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Lessons Learned at the Magnox Swarf Storage Silo Facility (Sellafield Nuclear Site, UK) on Planning and Optimization of intervention and Clean Up Approaches

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Understanding the impact to ground and groundwater

John Heneghan – Sellafield Ltd., UK

Overview

- Characterisation & Monitoring
  - Historic investigations
  - Current approach
- Local & site wide leak impacts
- Ongoing work
- Planned work

Site setting

- Coastal plain setting
- Cumbrian mountains rise from approx. 5km inland
- 80 years of development have significantly modified the site topography and ground cover

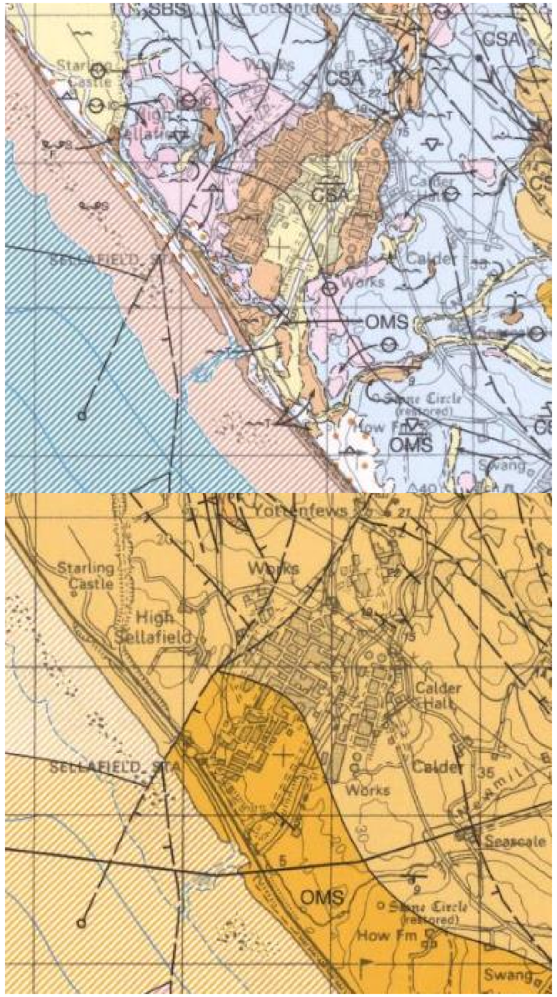
1940's

2010's

Photographs copyright NDA

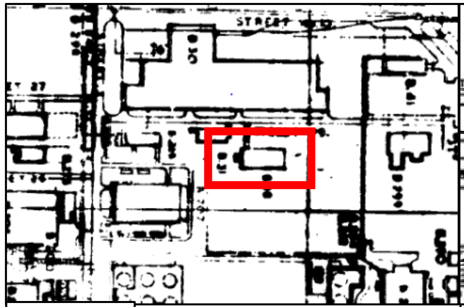
Sellafield geology & hydrogeology

- The site is underlain by a complex sequence of glacio-fluvial deposits, overlying Permo-Triassic age sandstone
- Depth to bedrock across site ranges between approx. -60m to 35m AOD
    - Approx. -20m AOD in the area of MSSS
- A number of faults are projected across the site footprint
- Multiple discrete groundwater units
    - Multiple flow directions
    - Complex contamination distribution

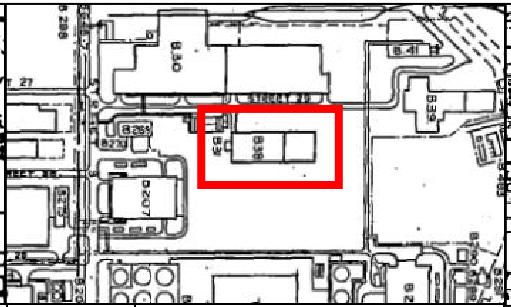


MSSS development

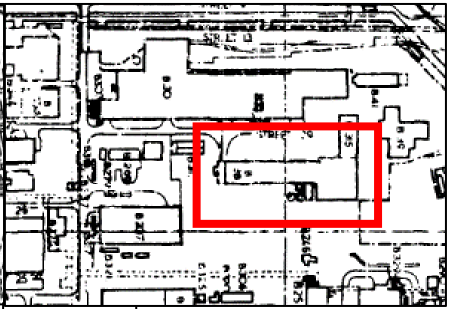
- Majority of MSSS development took place before intensive geological investigations were undertaken
- Location selected on the basis of operational need – no consideration of ground conditions
- Ground investigations were fairly ad-hoc until site wide study in 1977 - 79



