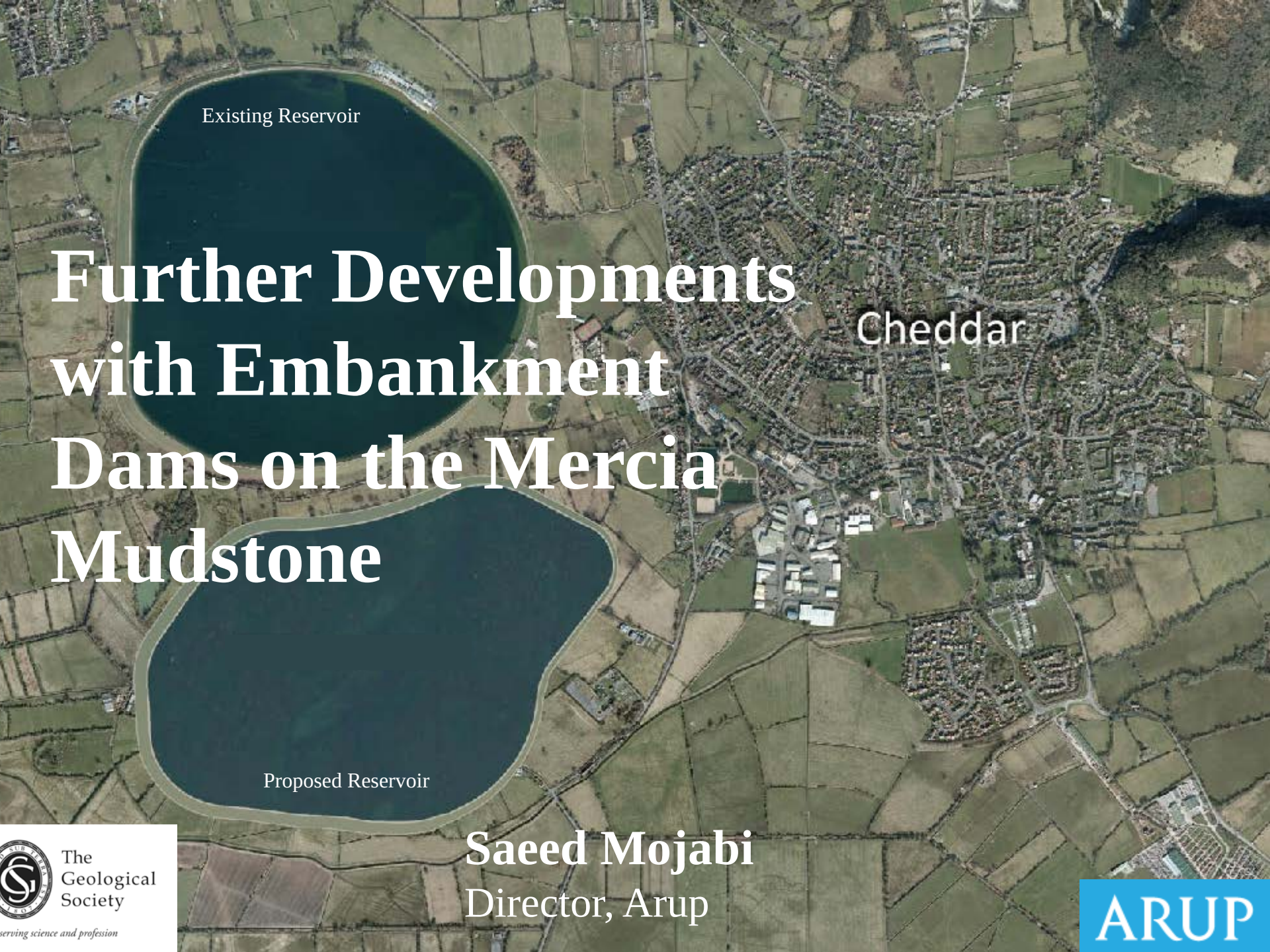

Further Developments with Embankment Dams on the Mercia Mudstone

Saeed Mojabi
Director, Arup

The Geological Society
serving science and profession

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Mercia Mudstone Group UK outcrops

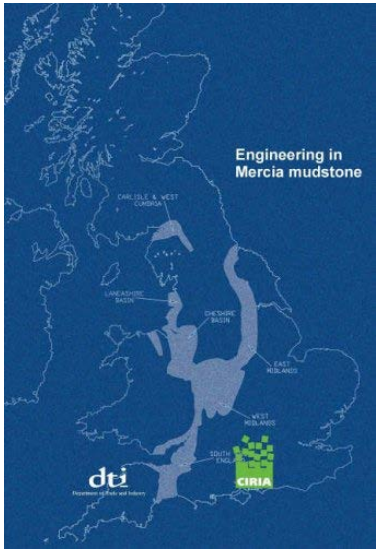
- BGS RR/01/02

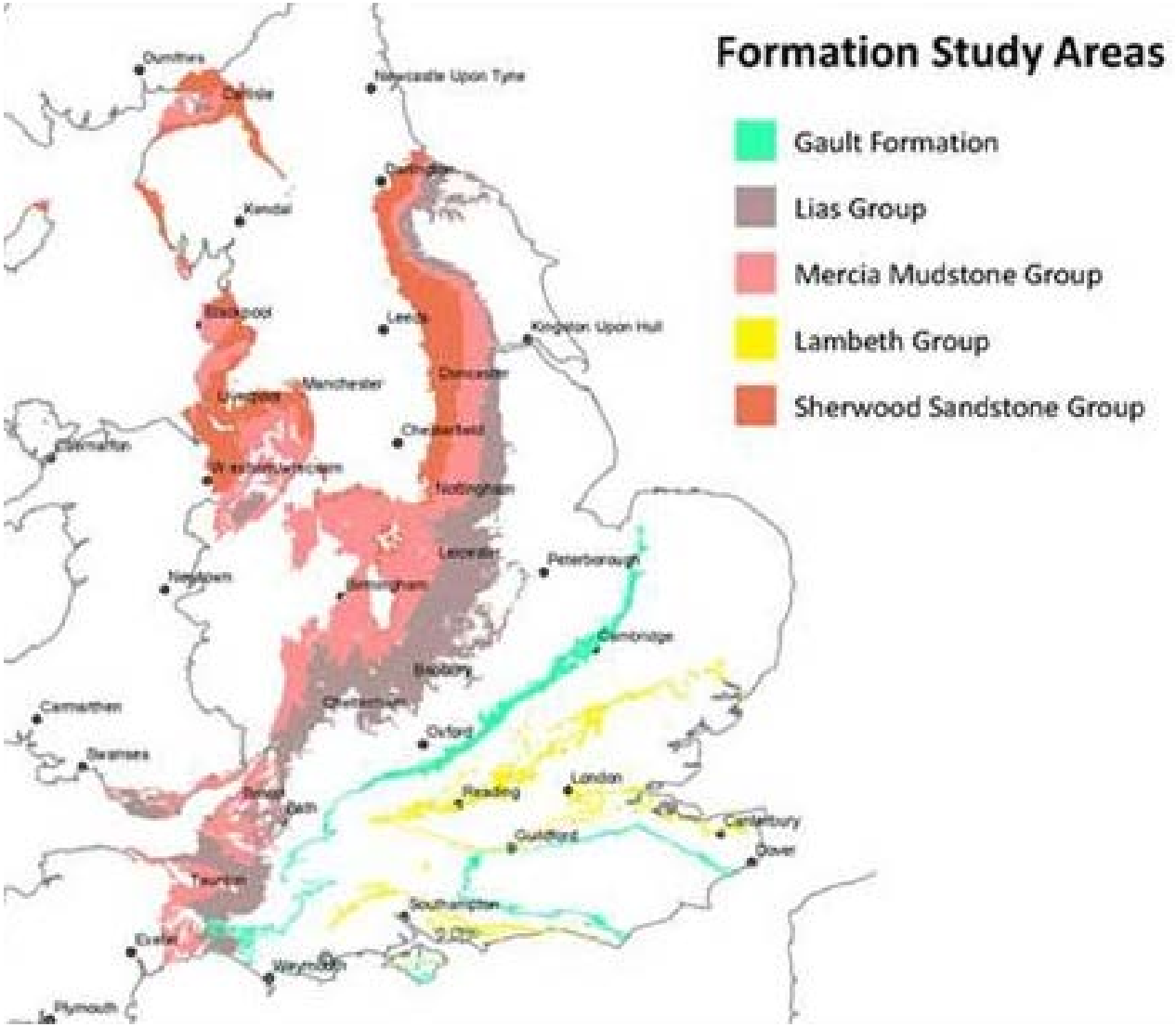
Engineering geology of British rocks and soils

Mudstones of the Mercia Mudstone Group

British Geological Survey
Urban Geoscience and Geological Hazards Programme
Research Report RR/01/02

- CIRIA C570





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Cribbs Causeway (Bristol)

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Mercia Mudstone outcrops

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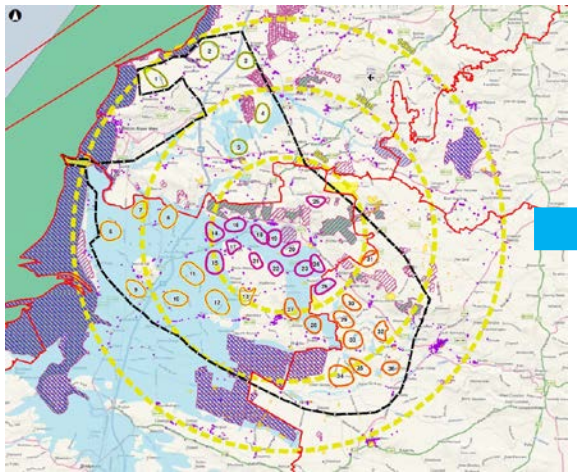
Site Selection

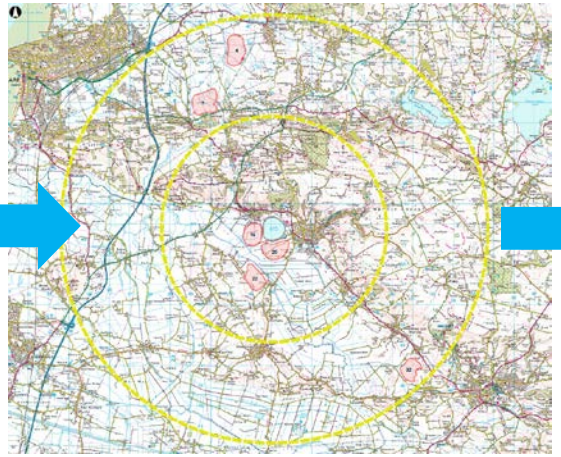
Three phase selection process.

