

Applications of Sequence Stratigraphic Reconstruction on the Site Scale in the Sustainable Remediation of Groundwater

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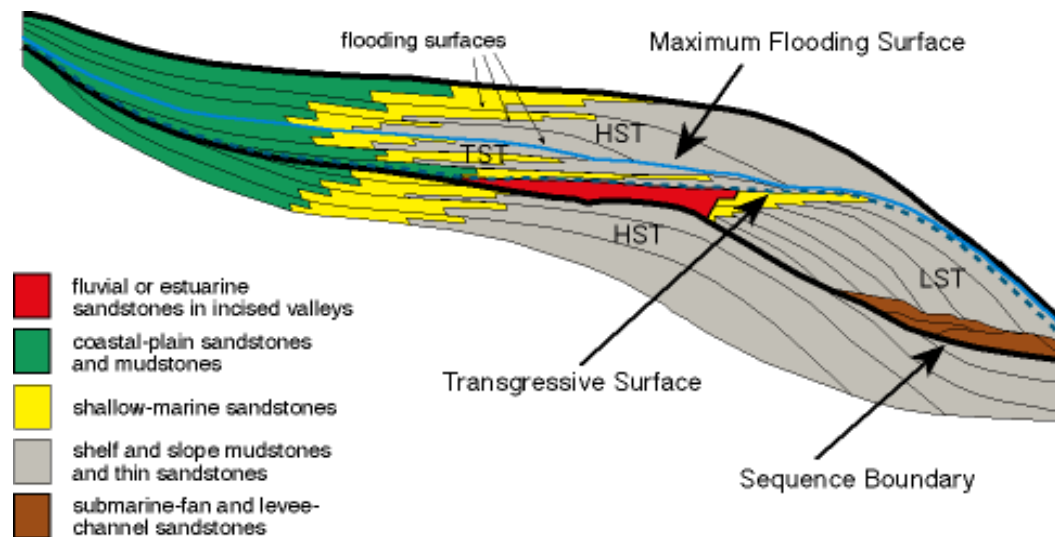
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Introduction – Sustainable Remediation



- ERM's approach is to manage contaminants using the principles of Sustainable Remediation - in practice, this means assessing the environmental, social and economic costs and benefits – then considering if the remediation is really needed, and if so how to minimise the footprint of the remedial work
- During the site investigation stage Sequence Stratigraphic Reconstruction is a tool that can fundamentally enhance conceptual site models such that risk assessment can be properly made, especially in the identification of pathway

Introduction – Sequence Stratigraphy

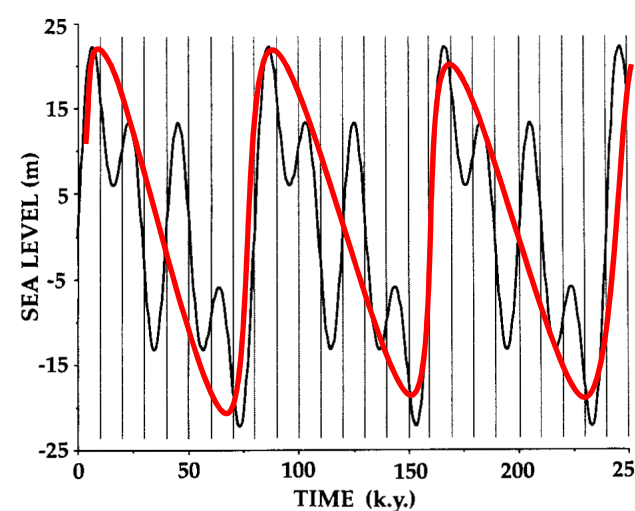


- Sequence stratigraphy was originally developed as a basin-wide approach that classifies and links sedimentary deposits into unconformity-bound units
- The method was developed by Vail et al (1977) specifically for use on seismic profiles on the basin scale to aid hydrocarbon exploration, but the principles have long been applied more widely and generally in stratigraphic studies
- Paleogeography recognises different *system tracts* in the sea-level cycle that together form a *sequence*

Environmental Applications – basin to site scale

- Although the site scale is much smaller than the basin scale, the same principles of sequence stratigraphy may be identified
- This is especially true as higher-frequency relative sea-level cycles produce *para-sequences* within system tracts, which could be due to;

- Climate changes
- Local subsidence
- Localised tectonic events
- Changes in sediment supply



