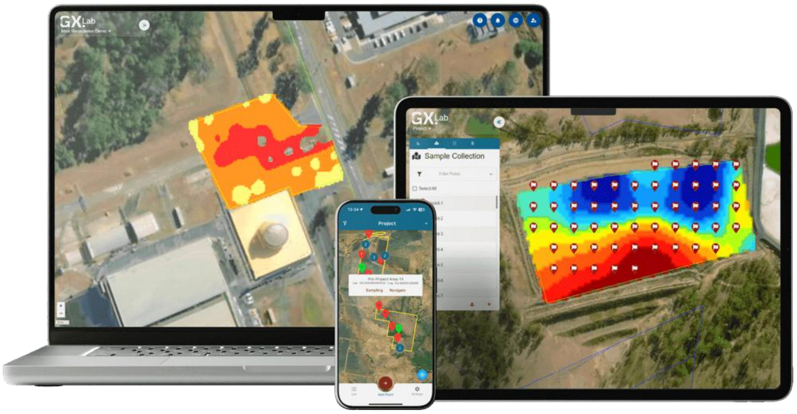
TECHNICAL PAPER

RemScan Enabled Excavation Delineation for Hydrocarbon-Impacted Soil

A Monte Carlo Cost–Risk Comparison of
Lab-Only vs RemScan Workflows
Integrated with the GXLab Platform



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Date
December 14, 2025

Executive Summary

This report evaluates excavation delineation outcomes for hydrocarbon-impacted soil using a Monte Carlo simulation framework. It compares a **conventional lab-only sampling** workflow against a **Rapid Scan (RemScan)** workflow integrated with the GXLab platform.

Across thousands of simulated plumes, the analysis shows that increasing vertical measurement density using low-marginal-cost Rapid Scan data materially reduces under-excavation risk. This reduction in missed contamination events dominates total project cost when the consequences of rework, delay, and regulatory exposure are moderate to high.

Key findings from the simulations

- Holding borehole locations constant but increasing vertical resolution reduced mean total remediation measurement cost by ~17–20 percent across low, medium, and high penalty scenarios.
- Modestly increasing borehole density while maintaining high vertical resolution reduced mean measurement cost by ~48–60 percent.
- In all scenarios, the RemScan workflow reduced the high-cost tail driven by under-excavation events, even when conservative assumptions were applied to measurement error.
- Once a core exists, dense vertical data becomes economically rational because marginal analysis cost is low relative to excavation and rework risk.
- Near-real-time integration with GXLab compounds value by shortening decision cycles and reducing stop-start excavation behaviour.

Table ES-1. Total cost per plume (simulation summary; currency in AUD million (approx. 1.4 USD Million)

Case	Penalty	Lab mean	RemScan mean	Lab median	RemScan median	Mean reduction
1	Low	0.37	0.31	0.21	0.12	17.3%
1	Medium	1.07	0.86	0.60	0.32	19.0%
1	High	2.64	2.12	1.46	0.78	19.6%
2	Low	0.55	0.28	0.30	0.16	48.0%
2	Medium	1.59	0.68	0.87	0.19	57.0%
2	High	3.95	1.59	2.15	0.21	59.8%

Interpretation of the cost tiers: The simulations compute total cost as (over-excavation volume × $\$80/m^3$) + (under-excavation volume × penalty) + sampling/analysis costs. Under-excavation penalty is evaluated as Low=$\$200/m^3$, Medium=$\$600/m^3$, High=$\$1,500/m^3$. These tiers represent best-case through worst-case consequences when contamination is missed and rework is required.

GXLab platform integration value: The direct financial savings shown above do not fully capture the operational value of a fast feedback loop. With RemScan results uploaded into GXLab in near real time, excavation boundary updates and volume estimates can be produced immediately, enabling tighter decision cycles, fewer demobilisation/remobilisation events, and less idle time waiting on laboratory turnaround.

1. Background and problem statement

Hydrocarbon remediation projects frequently rely on discrete soil sampling and off-site laboratory analysis to determine excavation limits. This workflow creates two core constraints: (i) limited sampling density due to cost and logistics, and (ii) decision latency due to laboratory turnaround. Both constraints increase uncertainty when defining excavation boundaries and volumes.