- Long List Assessment
- Short List Assessment
- Cheddar vs Wookey

Considerations

- ground conditions/geology
- proximity to source
- integration with BW network
- absolute constraints
- whole life cost
- environmental





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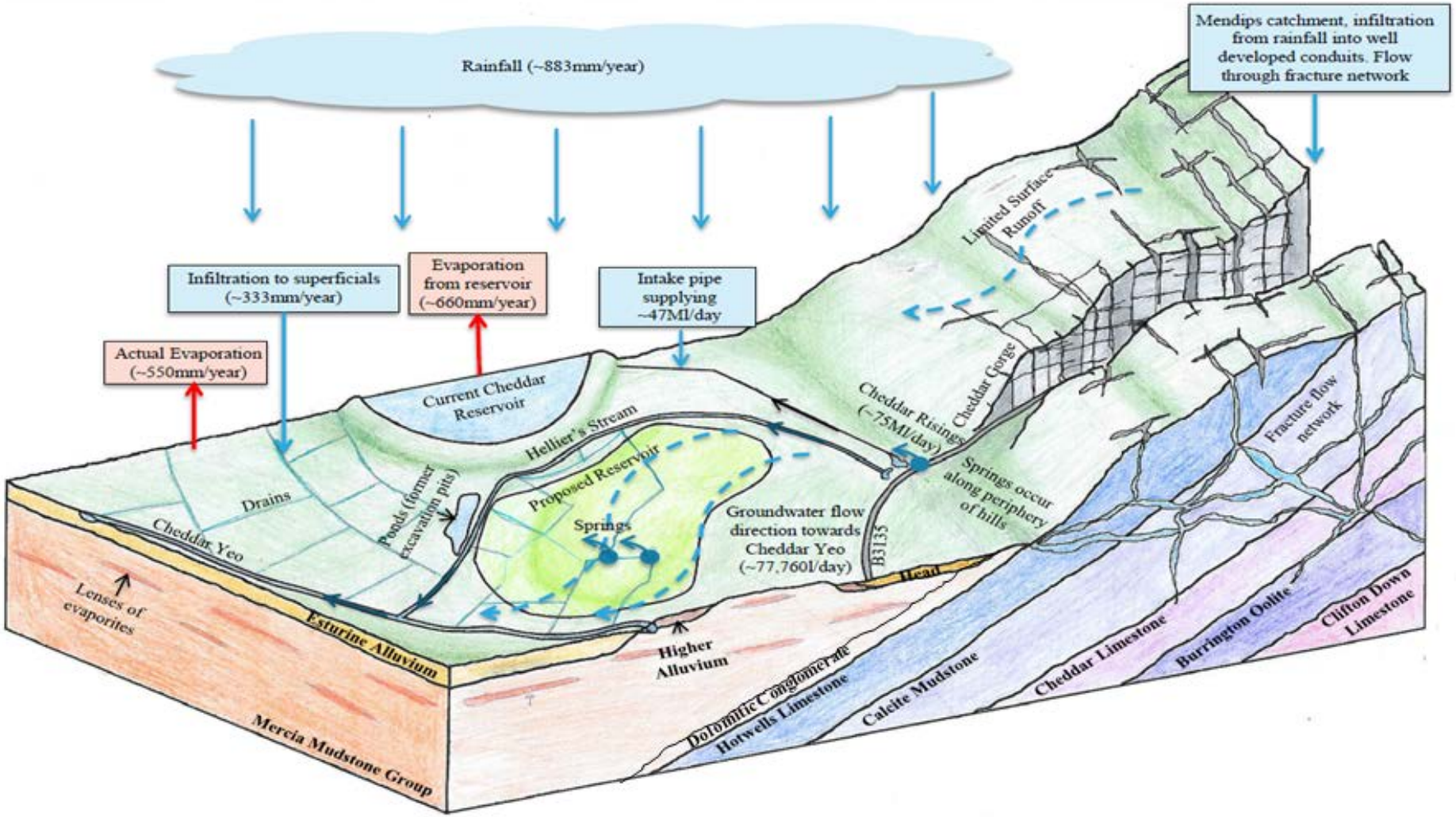
Hydrogeological conceptual model



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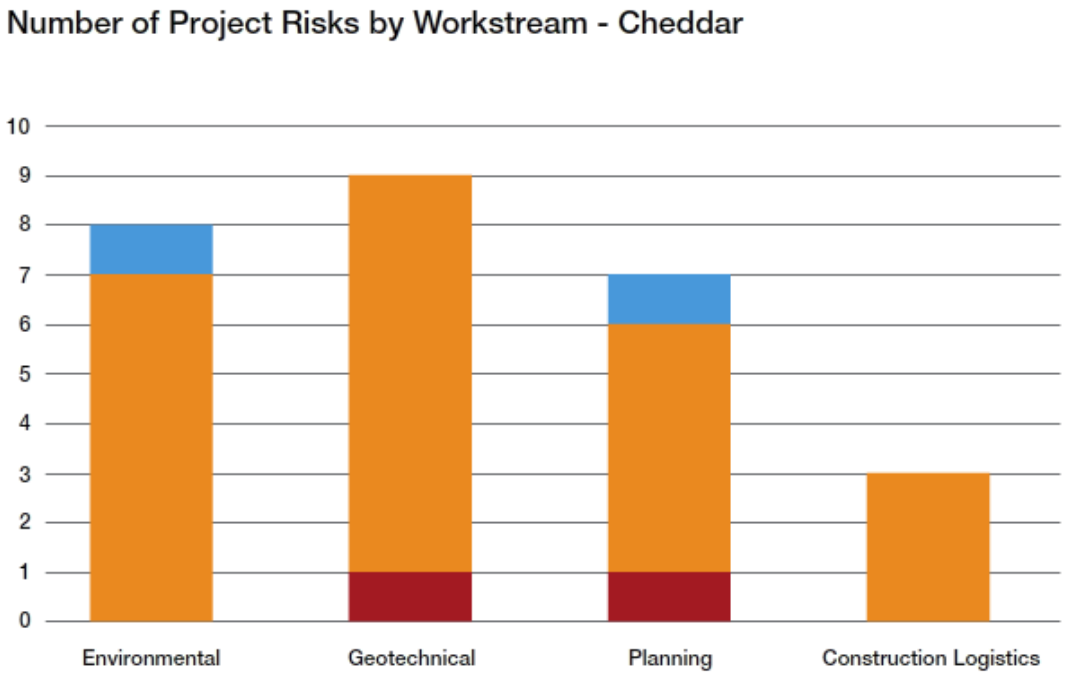
Cheddar Springs – Abstraction licence summary

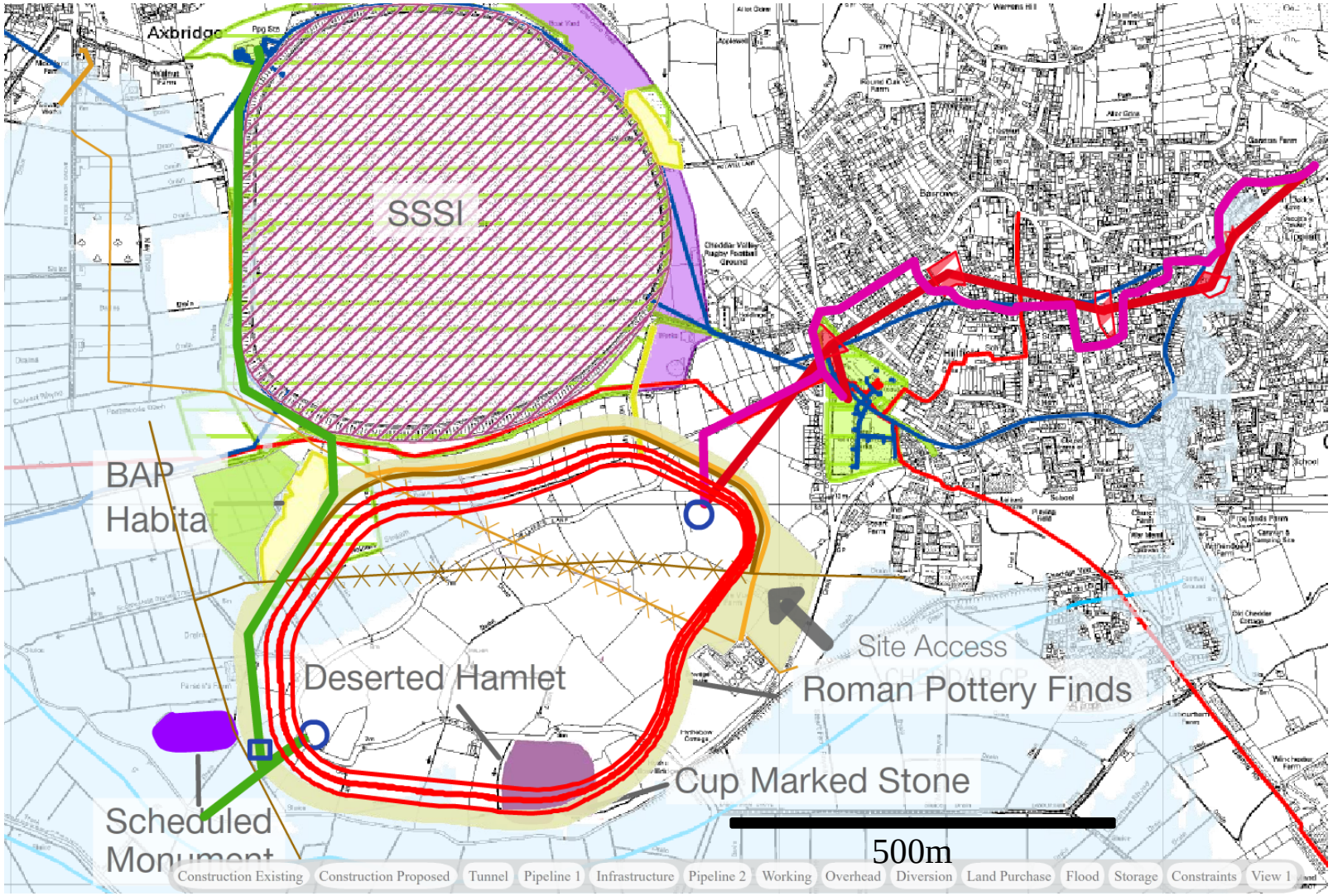
Condition	Flow	Period of Application
Daily Maximum	250,000 m^3/day	Any 24 hour period
Annual Total	22 million m^3/year	1 April to 31 March
Annual Average	60,300 m^3/day	Annual
No Abstraction Allowed	If minimum flows in Cheddar River Yeo < 11,365 m^3/year	15 May to 30 November (inclusive)
No Abstraction Allowed	If minimum flows in Cheddar River Yeo < 6,819 m^3/year	1 December to 14 May (inclusive)
Abstraction Limited To	⅔ of the annual quantity	15 May to 31 October (inclusive)

Site Selection – Risk



Workstream	No. risks	Red	Amber	Green	Opportunities
Environmental	8	0	7	0	1
Geotechnical	9	1	8	0	0
Planning	7	1	5	0	1
Construction Logistics	3	0	3	0	0
	0	0	0	0	0
Total	**27**	**2**	**23**	**0**	**2**

Site Selection – constraints



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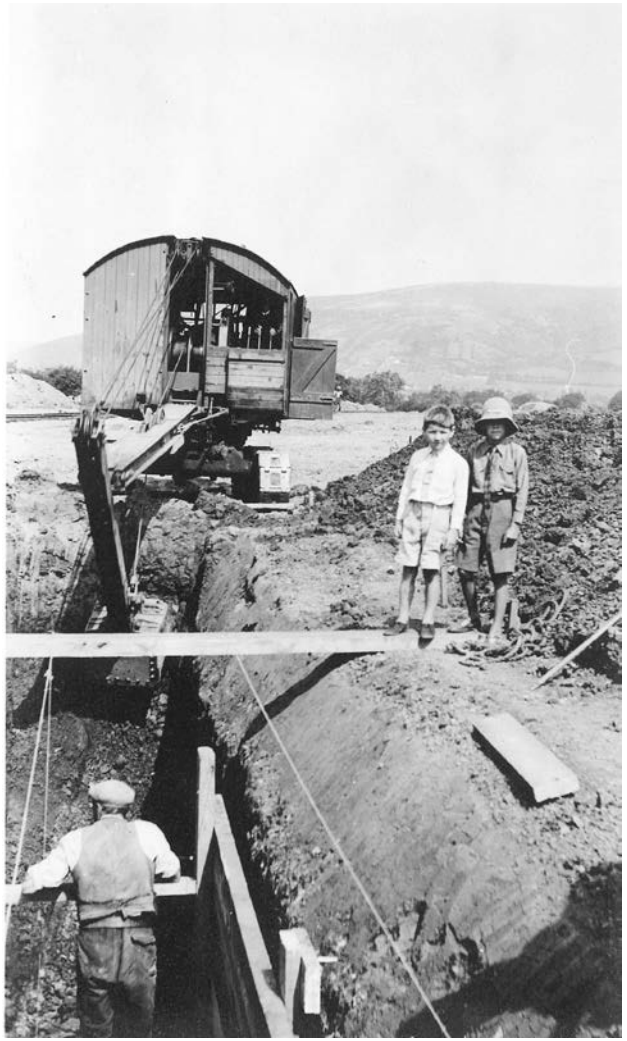
Existing Cheddar Reservoir

- Constructed between 1933 and 1937
- Total Capacity: 6140 Ml
- Top Water Level: 18.288m AOD
- Embankment Height: 1 – 14m
- Cost: £450,000
- Approx. workforce of 270 men