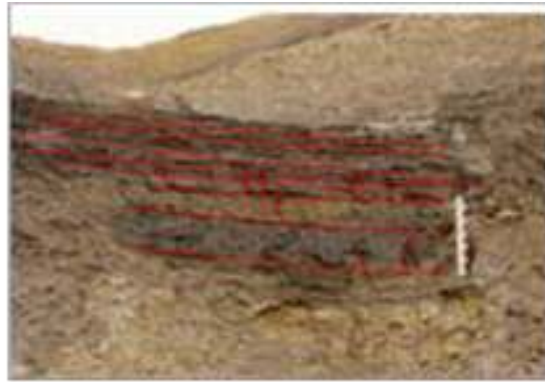
Example sea-level curve for sequences (red) and para-sequences (black), Kaufman et al 1991

- Identifying system tracts (or more likely at the site scale; para-sequences) in the field relies on the identification of unconformity and maximum flooding surfaces, combined with paleogeographic reconstruction

Environmental Applications – using the data

- many projects have large datasets (e.g. HRSC), often collected by different consultants and techniques. Frequently this data is never synthesised and interpreted as a whole, but can provide enough data for paleogeographic reconstruction at site-scale
- In some cases the for paleogeographic analysis at the site scale identifies elements of the sequence stratigraphy, especially at the para-sequence scale, and this understanding can be a vital tool in correlating borehole data, mapping areas of the site with low borehole density and placing the stratigraphy in a regional context
- From this understanding of the stratigraphy, the permeability structure can be predicted on a site scale for both:
 - unconsolidated soils or sediments – where coarser deposits (sands and gravels) are significant groundwater pathways via primary matrix porosity; and
 - cemented or consolidated sediments (up to and including metamorphosed sediments), where fracture density, orientation and connectivity control permeability and are a function of the rheology of the rock type

