Sustainable In-situ Thermal Remediation

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(*RemTech*™ 2013)

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ERM

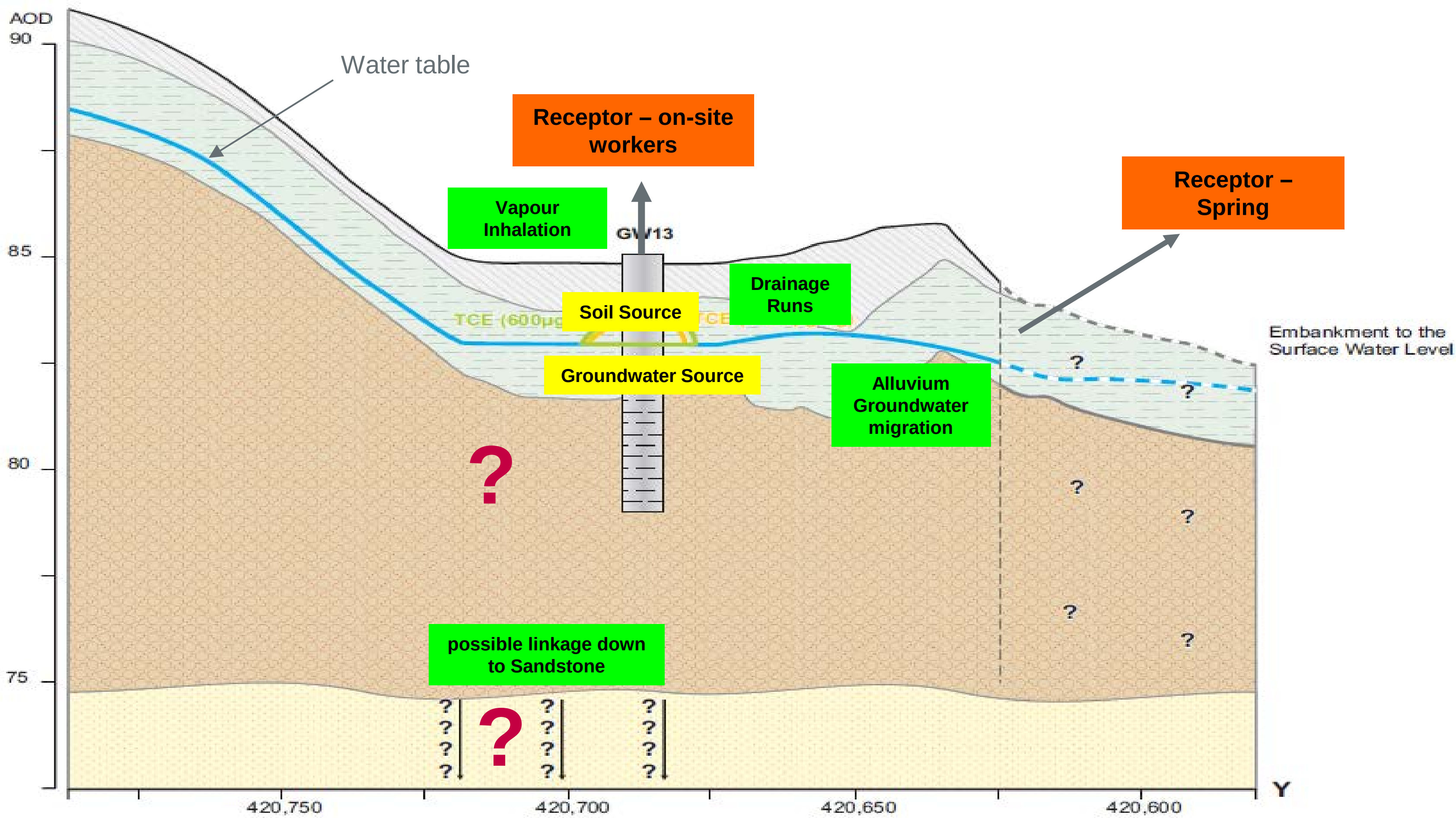
Safety Checklist – Steam Injection

- ❑ Thermal Burns
  - Insulate exposed piping
  - Wear leather gloves with gauntlets
- ❑ Hot/Pressurized Gases
  - Install temp. & press. gauges
  - Wear face shields and leather gloves w/ gauntlets
  - Install piping anchors and expansion loops
  - Utilize lockout/tag out
  - Install whip stops on flexible hose connections

