BARO-PNEUMATIC ESTIMATION OF LANDFILL GAS GENERATION RATES AT FOUR SOUTHEASTERN U.S. LANDFILLS

by

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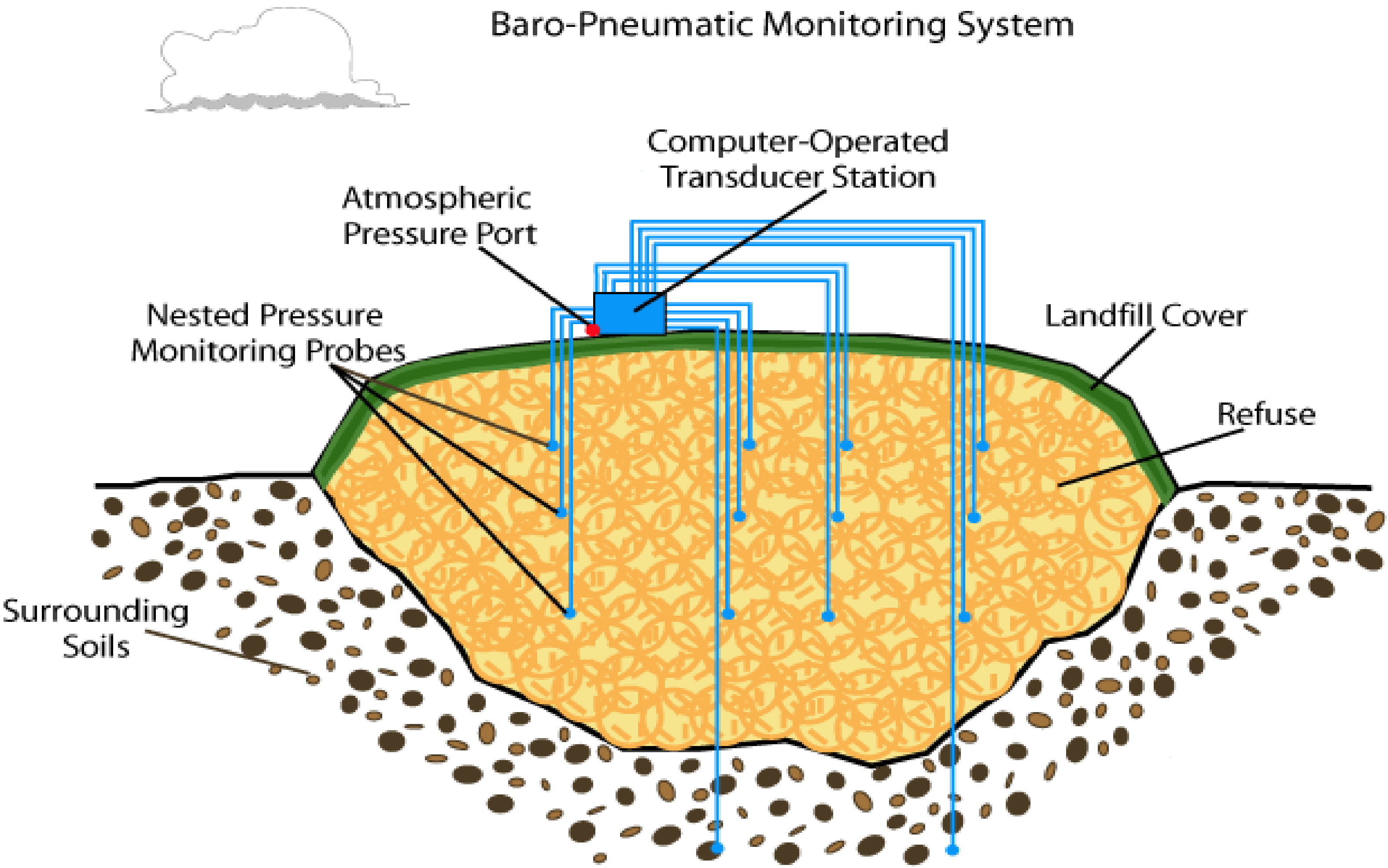

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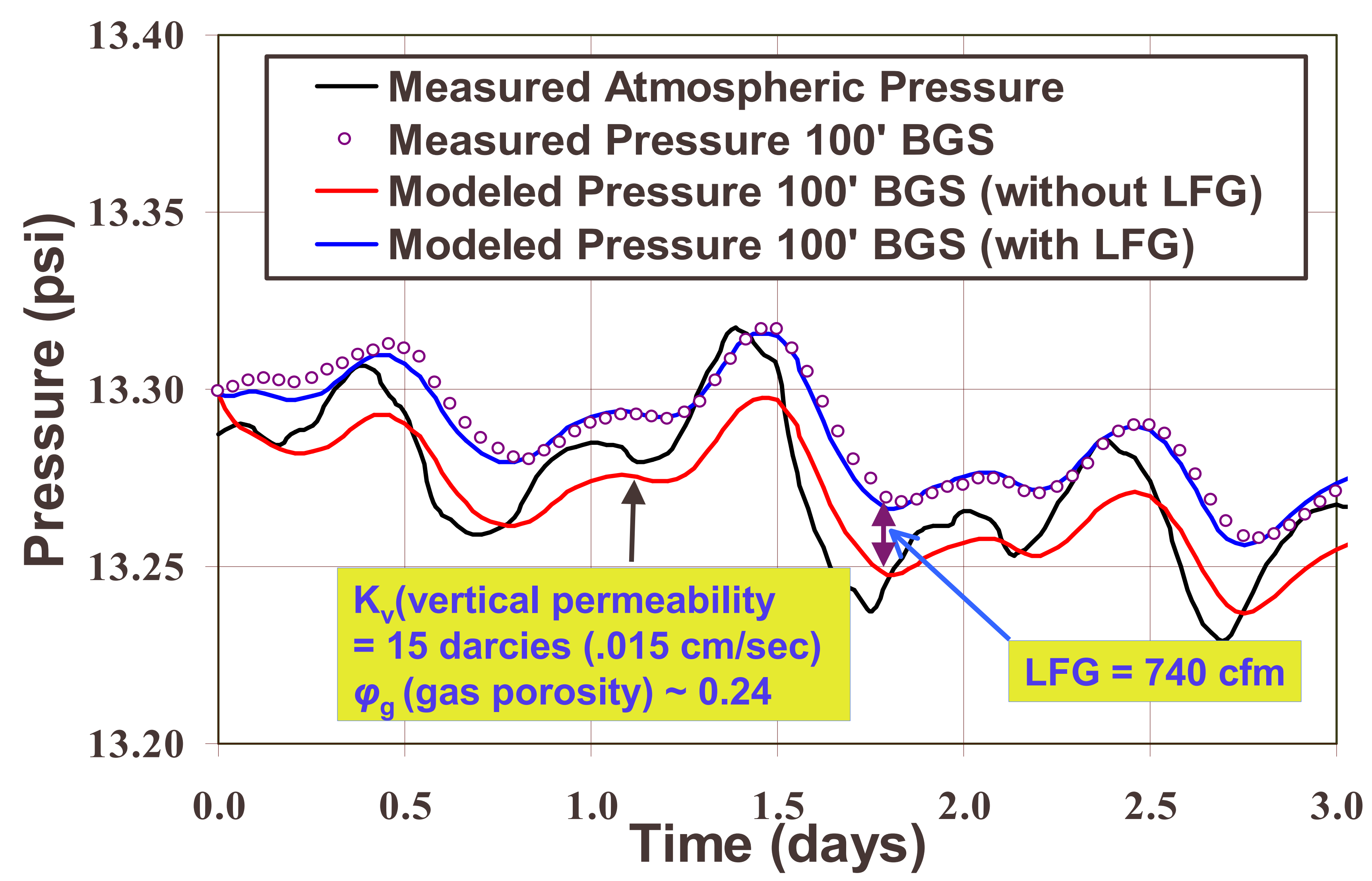
Modeled vs. Actual Pressures for SVI-1, Harrison Landfill, Tucson



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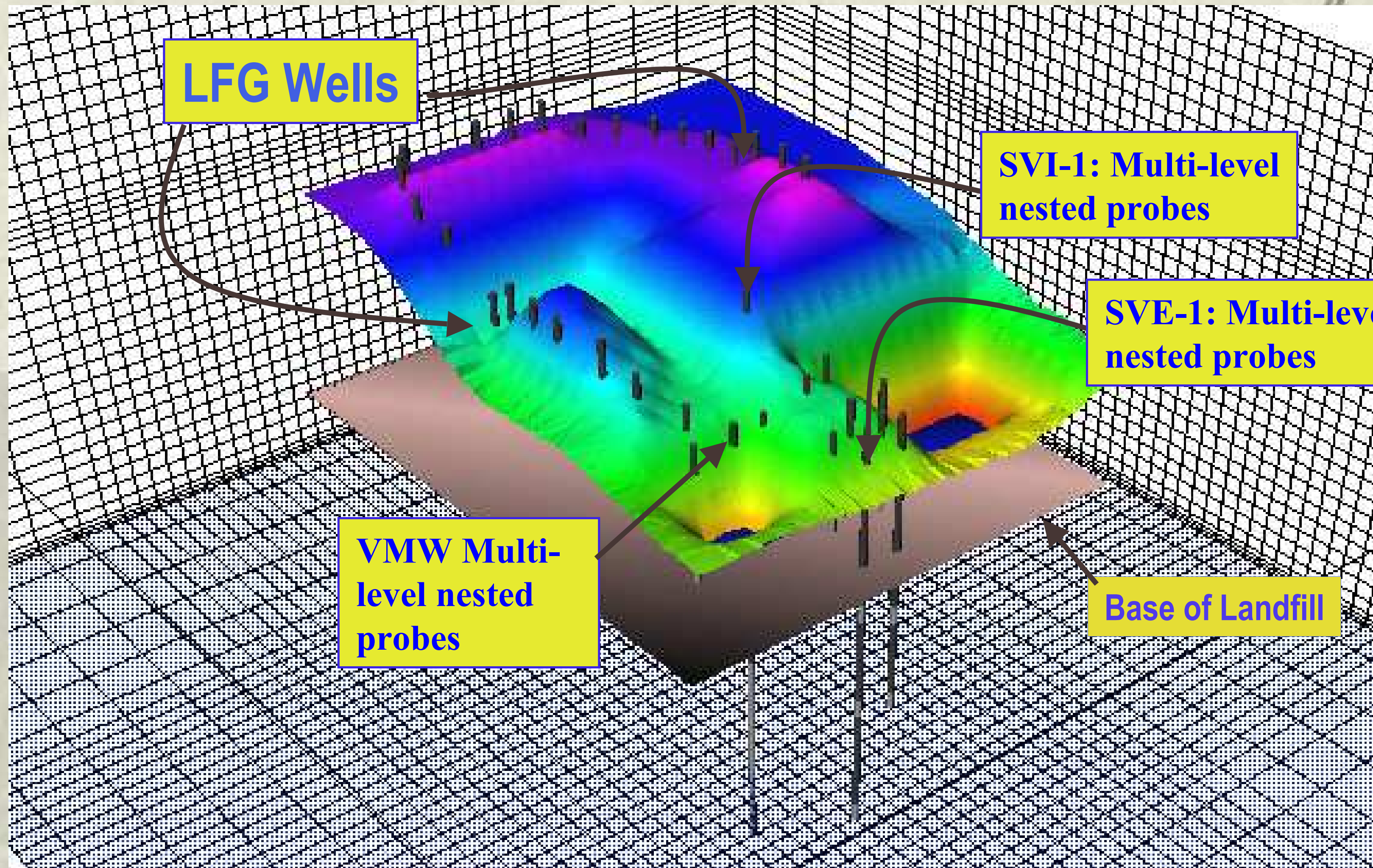
Governing Equation For Gas Flow (Based on Darcy's Law and the Continuity Equation)

$$\boxed{\nabla \bullet \frac{-\overline{\overline{k}}_e \rho}{\mu}\left(\nabla \mathrm{P} + \rho g \overline{n}\right) = \varphi \frac{\partial \rho}{\partial t} + \rho \dot{Q}}$$

- $\overline{\overline{k}}_e$ **is the effective gas permeability tensor**
- $\overline{n}$ is the unit normal vector
- ρ is the gas density
- P is the pressure at a point in the landfill
- g is gravitational acceleration
- $\boldsymbol{\varphi}$ **is gas-filled porosity**
- μ is gas dynamic viscosity
- t is time
- $\dot{Q}$ **is gas generation per unit volume porous material**
- μ and ρ are dependent on t, P, and gas composition
- ∇ is the gradient operator

Three-Dimensional Model Structure



Looking southwest

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Why This Approach?
Other Methods Not Very Accurate

- Methods that depend on site-specific, field measurements:
  - ✓ are plagued by heterogeneous permeabilities and LFG production
  - ✓ or don't work at all (EPA Method 2E, Tier III method)

    (G. Walter, 2003. J. Air & Waste Management 53, p 461)

- Those depending on generic estimates of rate (*k*) and methane potential (L_0),don't account for site conditions that affect LFG rates.

- Baro-pneumatic interpretation is based on rigorous, well-established gas-flow equations
  - ✓ Variety of tested numerical and analytical models available for analysis

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What is the Value of More Quantitative LFG Measurement ?

