

Remediation Endpoints – Factors for Consideration when Determining Appropriate Remediation Endpoints for Aggressive LNAPL Recovery

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Introduction

- This presentation is a continuation of the presentation from RemTech 2005 entitled “*Remediation of Deep LNAPL from Glacial Soils Using High Vacuum Multi-Phase Extraction (MPE), Pneumatic Air Lift (PAL), and Pneumatic Fracturing (PF)*” by Cushman et al.

Historical LNAPL Perception

- Historically, the presence of LNAPL triggered the need for active recovery/remediation due to a “perceived risk” by the regulatory community;
- Recent research, including LNAPL mobility and plume stability evaluations, indicate that “perceived risks” are often unfounded;
- LNAPL plumes are spatially self-limiting unless continually from an on-going release, thus distinguishing LNAPLs from dissolved and vapour phase plumes that may migrate significant distances (API, 2004).

LNAPL Remediation Considerations

- The following factors should be considered and decided upon prior to selecting a remedial technology and commencing remedial operations:
 - Remedial drivers;
 - Remediation metrics; and
 - Remediation endpoints.

Why Remediate LNAPL?

- Risk-Based Remedial Drivers: when risk assessment shows that there is an unacceptable risk associated with current or future completed exposure pathways resulting from the LNAPL (includes potential explosion hazards);
- Non-Risk-Based Remedial Drivers: when LNAPL remediation is required for other reasons unrelated to risk (e.g., property development or redevelopment, property transaction, etc.).

Non-Risk-Based Remedial Drivers (ASTM, 2005)

- Reduction of LNAPL mass;
- Reduction of observable LNAPL in wells;
- Mitigation of nuisance conditions;
- Reduction of plume mobility;
- Reduction of plume longevity;
- Reduction of flux from daughter plumes; and
- LNAPL mass recovery to a specific limit.

Remediation Metrics (ASTM, 2005)

- Should be defined prior to commencing remedial operations where possible;
- Two main types: benefit metrics and cost metrics;
- Benefit Metrics: reduced risk; plume longevity; chemical distribution; flux-based levels; concentration based targets; LNAPL thickness;
- Cost Metrics: system equipment and power use; raw materials; land use impairment, labour, etc.

Remediation Endpoints

(U.S. EPA, 2005)

- Endpoints are consistent with and similar to remedial drivers except they outline the specific goals that must be achieved;
- Should be established for active, passive, and engineering control systems at various points along the path to closure;
- May be performance-based to the particular remedial technology (removal of “x” amount of LNAPL), or results-based to reflect a long-term condition (specific soil or groundwater concentration).

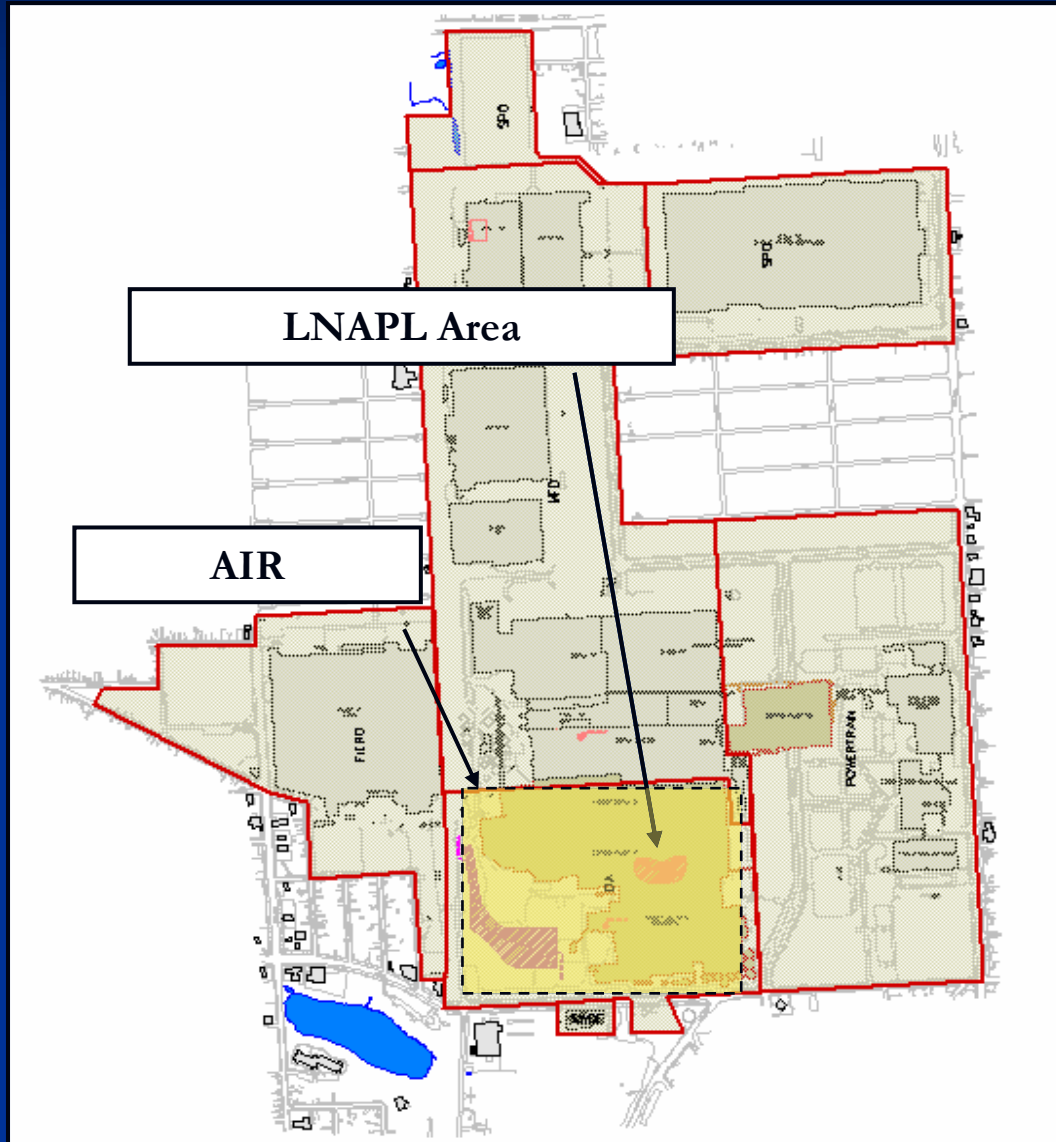
Remediation Endpoint Examples (U.S. EPA, 2005)