Background

- Former 8 hectare manufacturing site in UK
- Extensive traditional site investigations (costs of $1.5MM)
  - borehole drilling and soil sampling
  - limited monitoring well installation
  - initial Conceptual Site Model (CSM)
- A long term (20 years) groundwater remediation system was proposed
  - vacuum extraction and groundwater pump and treat
  - estimated remedial costs of $15MM – $16.7MM

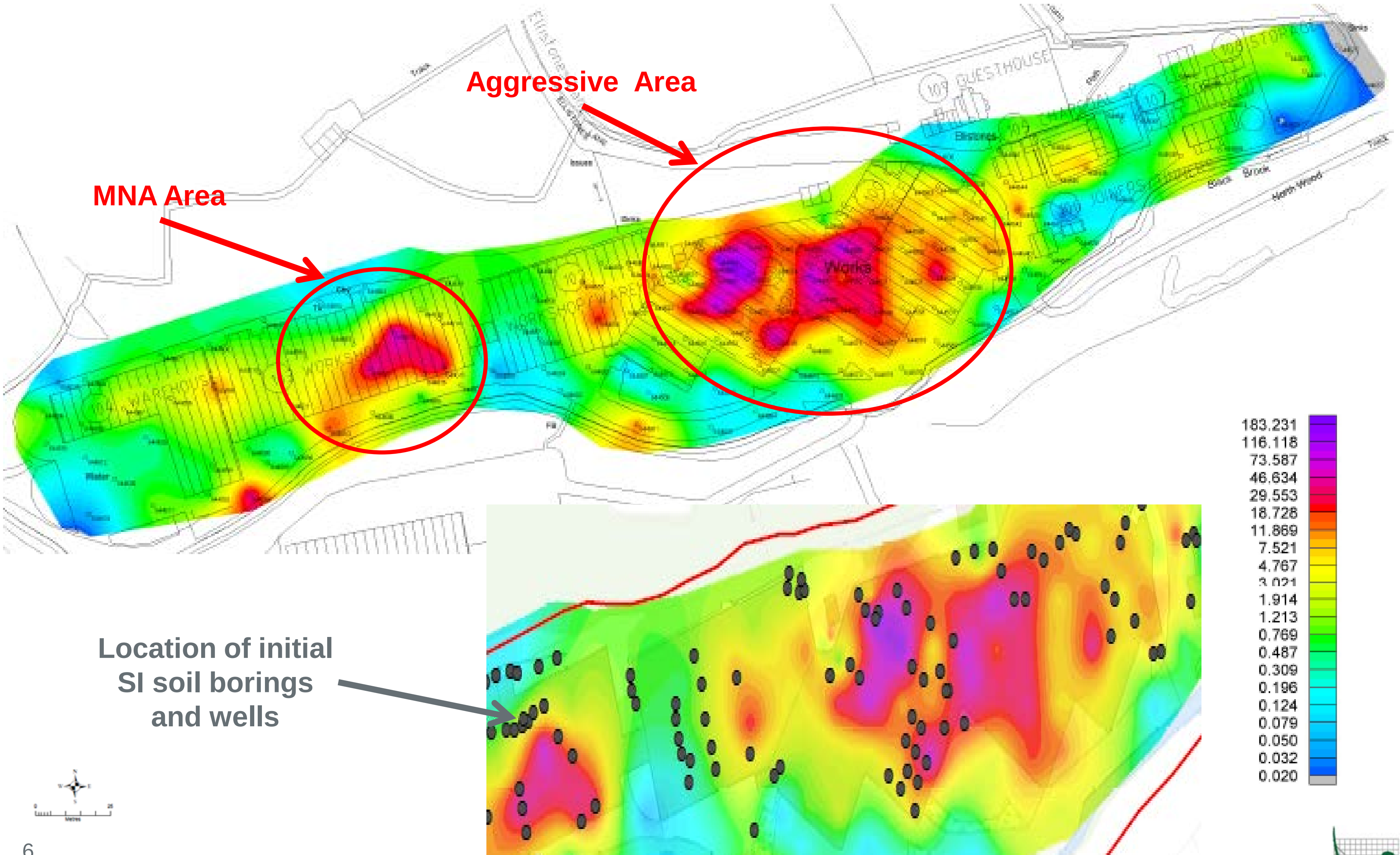
Preliminary Conceptual Site Model



High Resolution Site Characterisation (HRSC)