RemScan is a field-deployable mid-infrared (MIR/FTIR) system designed for rapid Total Petroleum Hydrocarbon (TPH) screening. In a RemScan workflow, additional vertical (and potentially horizontal) measurements can be collected at low incremental cost once a borehole/core is obtained. This enables a different optimisation point: spend more effort on measurement density up front to reduce under-excavation tail risk and accelerate decision-making.

2. Objectives

- Quantify how sampling density and measurement cost assumptions change expected excavation error and total cost.
- Compare two practical deployment scenarios: (1) same boreholes as lab-only but higher vertical resolution using RemScan; (2) modestly increased borehole density plus higher vertical resolution using RemScan.
- Represent RemScan measurement performance using an empirical, binned error model derived from observed accuracy vs TPH level.
- Demonstrate how GXLab platform integration compounds value by reducing turnaround time and enabling iterative boundary updates.
- Provide a methodological template that can be adapted to specific projects and client constraints.

3. Overview of Simulation Approach

A Monte Carlo simulation framework was used to generate many plausible 3D TPH plumes and evaluate excavation decisions under different sampling strategies. Each Monte Carlo iteration consists of:

(i) plume generation,
(ii) sampling (borehole grid + depth increments),
(iii) measurement/classification (lab-only assumed perfect classification; RemScan uses an empirical error model),
(iv) depth-to-clean estimation per borehole,
(v) excavation volume estimate via a cell-area summation.
(vi) cost calculation under over/under excavation penalties.

4. Plume Generation Model

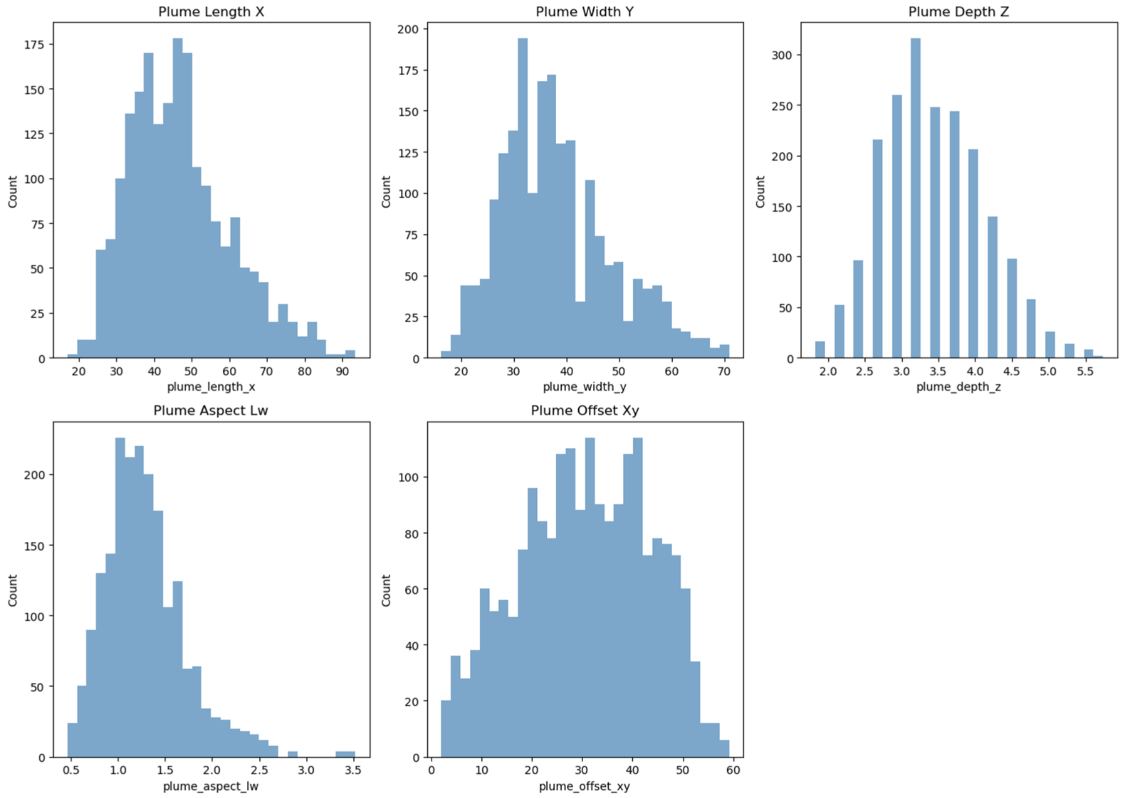
The plume generator produces asymmetric, surface-originating hydrocarbon impacts across a nominal 120 m × 80 m × 6 m domain. A single surface source location is selected and contamination is modelled as one or more anisotropic ‘lenses’ whose centres drift laterally with depth. This captures the field observation that many plumes are not symmetric about the source due to preferential pathways, stratigraphy, and gravity-driven migration.