1964



1971



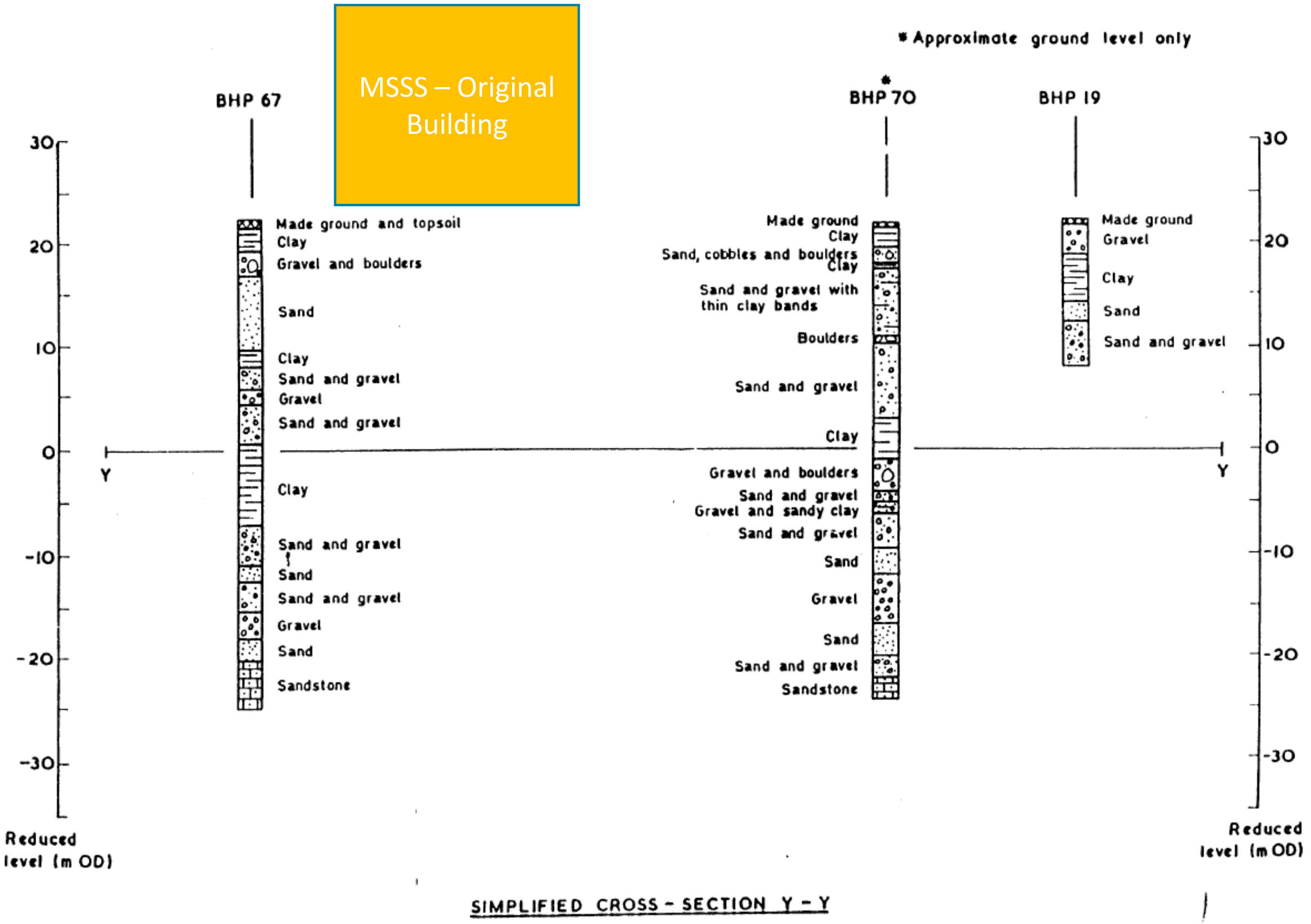
1980

Geological characterisation at Sellafield

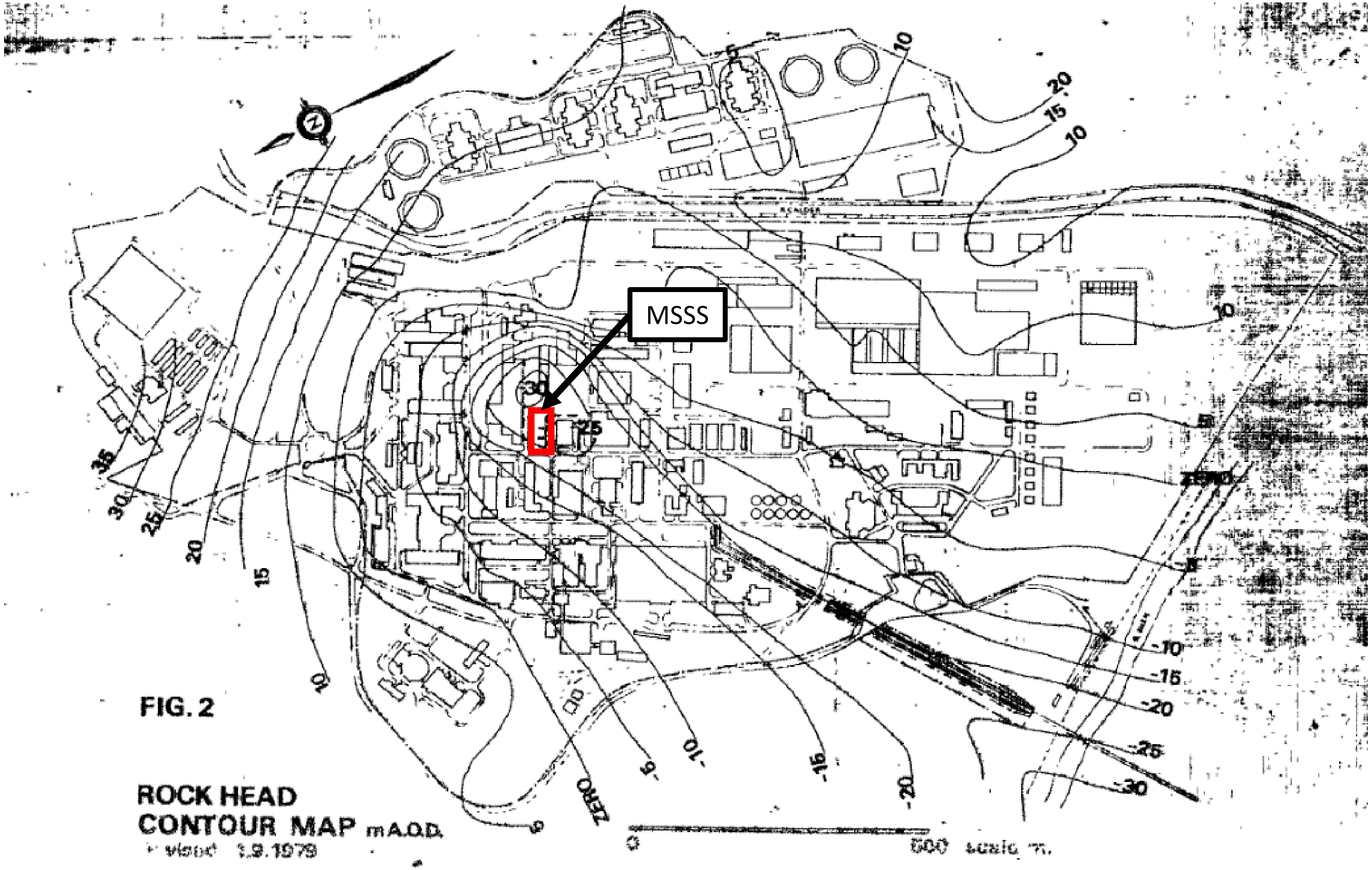
- Early geological investigation at the site was focused on geotechnical requirements
- Historic drilling records are relatively poor
  - Limited lithological logging
  - Focus on geotechnical parameter data only
  - Development specific
  - Contemporary reporting is limited
- More focus on sitewide geological & hydrogeological investigation from the mid-1970's onwards
  - Major study by the Institute of Geological Sciences (IGS) (now the British Geological Survey (BGS)) between 1977 – 79
  - Some MSSS specific hydraulic testing (limited) – 1981
- Historic leak stopped ca.1980