- Recovery rate for LNAPL reduced to established value (e.g., less than 10 litres per day);
- Specific COC reduced to target concentration at “x” monitoring locations over “y” time;
- Plume stability is demonstrated based on dissolved COC concentrations;
- LNAPL transmissivity reduced at “x” locations;
- LNAPL saturations below residual saturation;
- LNAPL velocity less than 10^{-6} cm/s threshold value (ASTM, 2005).

Case Study - Background

- Subject Site – 600 acre General Motors Corporation (GM) manufacturing facility in the U.S.;
- South portion of Site (approximately 100 acres) leased to a 3rd party and undergoing redevelopment for the construction of an 800,000 square foot building;
- Area referred to as Area of Industrial Redevelopment (AIR).

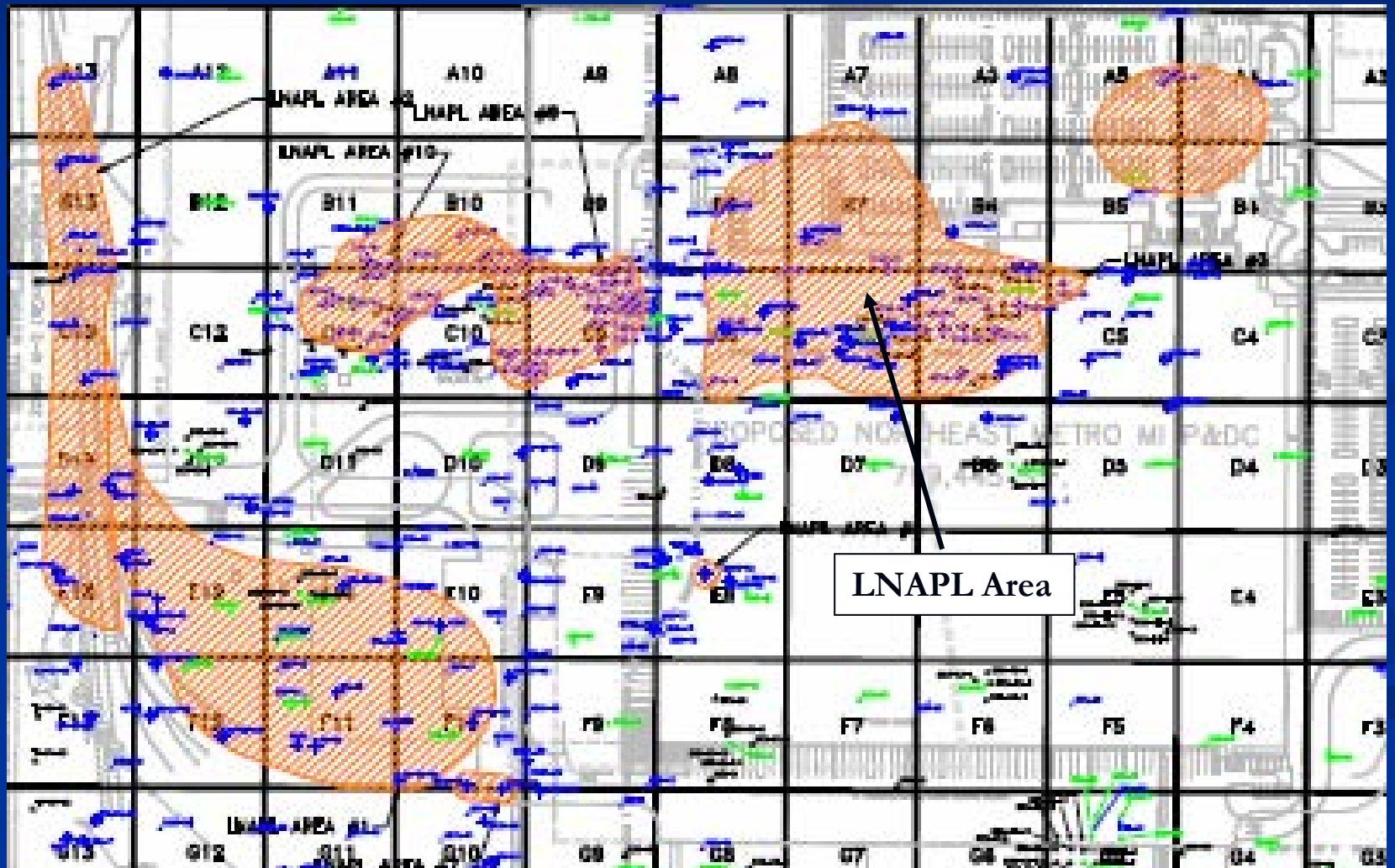
Site / AIR / LNAPL Area



Background (Cont'd)

- LNAPL was discovered in various areas in the AIR, including an area which in part, was located beneath the proposed building footprint;
- GM conducted an aggressive LNAPL recovery program in the footprint LNAPL Area in support of the construction schedule in the AIR;
- This presentation focuses on the LNAPL remediation efforts conducted in the footprint LNAPL Area.

LNAPL Area



Geology/Hydrogeology

- Geology is comprised of low permeability glacial soils (silts and clays with occasional sand seams);
- Depth to air/LNAPL interface in the LNAPL Area is approximately 30 feet bgs;
- LNAPL thicknesses vary from a sheen to 12 feet;
- LNAPL has been fingerprinted as a weathered No. 2 fuel oil/diesel with lesser amounts of No. 6 fuel oil.