Whenever LFG needs to be measured, collected, or controlled, the ability to quantitatively estimate and model LFG generation rates provides

- Better engineering,
- Ability to simulate and optimize system performance
- Produce more efficient LFG collection and control systems
- Less risk of project failure.

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Potential Applications

- Quantify potential methane (energy) resource*
- Predict costs and revenues of LFG-to-energy system*
- Quantify carbon credits
- Evaluate landfill emissions
- Odor control
- Evaluate anaerobic bioreactor
- Method provides numerical landfill model* for
- Design, evaluation, optimization, and cost estimates:
  - LFG collection systems*
  - LFG-to-energy systems*
  - Gas migration or emissions control systems*
- Can provide *calibrated* 1st order decay model * to estimate future LFG production

* discussed in this presentation

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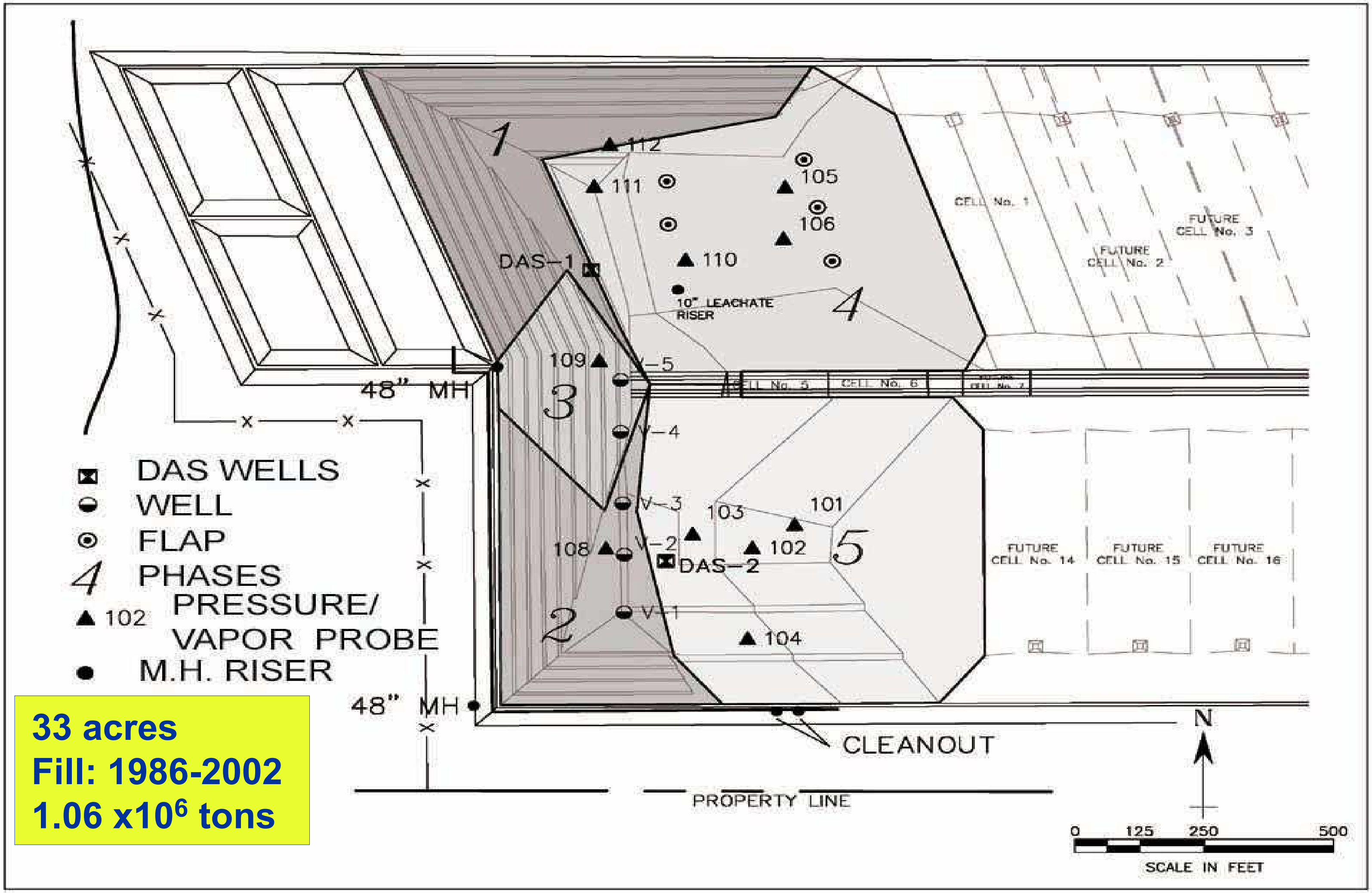
Saint Landry Parish Landfill, Louisiana



33 acres
Fill: 1986-2002
1.06 x10^6 tons

PLAN VIEW, TOPOGRAPHY, AND PRESSURE-MONITORING LOCATIONS

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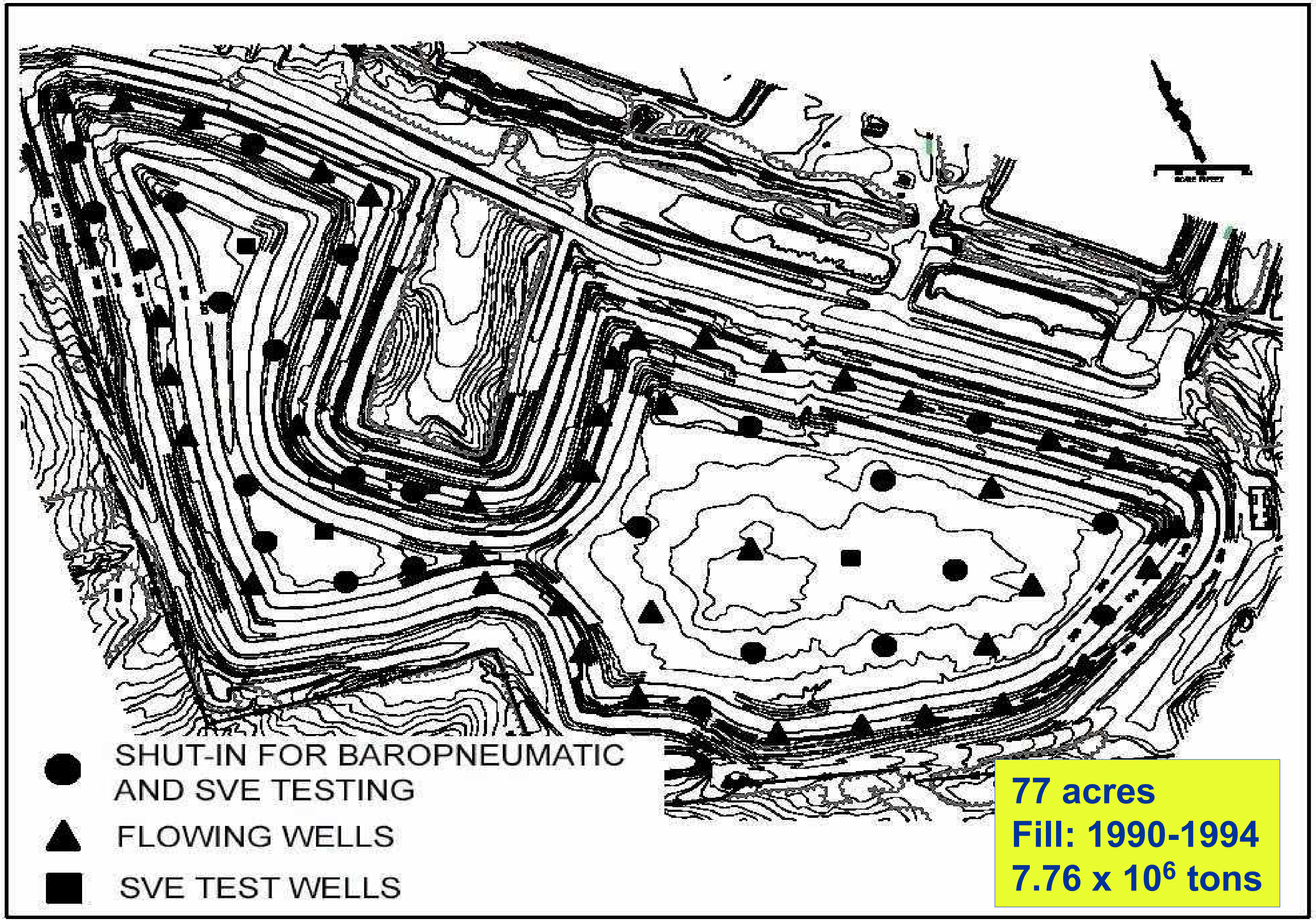
North Shelby Landfill, Phase 1, Millington, Tennessee



PLAN VIEW, TOPOGRAPHY, AND PRESSURE-MONITORING LOCATIONS

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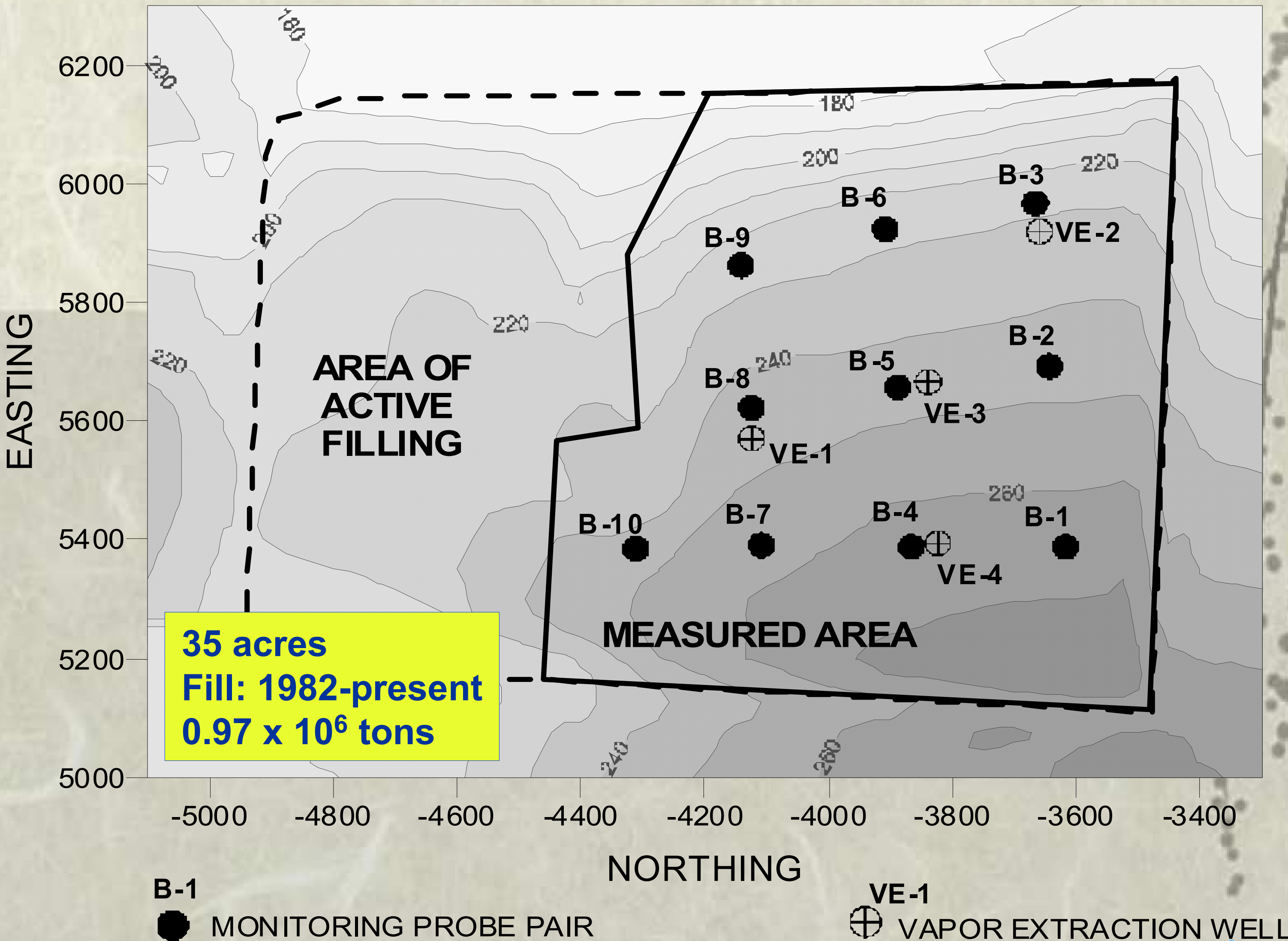
Decatur County Landfill, Georgia