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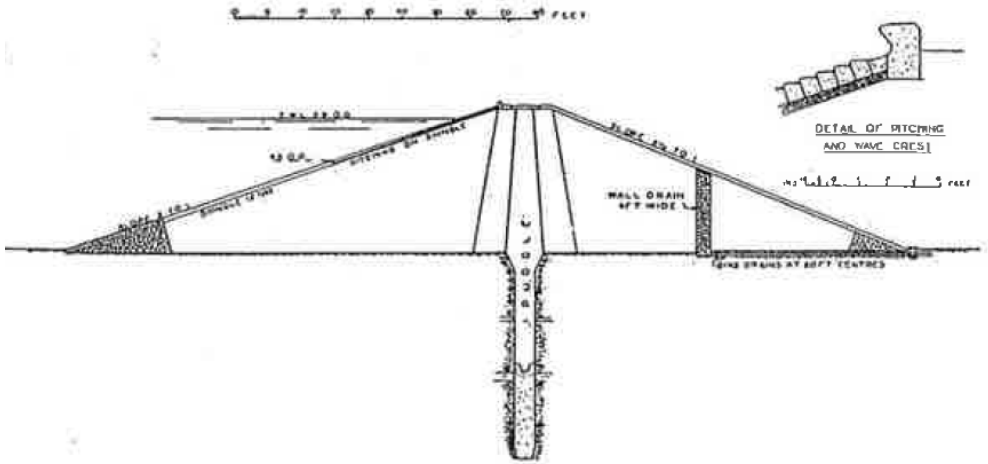
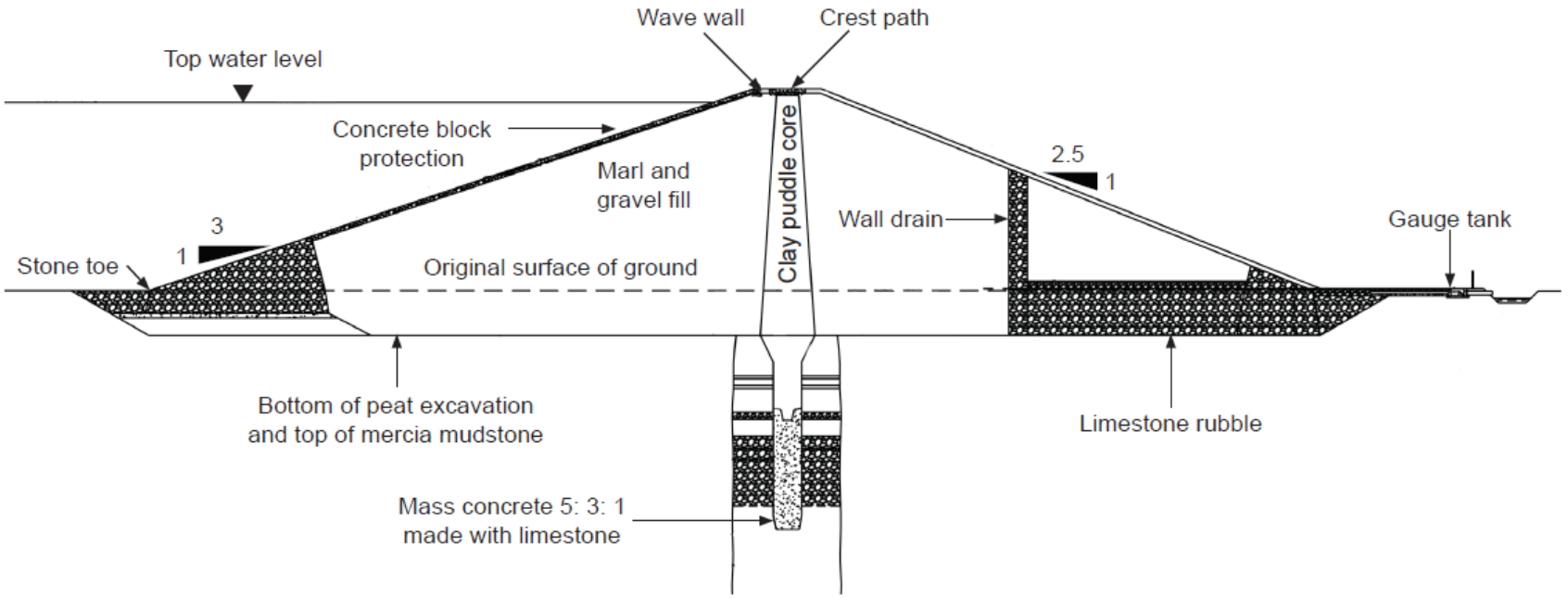
Existing Cheddar Reservoir – Cross section



(Hall, 1937)



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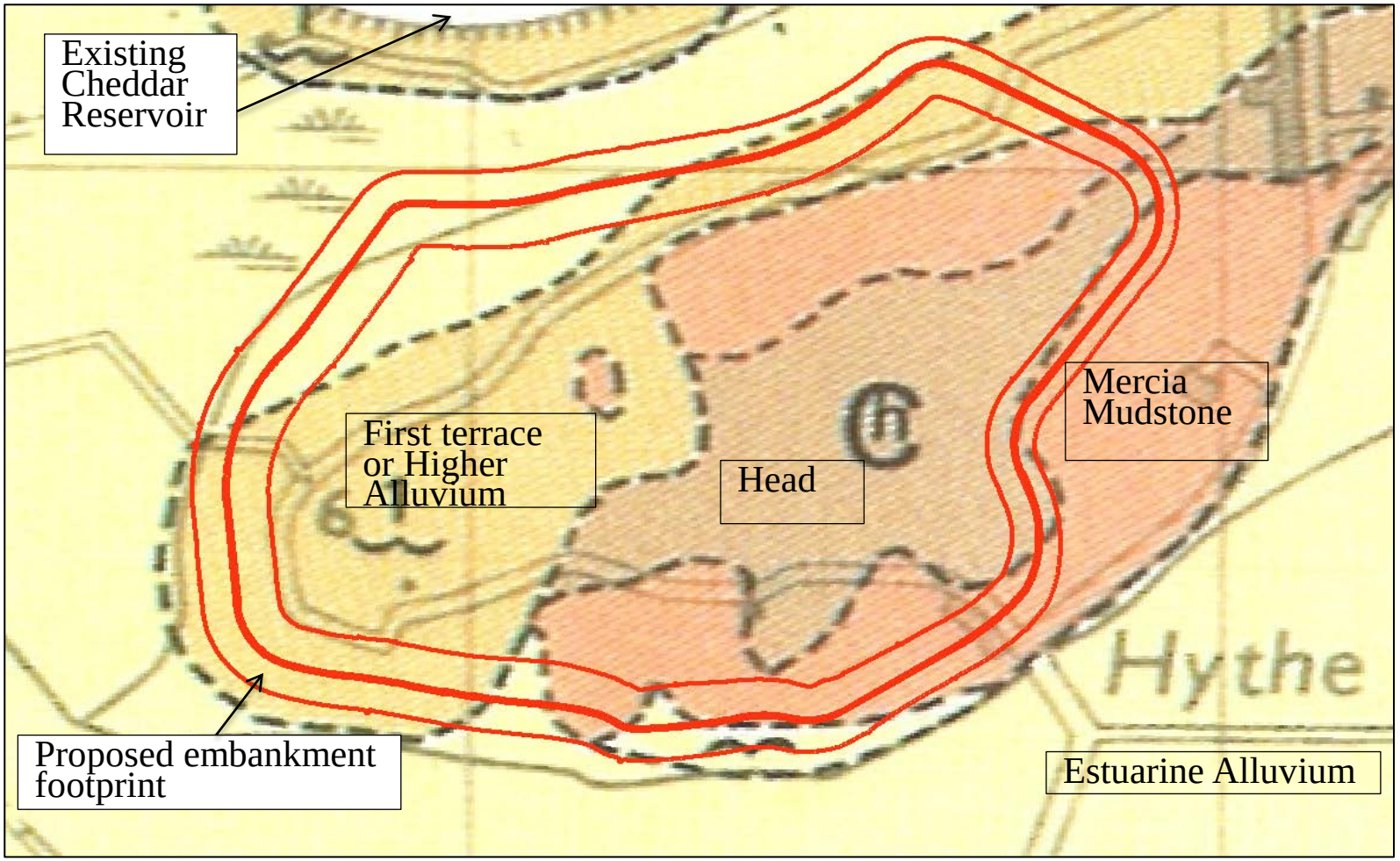
Cheddar 2 - Key Reservoir Parameters

- Embankment Length – 3.6 km
- Embankment height – from 9m to 15m
- Top water level – 19.288 mOD (1m above existing reservoir)
- Total capacity (to TWL) – 9,400,000 m^3
- Useable capacity – 8,200,000 m^3
- Yield – 16,100 m^3 per day
- Excavated quantity – 3.25 Mm^3

Outline Geology



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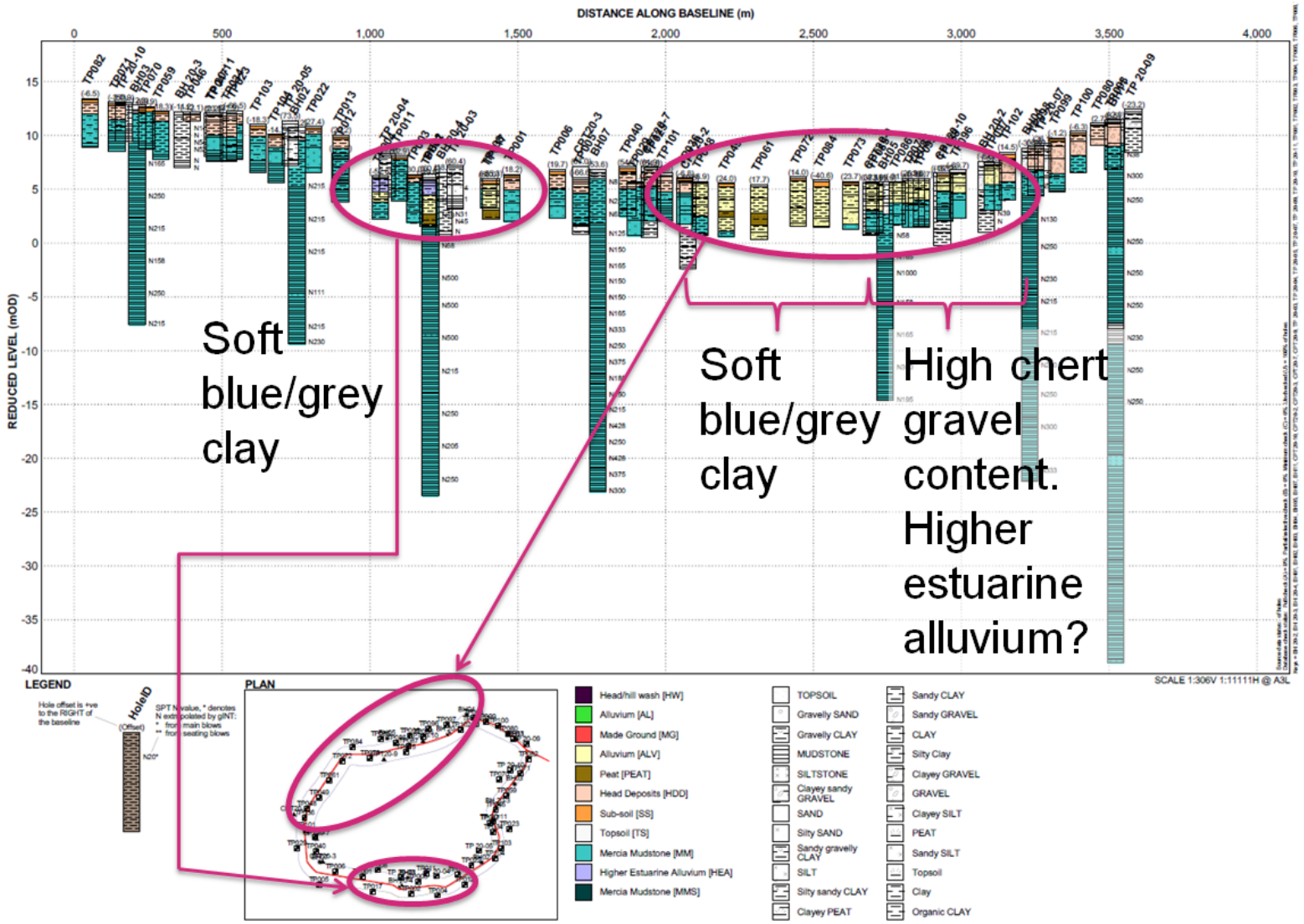
Sequence of Strata