Subsurface Structures

- Subsurface concrete structures (basements, walls, etc.) in the AIR remaining from buildings previously demolished;
- A large diameter storm sewer (72-inch) runs through the LNAPL Area at a depth of approximately 30 feet;
- The LNAPL appears to be migrating to/collecting around the storm sewer.

Previous Remedial Efforts

- Pneumatic skimmers were used from February through November 2004 to remove LNAPL from part of the LNAPL Area;
- Three skimmers were rotated amongst various wells containing LNAPL in an effort to maximize recovery volumes;
- Approximately 590 gallons of LNAPL was recovered over the 8-month period.

Remedial Driver – Non-Risk-Based

- Previous risk assessment calculations indicated that LNAPL did not pose an unacceptable risk to intended current or future users of the AIR;
- Primary driving force behind remediation program was the property redevelopment agreement negotiated with 3rd party;
- Construction of building in AIR was scheduled to commence Spring 2006.

Remediation Endpoint

- Endpoint - aggressively remove as much LNAPL as possible beneath building footprint prior to building construction.

Selected Technology

- High vacuum Multi-Phase Extraction (MPE) has been shown to be a superior technology (in comparison to traditional pump and treat methods) for recovering LNAPL from low permeability formations;
- High vacuum alone is generally limited to recovering LNAPL from depths of 25 feet or less (due to vacuum lift limitations).

Technology Description (Cont'd)

- Pneumatic Air Lift (PAL) may be used in conjunction with MPE to enable the evacuation of LNAPL/groundwater from extraction wells;
- Pneumatic Fracturing (PF) is used to artificially create a more permeable secondary porosity to better allow the flow of LNAPL through low permeable formations; fracture propagation continues with continued (or pulsed) air injection.

Technology Description (Cont'd)

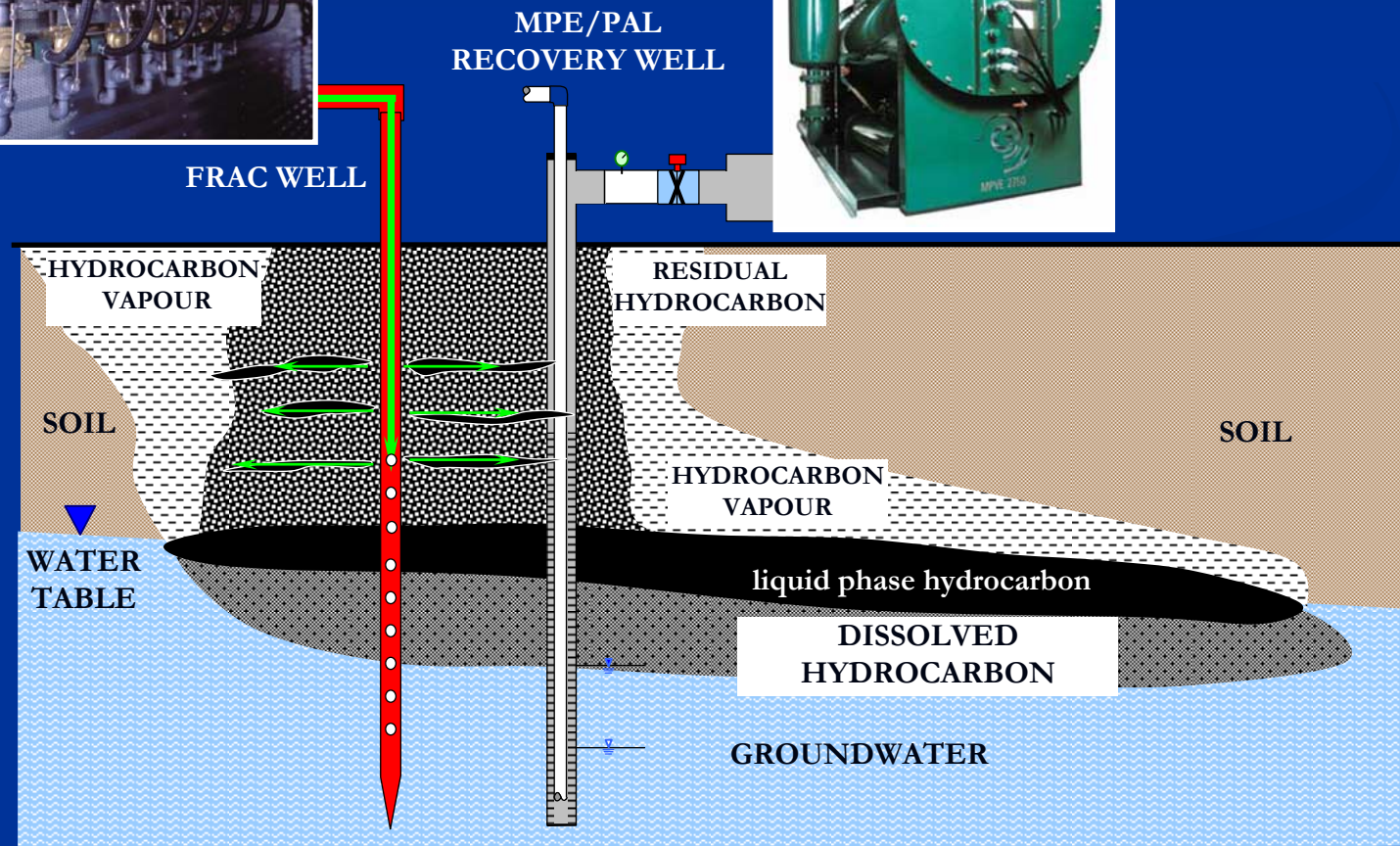
- When PF wells are surrounded by MPE/PAL wells, the resulting high pressure differential between the air injection and vacuum extraction creates a “push-pull” effect enhancing the flow of LNAPL (including previously trapped LNAPL) to recovery wells.