PLAN VIEW, TOPOGRAPHY, AND PRESSURE-MONITORING LOCATIONS



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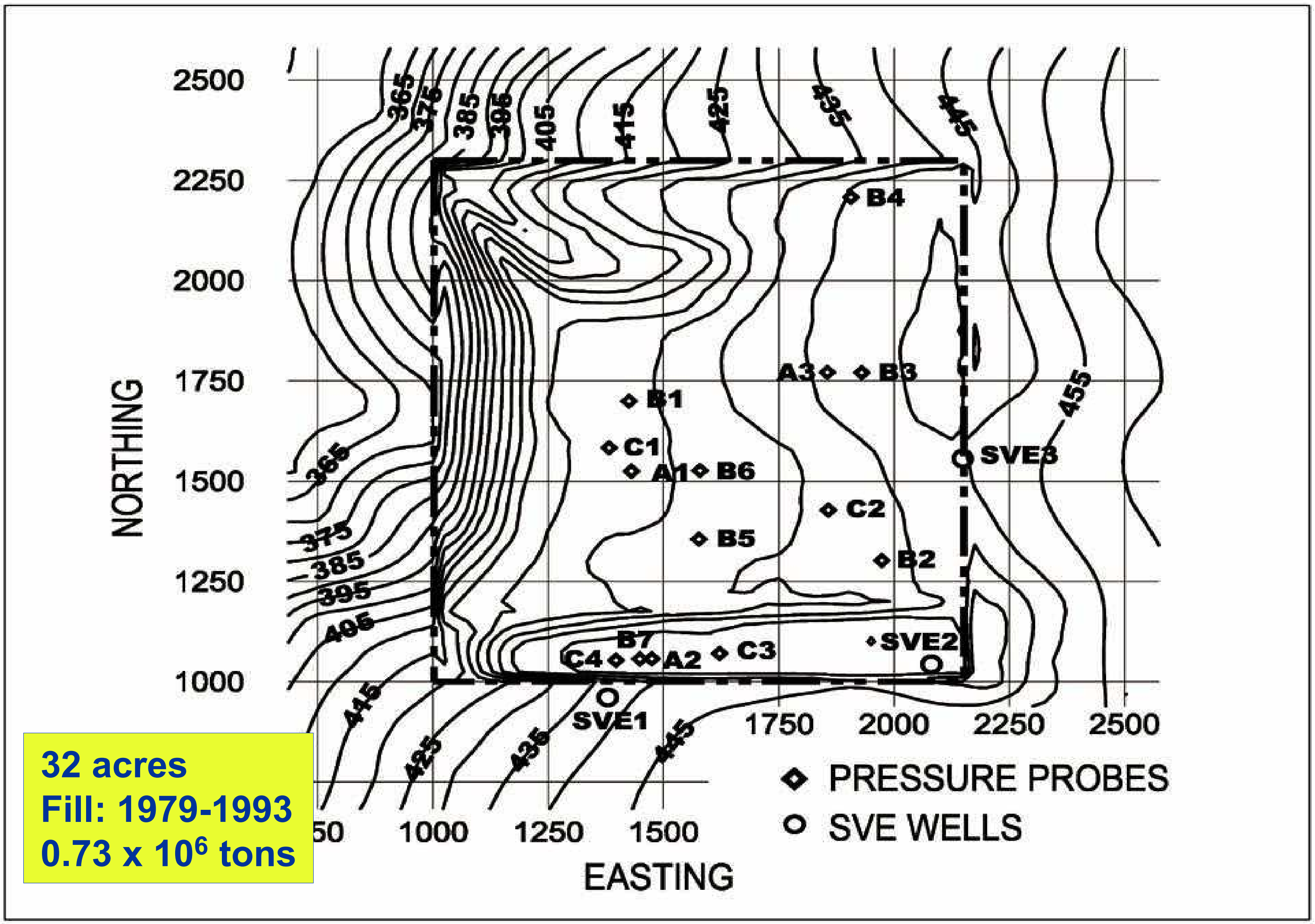
Houser's Mill Road Landfill, Orange County, Georgia



32 acres
Fill: 1979-1993
0.73 x 10^6 tons

PLAN VIEW, TOPOGRAPHY, AND PRESSURE-MONITORING LOCATIONS

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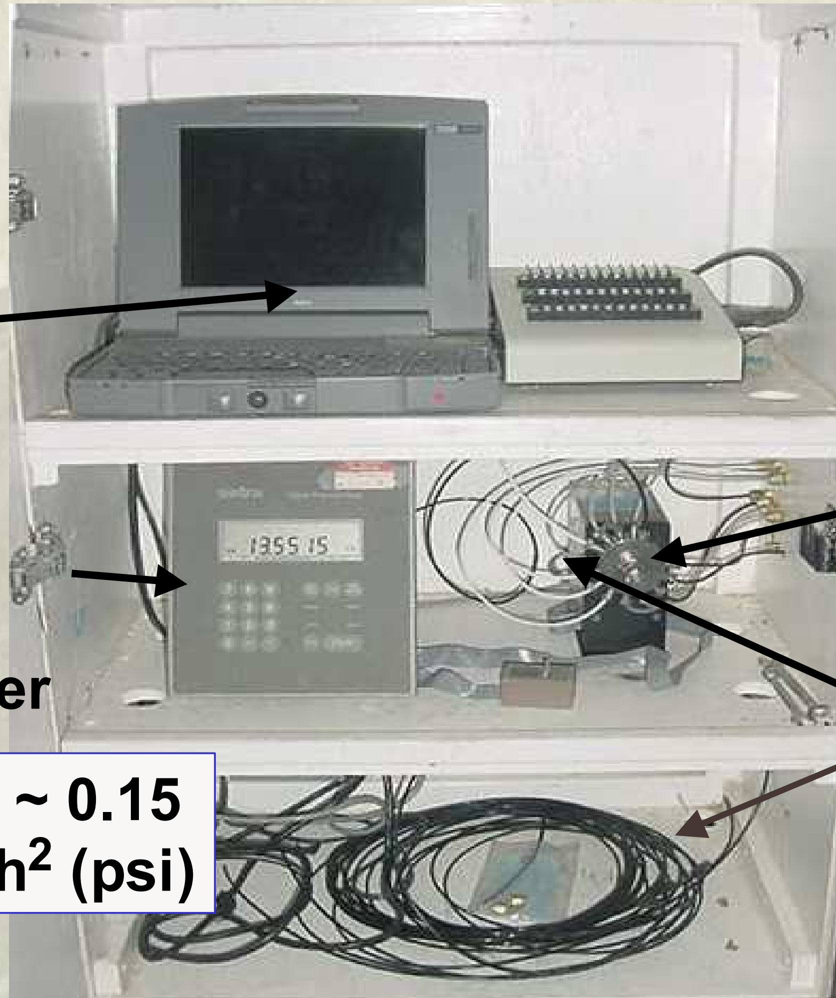
Data Acquisition System (DAS)



Laptop and data acquisition system

0.001 kPa Setra Transducer

Note: 1 kPa ~ 0.15 pounds/inch^2 (psi)

Computer-operated 16-Port Valco Switching Valve

Tubing to probes, one port to atmosphere

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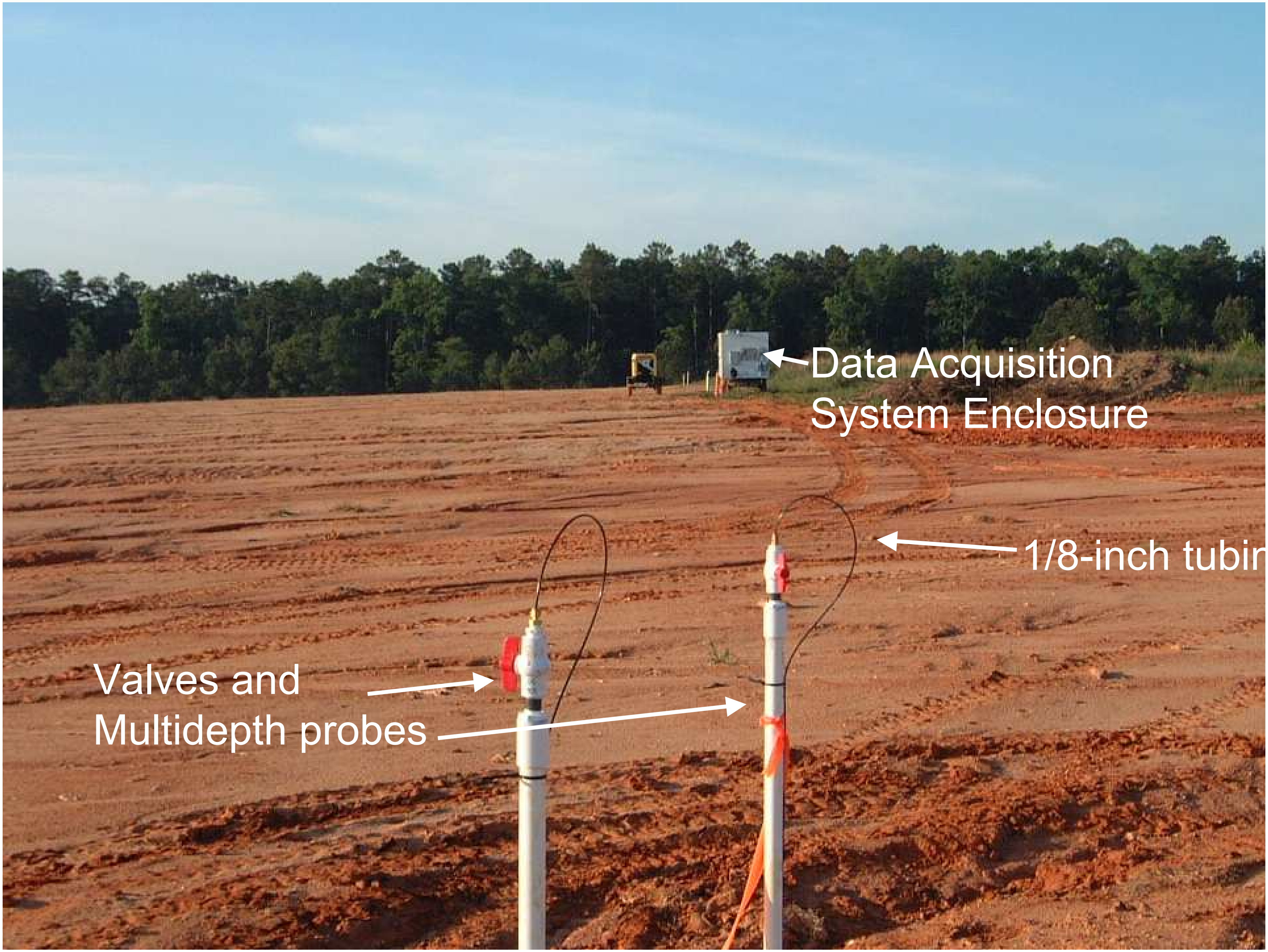
Data Acquisition
System Enclosure
1/8-inch tubin
Valves and
Multidepth probes

ALTERNATIVE DAS SYSTEM

(Used at Houser's Mill Road Landfill)

Downhole barometer/
data acquisition system
18.2 mm (In Situ Inc.)