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Sequence of Strata – cores

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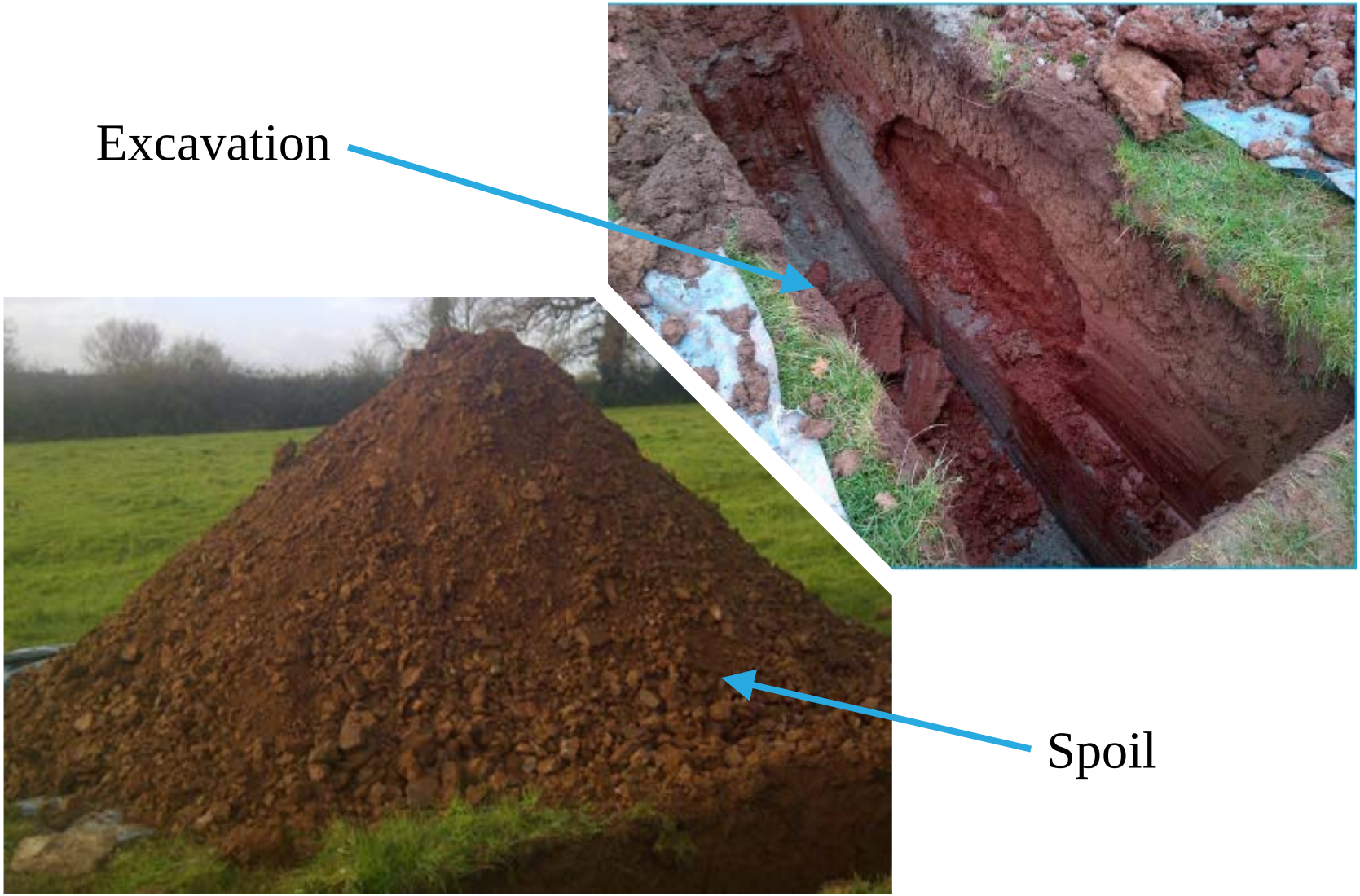
Sequence of Strata – trial pits



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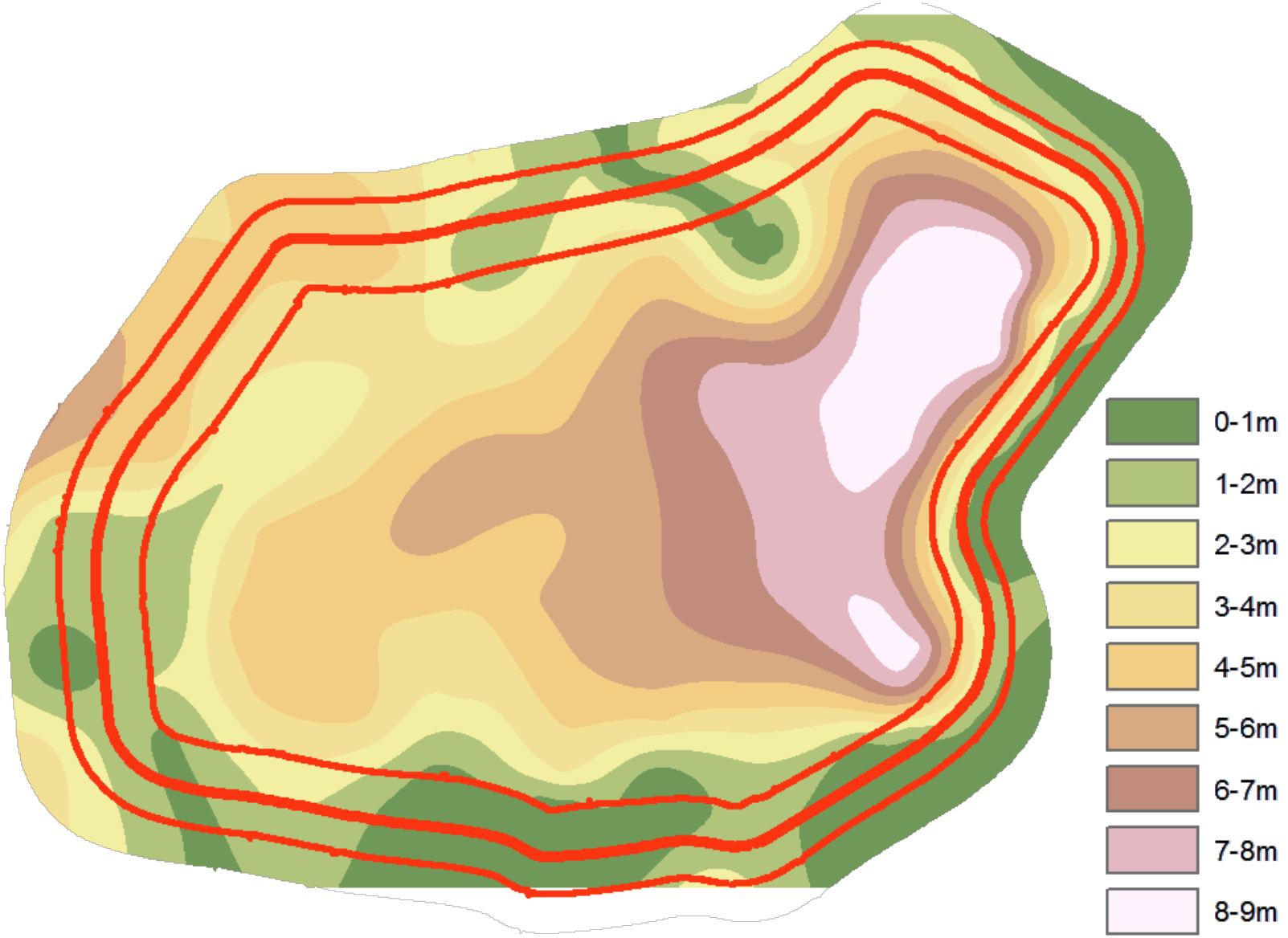
Key Objectives of the Ground Investigations

- To confirm the ground conditions and ground water conditions.
- To ascertain stratigraphy for cut/fill modelling.
- To obtain high quality samples for lab testing.
- Ascertain strength properties of in-situ and re-worked materials.
- To ascertain permeability of the in-situ and re-worked materials.
- To ascertain workability of the material.
- To inform impact of the proposed works on hydrogeology.
- To inform geo-environmental appraisal of the site.

Potential Geo-Hazards

- Periglacial ice wedges
- Gypsum interbeds
- Solifluction of Head
- Peat bands in Alluvium
- Calcite-filled fractures
- “2ft thick green block marl”

Excavation – Depth Contours



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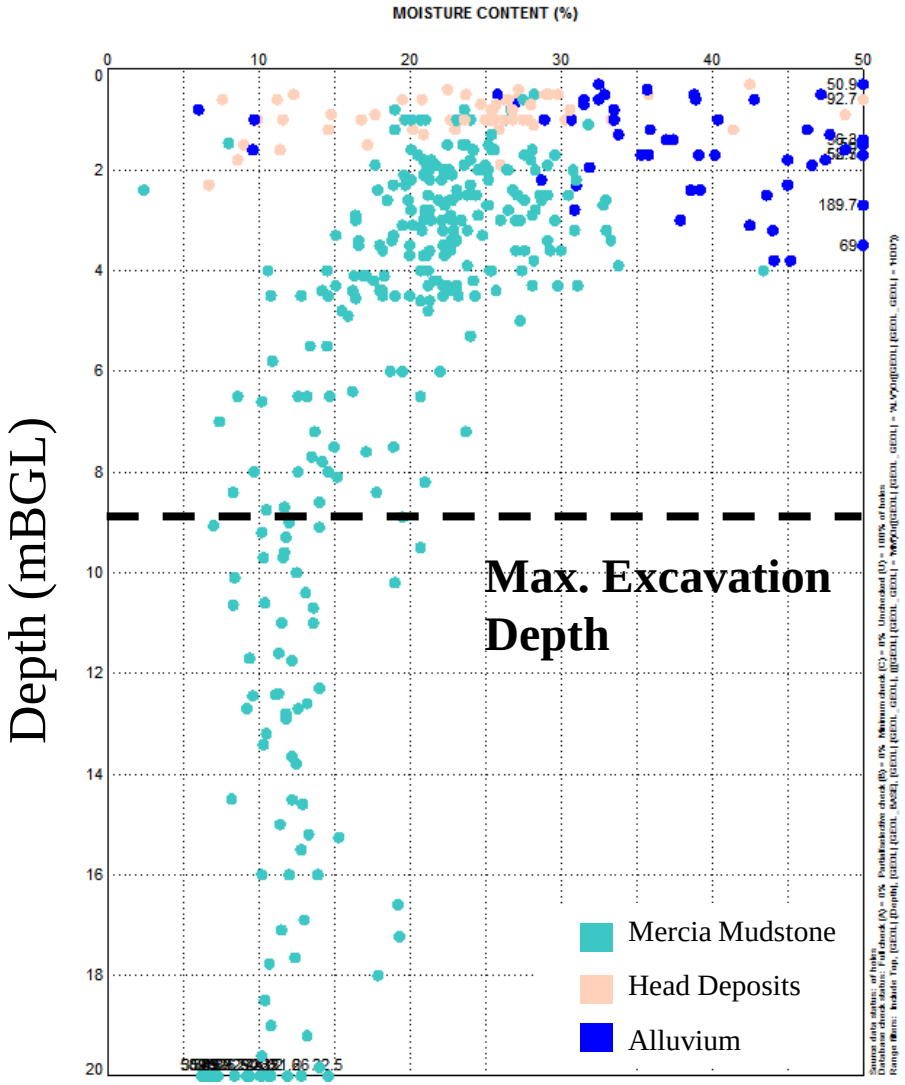
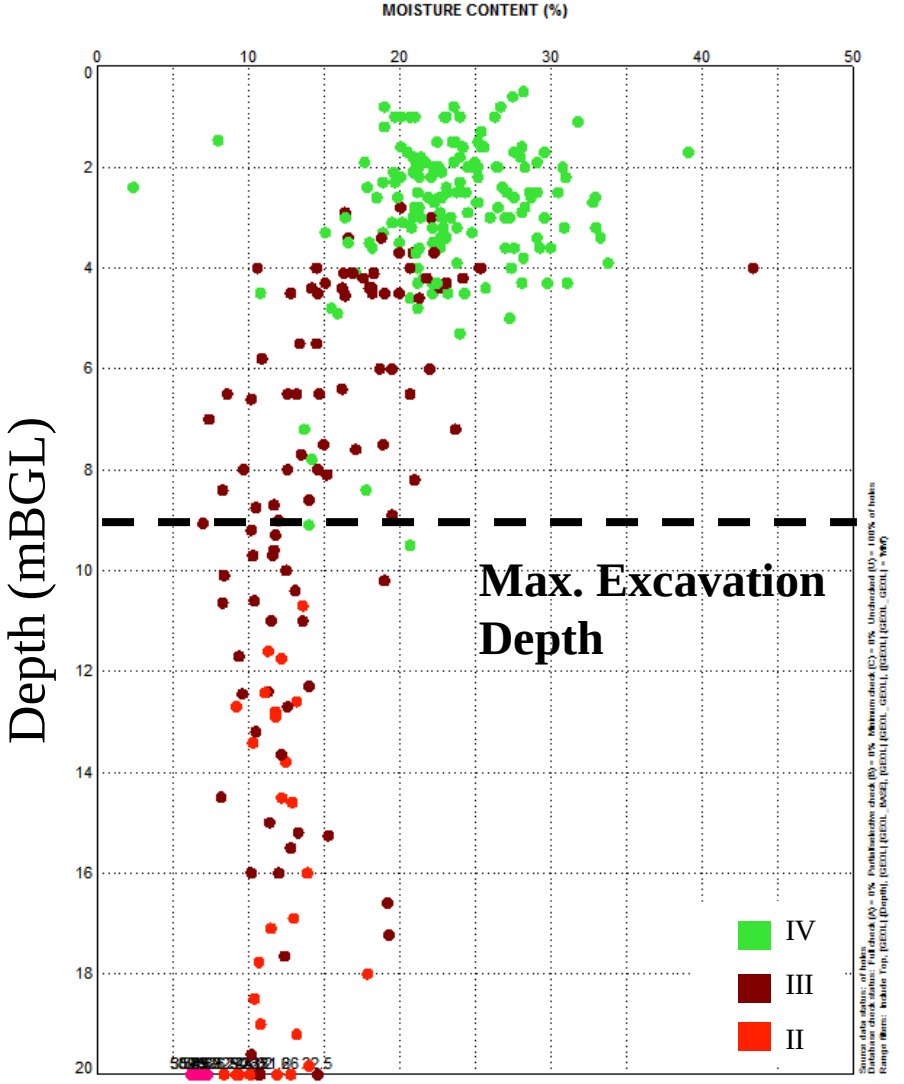
Geotechnical Properties – Moisture Content