- ❑ Remediation of the site was required and a long term solution (P&T) was initially proposed.
- ❑ ERM recognized the importance of developing a robust CSM to:
  - focus on accurate delineation of primary and secondary source zones;
  - define the remediation strategy and specification; and
  - focus future remedial efforts.
- ❑ A HRSC approach was adopted for the SI that initially included:
  - Gore Sorber™ Survey at 155 locations (largest survey of its type in the UK)
  - Modified Waterloo Profiler investigation (Alluvium/shale) – 100+ groundwater VOC samples collected
- HRSC investment ($900k) led to smaller remediation target and remedial costs. ($3.8MM vs. $16.7MM)

Gore Sorber™ Results (TCE)

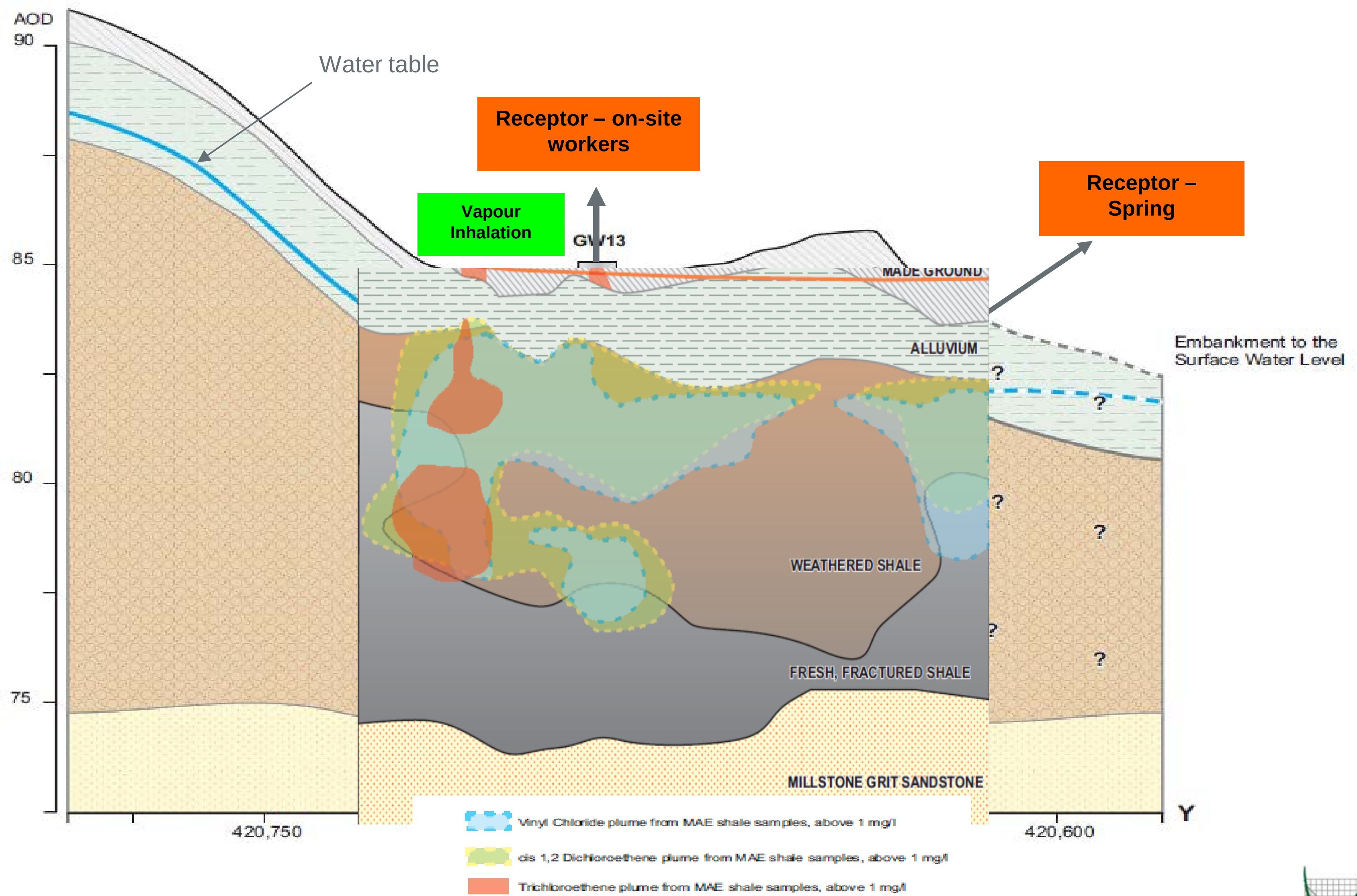


On-site Laboratory Analysis

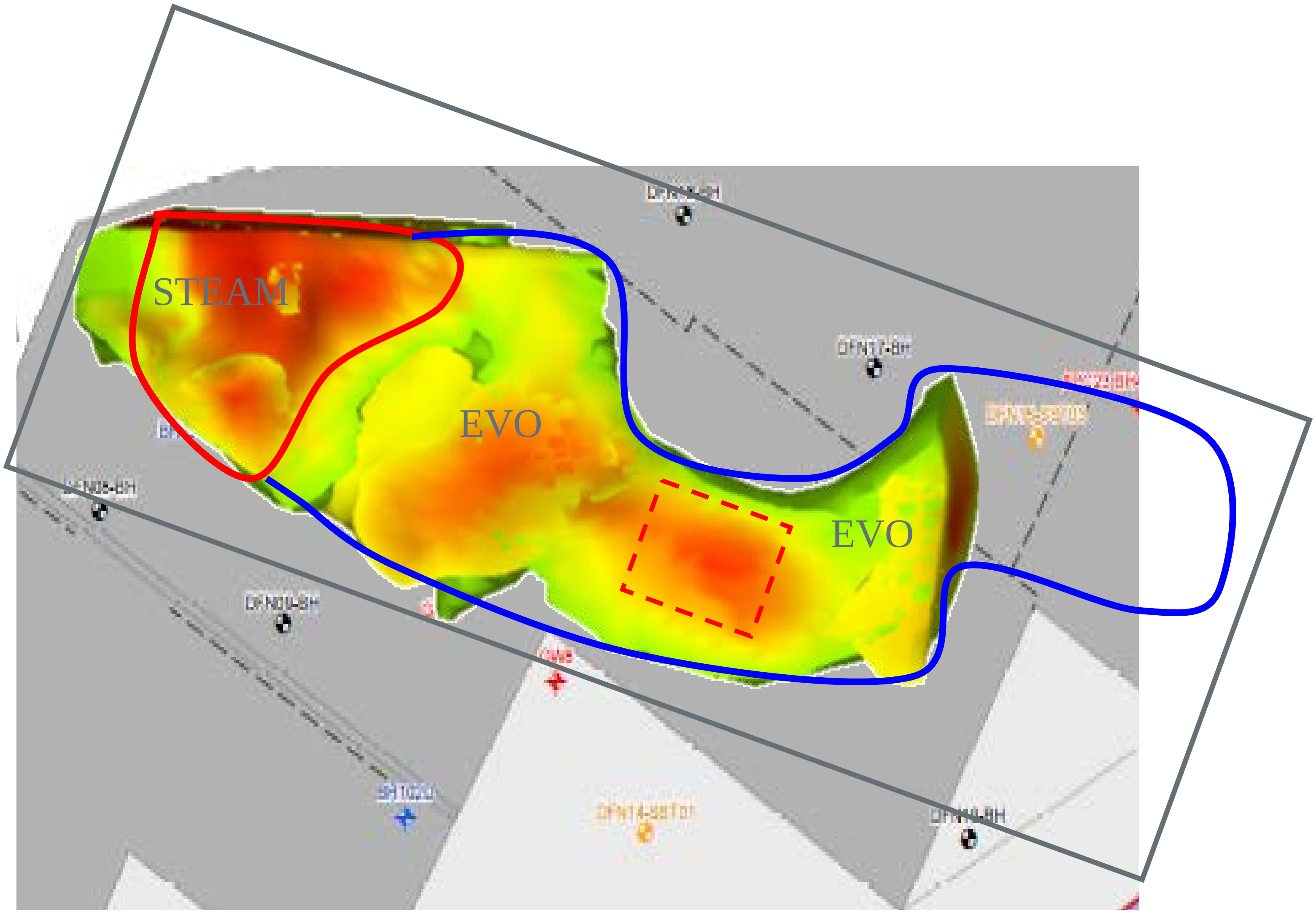
On-site laboratory analysis of pore water concentrations using Microwave Assisted Extraction (MAE)