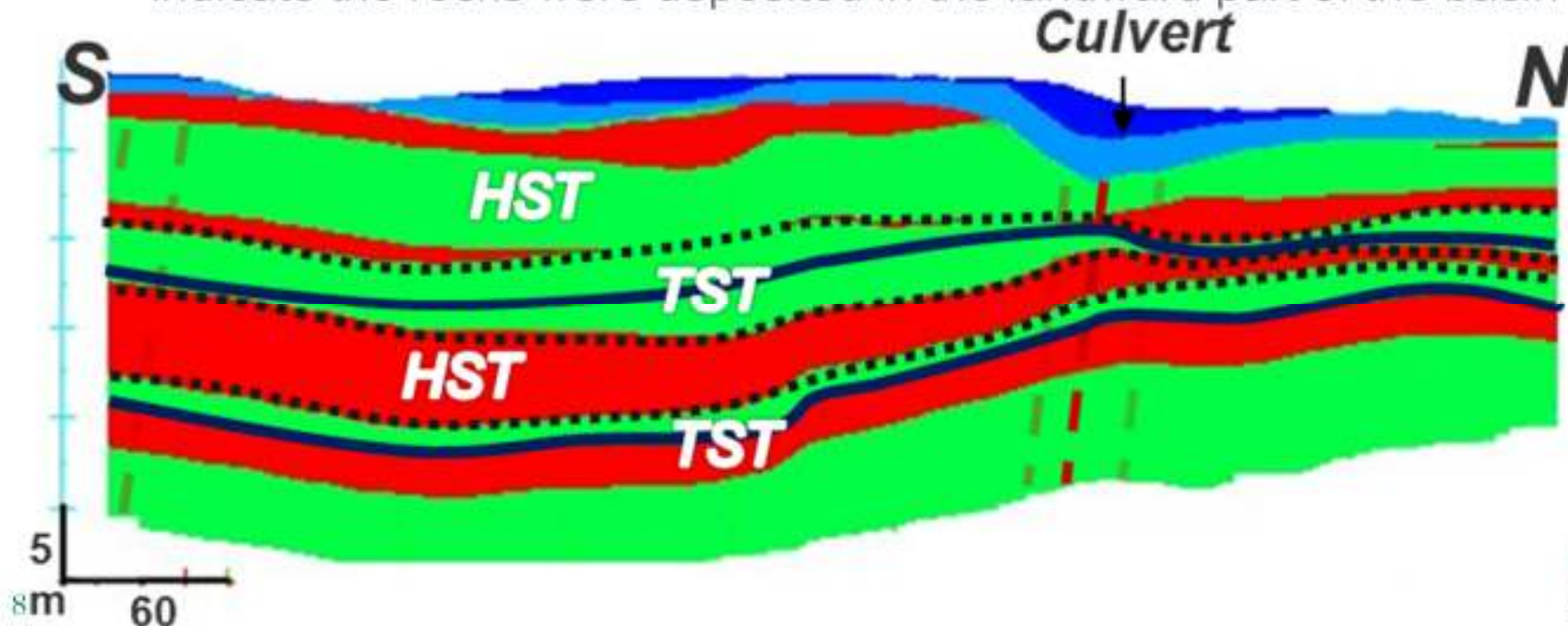
Case Study 1 – field data



- a lubricant and adhesive manufactory, northern UK
- Upper Carboniferous Coal Measures – cyclical fluvio-deltaic and nearshore sandstones, siltstones and thin coal, interbedded with marine shales
- on the left sandstone (stacked fluvial channels) with widely-spaced high-angle fractures in outcrop and core, compared to shales with bed-parallel fractures dominating

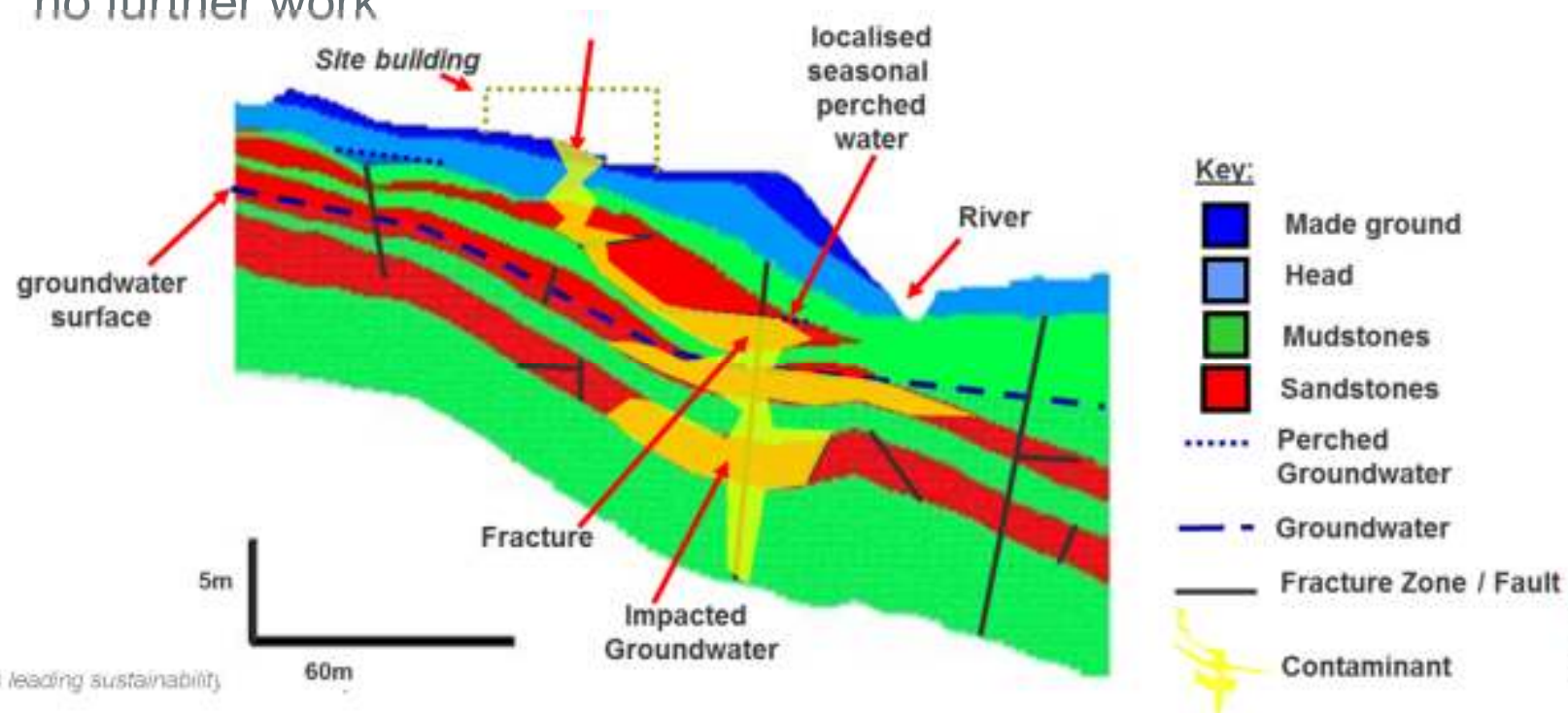
Case Study 1 – para-sequence identification