All Soils



Mercia Mudstone



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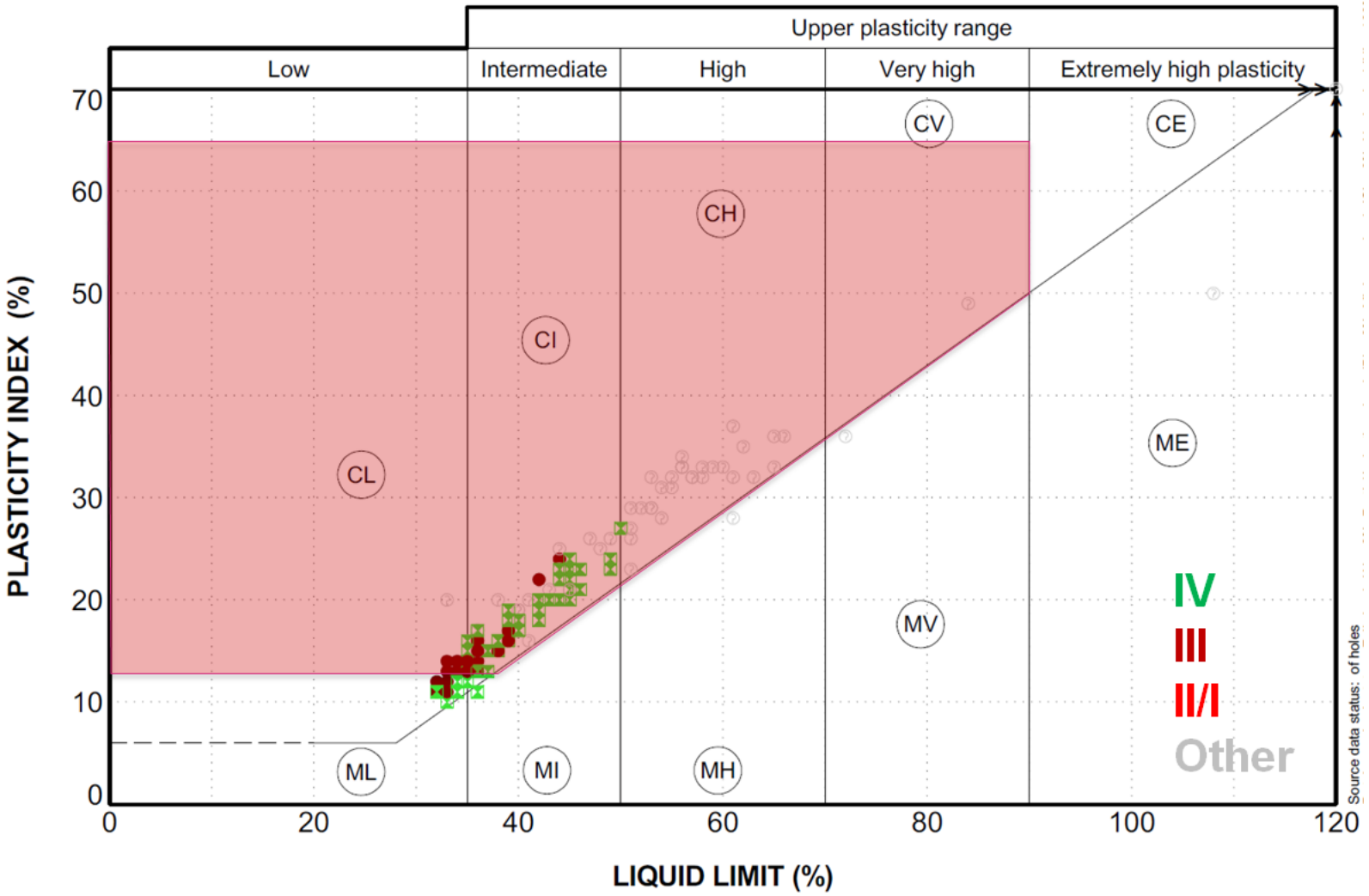
Geotechnical Properties – Plasticity



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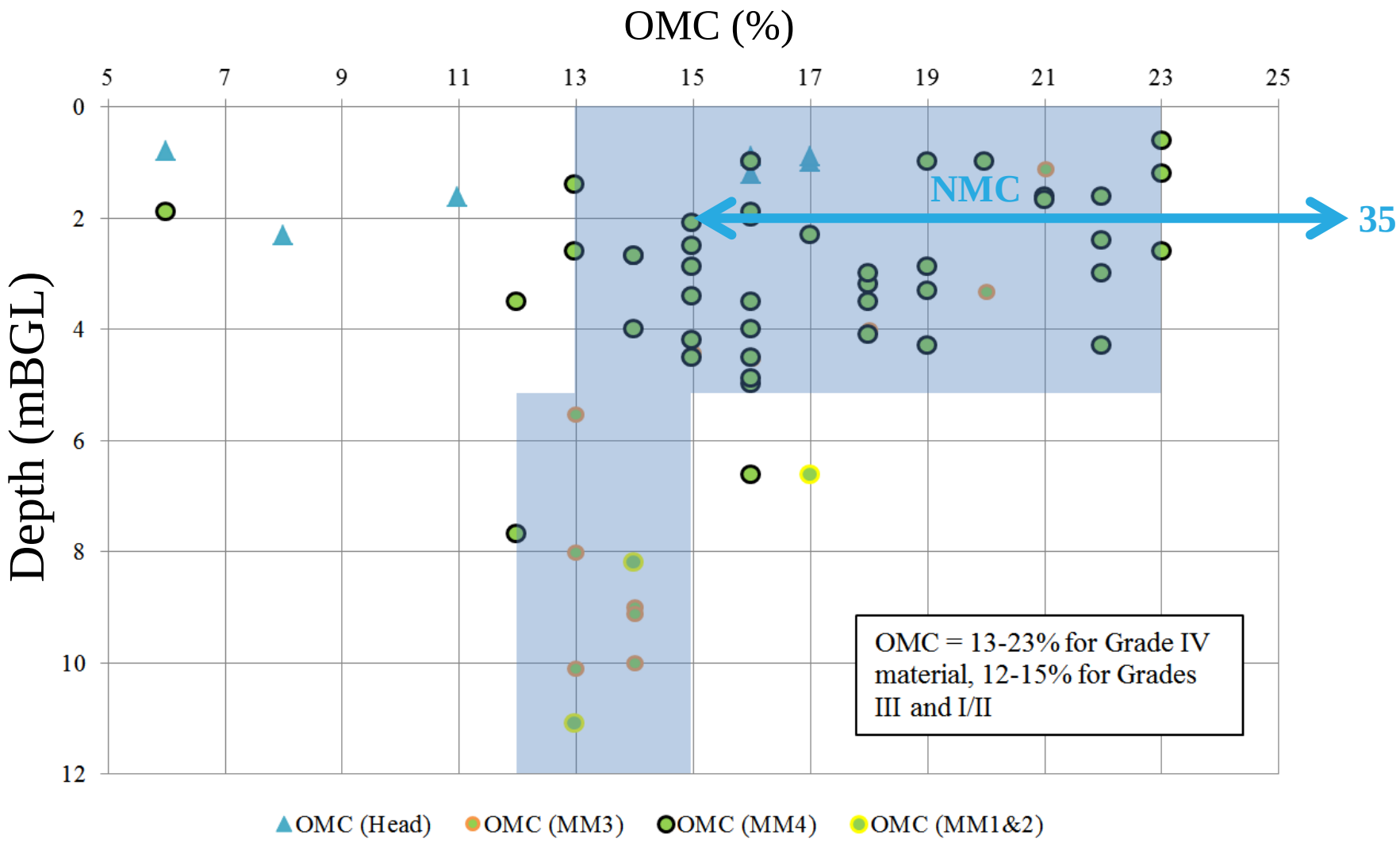
Geotechnical Properties – OMC



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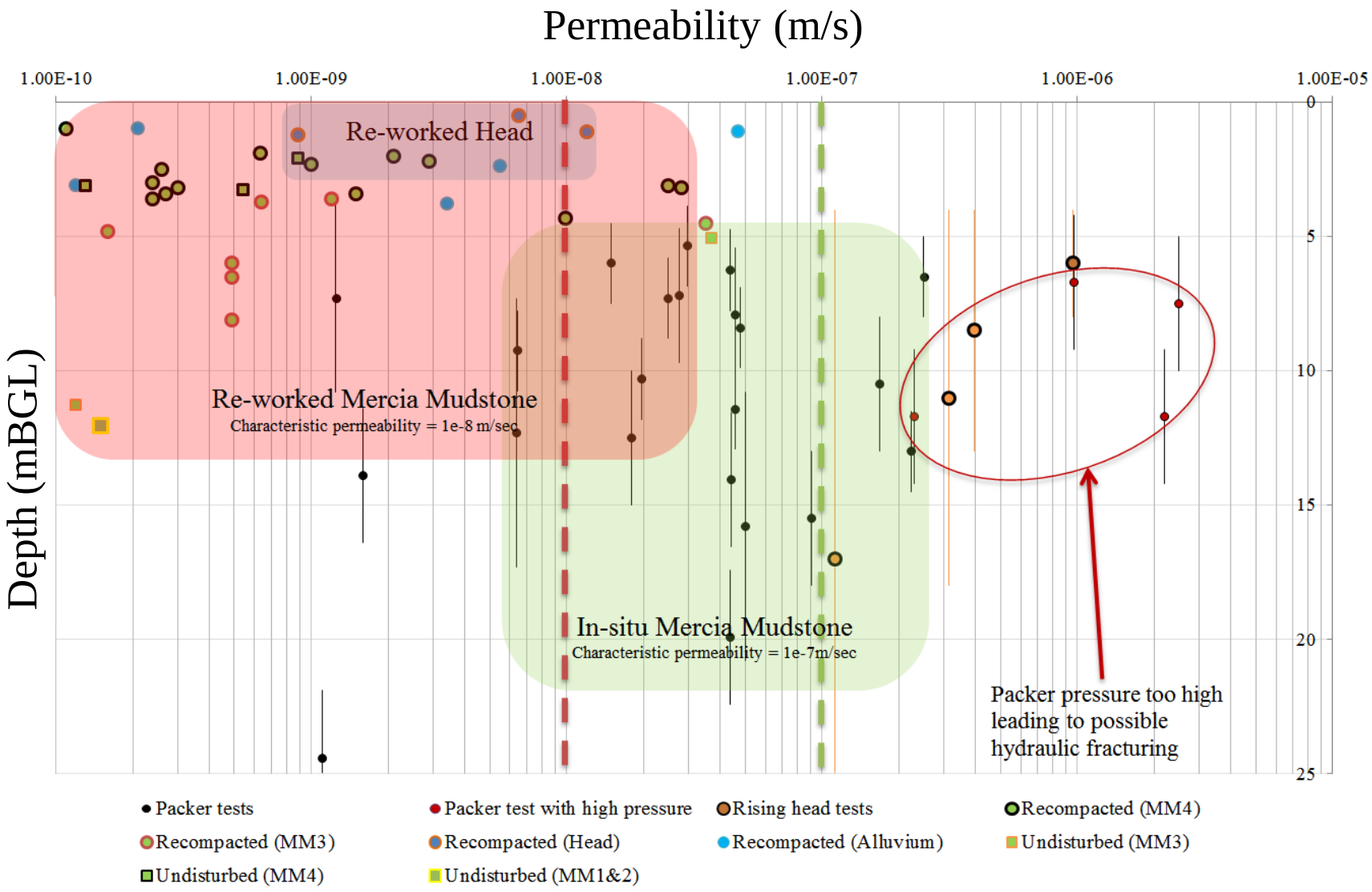
Geotechnical Properties – Permeability