Key features of the plume model:

- Surface origin: source is on z=0 plane; contamination centres are placed below surface (0.5–3 m) with down-gradient drift proportional to depth.
- Asymmetry: different spread parameters are used on the positive vs negative sides of the plume in x and y directions (piecewise anisotropic Gaussian).
- Heterogeneity: a mild 3D random field and sinusoidal layering are applied multiplicatively to represent variability in soil/porosity and stratigraphy.
- Smear/halo zone: an added low-amplitude lateral halo broadens the footprint around the main lens (representing weathered or smeared hydrocarbons).
- Volume constrainting: plumes are accepted only if the true contaminated volume above threshold (TPH ≥ 1,000 mg/kg) falls within a realistic range (500–3,000 m^3 in the current configuration).

Plume geometry statistics

Figure 1 shows the distribution of generated plume geometries. In the current configuration, plan-view length and width are typically on the order of tens of metres, with a spread that includes both compact and elongated plumes. Depth is concentrated around ~2–5.5 m, constrained by the 0–6 m domain, and aspect ratios are commonly ~0.8–1.8 with a tail to >3. Offset distributions reflect that the ‘centroid’ of contamination can be displaced from the source due to depth-dependent drift.

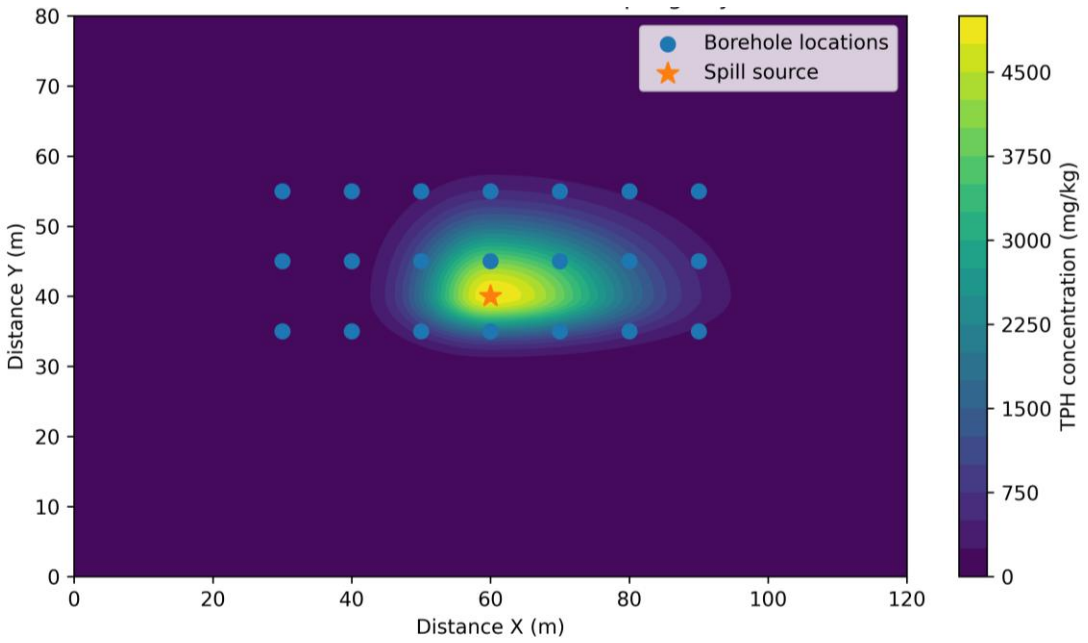


[Figure 1: Histograms of plume_length_x, plume_width_y, plume_depth_z, plume_aspect_lw, plume_offset_xy]

5. Sampling model

Sampling is represented as a rectangular grid of boreholes centred on the known spill source location. This encodes a realistic operational assumption: field teams typically have at least a rough source location from site history, infrastructure, and visual/odour cues, and they do not sample uniformly at random over an entire site.