- Critical to the identification of sequences (or in this case, probably para-sequences) was the presence of two ‘marine bands’ (organic shales with marine bivalves) directly overlying thin coals and plant-rich shale
- A stacked series of highstand and transgressive system tracts were observed. The absence of clear lowstand & regressive system tracts indicate the rocks were deposited in the landward part of the basin



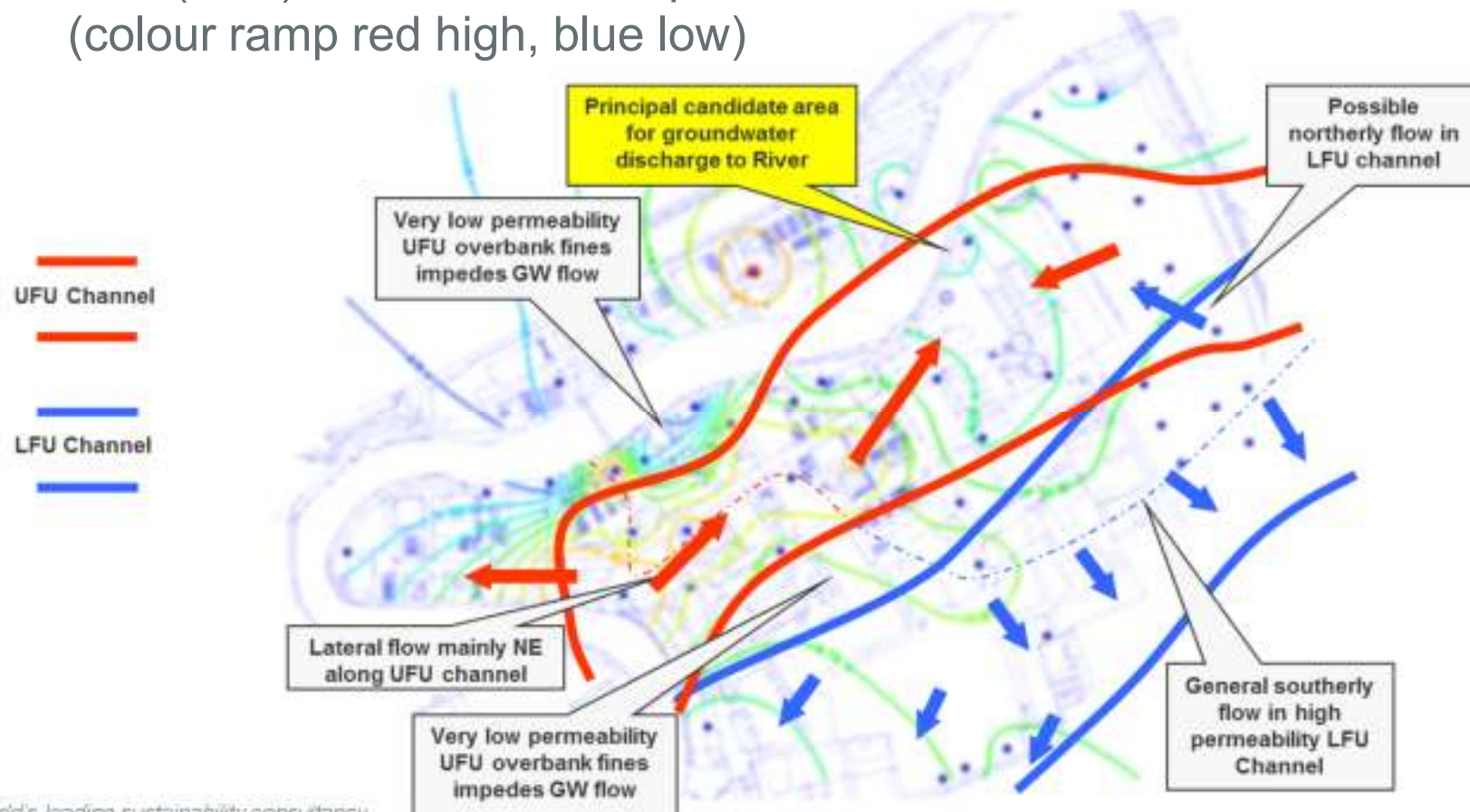
Case Study 1 – sustainably remediated

- Contaminant transport was found to be strongly controlled by fractures – a function of lithology, and therefore stratigraphy, and was shown not to connect via baseflow to the river
- Remediation was focussed in a sustainable manner on source area removal and removal of NAPLs from stratigraphic pinch-outs
- Following remedial works the regulator signed-off the site as requiring no further work