Technology Description (Cont'd)

PF (Pneumatic Fracturing)



MPVE



Technology Description (Cont'd)



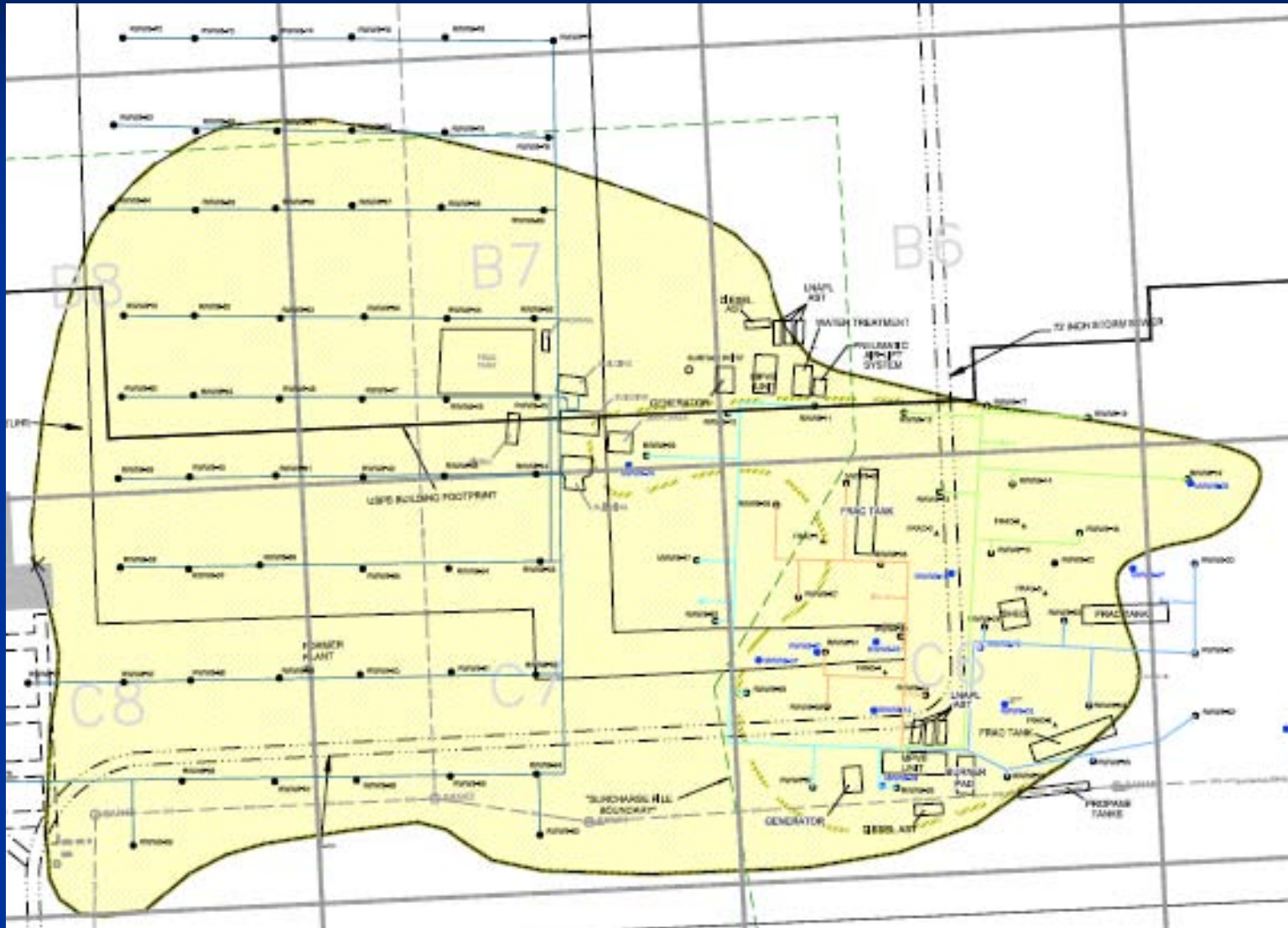
Pilot Study / Equipment

- Remedial pilot study and full-scale remediation utilized Multi-Phase Vacuum Extraction (MPVE) units manufactured by Ground Effects Environmental Services Inc. of Regina, Saskatchewan;
- Three MPVE systems used simultaneously (2750 Titan, 2750 and 27100 Titan);
- See Cushman et al. (2005) for complete description of pilot study results and full-scale equipment.

Equipment (2750 Titan)