- MAE was used to extract VOCs from the rock core into methanol
- Concentrations were measured in the methanol extract (by GC/MS)
- The entire process took <90 minutes (compared to about 5 weeks via traditional methods)
- 450 rock core samples were tested for VOCs in a period of 15 days (> $50k savings over fixed lab costs)

Original Conceptual Site Model



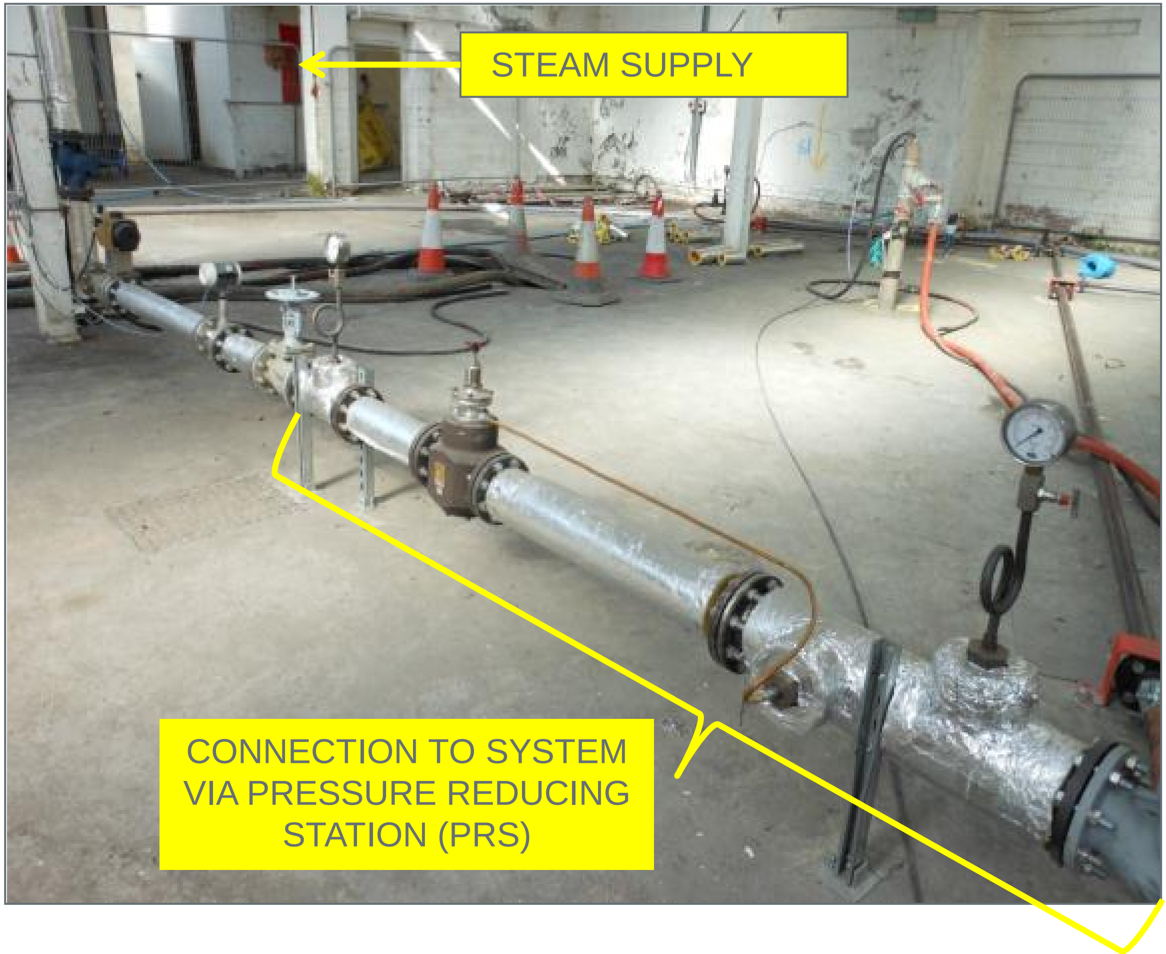
Remedial Treatment Zones



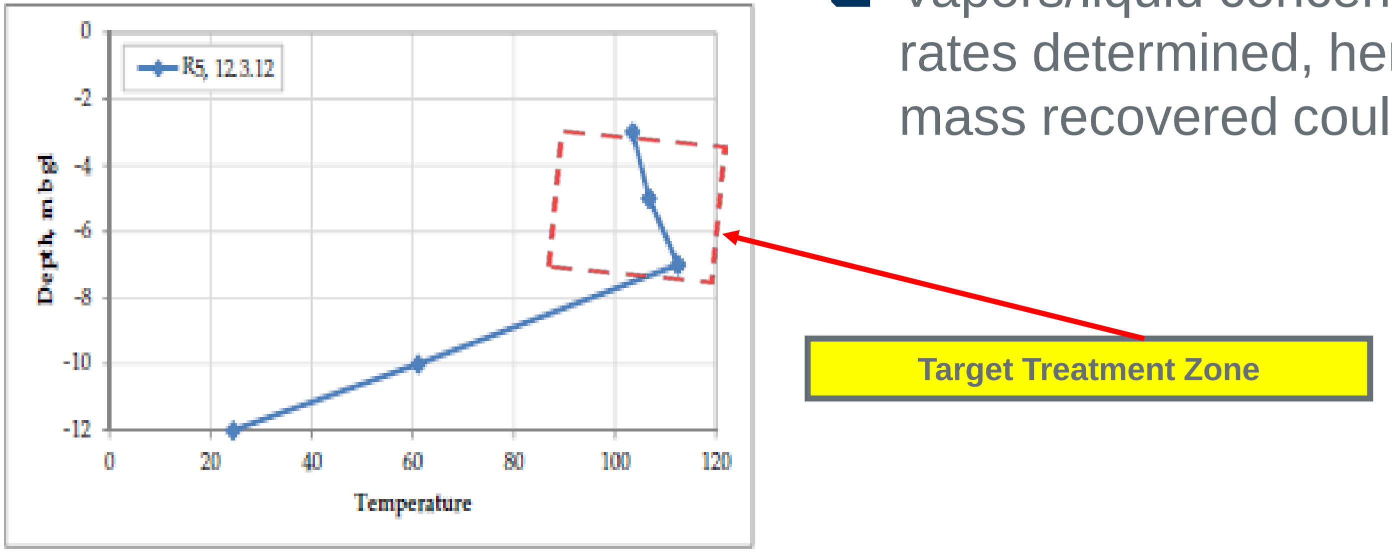
Remediation Design Concept

- In situ thermal remediation only technology available to remove mass from shale bedrock matrix.
- Steam injection is well suited to implementation in high permeability formations.
- On-site steam source was used for the work
- Operation of the remediation system was focussed upon:
  1. Heating the clay from beneath to artificially increase its permeability via ‘fracing;’ and
  2. Development of a ‘*Steam Bubble*’ to allow vapor recovery through a zone created by boiling the groundwater (captured by vertical DPVE wells)
- Asymptotic mass recovery endpoint agreed with regulators. No requirement for ‘rebound’ monitoring