Site geology & hydrogeology

- Early recognition that the geology of the site, and around MSSS is complex
- Estimates of T & S (site wide)
    - T = 2 – 870 m^2/d
    - S = $7x10^{-5}$ – 0.28
- Sandstone flow is fracture dominated
- Groundwater mounds identified



Buried channel feature identified

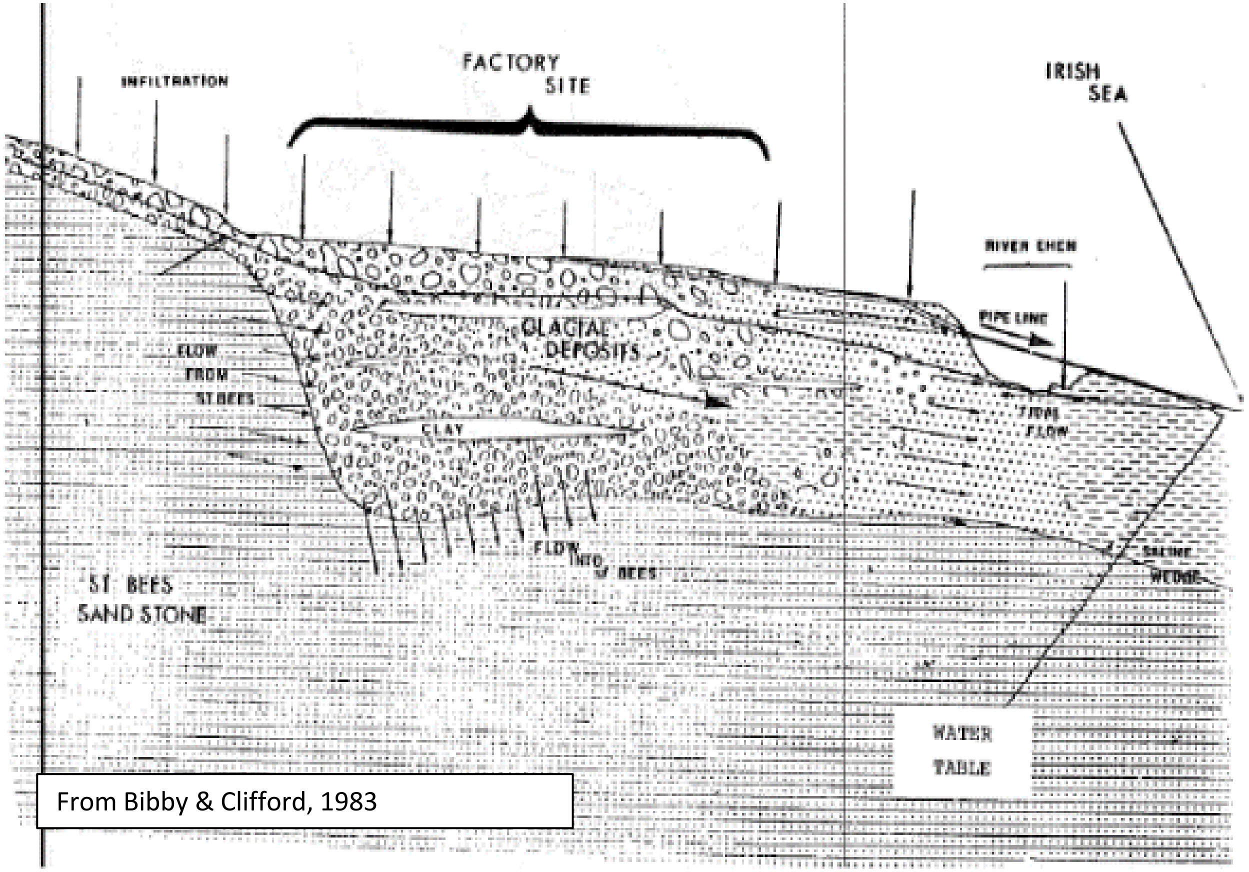


Heterogeneity in superficial deposits

Nearby Drigg site

Contamination fate and transport

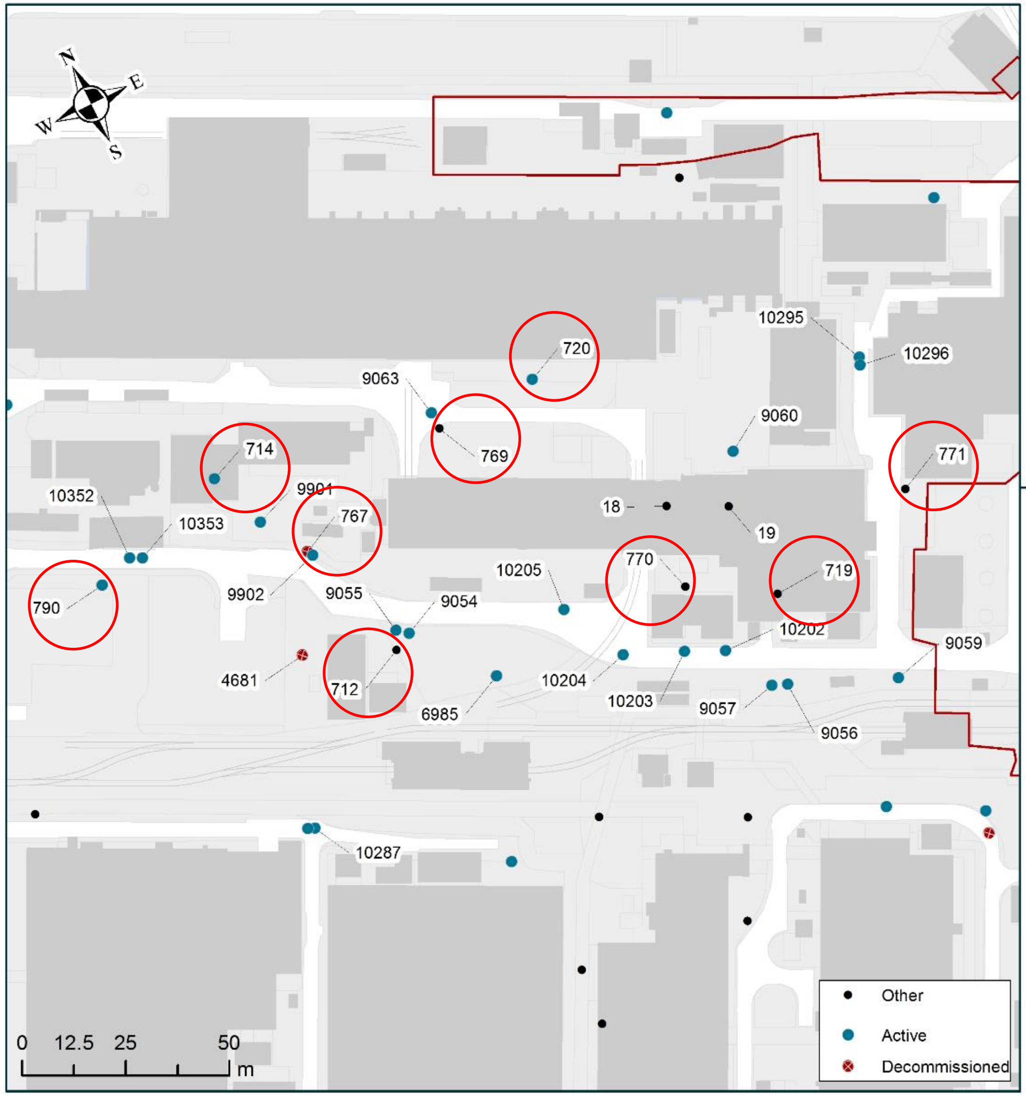
- River and beach spring monitoring suggested that the majority of contamination was migrating in the buried channel pathway
- Further investigation, conceptualisation and modelling supported this assumption
- Later recognition that some contamination was moving towards the River Calder
    - River Calder originally conceptualised as a recharge boundary – no GW discharge
    - Changes to river morphology (straightening) in 1970's may have altered relationship to groundwater