Overall System Configuration



Overall System Configuration



Performance – MPVE 2750 Titan

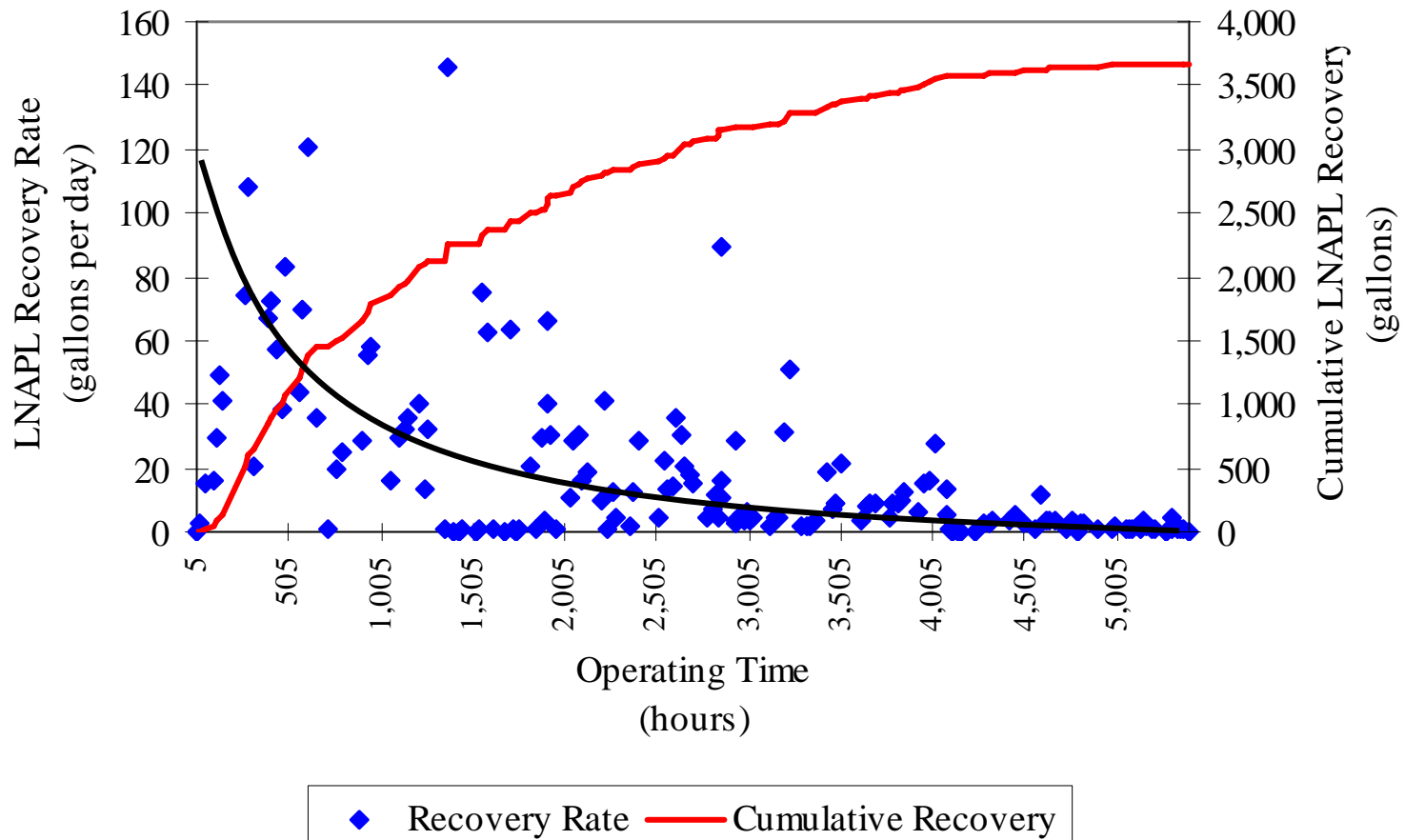
- Operated (intermittently) for 12 months (March 2005 – March 2006) in southeast portion of the LNAPL Area;
- Extracted from up to 12 MPE/PAL wells simultaneously and injected air in 2-3 PF wells;
- Recovered 3,685 gallons (U.S.) LNAPL and 90,000 gallons water in 5,400 hours operation (overall average of 16.4 gallons LNAPL recovery and 400 gallons water per day);

Performance – MPVE 2750 Titan

- 90-98% of LNAPL recovery was in the free phase;
- System shut down when LNAPL recovery rate decreased to less than 2 gallons per day.

Performance – MPVE 2750 Titan

MPVE 2750 Titan (System 1) LNAPL Recoveries

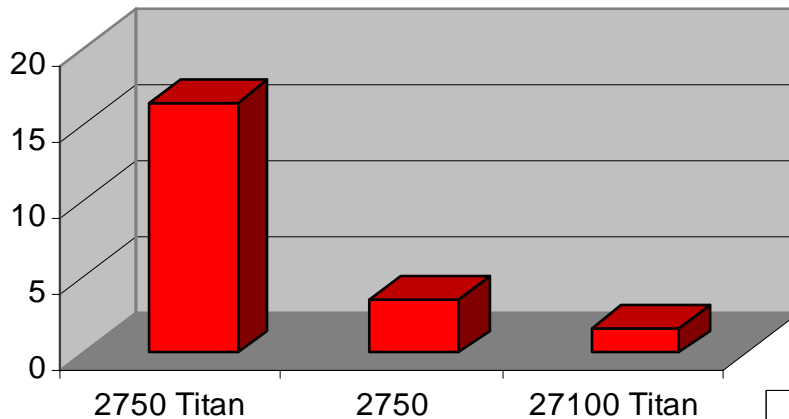


Performance – MPVE 2750 and MPVE 27100 Titan

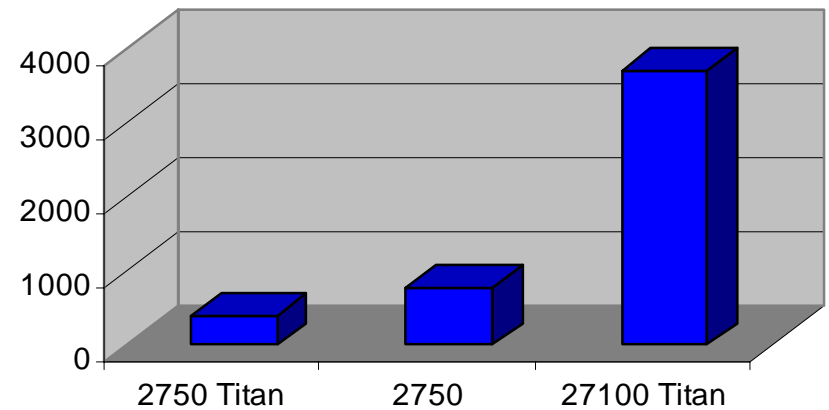
- Operated in all other parts of LNAPL Area excluding the southeast portion;
- MPVE 2750 – 298 gallons LNAPL and 65,000 gallons water in 2,000 hours operation (overall average of 3.6 gallons LNAPL and 780 gallons water recovery per day);
- MPVE 27100 Titan – 38 gallons LNAPL and 85,000 gallons water in 550 hours operation (overall average of 1.7 gallons LNAPL and 3,712 gallons water recovery per day).

Overall Average LNAPL and Water Recoveries

Average LNAPL Recovery (gal/day)



Average Water Recovery (gal/day)



Rationale for Performances

- The MPVE 2750 Titan (System 1) recovered more LNAPL/less water than the MPVE 2750 (System 2) and 27100 Titan (System 3) throughout the remediation program; and
- System 1 appeared to be drawing LNAPL from more permeable sand seams likely associated with the adjacent 72-inch storm sewer.

