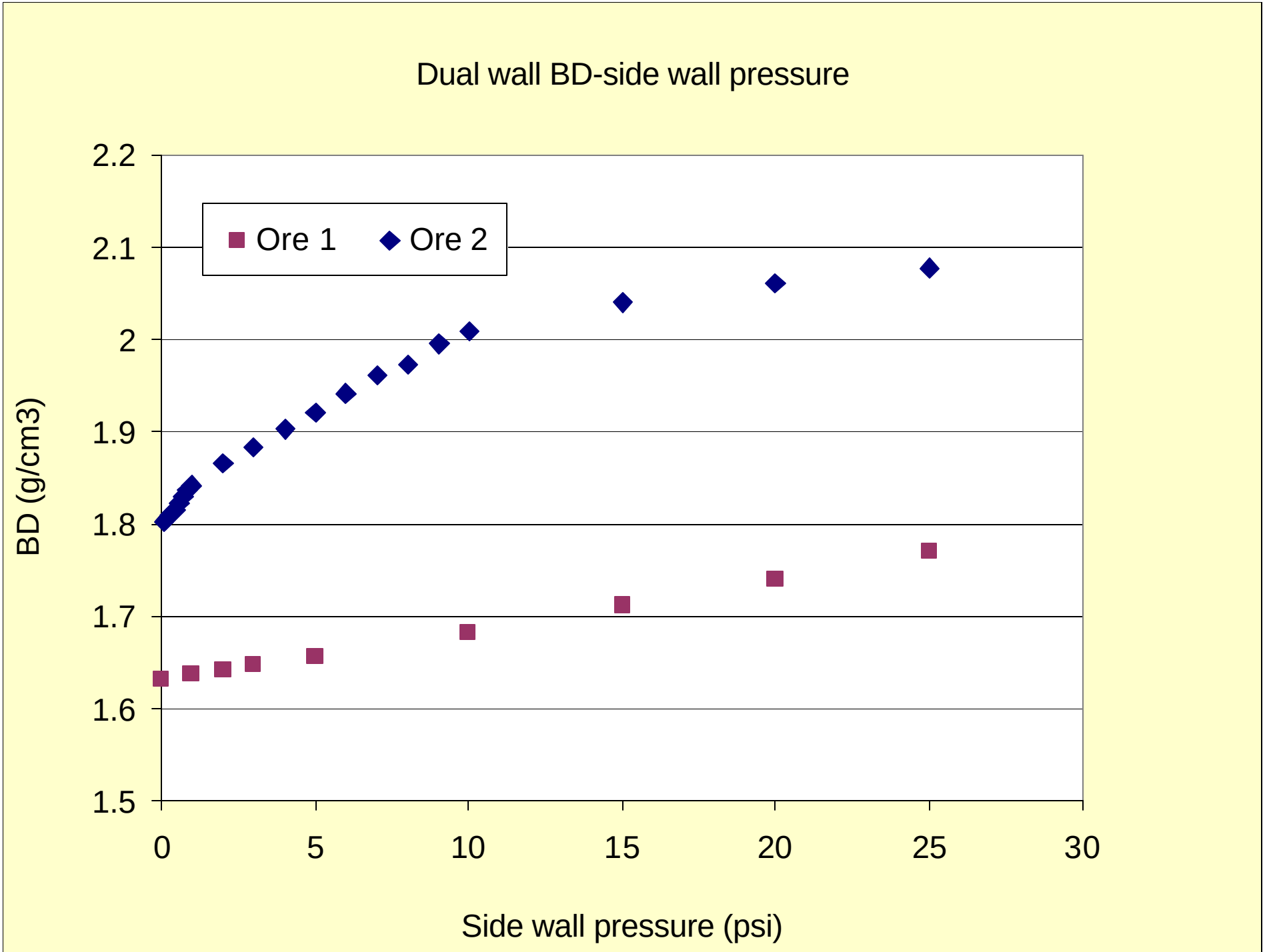
- The purpose of developing the dual wall testing device and protocols are:
  - To minimize the edge effect between test material and rigid wall
  - To enable different tests in one flow cell, thus less samples needed
  - To avoid vertical differential compaction
  - To reach more uniform compaction