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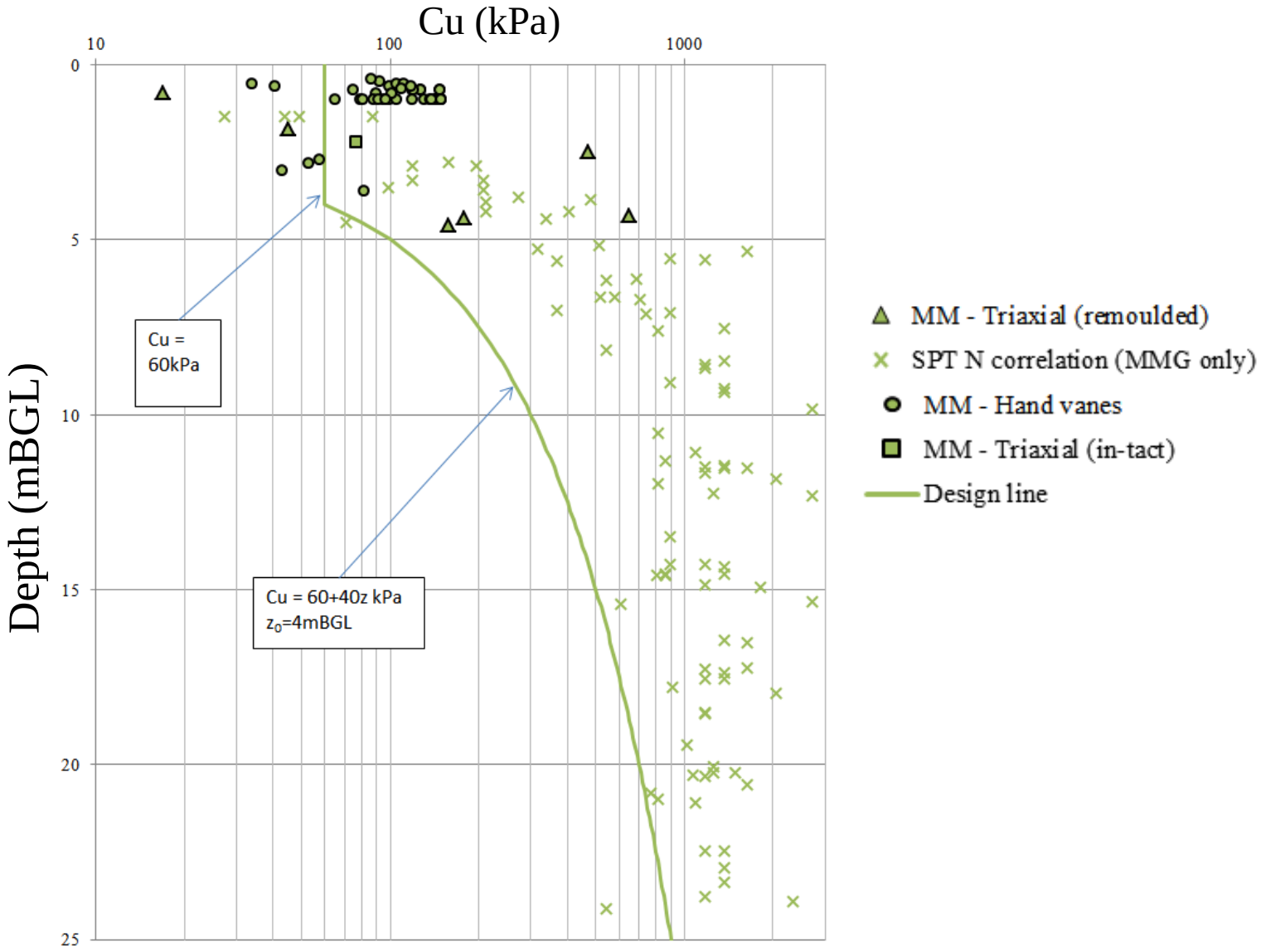
Geotechnical Properties – Strength



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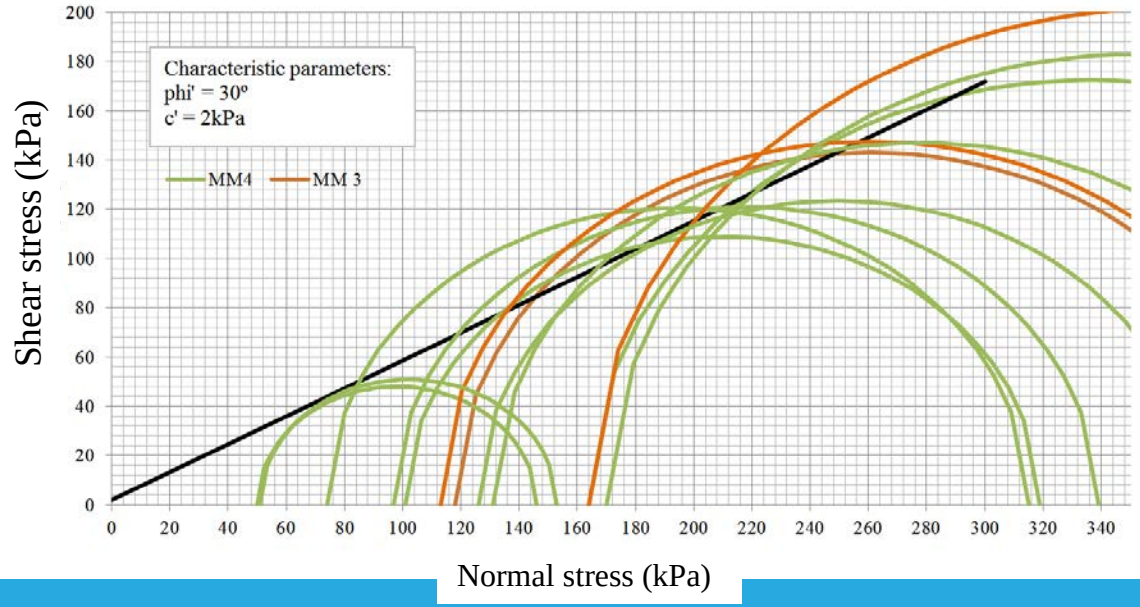
Geotechnical Properties – Drained Parameters

Weathering Grade	c’	φ’
IV	<20	32º - 25º
III	<20kPa	42º - 32º
I-II	>25kPa	>40º

The literature suggests the above drained strength parameters.

Bulk characteristic strength parameters of phi’ = 30 and c’ = 2kPa are assumed for the reworked Mercia Mudstone.

Consolidated drained triaxial tests on re-worked material



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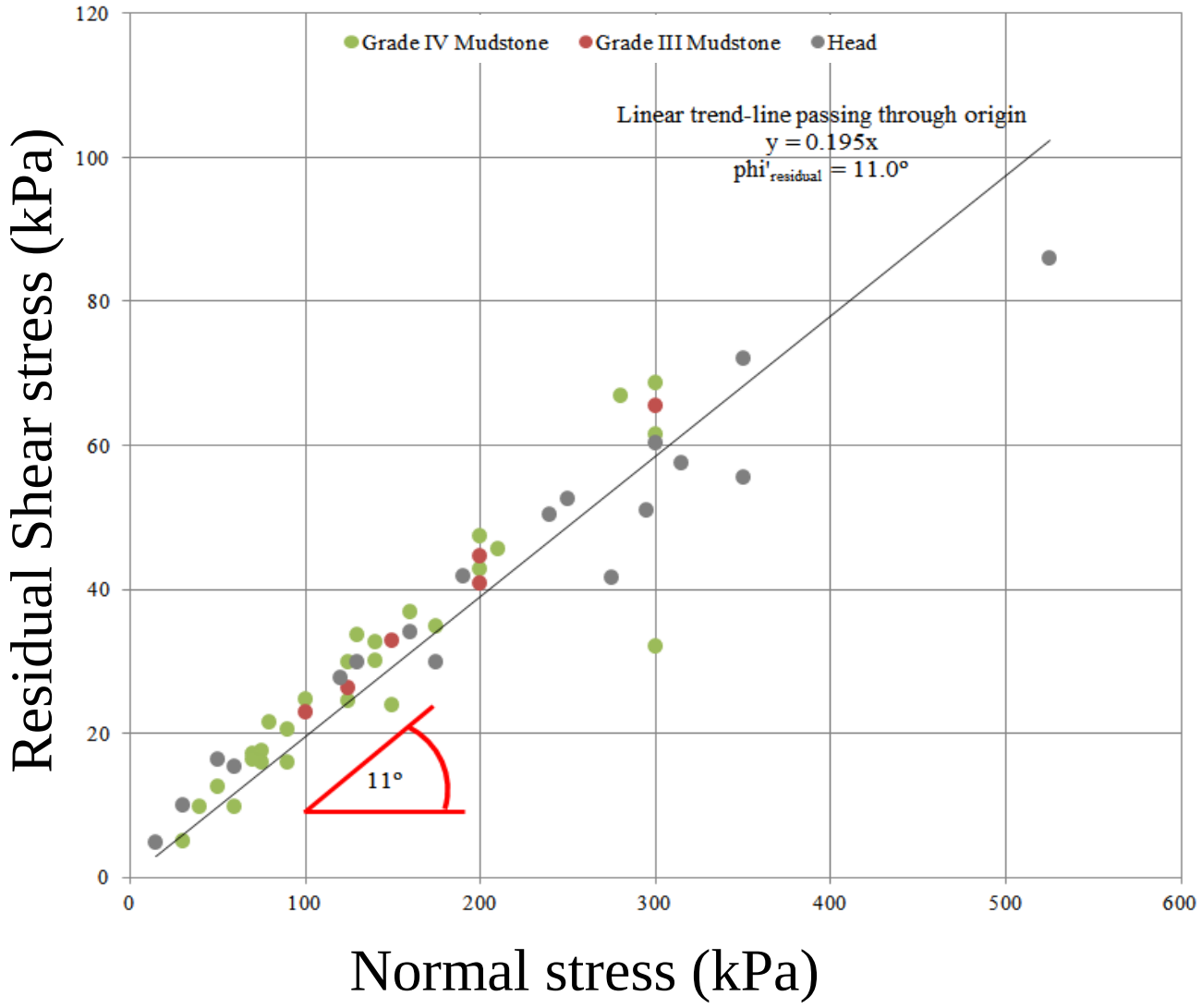
Geotechnical Properties – Residual Shear