Within each borehole, samples are taken at fixed depth increments (depth_step). The TPH value at each sample is obtained by trilinear interpolation of the underlying 3D plume field.



[Figure 2: Example synthetic surface originating hydrocarbon plume and source centered borehole sampling layout]

Two scenarios evaluated

Scenario	Lab grid (nx×ny)	Lab depth step	RemScan grid (nx×ny)	RemScan depth step	Per-sample analysis cost assumption
Case 1	5×2	1.0 m	5×2	0.25 m	Lab: $100; RemScan: $5
Case 2	5×2	1.0 m	7×3	0.25 m	Lab: $100; RemScan: $5

Note: In both cases, the additional RemScan vertical sampling is treated as ‘free data’ in the sense that the core has already been recovered; the marginal cost is analysis and handling time, not drilling.

6. Rapid Scan Measurement Model

Lab-only measurement is treated as a perfect classifier at the threshold (TPH ≥ 1,000 mg/kg) for the purpose of isolating the decision impact of sampling density vs measurement error. RemScan Rapid Scan is simulated using an empirical, binned error model (Table 3) derived from observed performance trends: error rates are low far from the threshold and highest in the ‘grey zone’ around ~1,000–4,000 mg/kg.

Rapid Scan empirical error model

True TPH Range (mg/kg)	Environmental Context	Classification Error Probability	Classification Accuracy	Model Behaviour
0 – 200	Clean soil background	1%	99%	Rare false positives
200 – 600	Low contamination / noise zone	1%	99%	Stable classification
600 – 900	Near-threshold transition	2%	98%	Minor boundary uncertainty
900 – 1,200	Regulatory decision boundary	10%	90%	Elevated ambiguity near threshold
1,200 – 2,000	Mixed contamination zone	75%	25%	High classification volatility
2,000 – 4,000	Moderate contamination	40%	60%	Transitional recovery in accuracy
4,000 – 8,000	Strong contamination signal	10%	90%	Reliable detection
> 8,000	Highly contaminated soil	1%	99%	Near-certain classification

[Table 3: TPH bin ranges and assumed probability of misclassification (or probability of correct classification). Include provenance note referencing the internal validation plot.]

Implementation detail: for each simulated sample, the model draws whether the Rapid Scan classification is correct based on the bin-specific probability. If incorrect, the binary classification is flipped (false positive becomes false negative and vice versa). This approach is deliberately simple and transparent; it can later be replaced with a calibrated probabilistic model (e.g., continuous probability curve or confusion matrix conditional on soil type/interferences) as more field validation data is accumulated.

7. Excavation Volume Estimation

For each borehole, the 'depth-to-clean' is taken as the maximum sampled depth at which the method indicates contamination (true contamination for lab-only; predicted contamination for RemScan). The excavation volume estimate is then computed by summing depth-to-clean over the borehole grid multiplied by the cell area defined by borehole spacing. This is a first-order model of an excavation surface; it intentionally avoids overfitting a smooth surface model that could conceal uncertainty.

8. Cost Model

Total cost per plume is computed as the sum of: (i) sampling + analysis cost, (ii) cost of over-excavation (clean soil removed unnecessarily), and (iii) penalty cost of under-excavation (contamination left behind). The latter is evaluated across low/medium/high penalty tiers to reflect the reality that missed contamination can range from minor to catastrophic depending on site context, regulatory setting, and project logistics.