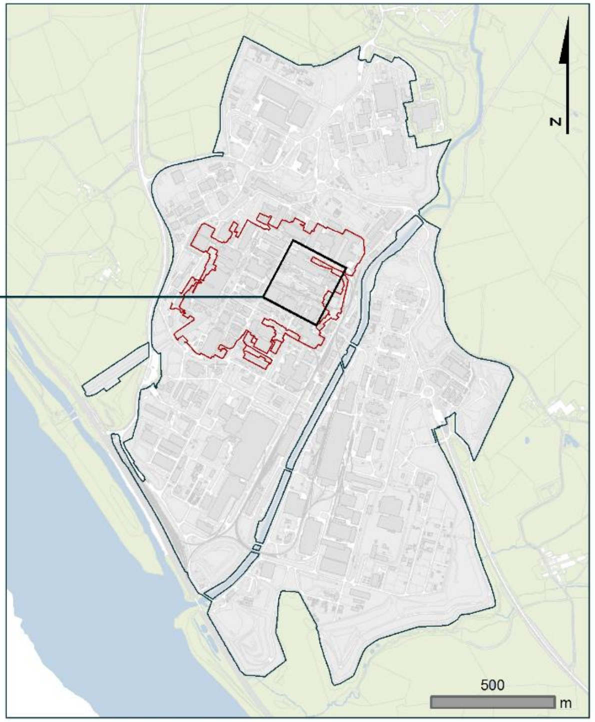
From Bibby & Clifford, 1983

MSSS Contamination monitoring

- Groundwater and blind tube (gross gamma) monitoring commenced in the 1970's (700 series wells)
- Quickly realised that Cs-137 (bulk of activity) has limited mobility in ground
  - 95% of total activity remains within a few meters of the leak point
- Sr-90 more mobile than Cs-137, but travel time to biosphere estimated at 50 years (worst case)
- Monitoring infrastructure focused in the area of MSSS
- Downgradient monitoring network relatively sparse (laterally and vertically)
  - Limited monitoring in bedrock
  - Long well screens
  - Nested piezometers



Groundwater Monitoring Well Locations



Further characterisation

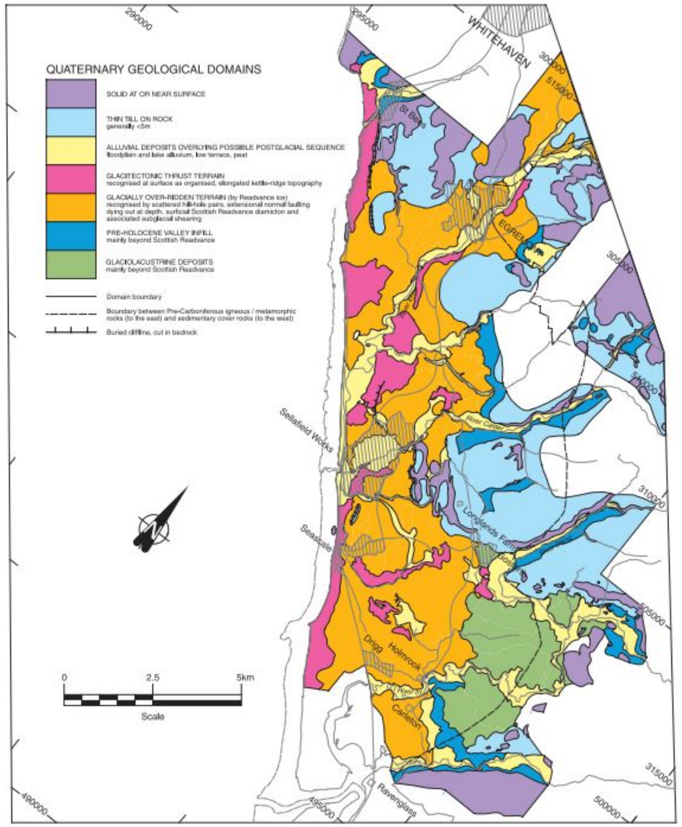
- Limited further in-ground characterisation until 2000's
  - Focus during 1980's on potential mitigation solutions
    - Hydraulic containment
    - Cut-off walls
  - Site wide focus move to broader environmental monitoring – aerial & marine discharges
- NIREX regional work in 1980/90's
- Sellafield Contaminated Land Study (SCLS) – early 2000's
- Sellafield Contaminated Land & Groundwater Monitoring Project (SCL&GMP) – late 2000's
- Revisions to geological / hydrogeological conceptual model (domains)
- New groundwater flow model