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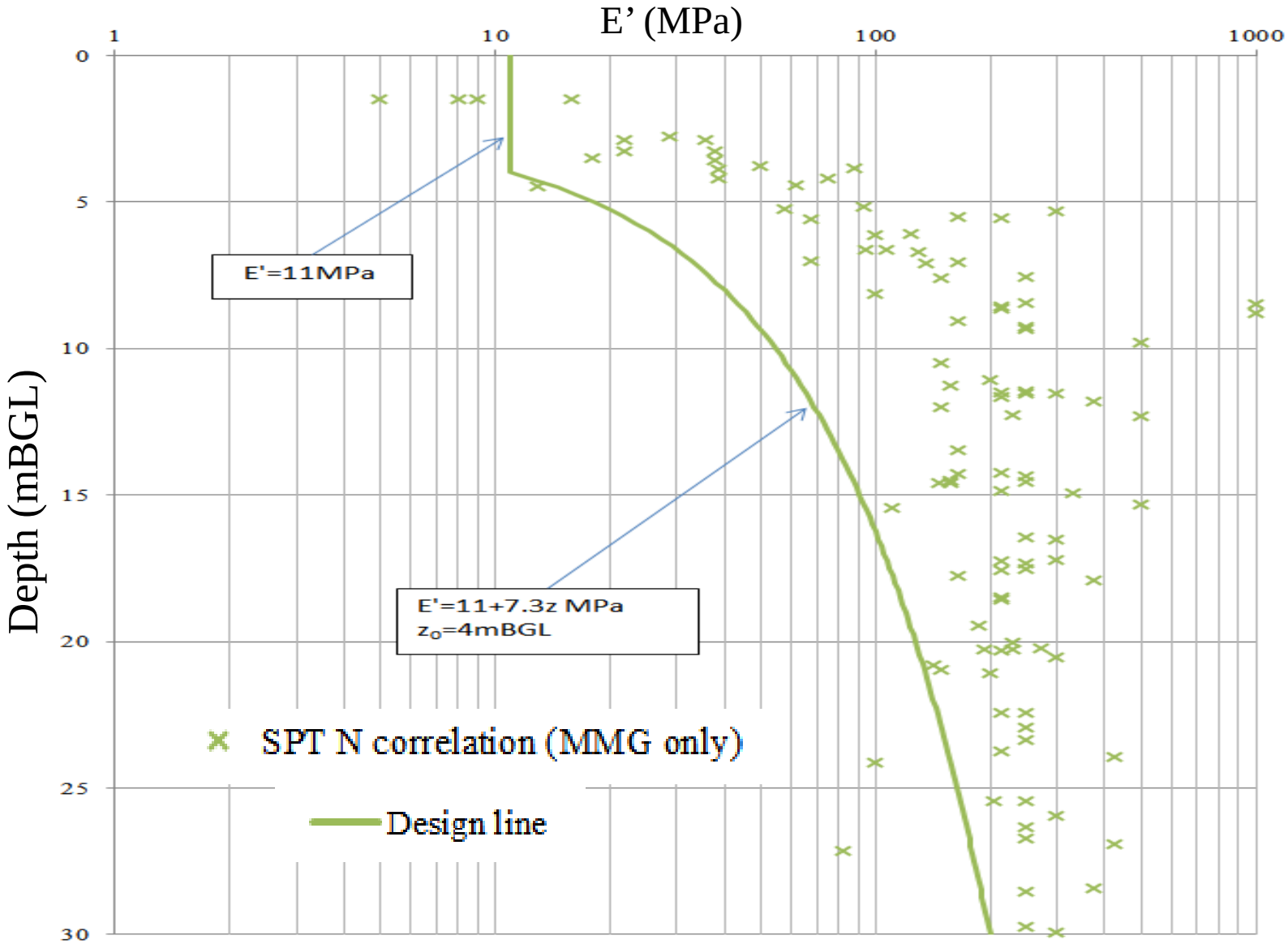
Geotechnical Properties – Stiffness



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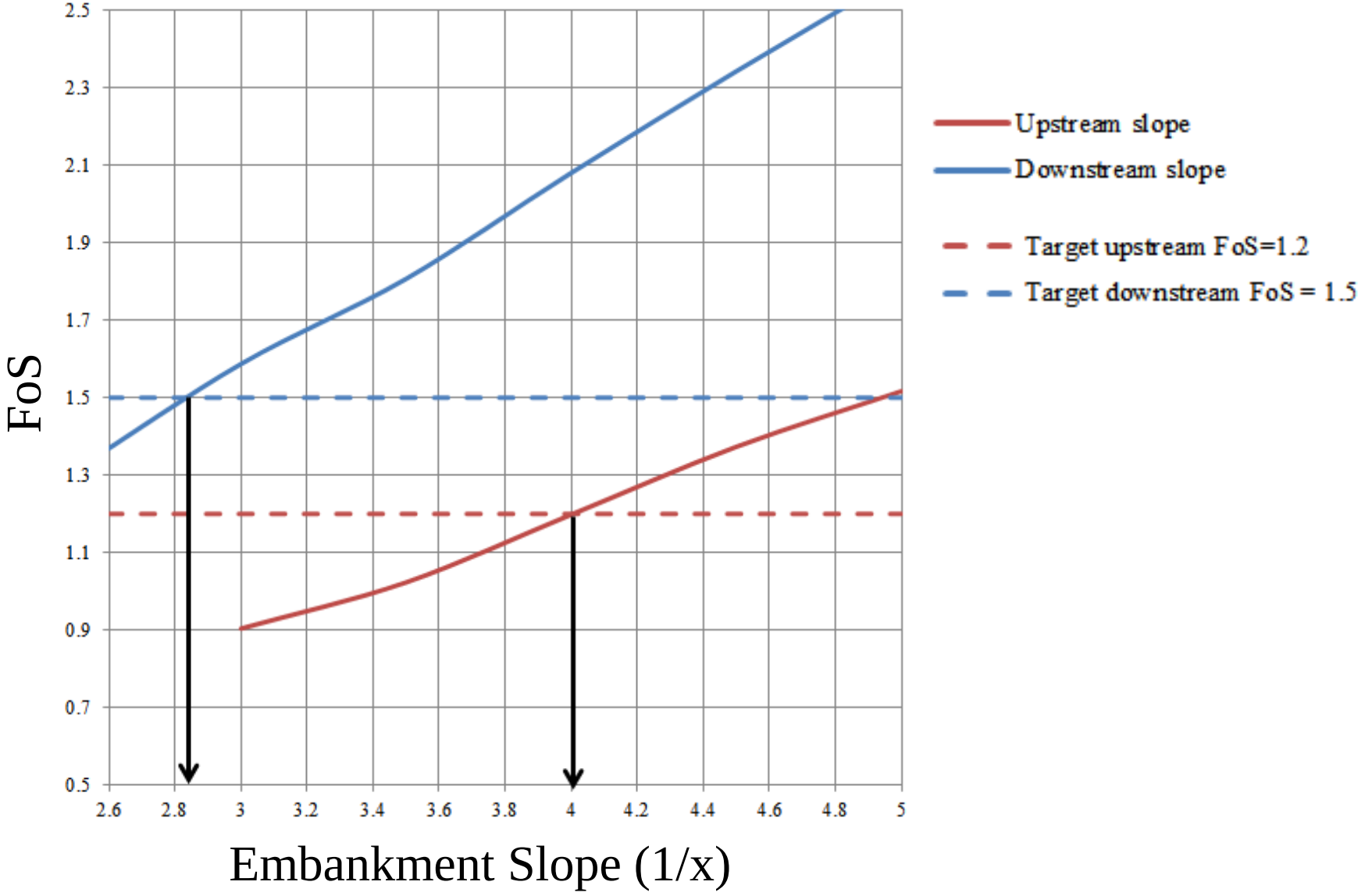
Design Parameters

Property	Mercia Mudstone				Head		Alluvium	
	I/II	III	IV	Re-worked	Intact	Re-worked	Intact	Re-worked
γ (kN/m³)	22	20.5	20.5	20.5	18	18	18	
φ_{peak} (°)	30	30	30	30	30	30	24	
c' (kPa)	20	20	2	2	2	2	0	
$\varphi_{residual}$ (°)		11°	11°	11°	11°	11°		
c_u (kPa)	60+40z		60	60	60		30	
E' (MPa)	11+7.3z		11	11				
v'	0.15	0.15	0.15	0.15				
k (m/sec)	1e-7	1e-7	1e-7	1e-8	1e-5	1e-7		1e-7

Stability Considerations – Critical cases

Case	Embankment side	Required factor of safety	Pore water pressure condition
End of construction	Both, down stream critical due to steeper gradient	1.3	Undrained in all materials
During operation	Down stream	1.5	r_u=0.15 in the embankment r_u=0.5 in the underlying geology
During rapid drawdown	Up stream	1.2	r_u=0.5 everywhere
Seismic loading during operation	Down stream	1.0	r_u=0.15 in the embankment r_u=0.5 in the underlying geology

Stability Considerations – Side slopes



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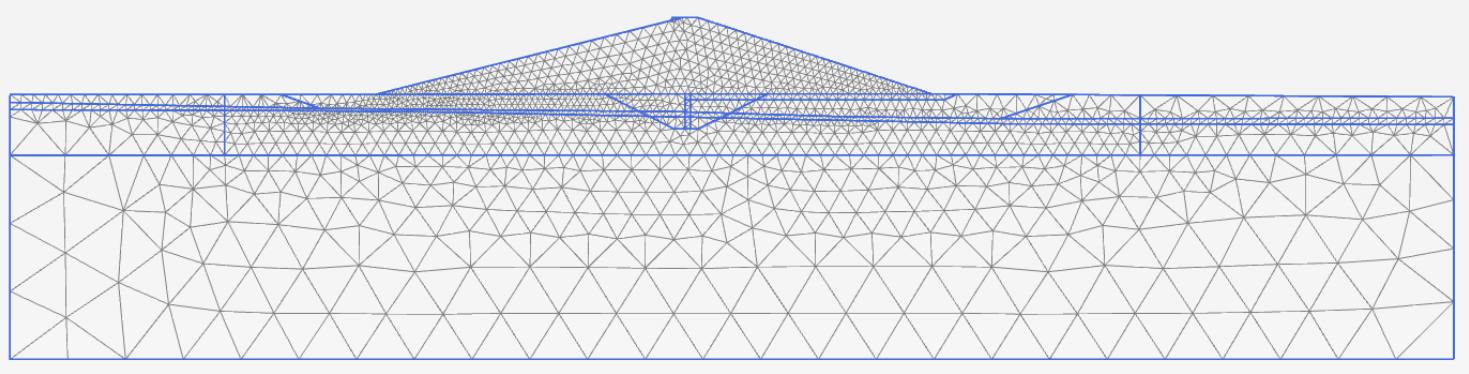
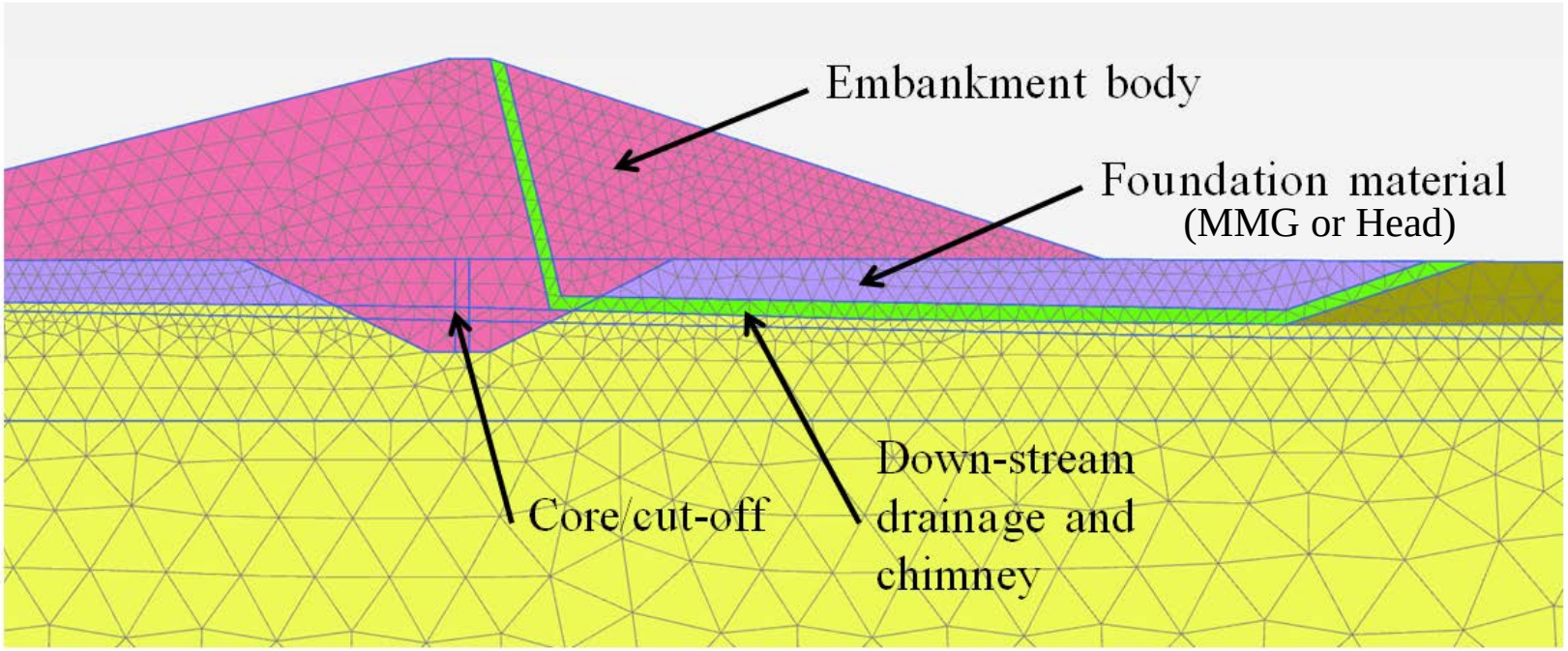
Seepage – Geometric Configuration