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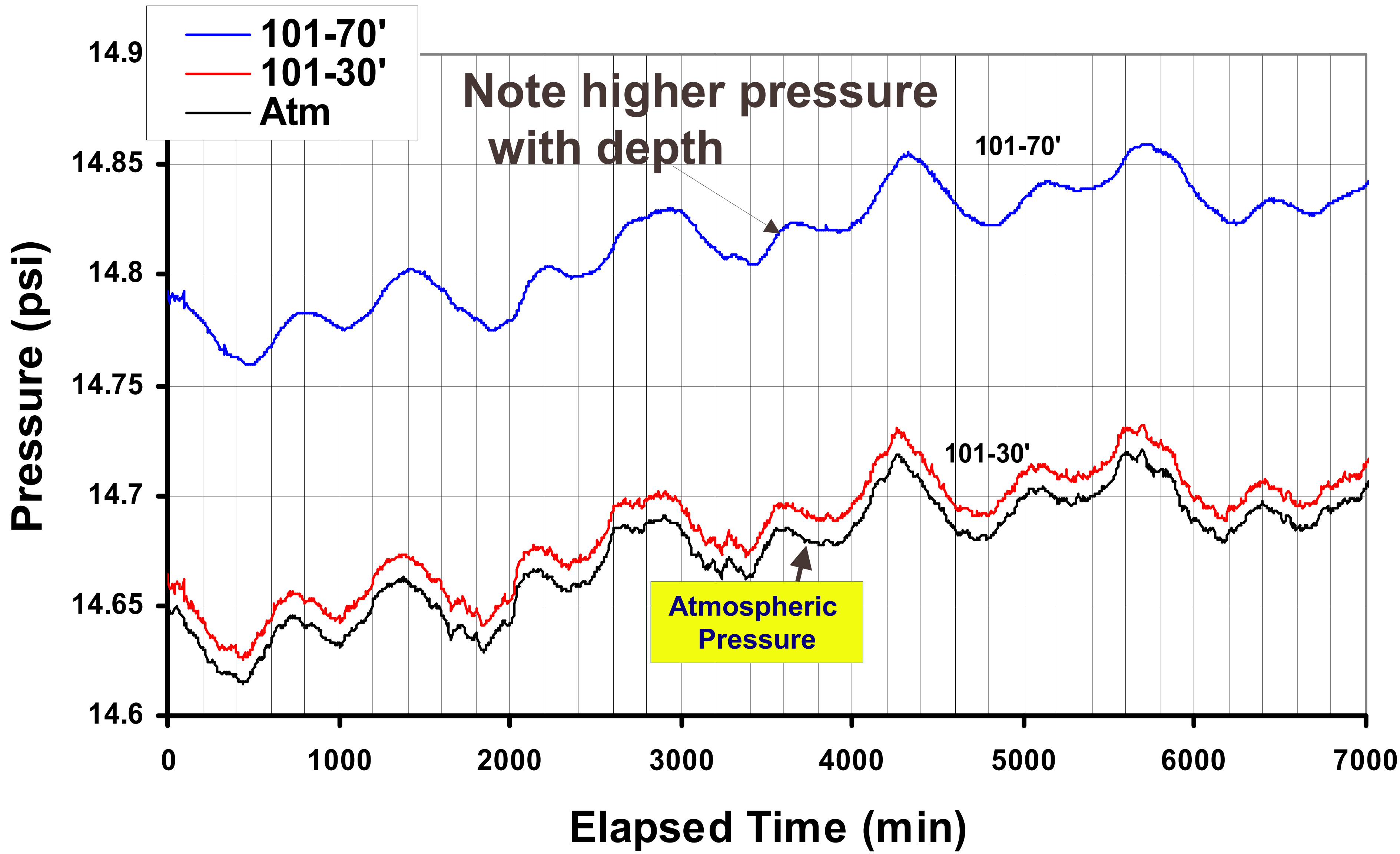
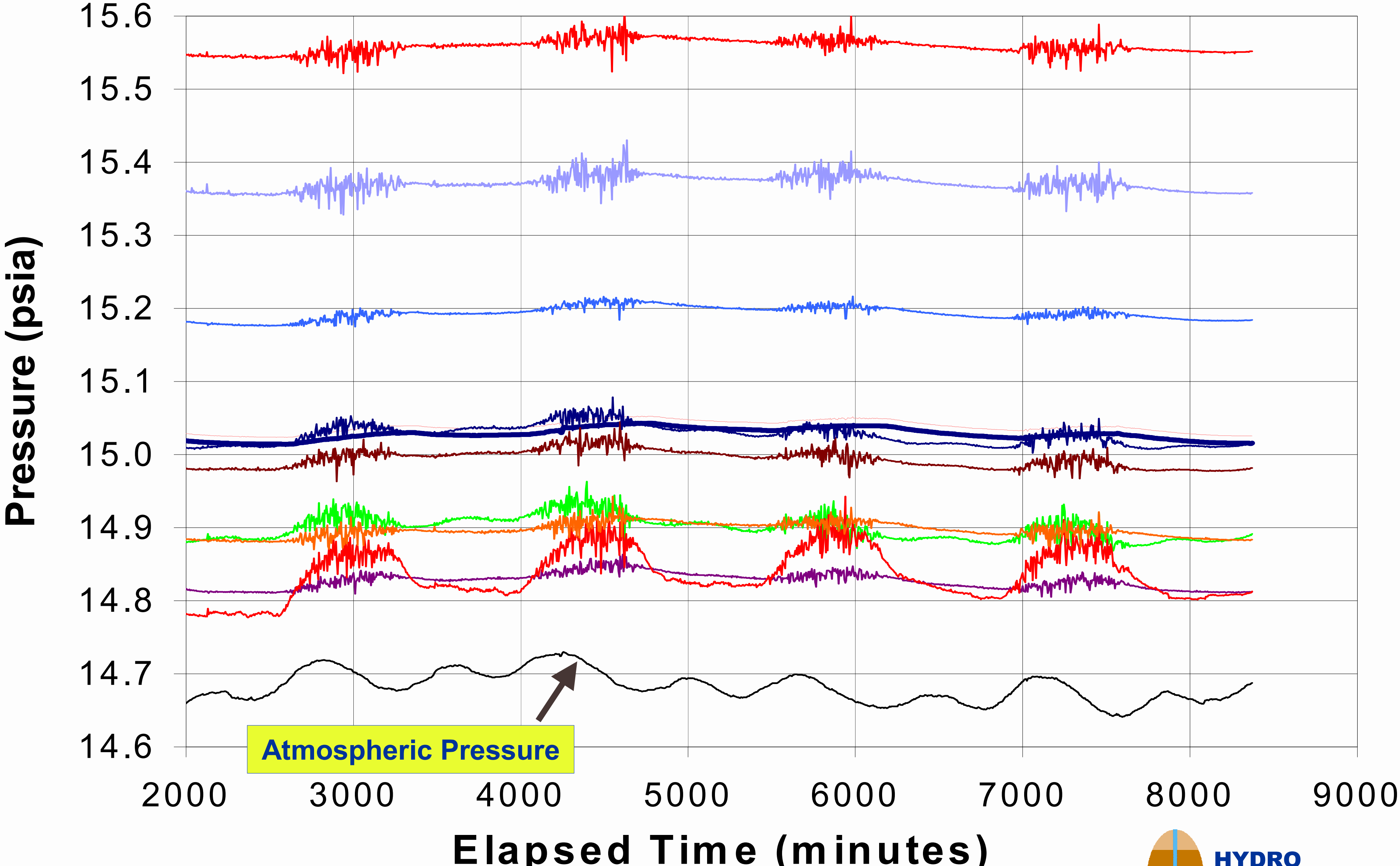
Baro-pneumatic Data Obtained at a Probe Nest at St. Landry Parish Landfill, Louisiana



Monitoring data from 12 probes plus atmosphere West Sector, Decatur County Landfill, Georgia



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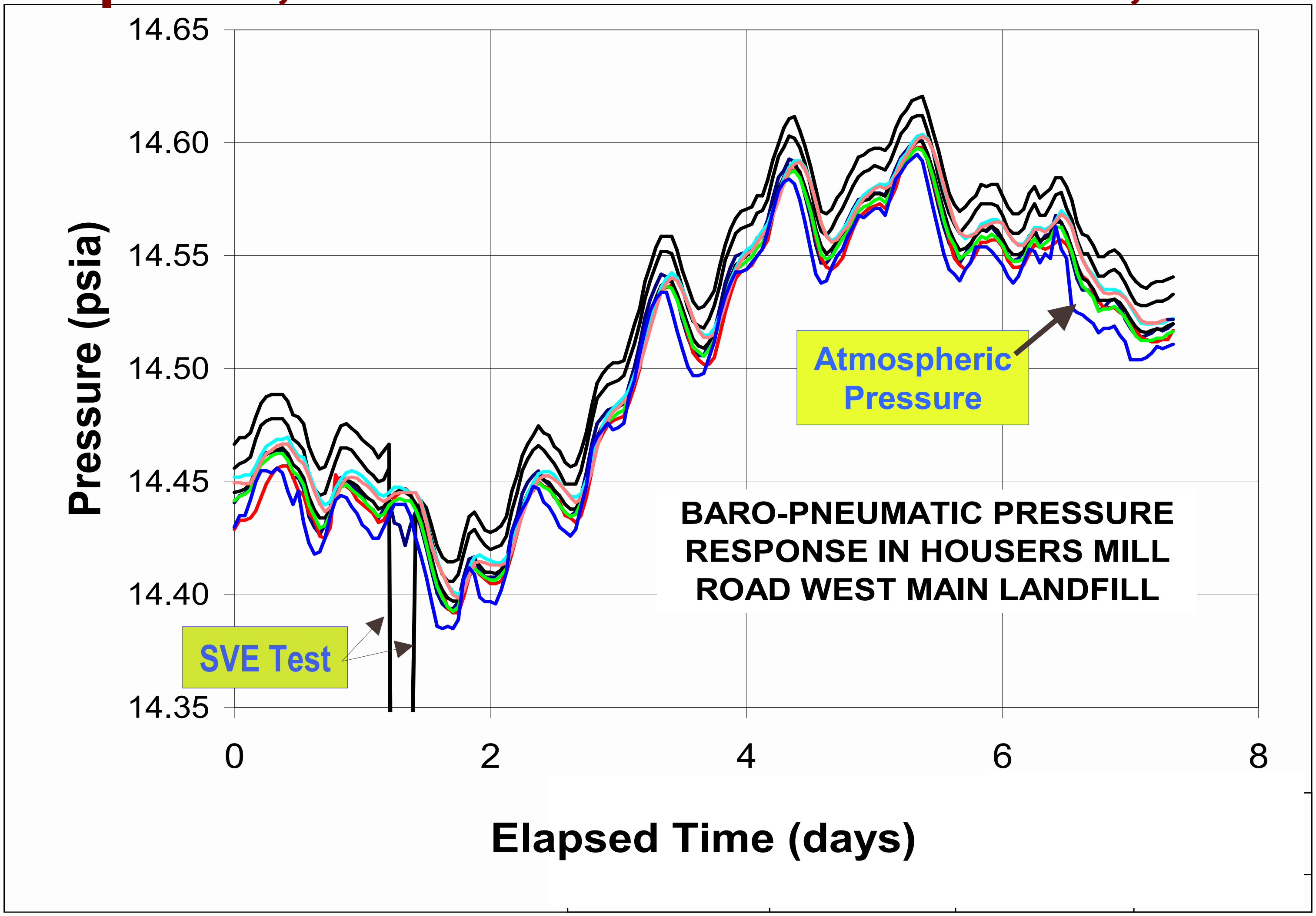
Baro-pneumatic data from 7 probes and the atmosphere,Houser's Mill Road Landfill, Georgia



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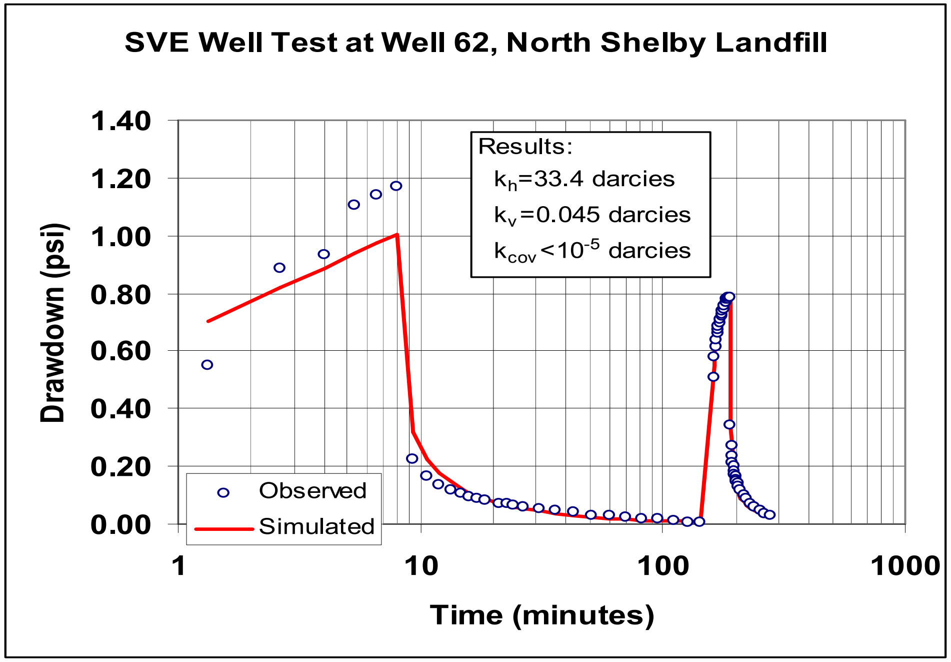