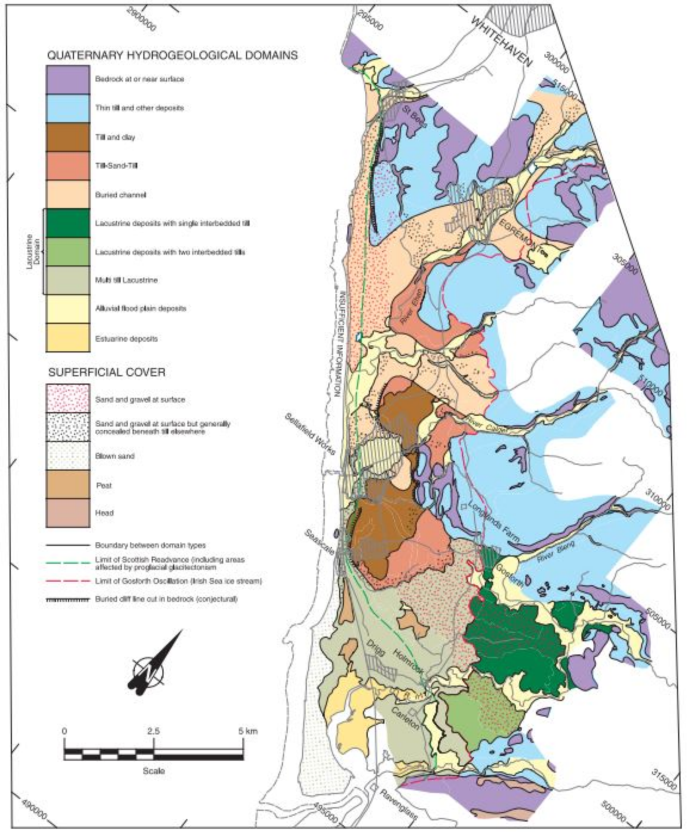
Regional understanding

- NIREX work improved understanding of geological and hydrogeological domains

Domains approach

- Sub-divisions based on material deposition and type
    - Geological domains
    - Hydrogeological domains
- Broad alignment of groundwater behaviour
- Focus on broad areas
- Local variability can be significant
    - Important for understanding contamination fate and transport





McMillan et. al., 2000

Characterisation techniques

- Up to SCL&GMP most wells were drilled by shell & auger in superficial deposits (cable percussion techniques)
- Move to rota-sonic technique during SCL&GMP

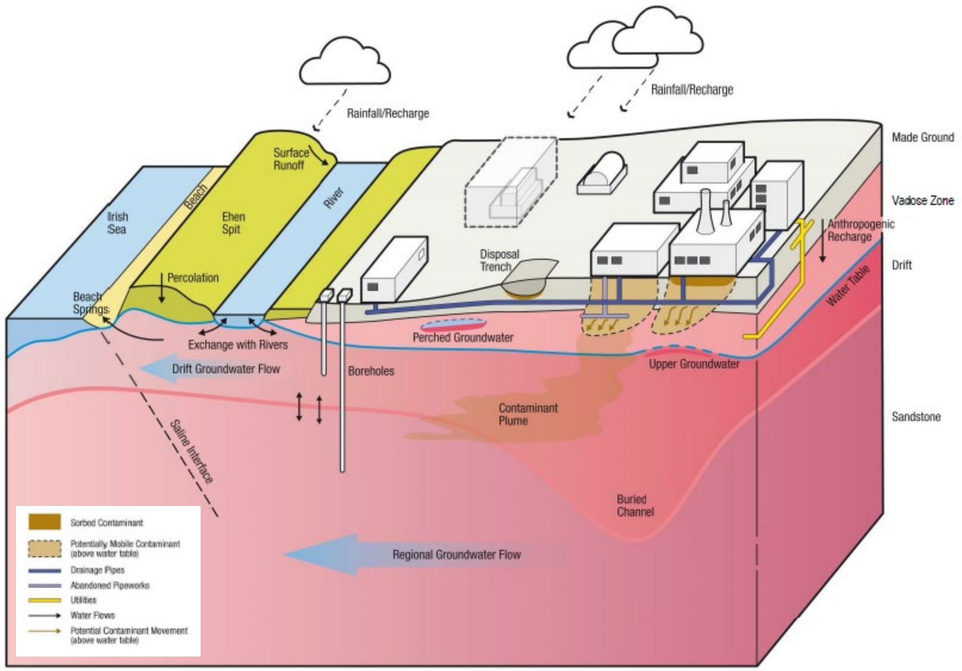
Characterisation techniques

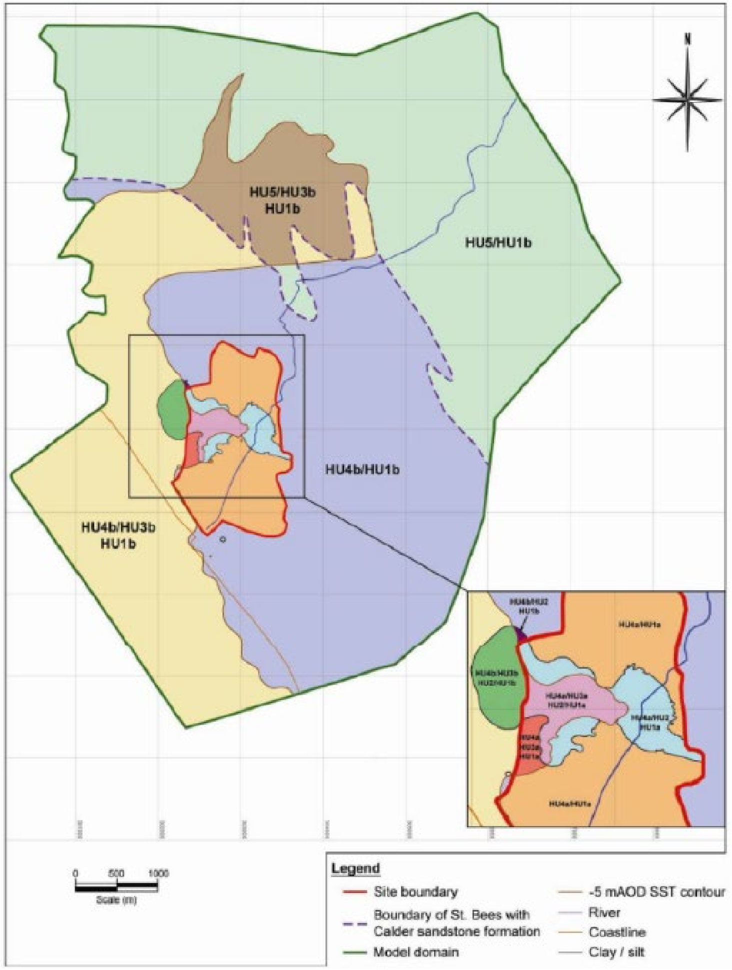
- Rota-sonic drilling typically provides much higher fidelity data
  - Log extracts are from two adjacent wells – shell & auger and sonic
  - Much greater detail to comparable depth in sonic log