Evaluation of Endpoints (System 1 Only)

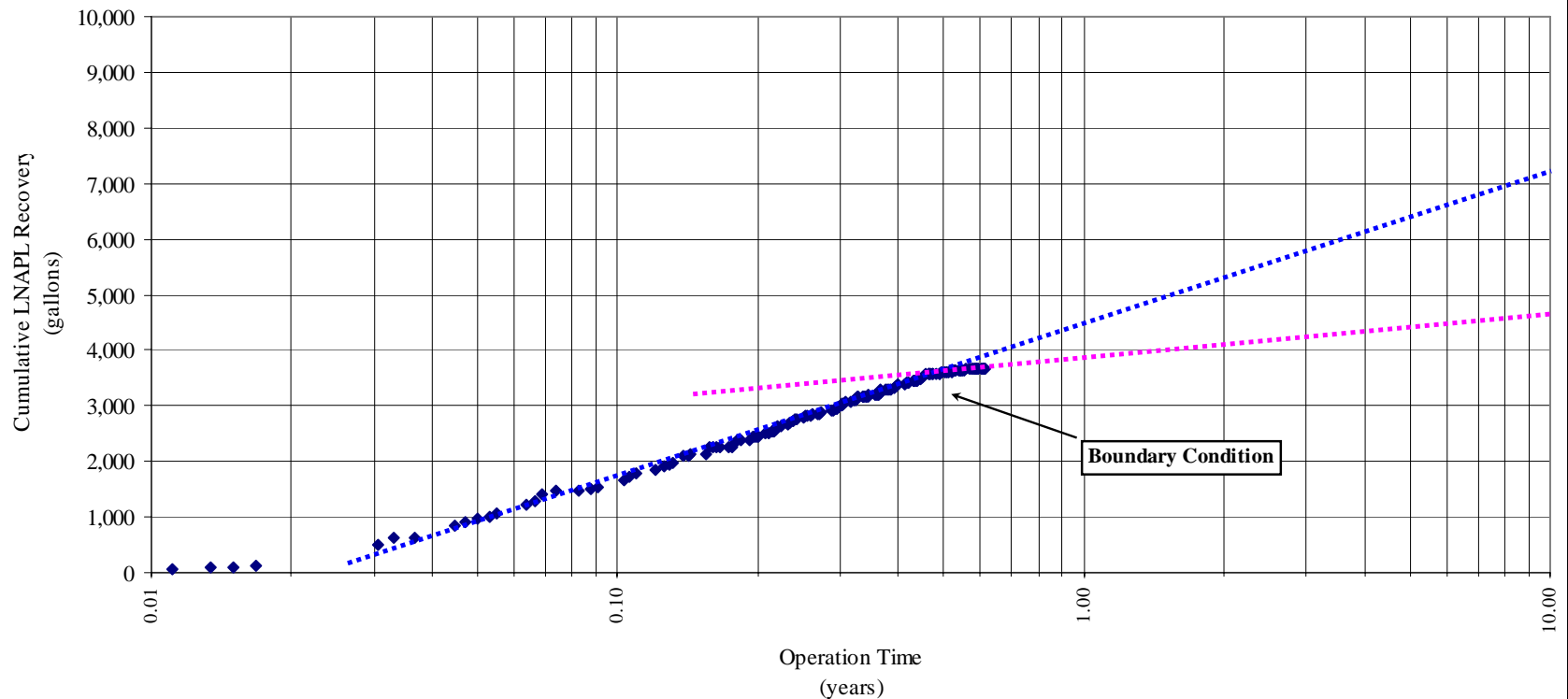
- Asymptotic LNAPL recovery;
- Remediation cost metrics;
- LNAPL mobility/plume stability (adjacent LNAPL areas);
- Remaining in-well LNAPL thicknesses.

Asymptotic LNAPL Recovery

- Reviewed existing recovery data which suggested that LNAPL recovery was near asymptotic;
- Predicted potential future LNAPL recovery using two methods: semi-log plot extrapolation and decline curve analysis;
- Semi-log plot (time on log x-axis versus cumulative LNAPL recovery on y-axis);
- Decline Curve Analysis (cumulative LNAPL recovery on x-axis versus LNAPL recovery rate on y-axis).