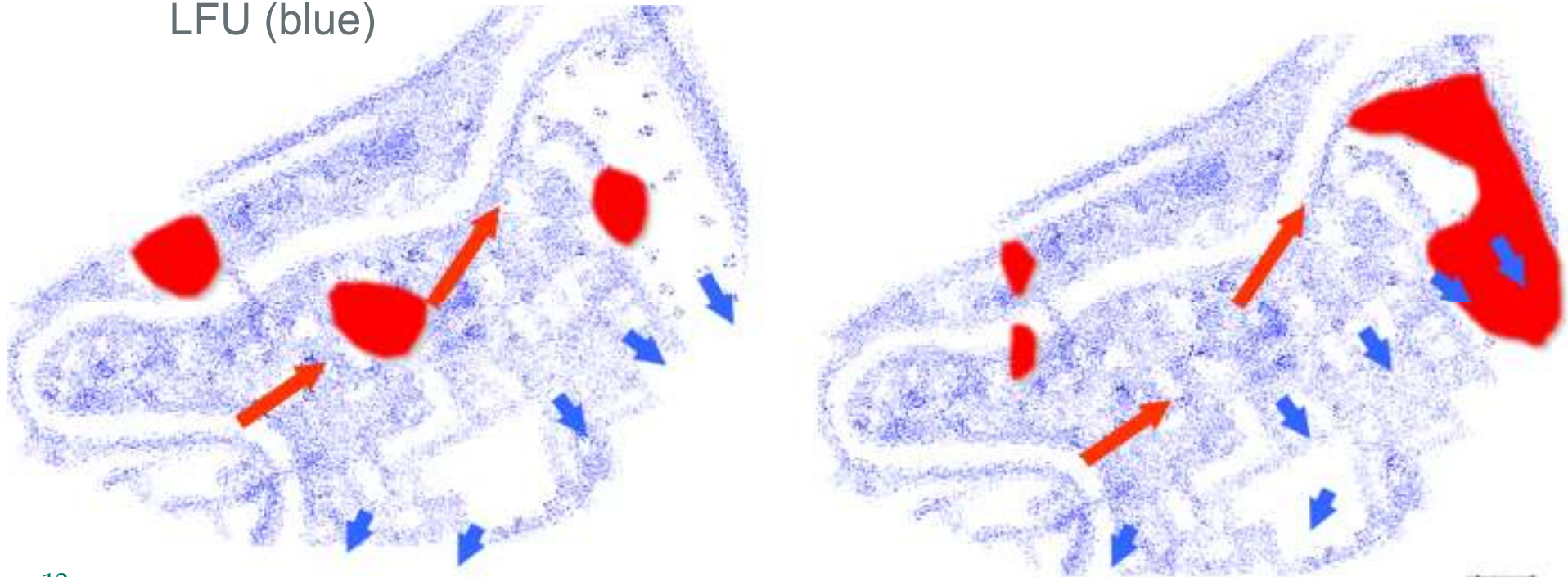
Case Study 2 – influence on hydrogeology

- UFU and LFU units exert a measure of control over groundwater movement in the subsurface
- Arrows show the principle groundwater vectors in the UFU (red) and LFU (blue). Contours are of potentiometric head at 25 cm intervals (colour ramp red high, blue low)



Case Study 2 – contaminant transport

- the sedimentary architecture (channels and overbank fines) controls the permeability structure of the subsurface. This is seen in contaminant plume plots in monitoring rounds taken at the end of the site operation, and then again eight years later
- red plumes depict chlorobenzene in groundwater at $>1\%$ solubility. Arrows show the principle groundwater vectors in the UFU (red) and LFU (blue)



Results and Conclusions

- In each of the case studies presented, depositional structures (e.g. channels, overbank fines or marine muds) produced very large contrasts in permeability, both in primary matrix and (for rock) in fracture sets
- These contrasts had a significant effect on contaminant distribution and, therefore, the CSM – helping to answer the key Sustainable Remediation lifecycle questions of:
 - ‘is the remediation really needed’ and
 - ‘how can the footprint be minimised’
- The findings of the paleogeographic and sequence stratigraphic reconstruction have also proved to be a critical factor in facilitating stakeholder and regulator engagement on the basis of a sound conceptual site model, allowing a more sustainable remedial strategy to be adopted and resulting in substantial cost and environmental footprint reductions for our clients