Description of Strata	Legend	Depth	Reduced Level	Sampling/ Core Run		U	In Situ Testing		TCR (SCR) RQD	FI	Install -ation
							Test	Result			
MADE GROUND: Tarmac.		0.10	23.88								
MADE GROUND: Type 1, hardcore.		0.50	23.48								
MADE GROUND: Brown and grey silty very sandy angular to rounded fine to coarse gravel of mixed lithologies including volcanics, sandstone and limestone with many cobbles and occasional orangish brown sandy lenses.				B D	2.00 2.00-2.45		S	26/125#			
				B	3.00						
		3.10	20.88								
Loose brown to reddish brown clayey very sandy angular to rounded fine to coarse GRAVEL of mixed lithologies including coal and carbonaceous lenses with occasional cobbles.				D	3.40-3.85		S	8			
		3.60	20.38								
Firm brown to orangish brown slightly gravelly sandy CLAY with occasional cobbles. Gravel is angular to rounded fine to medium of mixed lithologies with occasional partings of orangish brown fine to medium sand.				B	4.00						
. . . . from 3.80m to 4.50m, band of cobbles/boulders		4.50	19.48								

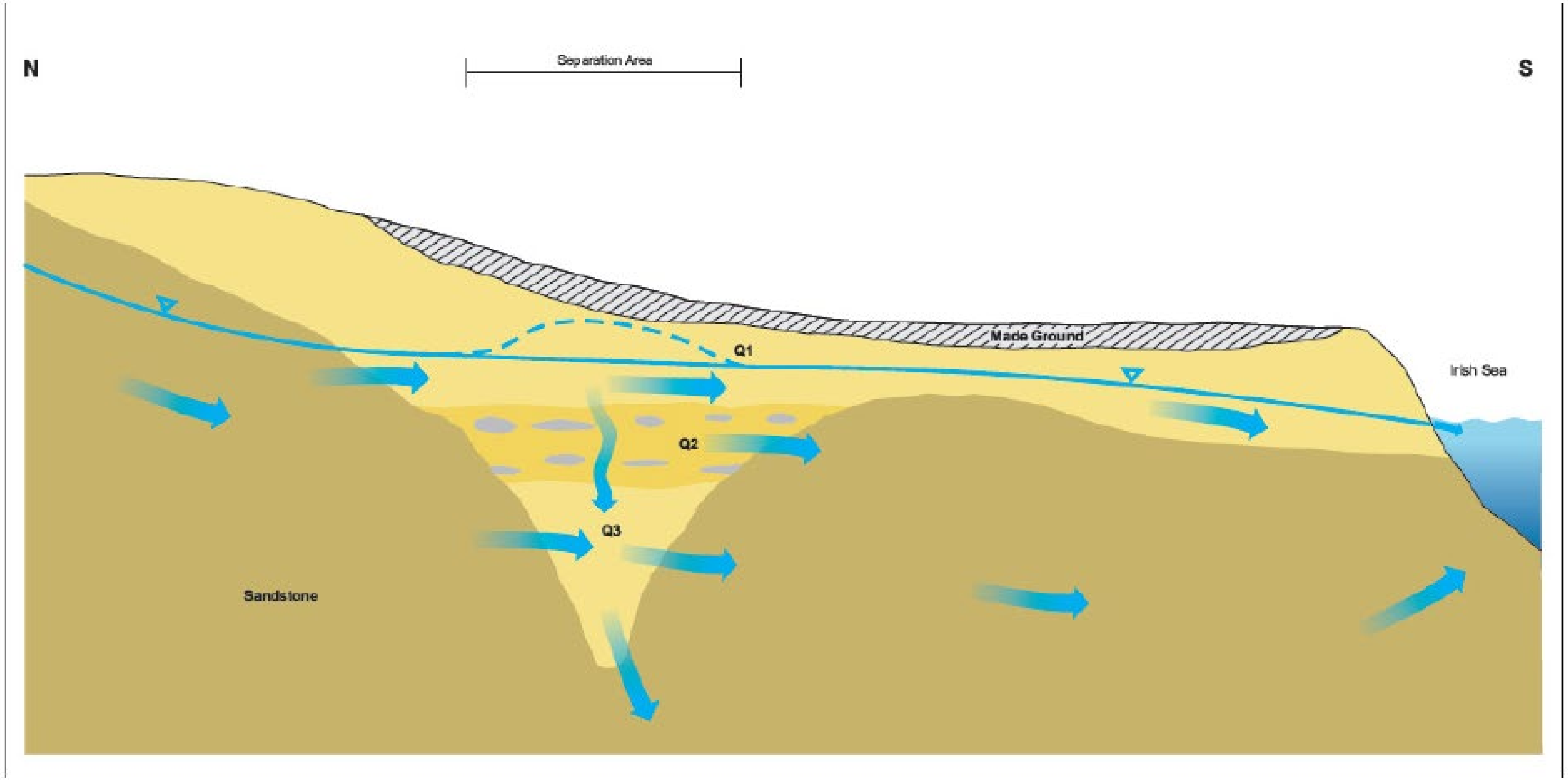
Well	Water Strikes	Sample Depth (m)	Sample Type	Coring			Depth (m)	Level (mAOD)	Legend	Stratum Description	
				TCR	SCR	RQD					
							0.10	23.88		TARMAC	
		0.20	ES				0.40	23.58		MADE GROUND: Type 1 fill material with geotextile membrane at base.	
		0.50	ES				0.80	23.18		MADE GROUND: Orangish brown sand and gravel with low cobble content. Sand is fine to coarse, gravel is fine to coarse, sub-angular to angular. Cobbles are sub-angular to angular up to 250 mm including low sphericity cobbles.	
		1.00	ES				1.40	22.58		MADE GROUND: Orangish brown sand, gravel and cobbles. Sand and gravel is fine to coarse. Gravel and cobbles are sub-rounded to angular, cobbles up to 200 mm. Gravel and cobbles are poorly sorted of mixed natural lithologies.	1
							1.60	22.38			
							1.80	22.18		Grey silty SAND AND GRAVEL with medium cobble content. Gravel is fine to coarse, rounded to very angular of mixed igneous and sedimentary lithologies. Cobbles are rounded to very angular.	
										Brownish grey slightly silty gravelly coarse SAND with low cobble content. Cobbles are sub-rounded to angular.	
							2.40	21.58		Brownish grey slightly silty very sandy GRAVEL with medium to high cobble content. Gravel is rounded to very angular. Sand is medium to coarse.	2
							2.60	21.38			
							2.80	21.18		Reddish brown silty very gravelly fine SAND with low cobble content. Gravel is rounded to sub-angular, often tabular. Cobbles are rounded. Sand fines downwards into silt below.	
							3.00	20.98		Firm reddish brown sandy gravelly SILT with low cobble content. Gravel is rounded to sub-angular, often tabular. Cobbles are rounded.	3
							3.20	20.78			
							3.40	20.58		Brownish grey slightly silty slightly gravelly medium to coarse SAND with low cobble content. Cobbles are sub-angular to sub-rounded.	
							3.70	20.28		Brownish grey very gravelly medium to coarse SAND. Gravel is fine to medium of igneous lithologies and occasional quartzite.	
										Brownish grey SAND AND GRAVEL. Gravel is coarse, fining upwards into fine to medium of occasional quartzite and igneous lithologies. Sand and gravel fractions both fine upwards into unit above.	4
							4.20	19.78		Reddish brown sandy very silty fine to coarse GRAVEL with medium to high cobble content. Gravel is very angular to well rounded, cobbles are sub-angular to sub-rounded.	
							4.50	19.48		Stiff thinly laminated reddish brown slightly gravelly silty CLAY with low cobble content. Occasional partings of dark coloured staining.	
							4.70	19.28		Dark brownish grey slightly gravelly silty fine SAND with low cobble content. Gravel is fine to coarse rounded to sub-angular.	
							4.90	19.08		Grey gravelly silty medium to coarse SAND. Gravel is fine sub-angular to sub-rounded of mixed igneous lithologies.	5