Semi-Log Plot Extrapolation

MPVESystem 1 Semi-Log LNAPL Recovery Projection



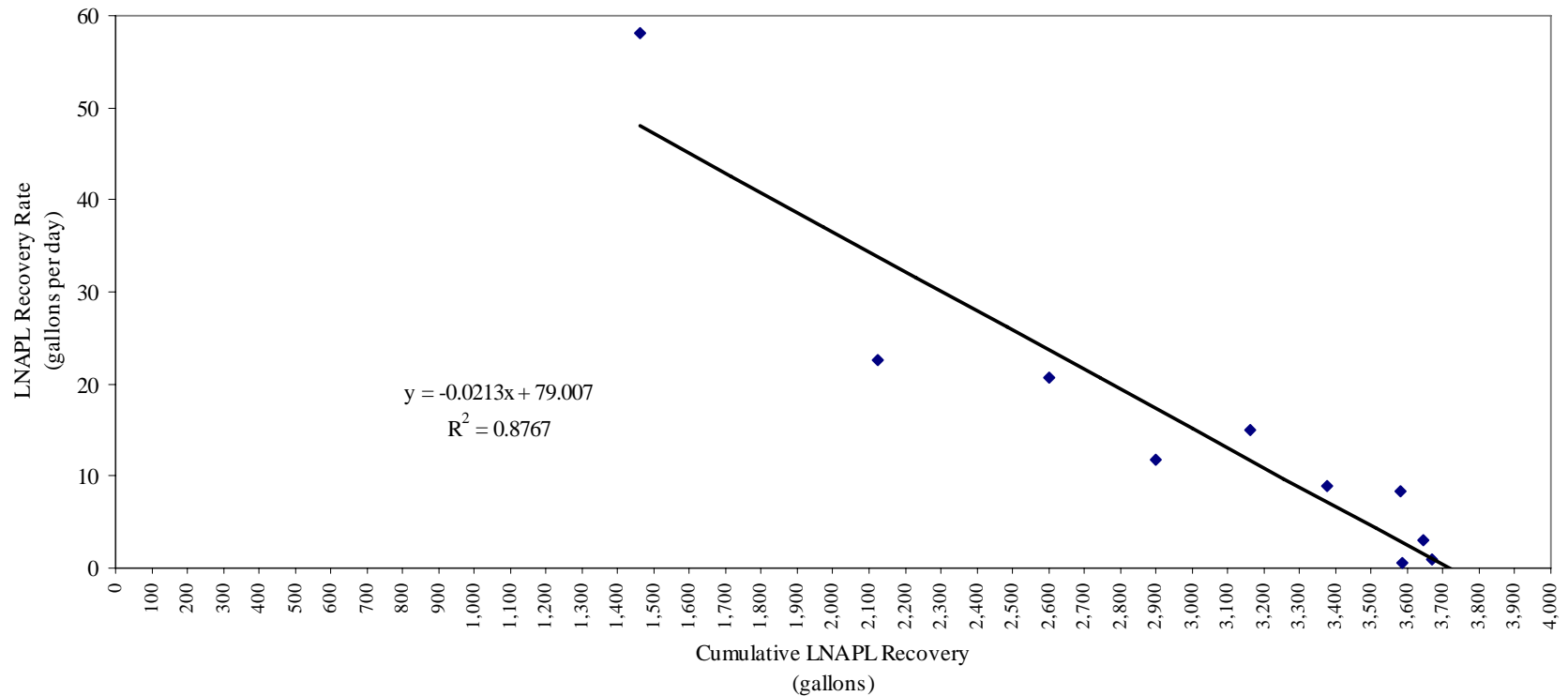
Future LNAPL Recovery Projections

■ Semi-log plot:

- Actual recovery (0.62 years operation time): 3,685 gallons;
- 1 year operation time: 3,950 gallons;
- 10 year operation time: 4,700 gallons.
- 78% of projected recovery for 10 years of operation time recovered in first 0.62 years alone (84% in first year);
- Boundary condition suggests that free, continuous LNAPL may have been depleted from permeable sand seams.

Decline Curve Analysis Extrapolation

MPVESystem 1 Decline Curve Analysis



Future LNAPL Recovery Projections

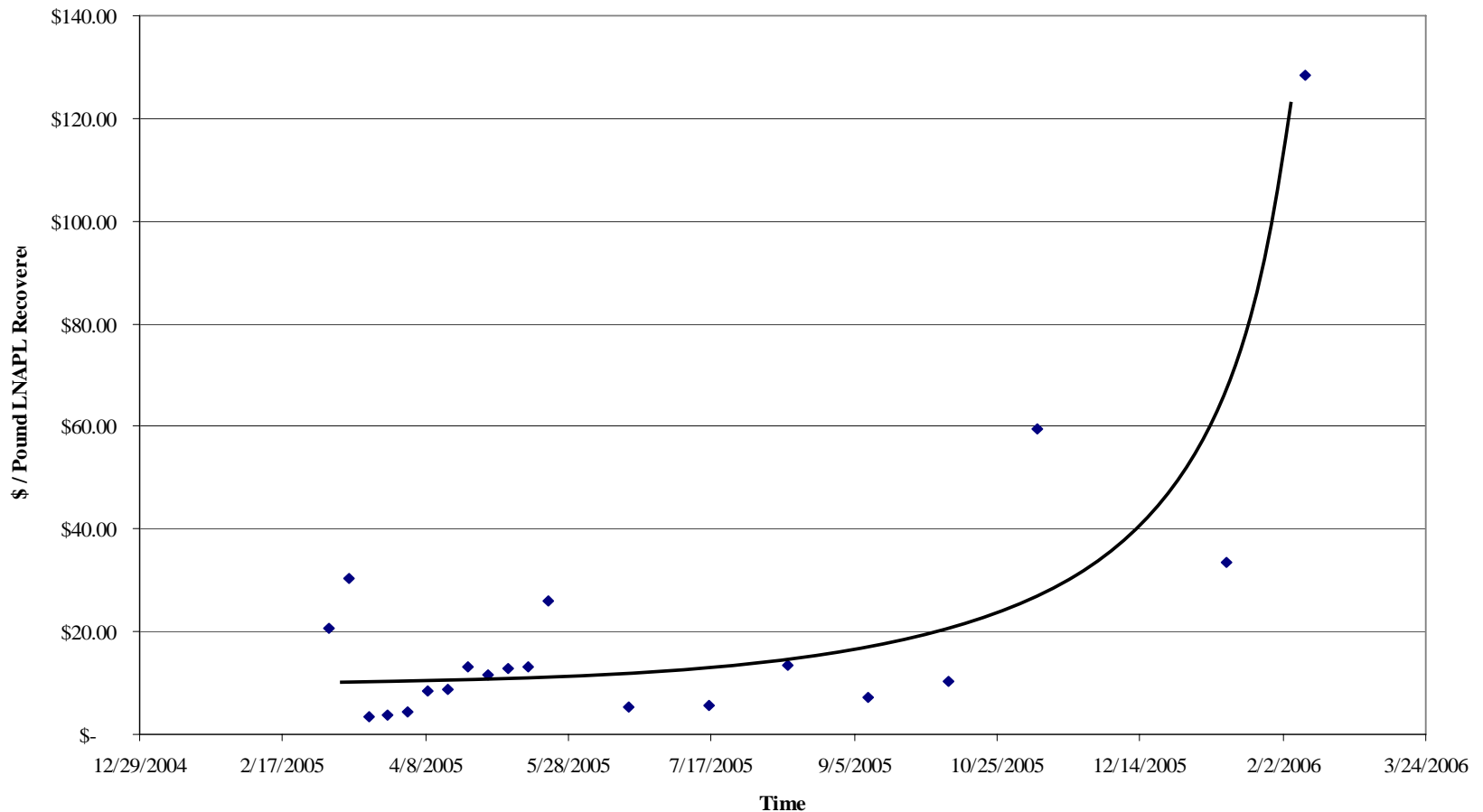
- Decline Curve Analysis:
 - x-intercept indicates that 3,725 gallons can be recovered (total);
 - Actual recovery (0.62 years operation time): 3,685 gallons;
 - Therefore an additional 55 gallons is deemed to be recoverable.