Cost components

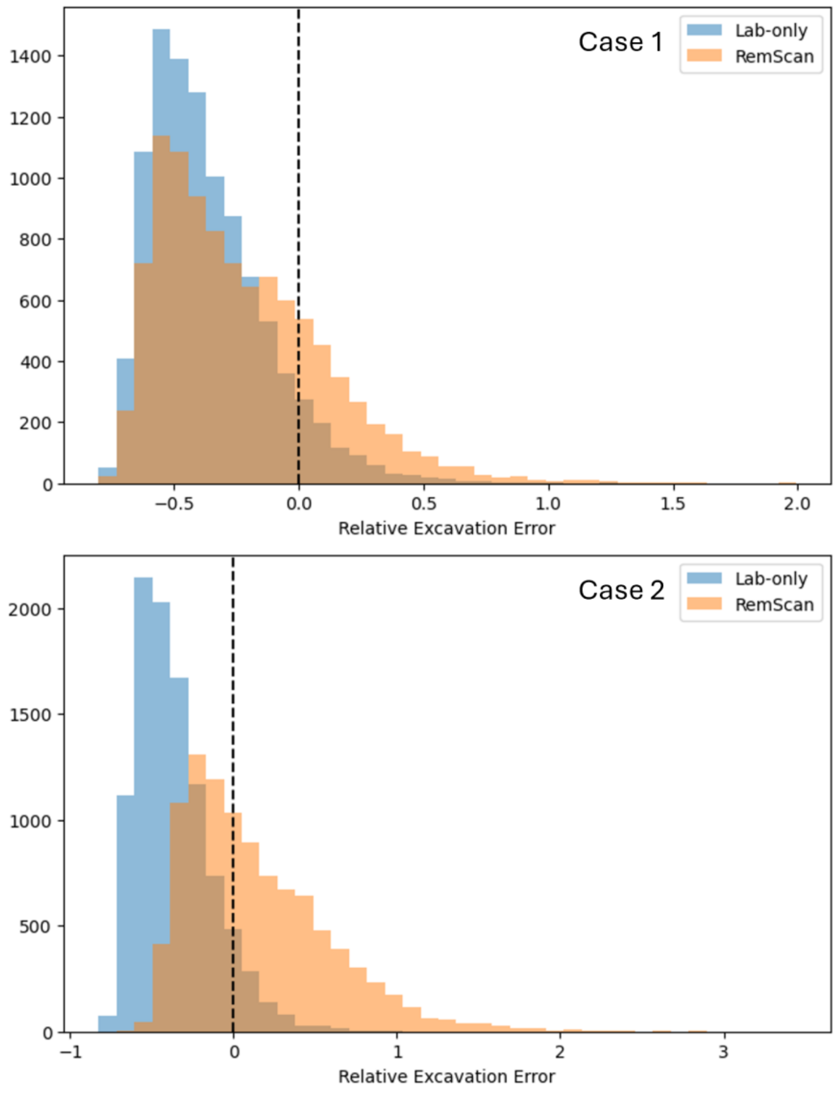
- Over-excavation: $80 per m^3 of clean soil excavated unnecessarily (represents dig/haul/disposal and reinstatement overhead).
- Under-excavation penalty tiers: Low=$200/m^3, Medium=$600/m^3, High=$1,500/m^3 (represents re-excavation, validation re-sampling, delays, mobilisation, and consequential costs).
- Sampling/analysis: per-sample analysis cost set by scenario e.g., lab $100/sample; RemScan $5/sample).

9. Results

Results are reported as distributions of relative excavation error and total cost per plume across Monte Carlo iterations. Key summary metrics include mean and median cost, and the shape of the distribution (particularly the high-cost tail, which is usually driven by under-excavation events).