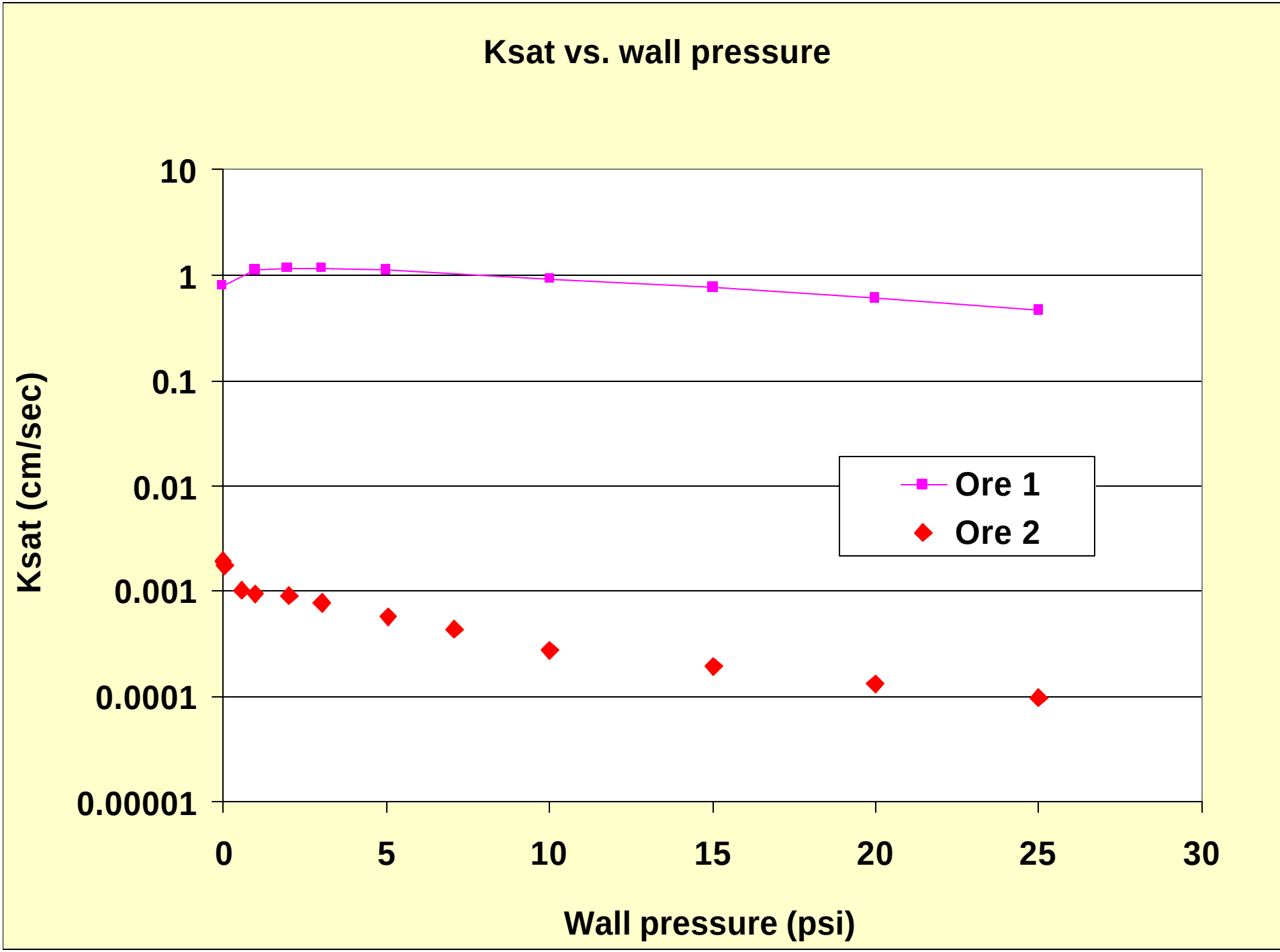
Ore 1

GeoSystems Analysis, Inc.
Arizona • Nevada • Oregon

Ore 2

GeoSystems Analysis, Inc.
Arizona • Nevada • Oregon


Dual wall BD-side wall pressure
Ore 1
Ore 2
BD (g/cm3)
2.2
2.1
2
1.9
1.8
1.7
1.6
1.5
0
5
10
15
20
25
30
Side wall pressure (psi)


Ksat vs. wall pressure
10
1
0.1
0.01
0.001
0.0001
0.00001
Ksat (cm/sec)
0
5
10
15
20
25
30
Wall pressure (psi)
Ore 1
Ore 2

Conclusions

- New laboratory methods appear to:
  - Significantly improve our ability to forward model
  - Question our ability to measure soil water retention characteristics for gravelly material at moderate and dry tensions
  - Question whether currently accepted laboratory methods can be used to model gravelly systems
- Removing gravel and determining MRC on 2-inch cores:
  - Does not scale to larger sample sizes
  - Can lead to gross errors in modeling
- Need to account for effect of macropore flow
- More research needed to:
  - Confirm new laboratory methods
  - Define when matrix flow ends and macropore begins?
  - Measure unsaturated flow rates at moderate tensions
  - Model macropore systems

GSA GeoSystems Analysis, Inc.
Arizona • Nevada • Oregon


Thank You