Steam Injection Infrastructure

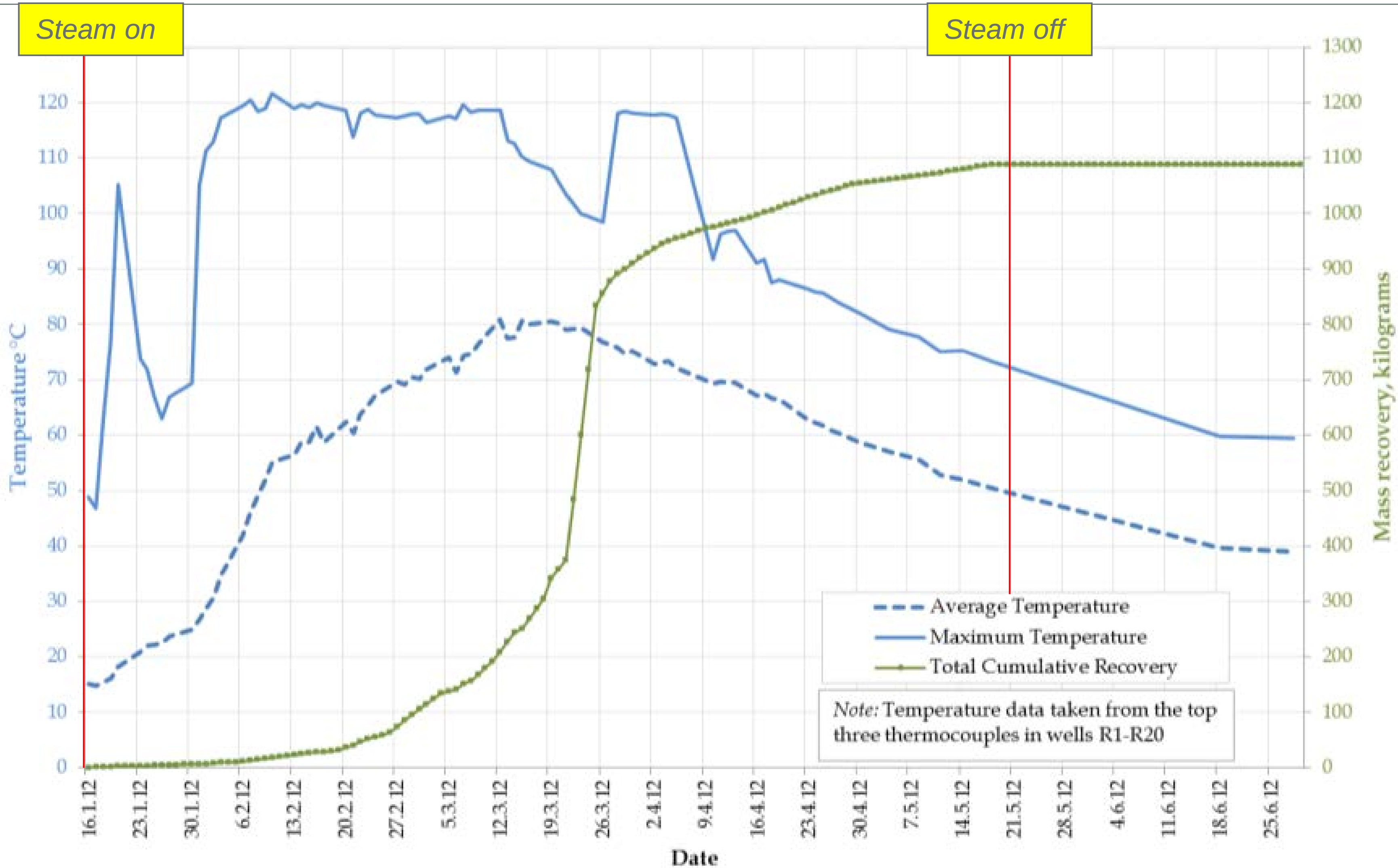


System Optimisation



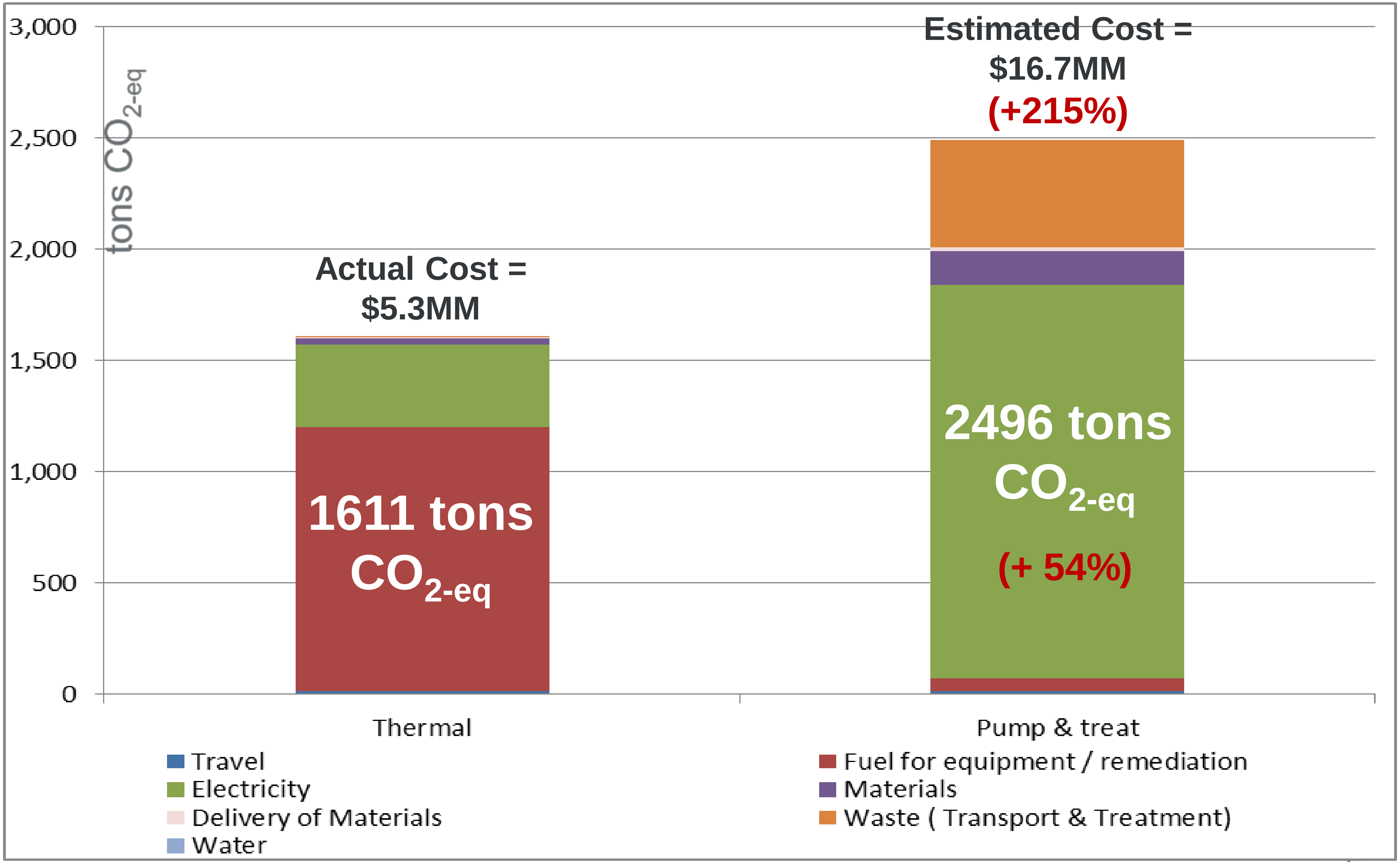
- Monitoring using thermocouples to determine subsurface temperatures. Real-time assessment of data
- Results entered into a thermal model to revise endpoint predictions, determine well injection configuration etc.
- Vapors/liquid concentrations and flow rates determined, hence estimate of mass recovered could be calculated

System Performance



Temperature data from thermocouples located at 3 m, 5 m and 7 m below ground level

Results – Sustainable Cost Reductions



Conclusions

- Remedial solution agreed with regulators: additional investigation (including $1.5MM previous investigation) and remedial solution delivered for < $5.3MM and met client expectations
- Sustainability considered at every stage of project, within context of overarching client/project requirements
- The carbon footprint (as one environmental indicator) for the thermal remediation system (1,611 tonnes $CO_{2\text{-eq}}$) and removed 1,100kg – P&T unlikely to have removed >50kg and the estimated carbon footprint for the pump and treat system (2,496 tonnes $CO_{2\text{-eq}}$)
- Aggressive investigation and remediation completed in less than 18 months at a savings of $11.4MM over 20 year P&T.