9.1 Relative error distributions

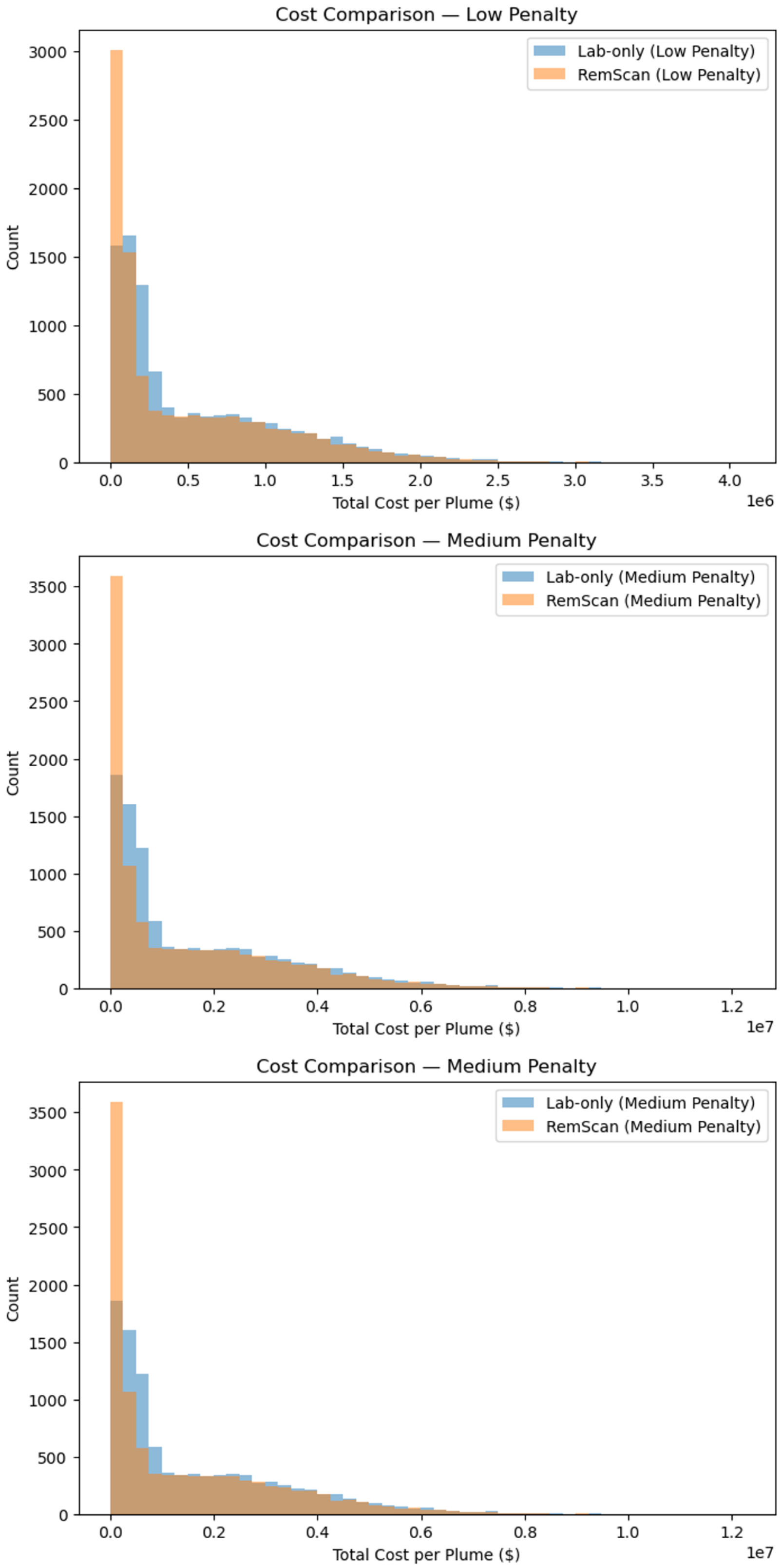
In the provided simulation outputs, lab-only tends to cluster toward negative relative errors (systematic under-excavation) when sampling density is limited. RemScan shifts this distribution toward zero by adding vertical resolution and—when configured—additional boreholes. This reduces the frequency of large under-excavation misses at the expense of occasional small over-excavation, which is typically cheaper than rework.