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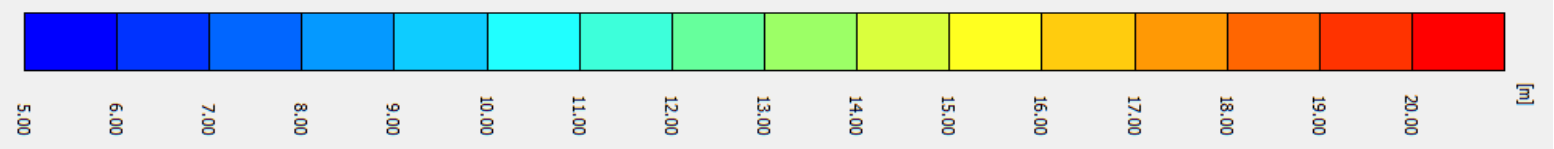
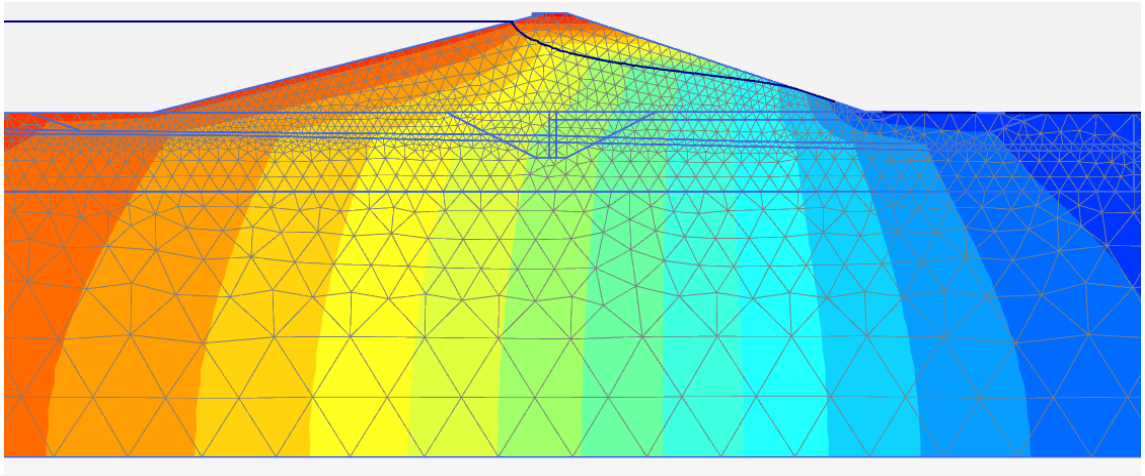
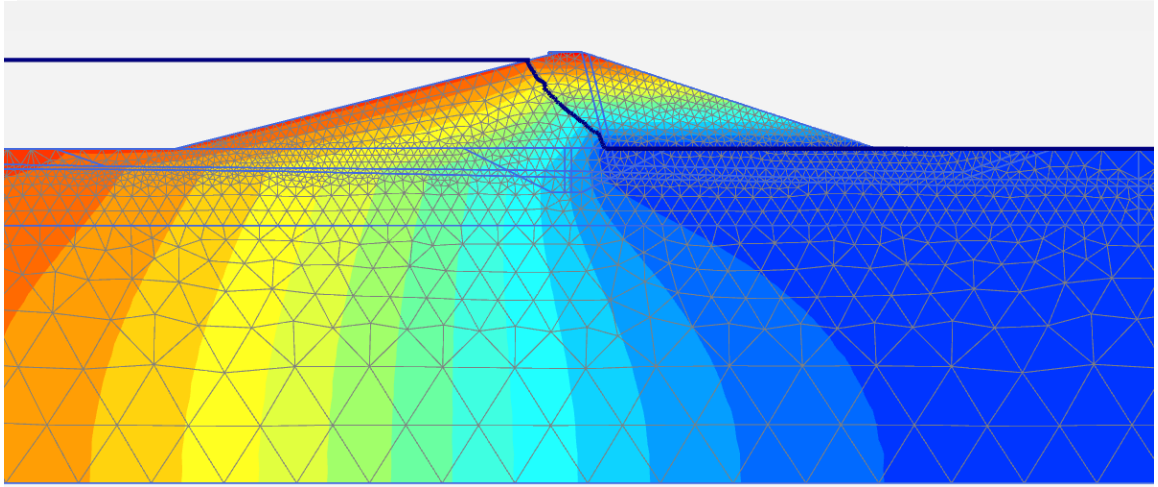
Seepage – Down Stream Drainage – Head above phreatic



Without drainage blanket/chimney



With drainage blanket/chimney



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Seepage – Output summary

Set	Case	Total flow (m^3/day/m)	Total flow, assuming 3.5km perimeter (m^3/day)	Total equivalent loss,(l/sec)
1	No cut-off on MMG foundation	0.037	130	1.5
	No cut-off on Head foundation	0.407	1425	16.5
	No cut-off on MMG foundation with down-stream drainage	0.061	214	2.5
	No cut-off on Head foundation with down-stream drainage	0.591	2069	23.9
2	Cut-off on MMG foundation	0.037	130	1.5
	Cut-off on Head foundation	0.086	301	3.48
	Cut-off on MMG foundation with down-stream drainage	0.058	203	2.3
	Cut-off on Head foundation with down-stream drainage	0.091	319	3.7
3	Core on MMG foundation	0.037	130	1.5
	Core on Head foundation	0.116	406	4.7
	Core on MMG foundation with down-stream drainage	0.060	210	2.4
	Core on Head foundation with down-stream drainage	0.122	427	4.9
4	No cut-off on MMG foundation with Head material on down-stream reservoir side	0.039	137	1.6
	No cut-off on Head foundation with Head material on down-stream reservoir side	0.408	1428	16.5
	Cut-off on MMG foundation with Head material on down-stream reservoir side	0.039	137	1.6
	Cut-off on MMG foundation with down-stream drainage and Head material on down-stream reservoir side	0.058	203	2.3

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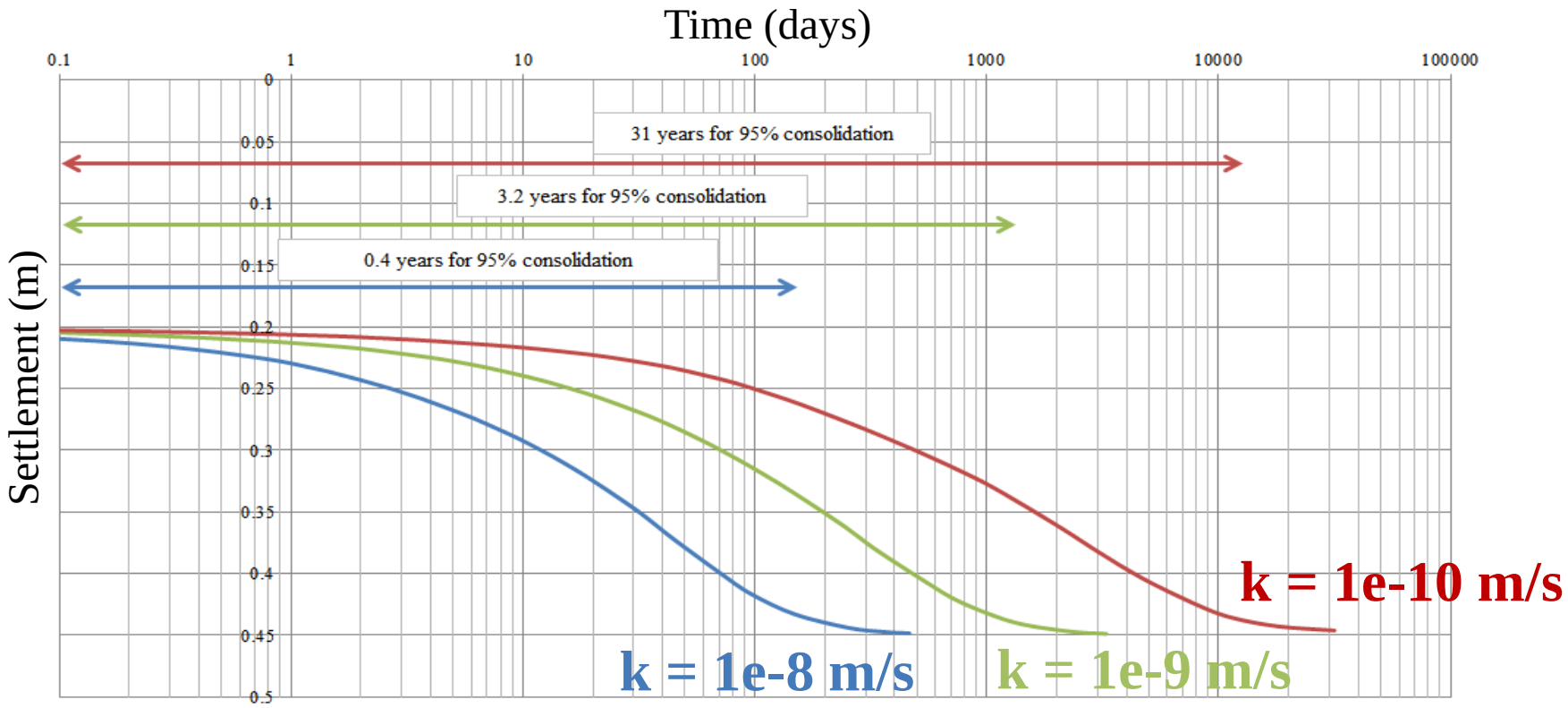
Settlement

	Embankment crest	Top of natural material
Immediate settlement	0.2m	0.1m
Consolidation settlement	0.25m	0.02m
Total settlement	0.45m	0.12m



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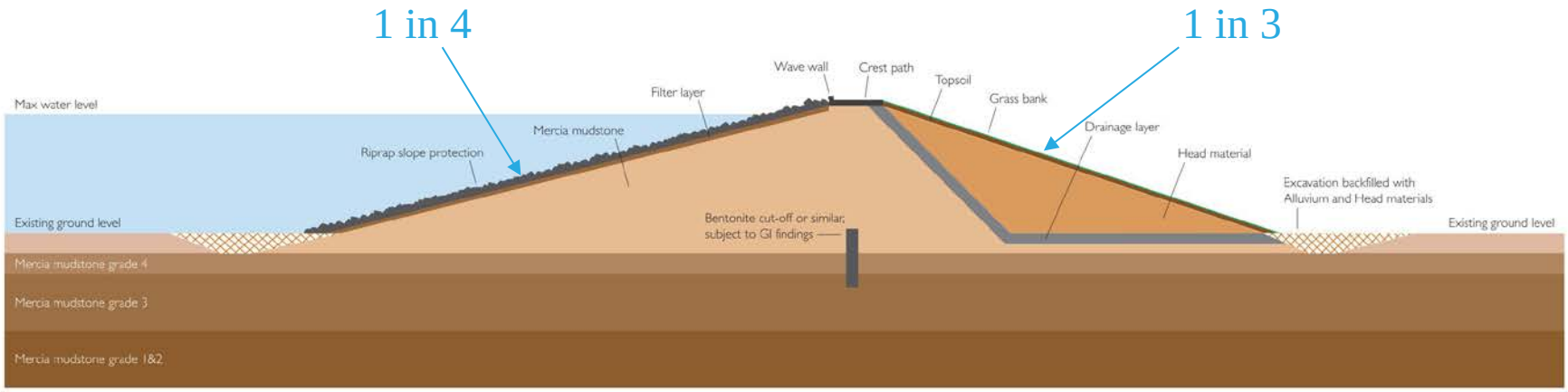
Embankment Design



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Concluding Remarks

- Cheddar 2 is a suitable site for Bristol Water Requirements
- The natural topography and geology can provide cut/fill balance
- Bulk of embankment materials from Mercia mudstone/Head
- Minimal foundation soils problems
- Acceptable long term stability at proposed gradients
- Minimal seepage/cut-off/clay core/drainage requirements
- No adverse effects on macro-ecology/hydrology.

A 21st Century Reservoir is not just the design of a major piece of infrastructure…

…this is the collaborative master planning of a new place (that happens to contain a major piece of infrastructure utilising a deep understanding of geology, hydrology and ecology)!

ANY QUESTIONS?

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