Conceptual model evolution (1)

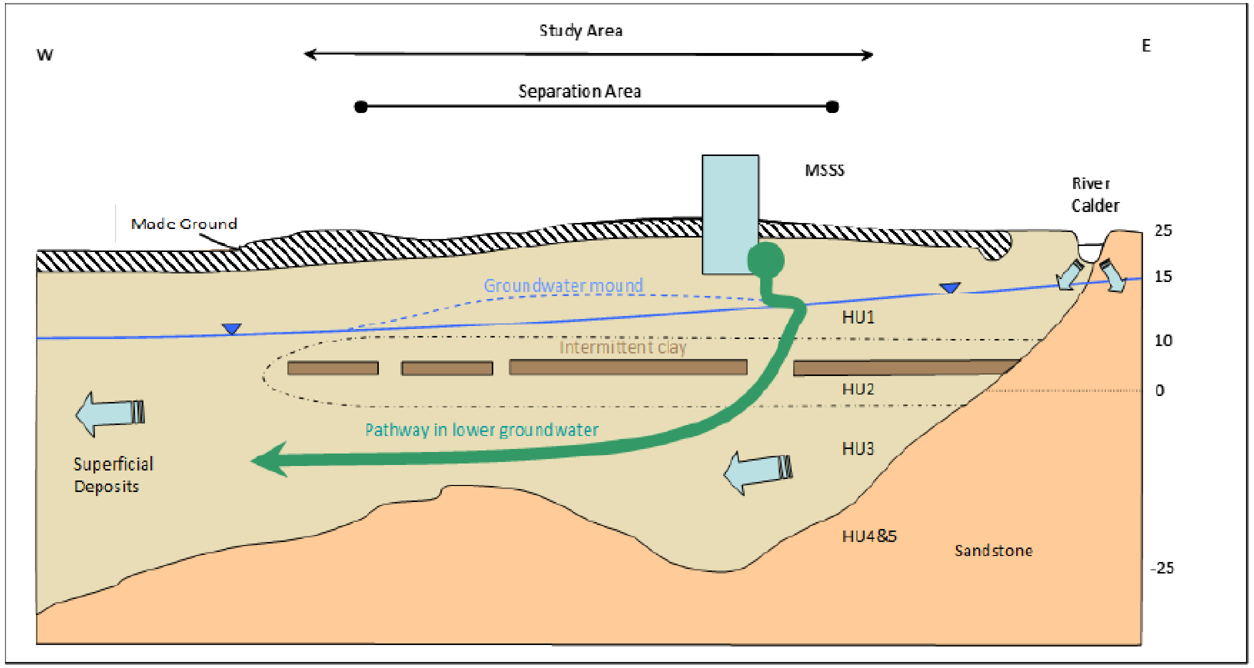


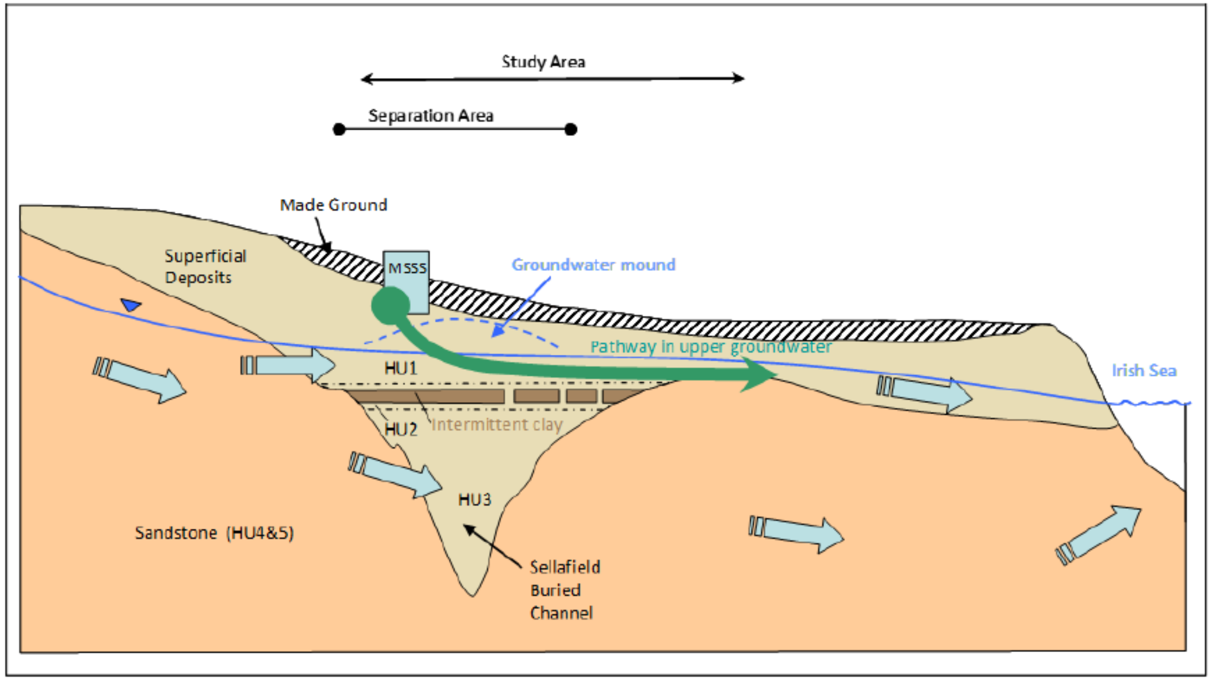


Conceptual model evolution (2)



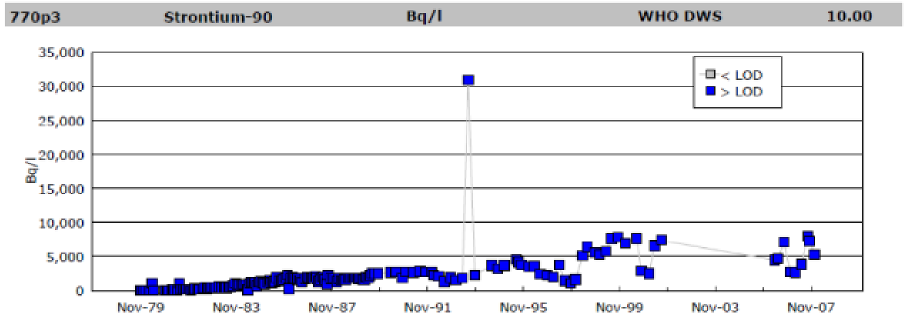
Conceptual model evolution (3)

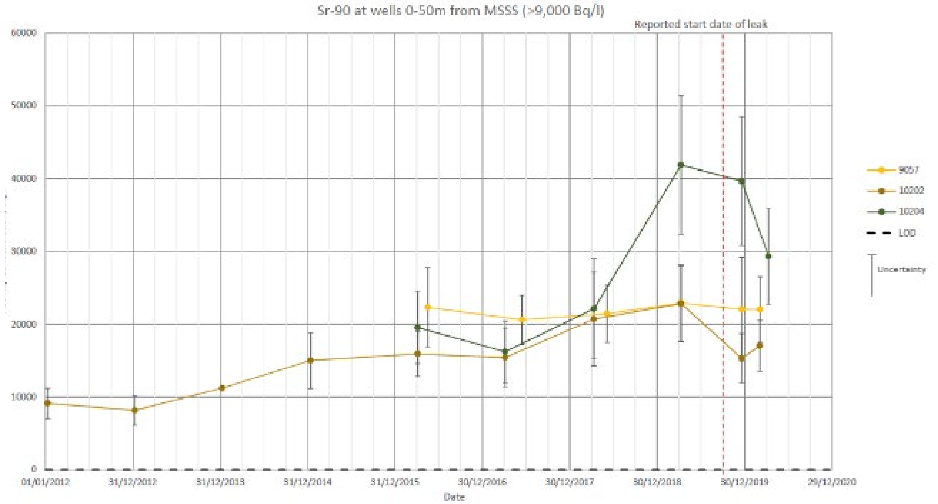




Contamination distribution