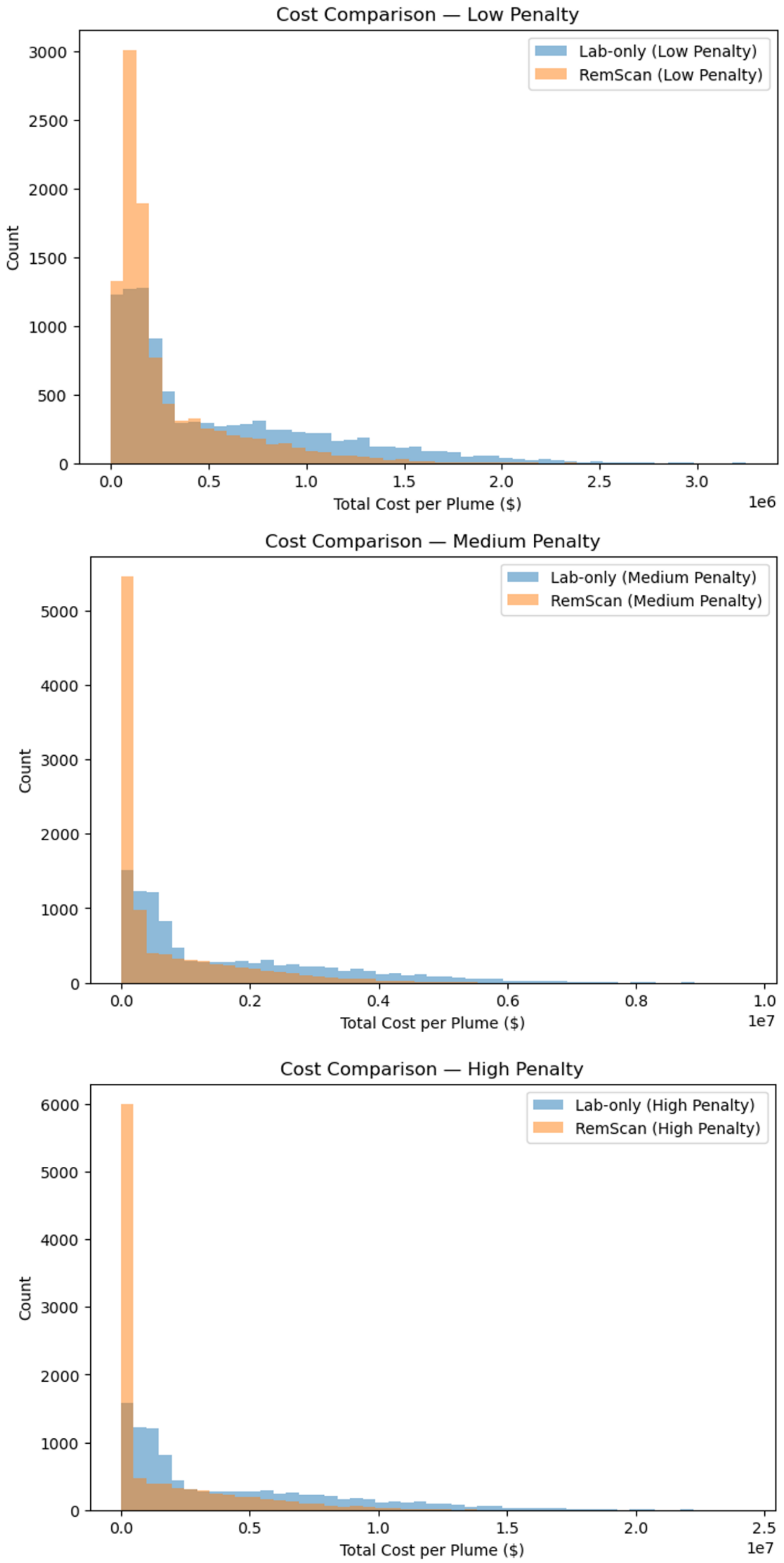
[Figure 4: Relative error distribution — Case 1 and Case 2, lab-only vs RemScan]

9.2 Total cost distributions and summary statistics

The cost histograms show that RemScan reduces both central tendency and tail risk. The advantage grows as under-excavation penalties increase, which matches field intuition: if missing contamination is expensive, investing in better delineation becomes the economically dominant strategy.



[Figure 5: Total cost histograms — Low / Medium / High under-excavation penalties for Case 1]



[Figure 6: Total cost histograms — Low / Medium / High under-excavation penalties for Case 2]

Key quantitative outcomes

- Case 1 — same boreholes, higher vertical resolution with RemScan
    - Low penalty: mean cost Lab $369,714 vs RemScan $305,786 (mean reduction 17.3%). Median Lab $211,899 vs RemScan $121,971.
    - Medium penalty: mean cost Lab $1,067,213 vs RemScan $864,349 (mean reduction 19.0%). Median Lab $597,148 vs RemScan $321,618.
    - High penalty: mean cost Lab $2,636,585 vs RemScan $2,121,115 (mean reduction 19.6%). Median Lab $1,463,958 vs RemScan $777,458.
- Case 2 — modestly higher borehole density + higher vertical resolution with RemScan
    - Low penalty: mean cost Lab $545,123 vs RemScan $283,521 (mean reduction 48.0%). Median Lab 302,920 vs RemScan 163,976.
    - Medium penalty: mean cost Lab $1,592,914 vs RemScan $684,660 (mean reduction 57.0%). Median Lab $870,210 vs RemScan $188,298.
    - High penalty: mean cost Lab $3,950,445 vs RemScan $1,587,224 (mean reduction 59.8%). Median Lab $2,146,612 vs RemScan $209,250.