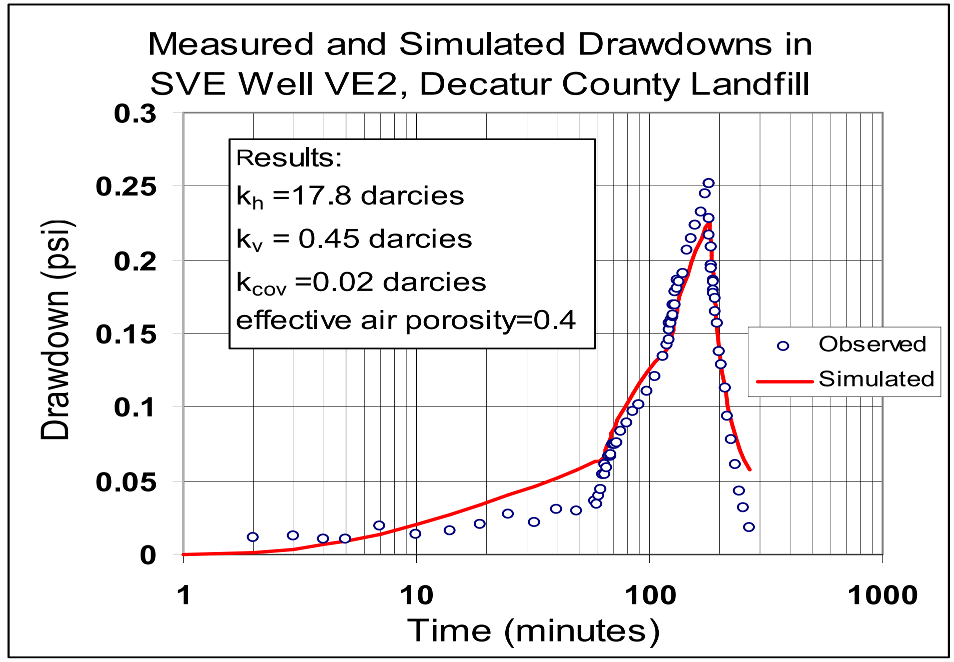

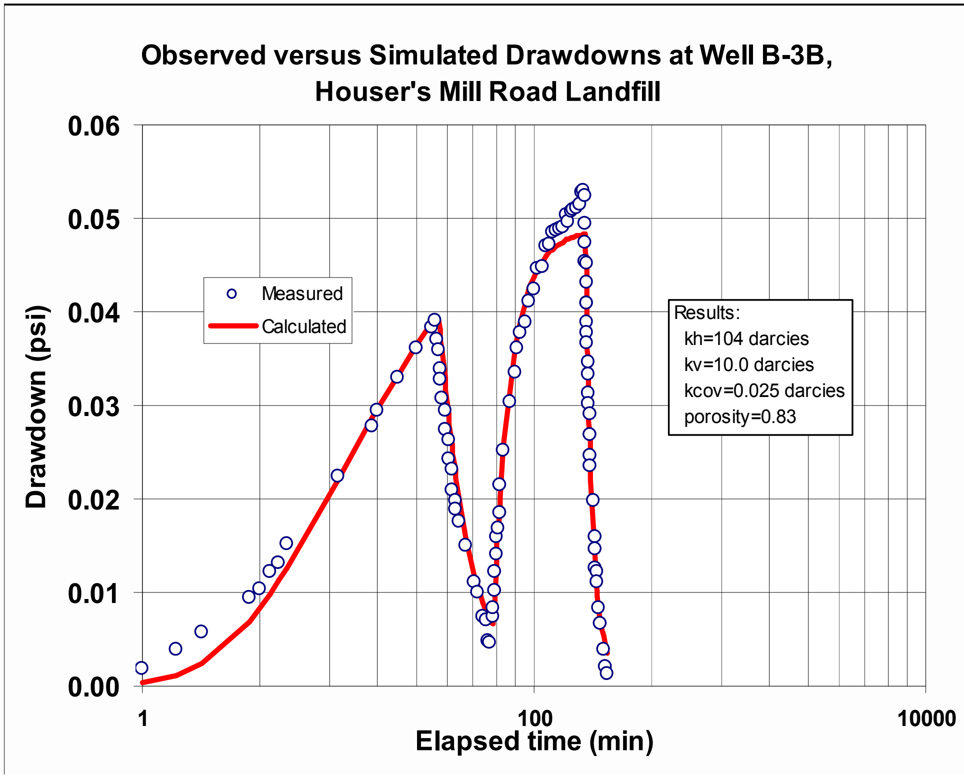

EXAMPLES OF PNEUMATIC SOIL VAPOR EXTRACTION WELL TEST RESULTS AT 3 OF THE 4 LANDFILLS

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Summary of Pneumatic Well Test Results

Pump Well	Obs. Well	Horizontal Permeability k_h (darcies)	Vertical Permeability k_v (darcies)	Gas Porosity	k_{cover} (darcies)
North Shelby Landfill					
EW-38	EW-38	8.9	0.01	na	<10-5
EW-46	EW-46	11.2	0.19	na	<10-5
Well 62	Well 62	33.4	0.05	na	<10-5
AVERAGE		**17.8**	**0.08**		**<10-5**
Houser's Mill Road Landfill					
SVE-1	SVE-1	50.9	2.82	na	2.82
SVE-2	SVE-2	28.5	6.11	na	6.11
SVE-3	SVE-3	51.3	0.03	na	0.03
A-1	C-1A	3.0	0.30	0.27	0.37
A-1	C-1B	8.6	0.86	0.08	0.00
A-2	C-4A	42.3	4.23	0.30	0.48
A-2	C-4B	43.7	4.37	0.30	0.28
A-2	C-3A	200.0	20.00	0.23	0.19
A-3	B-3B	104.0	10.00	0.83	0.25
AVERAGE		**59.1**	**5.41**	**0.23**	**1.17**

Pump Well	Obs. Well	Horizontal Permeability k_h(darcies)	Vertical Permeability k_v (darcies)	Gas Porosity	k_{cover} (darcies)
Decatur County Landfill					
VE1	B8-A	2.1	0.16	0.30	0.01
VE1	B8-B	45.0	4.50	0.70	1.0x10-4
VE1	B7-B	12.0	1.00	0.18	0.30
VE2	B3-A	30.0	0.20	0.40	1.0x10-3
VE2	B3-B	17.8	0.45	0.40	0.02
VE2	B6-A	40.0	0.10	0.30	1.0x10-3
VE3	B5-B	2.2	0.52	0.10	1.3x10-3
VE3	B2-A	32.6	3.22	0.09	1.0x10-4
VE4	B4-A	3.1	1.0x10-3	0.19	1.0x10-4
VE4	B1-A	5.0	7.9x10-4	0.03	4.8x10-7
AVERAGE		**20.9**	**1.43**	**0.22**	**0.03**

= deleted from average

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Analysis of Baro-pneumatic Tests Using Numerical Model based on Governing Equation

- Construct model (TRACRN or MODFLOW SURFACT) using landfill geometry and structure (cover, refuse, underlying soils)
- Input estimated porosity (preferably from field pneumatic test measurements)
- Use measured (time-variable) atmospheric pressure as model surface boundary
- Input trial estimates of 1) permeability (preferably from pneumatic SVE tests) and 2) LFG generation rates
- Vary permeabilities (initial calibration) to match observed baro-pneumatic data lag and attenuation
- Vary LFG generation rates (final calibration) to match offset

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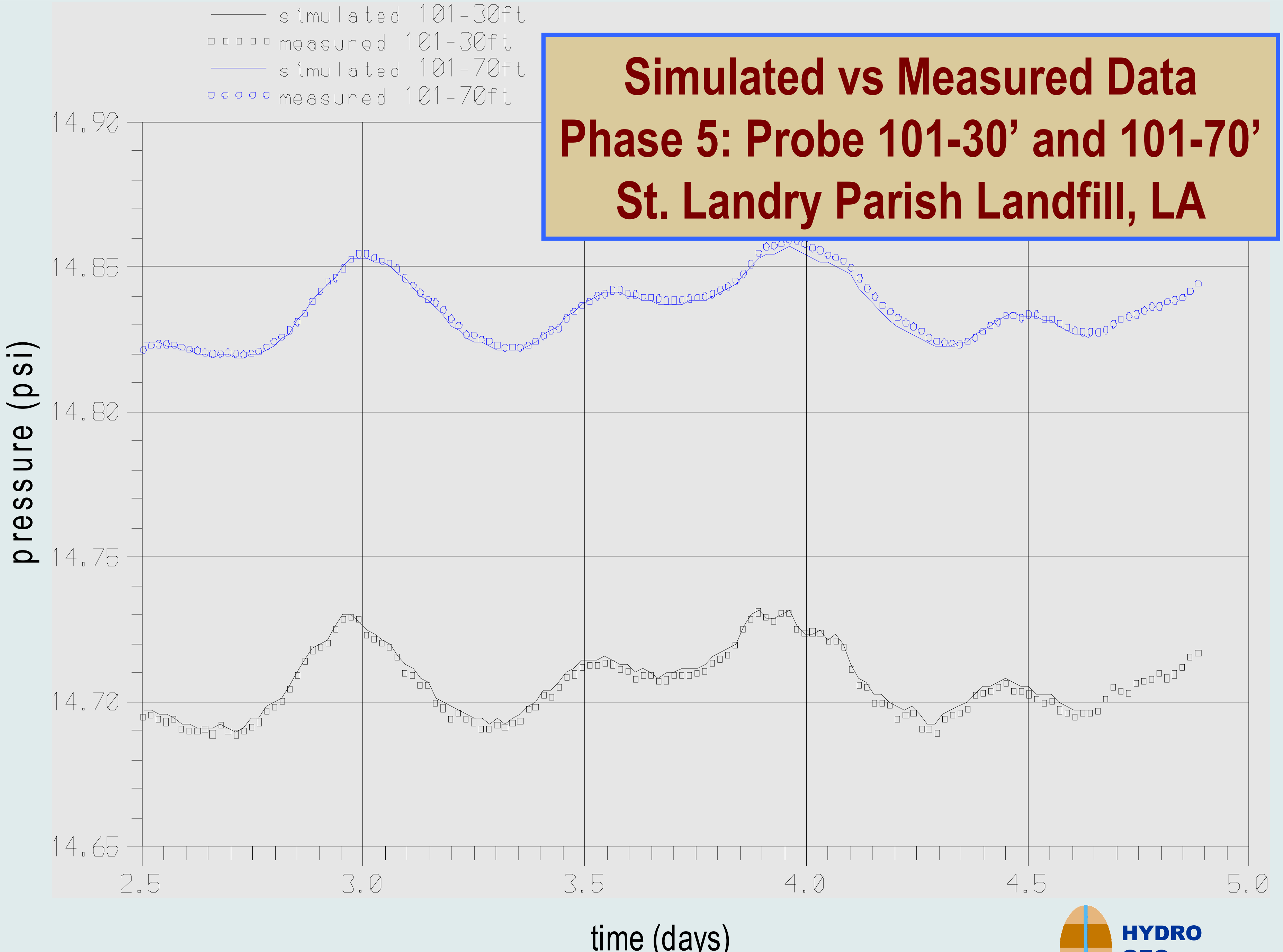
Simulated vs Measured Data
Phase 5: Probe 101-30' and 101-70'
St. Landry Parish Landfill, LA



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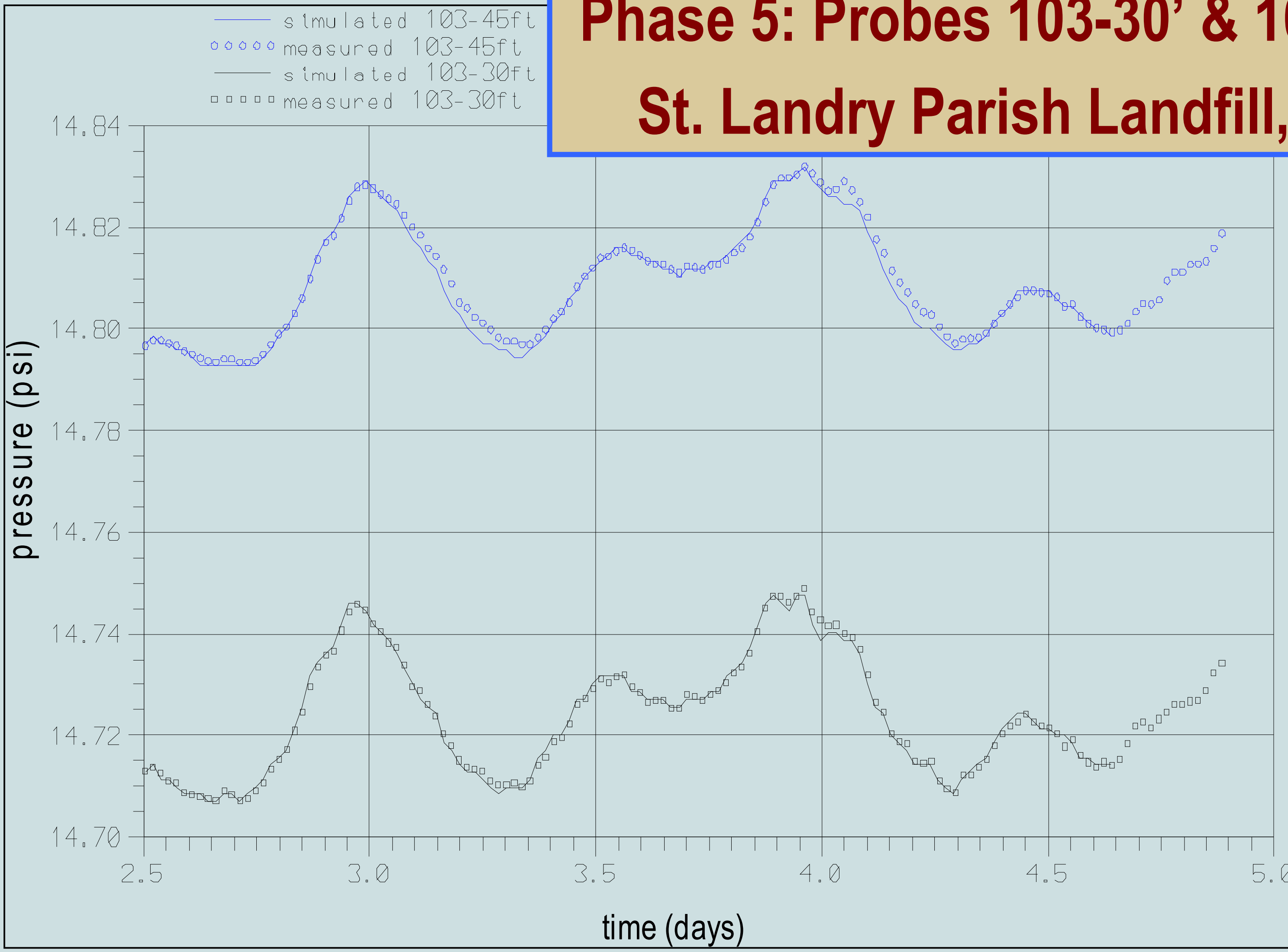
Simulated vs Measured Data
Phase 5: Probes 103-30’ & 103-45’
St. Landry Parish Landfill, LA