Remediation Cost Metrics Evaluation

- Plotted cost per pound of LNAPL recovery versus time;
- Plotted cost per gallon of LNAPL recovery versus time;
- Both graphs indicated that ongoing operation of the MPVE system was cost prohibitive.

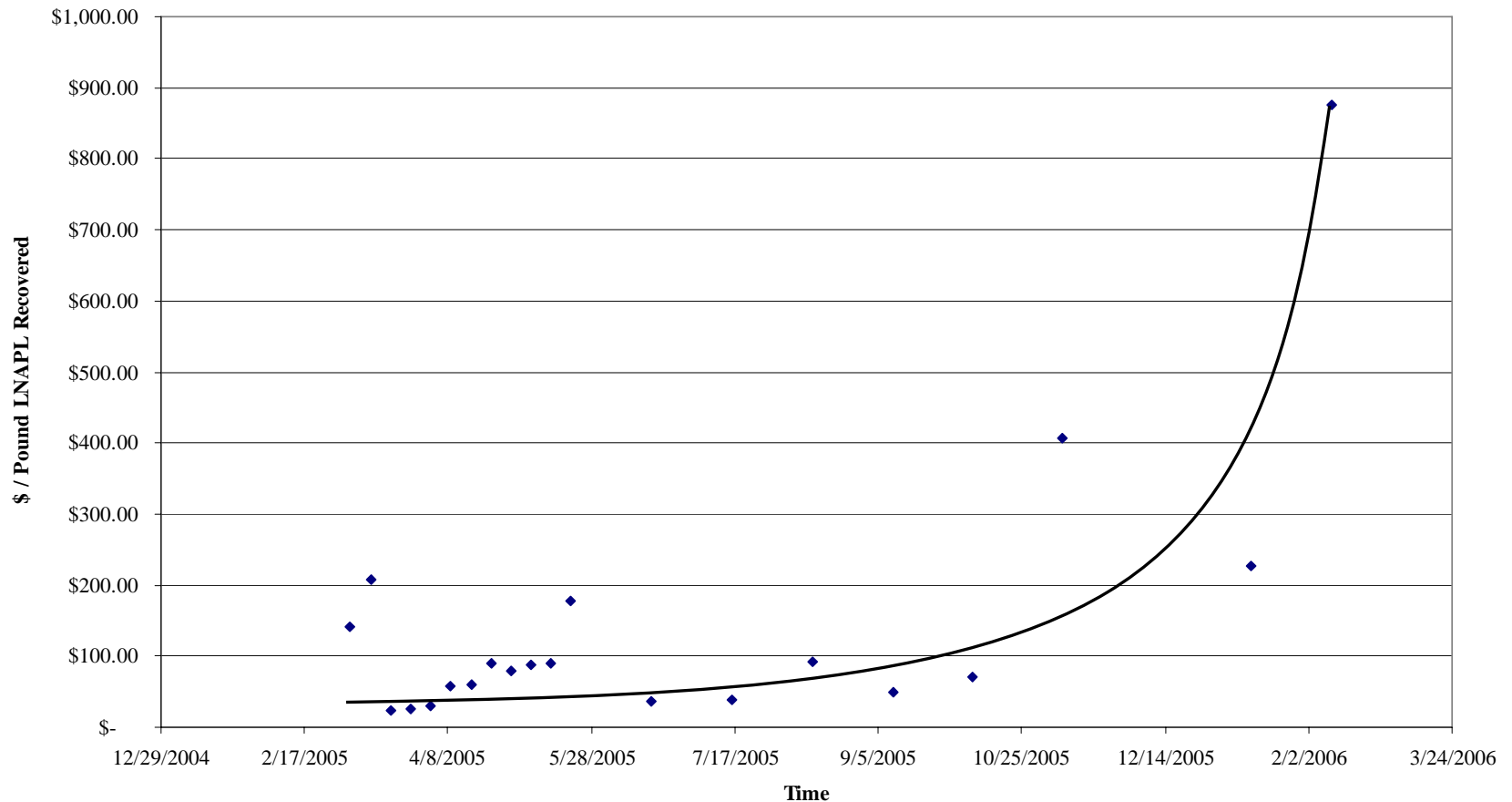
Operation Cost Per Pound LNAPL Recovery

MPVE 2750 Titan (System 1) Operation Cost Per Pound LNAPL Recovery



Operation Cost Per Gallon LNAPL Recovery

MPVE 2750 Titan (System 1) Operation Cost Per Gallon LNAPL Recovery



LNAPL Mobility Evaluation

- GM conducted Site-specific LNAPL mobility evaluation in other LNAPL areas immediately adjacent to subject LNAPL Area;
- Results suggest that the LNAPL plumes are stable with varying degrees of inherent mobility within areas;
- See Rousseau et al. (RemTech 2006).

Remaining In-Well LNAPL Thicknesses

- Some wells in the LNAPL Area, outside of the southeast portion, contained appreciable thicknesses of LNAPL ranging up to 8 feet;
- These thicknesses were in predominantly silty clay areas that yielded negligible LNAPL recovery during the operation of the MPVE systems;
- Large in-well thicknesses despite low recovery suggest that LNAPL is present in various seams under confined conditions.

Regulatory Feedback

- U.S. Environmental Protection Agency (U.S. EPA) reviewed LNAPL performance and agreed that GM could terminate aggressive recovery using MPVE systems;
- Some additional monitoring is required to ensure that plume is stable;
- Scope of monitoring yet to be determined.

Acknowledgements

- The authors wish to thank General Motors Corporation for their contributions to this paper and to the ongoing LNAPL recovery efforts.