10. Discussion

The simulations support a practical conclusion: where the consequences of under-excavation are meaningful, the optimal strategy is often to increase delineation density—especially vertical density—rather than accept sparse data and rely on lab turnaround. RemScan enables this shift because it changes the marginal cost of additional measurements.

10.1 Why vertical resolution matters

Hydrocarbon impacts commonly exhibit strong vertical gradients due to infiltration, layering, and capillary/retention effects. If vertical sampling is coarse (e.g., 1 m increments), a single missed interval can cause the depth-to-clean estimate to be biased shallow, producing systematic under-excavation. Increasing vertical resolution to 0.25 m reduces this discretisation error and makes the excavation surface estimate more robust.

Example (conceptual): a plume with contamination between 1.2–2.0 m depth can be missed entirely by a 1 m schedule if sampling occurs at 0.25, 1.25, 2.25 m and the classification around threshold is noisy; denser vertical sampling reduces that risk.

10.2 Why modestly more boreholes can still be economical

Increasing borehole density increases drilling cost, but it also reduces spatial aliasing—missing lateral plume extent between holes. Because RemScan reduces per-sample analysis cost, part of the added drilling overhead can be counterbalanced by reduced laboratory spend, while still delivering a material improvement in certainty.

10.3 Platform integration: the compounding effect of time

The simulation cost model captures only direct financial consequences from excavation error and sampling costs. In real projects, time is often the hidden multiplier. Lab turnaround introduces idle time, conservative decision-making ('excavate extra to be safe'), or stop–start operations. Integrating RemScan field data into the GXLab platform enables near-real-time mapping, volume calculation, and boundary updates. This can reduce demobilisation/remobilisation risk, compress schedules, and improve coordination between field crews, contractors, and client representatives.

11. Limitations and recommended next improvements

- Perfect lab assumption: the lab-only scenario assumes perfect classification at threshold; in reality labs have sampling and analytical uncertainty. This assumption is conservative with respect to RemScan if lab uncertainty is non-trivial.
- Simplified excavation surface model: volume is computed via a grid-sum over depth-to-clean; future versions could fit smooth surfaces and quantify uncertainty bands (but must avoid hiding risk).
- Rapid Scan error model is binned and context-free: it does not yet condition on soil type, moisture, shell grit/carbonate, or other spectral interferences. Those can be added as modifiers once site-specific validation data is available.
- Plume generator is stylised: it generates plausible shapes but is not a physics-based multiphase flow model. The goal is decision stress-testing, not predictive hydrogeology.
- Cost tiers are generic: under-excavation penalties should be parameterised to site realities (regulatory burden, mobilisation cost, disposal pathways, schedule criticality).

12. Practical Guidance for Deployment

A practical adoption pathway that aligns with typical remediation operations:

- Start with Case 1 behaviour: maintain borehole counts consistent with current practice but increase vertical resolution (e.g., 0.25 m) using RemScan to reduce discretisation-driven under-excavation.
- Where uncertainty or consequence is high, move toward Case 2: modestly increase borehole density (e.g., +40–60% holes) while keeping vertical resolution high; use GXLab live maps to decide if extra holes are needed mid-shift.
- Treat RemScan as a decision accelerator: integrate field results into GXLab to generate excavation polygons/volumes rapidly, and use targeted confirmatory lab samples for audit/QA rather than as the primary decision bottleneck.
- Log outcomes: record where Rapid Scan disagreed with excavation outcomes and lab confirmation to continuously recalibrate the binned error model for GXLab's client base and soil types.

For more information, or to access RemScan for environmental remediation, visit www.gxlab.com or contact support@gxlab.com.