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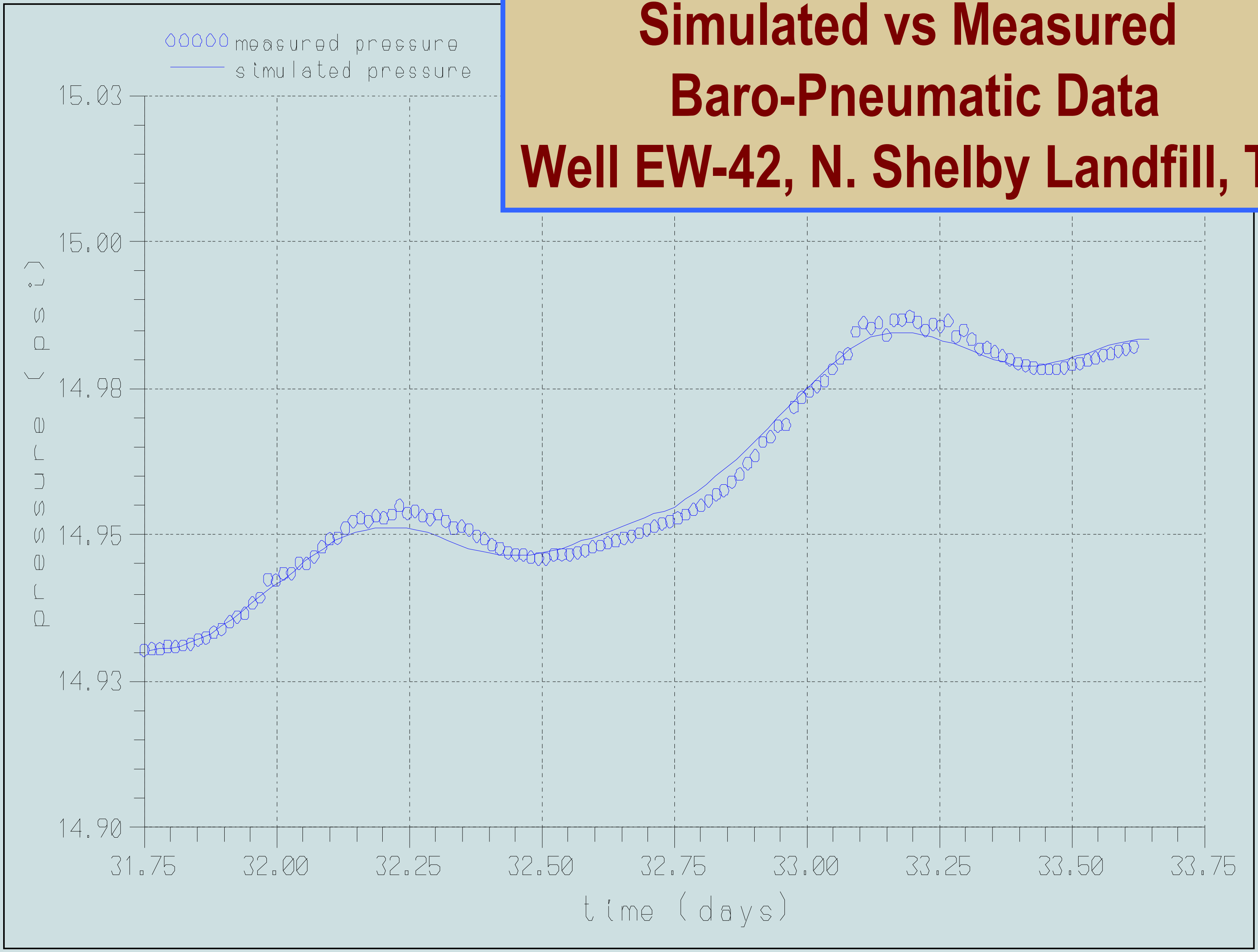
Simulated vs Measured Baro-Pneumatic Data Well EW-42, N. Shelby Landfill, TN



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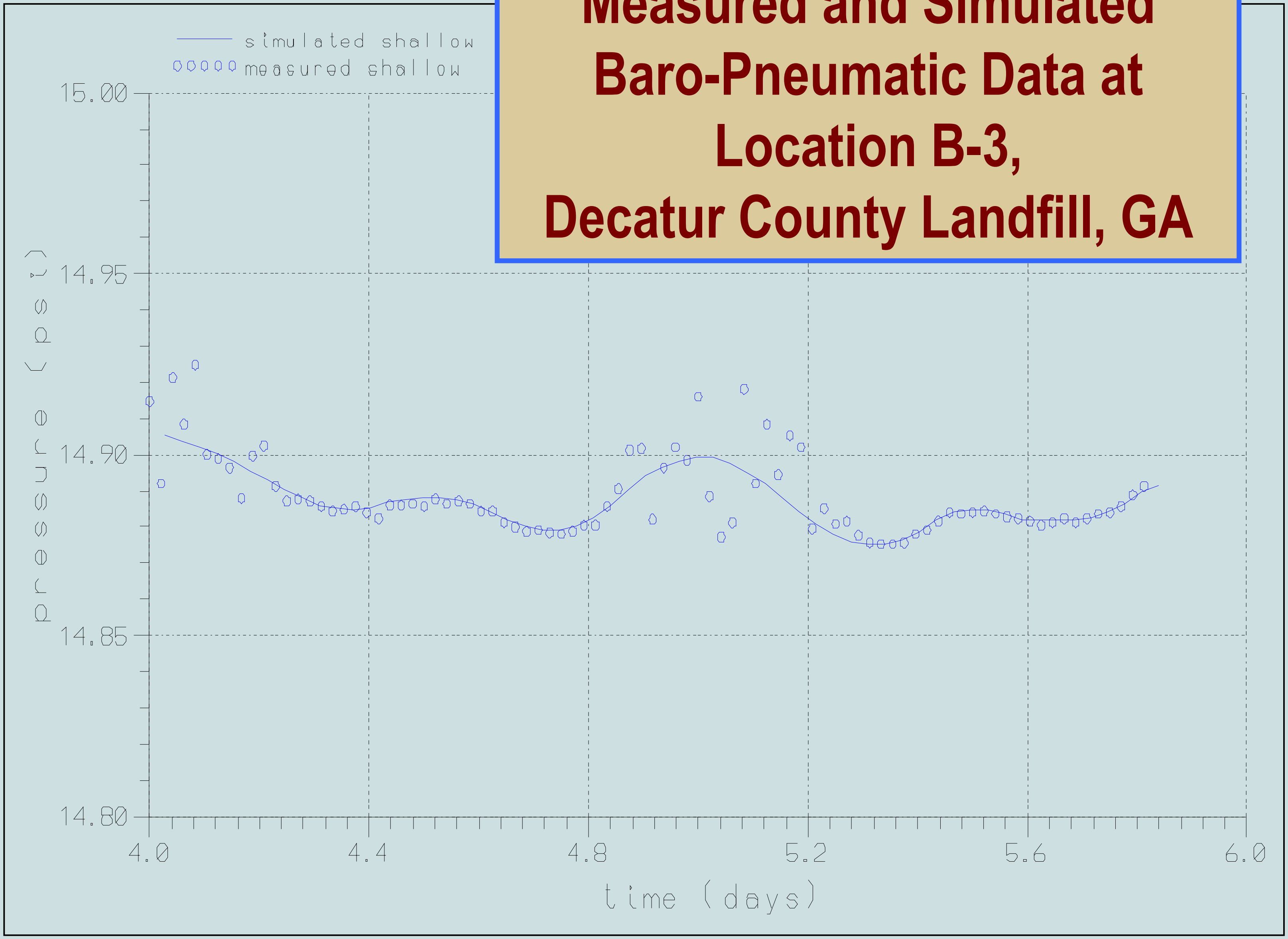
Measured and Simulated Baro-Pneumatic Data at Location B-3, Decatur County Landfill, GA



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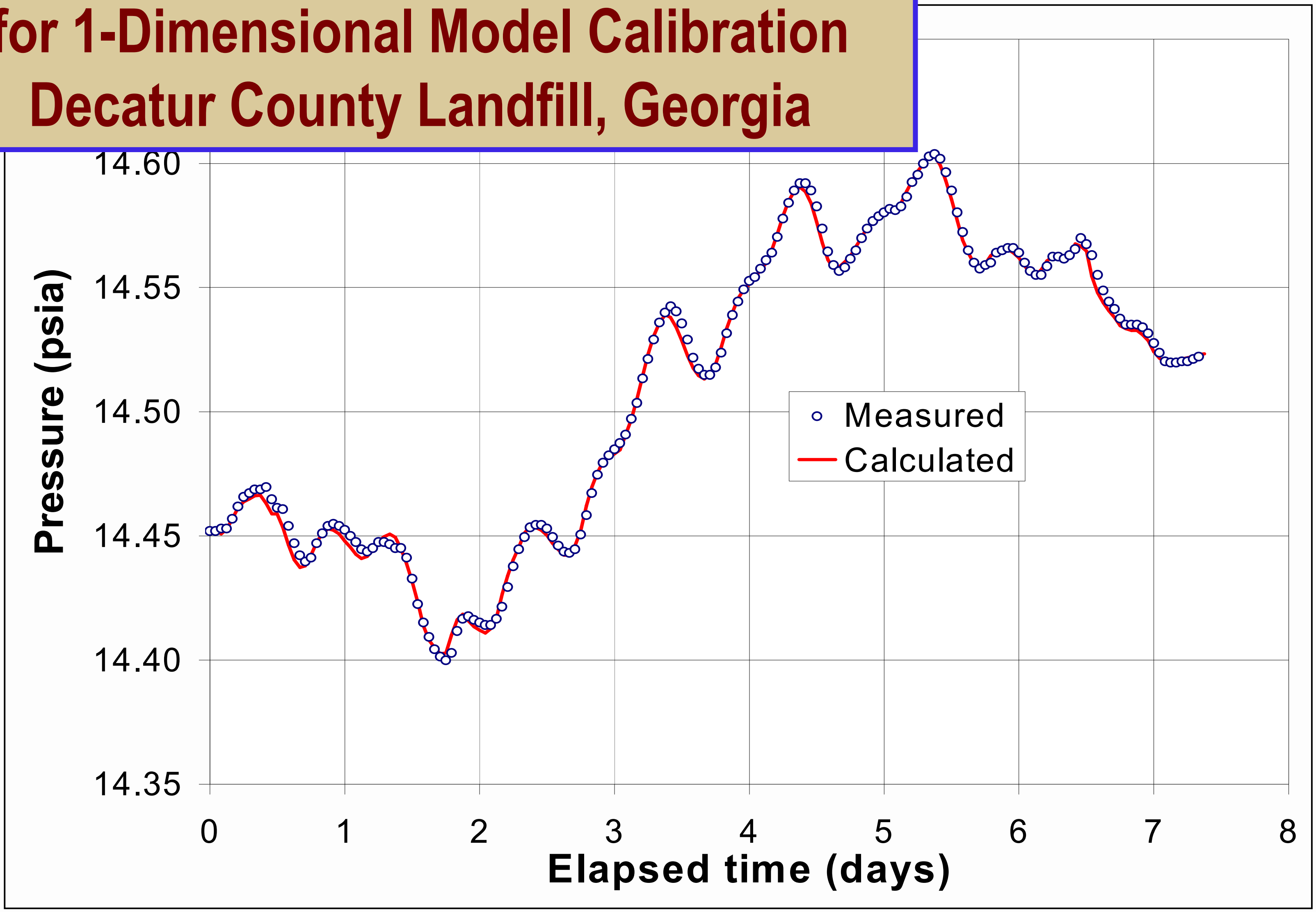
Measured vs. Simulated Gas Pressures for 1-Dimensional Model Calibration Decatur County Landfill, Georgia



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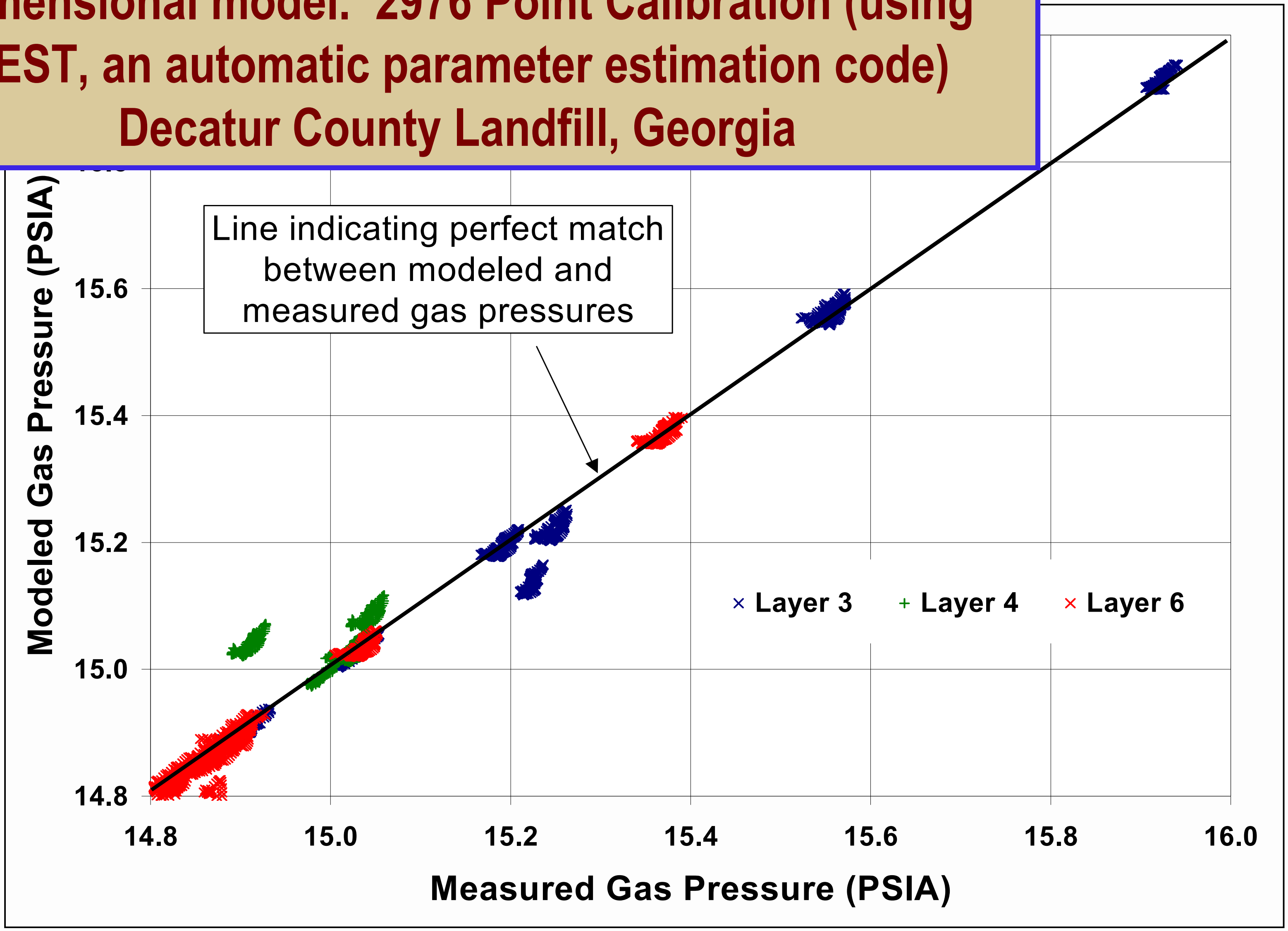
Measured vs. Simulated Gas Pressure for 3-Dimensional model. 2976 Point Calibration (using PEST, an automatic parameter estimation code) Decatur County Landfill, Georgia



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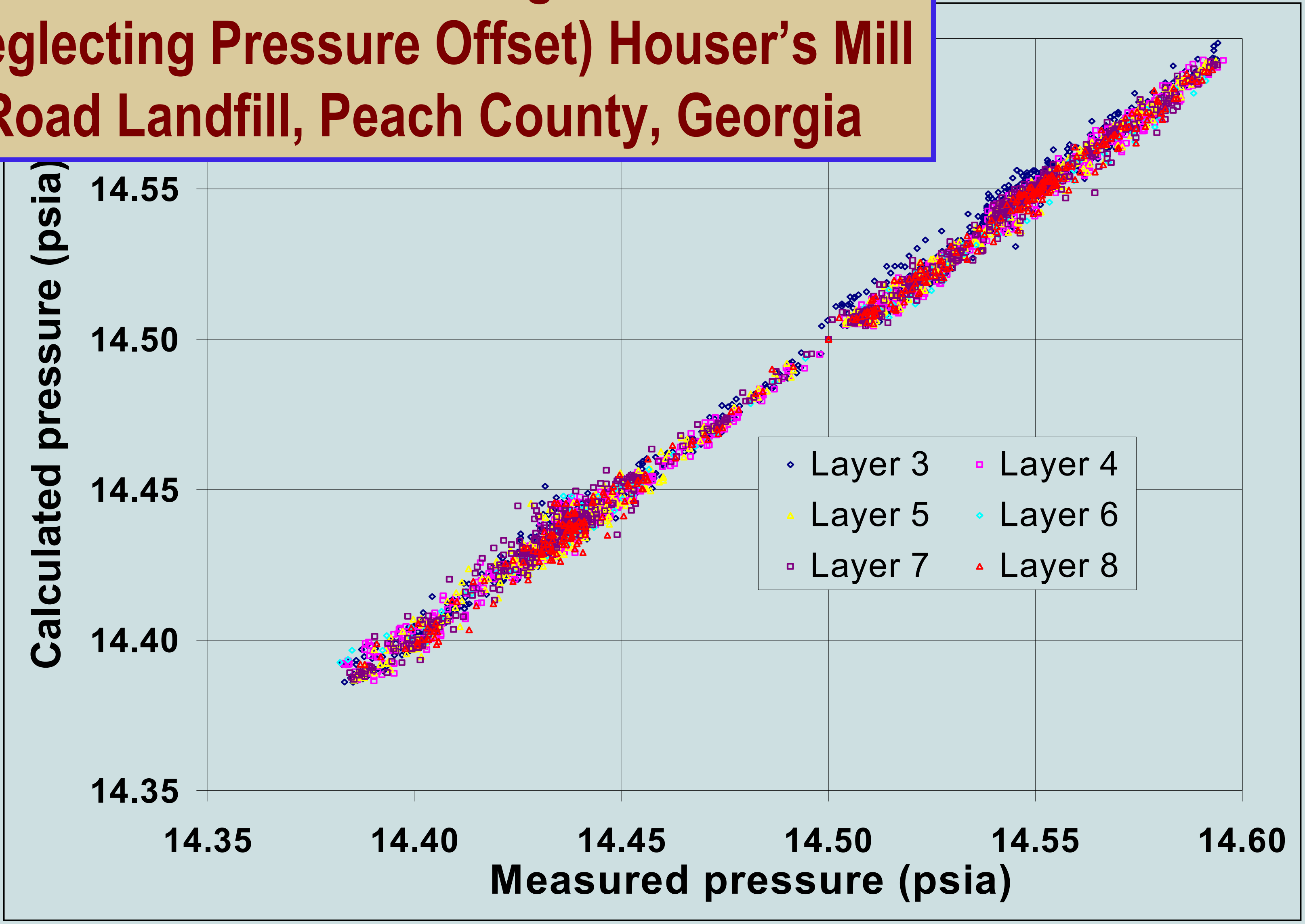
3-D Numerical Model Stage 1 Calibration (Neglecting Pressure Offset) Houser's Mill Road Landfill, Peach County, Georgia



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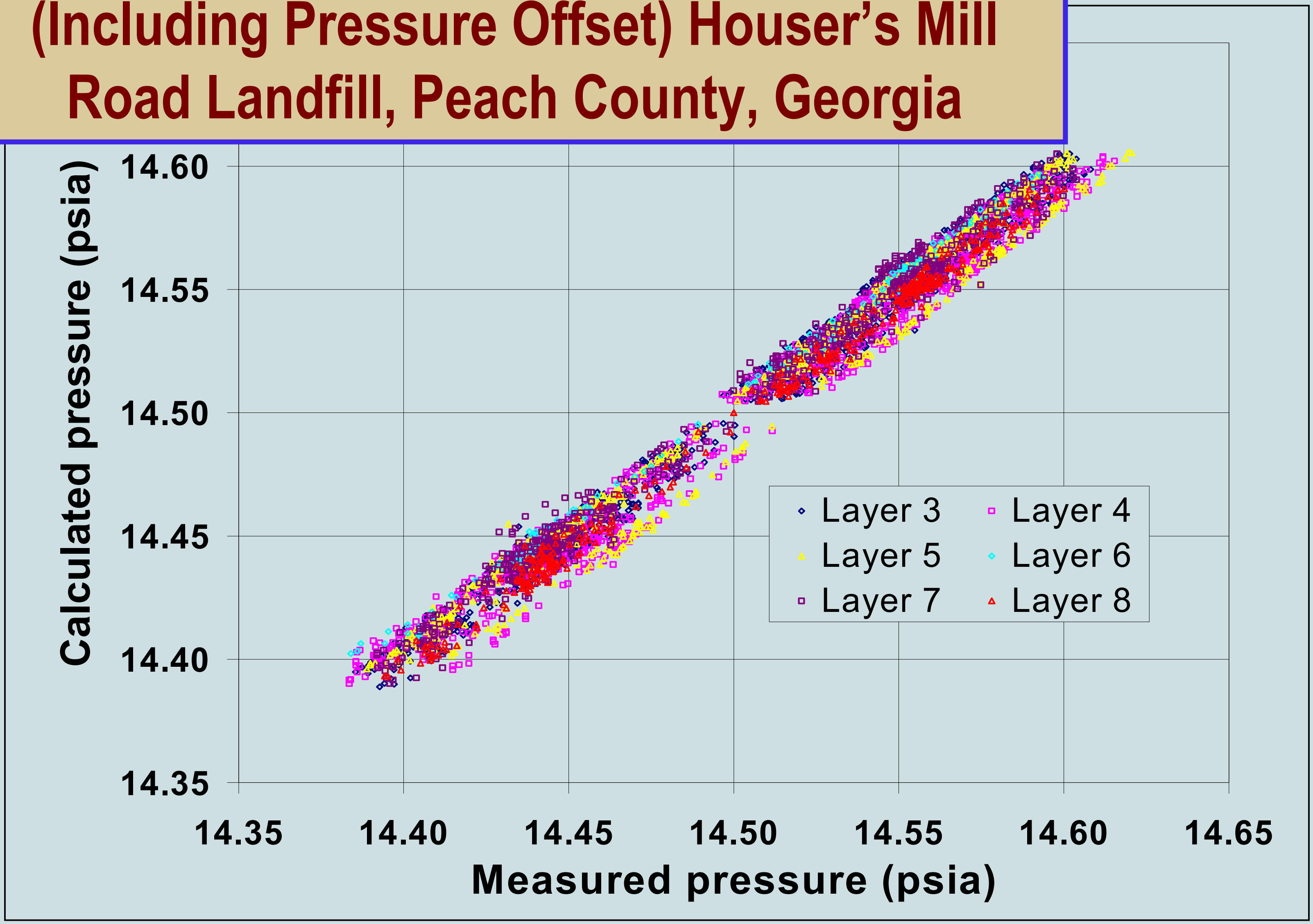
3-D Numerical Model Stage 2 Calibration (Including Pressure Offset) Houser's Mill Road Landfill, Peach County, Georgia



Next Step: Calibrate a Site-Specific 1st-Order Decay Model

$$LFGgen = (1/M)L_0R\left(e^{-kc} - e^{-kt}\right)$$

Where

LFGgen	is the landfill component's LFG production rate
M	is the gas volume fraction of methane
L_0*	is potential methane produced/unit waste mass
R	is the average waste acceptance rate during the active life of the landfill component (cell; phase)
k*	is the rate of LFG generation per unit mass of decaying waste
t	is the time since the landfill component opened
c	is the time since the landfill component closed

*** variables to be estimated**

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Construct and Calibrate a 1st Order Decay Model (Single- or Multi-phase)

- Obtain Baro-pneumatic LFG estimates for selected probes in different waste disposal history Phases.
- Determine start and finish time of MSW disposal and MSW disposal rate for each Phase.
- Develop a least-squares expression comparing the field estimates with decay model predictions.
- Get best-fit 1st Order Decay Equation variables by minimizing least squares

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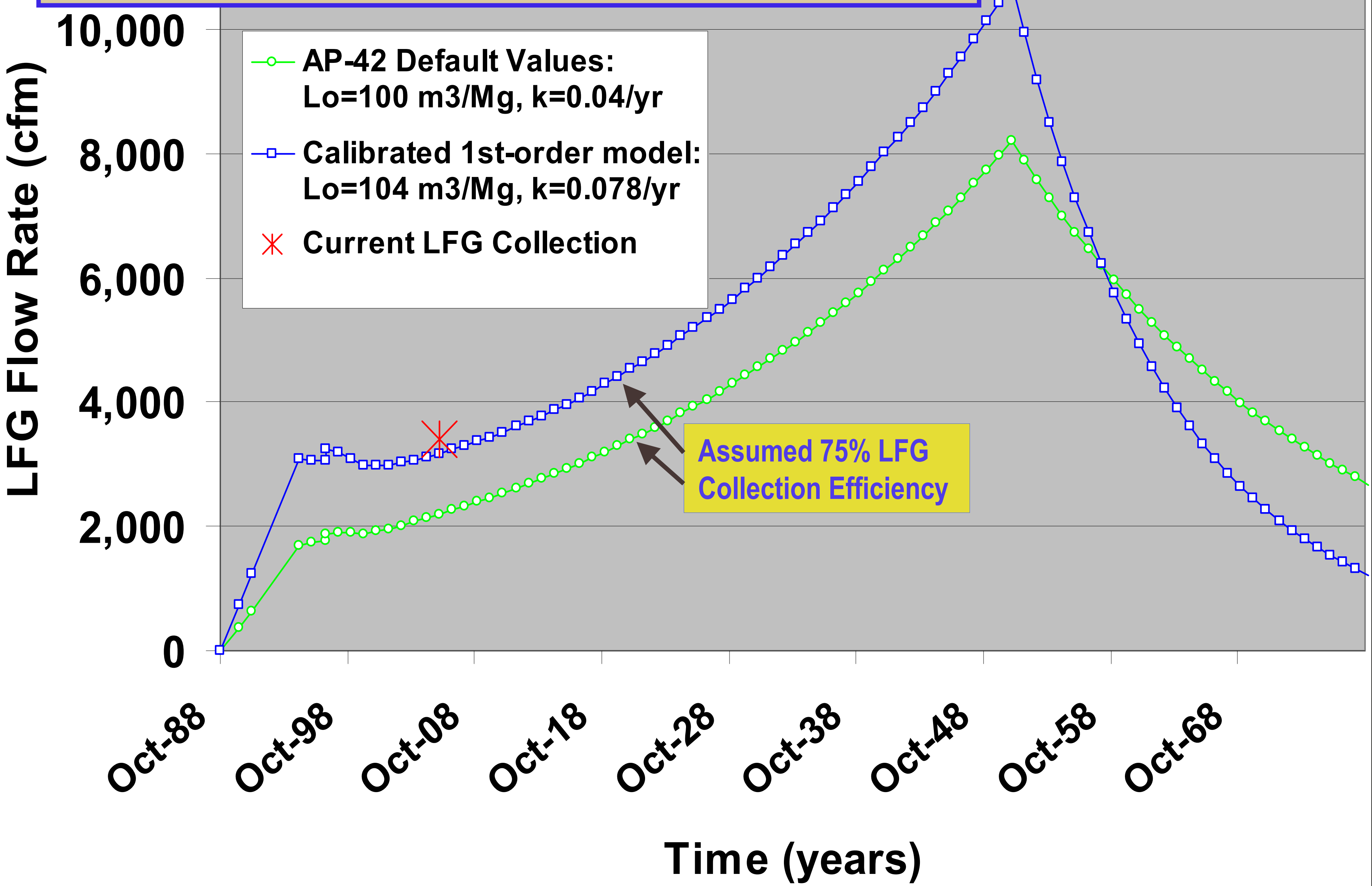
Results of the Calibrated 1st-order Decay Models

Landfill	L_o (m^3/Mg)	F_s	k_s (yr^{-1})	k_r (yr^{-1})	Methane Gas Fraction	*LFG flow Q* (Baro-pneumatic) (ft^3/min)	*LFG flow Q* (Calibrated 1st Order Decay Model)	Time Since Close (yrs)	Refuse, tons (at time of test)
N. Shelby Memphis TN	103	1	0.078	-	0.5	1,969	1,969	10	7.76E+06
Georgia Landfill	108	1	0.086	-	0.56	142	146	10	4.75E+05
Decatur County, GA	114.9	1	0.179	-	0.5	551	551	0-6	9.73E+05
St. Landry Parish, LA	111	1	0.2	-	0.56	785	757	active	1.06E+06
Louisiana Landfill	110	1	0.238	-	0.506	7,098	7,028	active	3.74E+06
Houser's Mill Road, GA	102	1	0.148	-	0.5	510	510	12	7.26E+05
St. Landry Parish, LA (2-PHASE)	121	0.722	0.104	0.693	0.56	785	784	active	1.06E+06
Mean	108.15		0.155						
% Standard Deviation	4.56		41.1						

(Southeastern U.S. Landfills)

Predicted vs Realized Recoverable LFG at North Shelby Landfill, TN

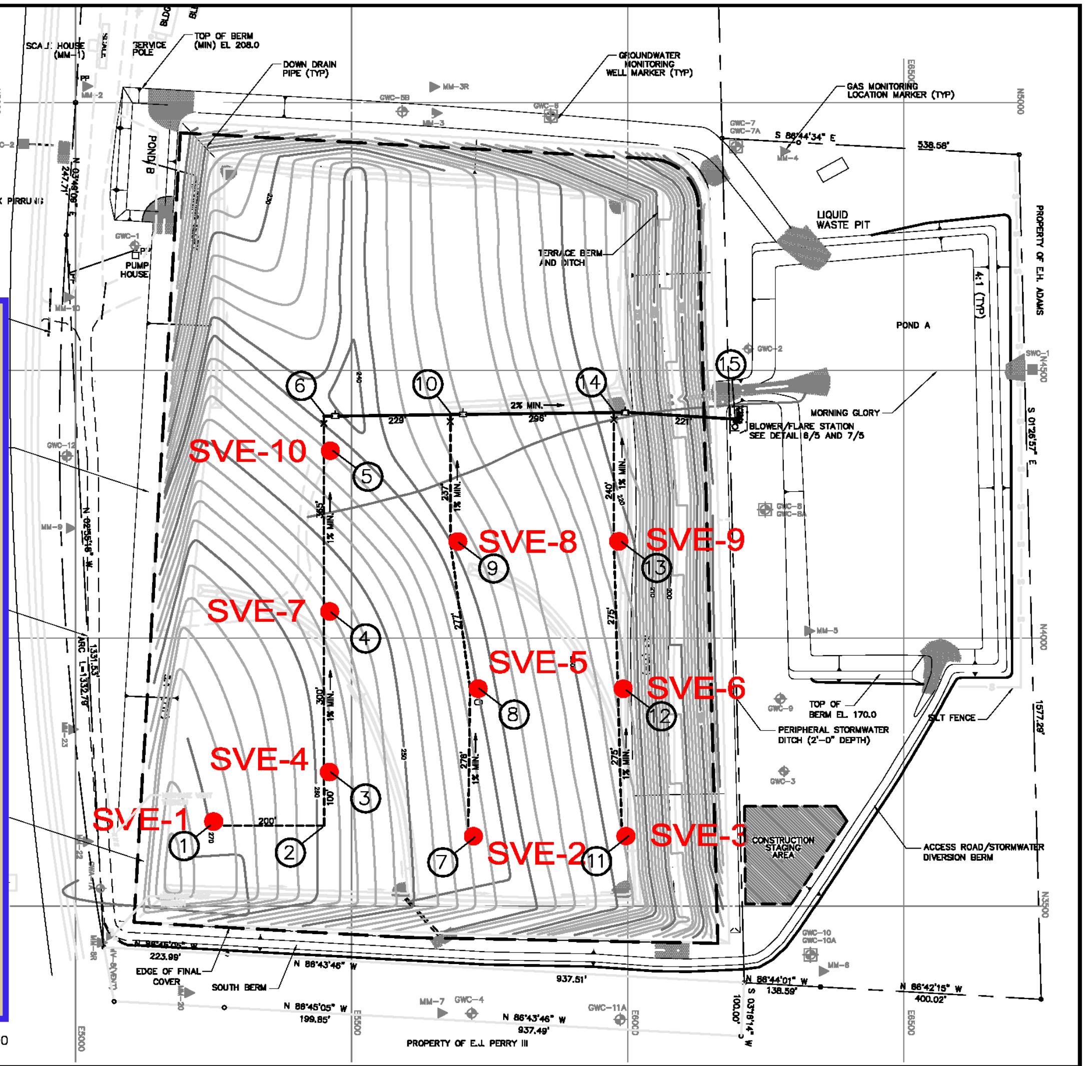


Decatur County Landfill South Phase LFG-Migration Control System.

Engineering design optimized by simulations using numerical model developed from baro-pneumatic investigation

EXPLANATION

- ● EXTRACTION WELL DETAIL 1/4
- × GATE VALVE DETAIL 2/4
- 8" TO 4" REDUCTION TEE (CAPPED)
- ① CALL OUT POINT
- 8" DIA. HDPE PIPE
- 4" DIA. HDPE PIPE
- LIMITS OF WASTE



SVE-6	55.0	26.8	21.7	8.5
SVE-7	49.8	6.2	28.7	16.9
SVE-8	57.2	6.0	38.3	14.9
SVE-9	51.3	15.0	30.6	7.7
SVE-10	45.6	12.8	20.1	14.7

0 100 200 300
SCALE IN FEET

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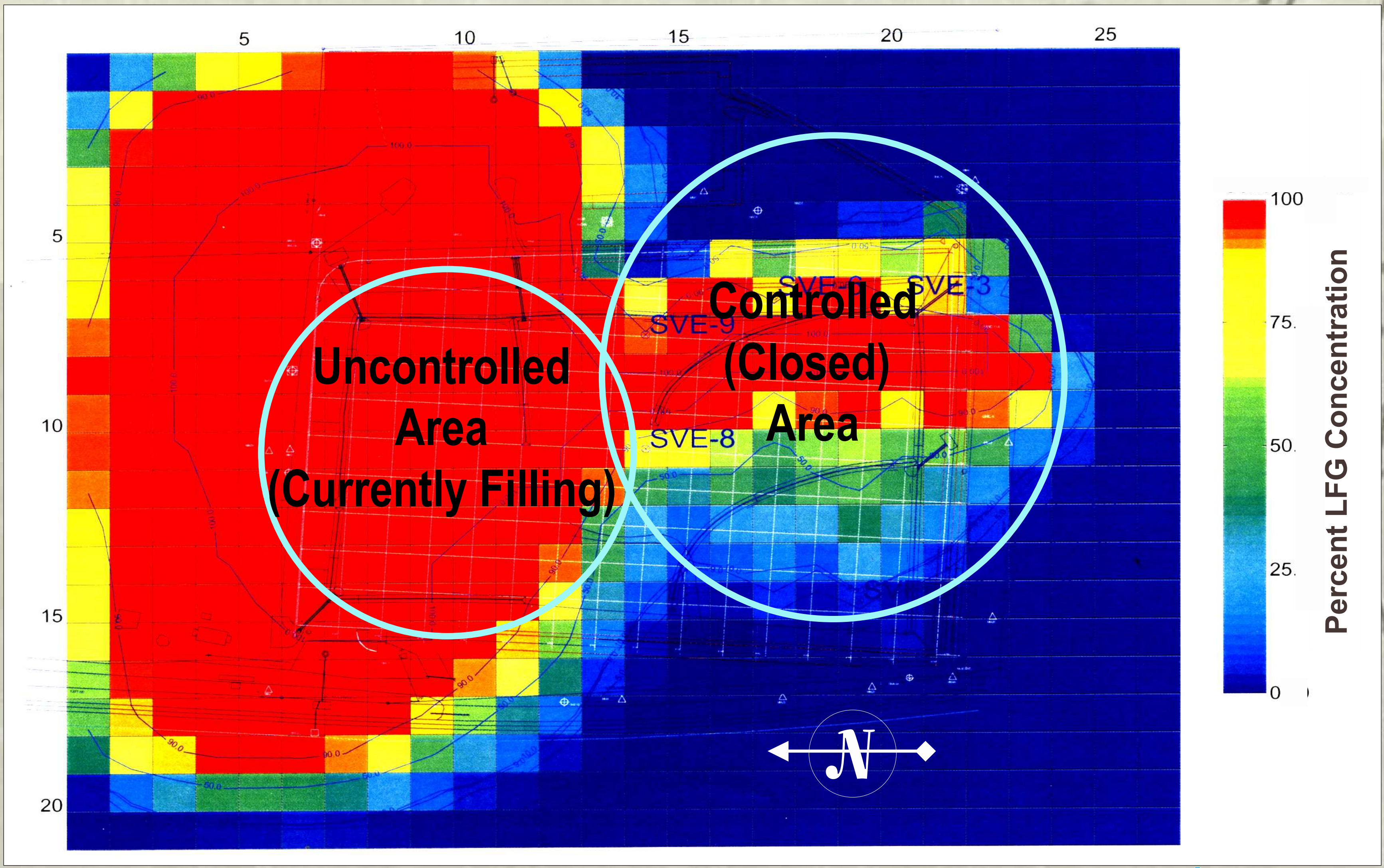
GAS COLLECTION SYSTEM - SOUTH PHASE

Approved	Date	Revised	Date	Reference:	FIG.
JP	10/05/04			7961003A	03

Simulated Steady-state Soil LFG Distribution in the Vicinity of the Decatur County Landfill equipped with the South Phase LFG Control System



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Results

- The baro-pneumatic method shows great promise:
  - Quantitative estimate of pneumatic properties including LFG generation and gas permeabilities
  - Provides important insights into landfill behavior
  - Produces numerical model suitable for engineering design, optimization, performance simulation
  - Allows calibration of site-specific 1st-order decay models, reducing risk of mis-assessing future LFG generation.

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Conclusions

- The consistency and plausibility of the results support the validity of the baro-pneumatic method :
  1. Excellent model fits to data in numerical calibration
  2. Narrow range and reasonable values for calibrated model L_0
  3. LFG collection data (where available) confirm results

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Recommendation

- Questions regarding the baro-pneumatic method should be addressed, and resolved, by careful, scientific tests at one or more adequately monitored landfills.
- Success of such tests would
  - Accelerate acceptance by the Landfill Industry
  - Help overcome regulatory inertia
  - Allow energy-related and environmental benefits of a validated baro-pneumatic method to be more quickly realized

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