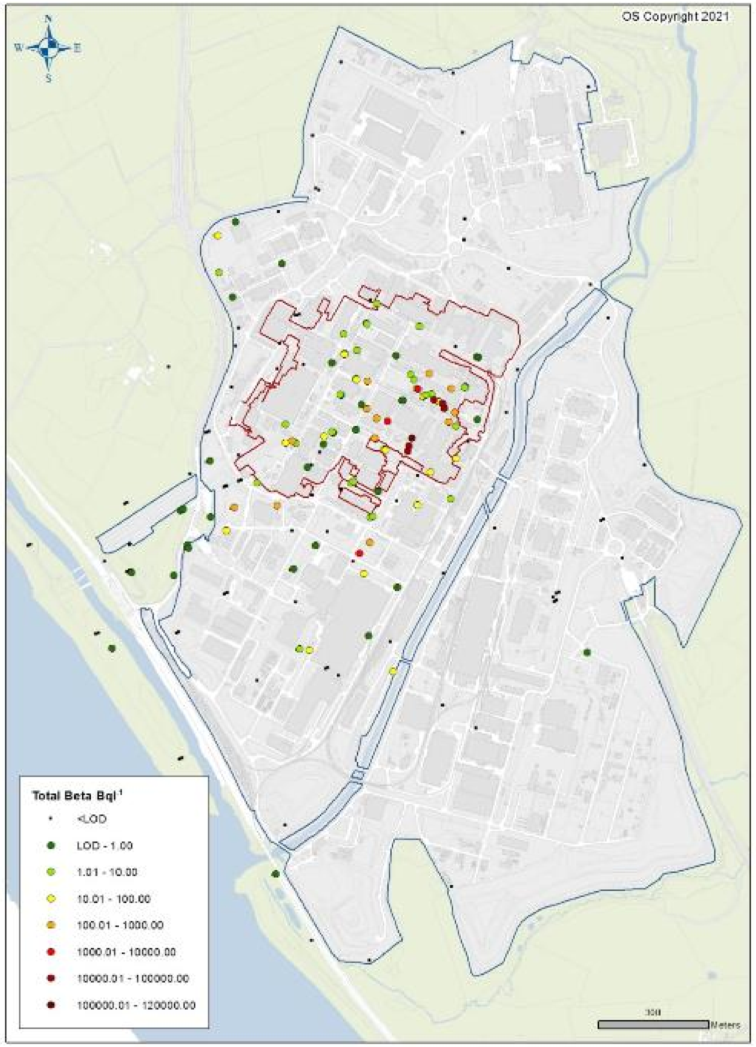
- Historic data provides good insights into contaminant trends and behaviour near silo
    - Limited information on relatively mobile radionuclides (e.g. Tc-99, C-14, Cl-36) – majority had advected away from the area prior to monitoring of these starting
- Good Cs-137 and Sr-90 data

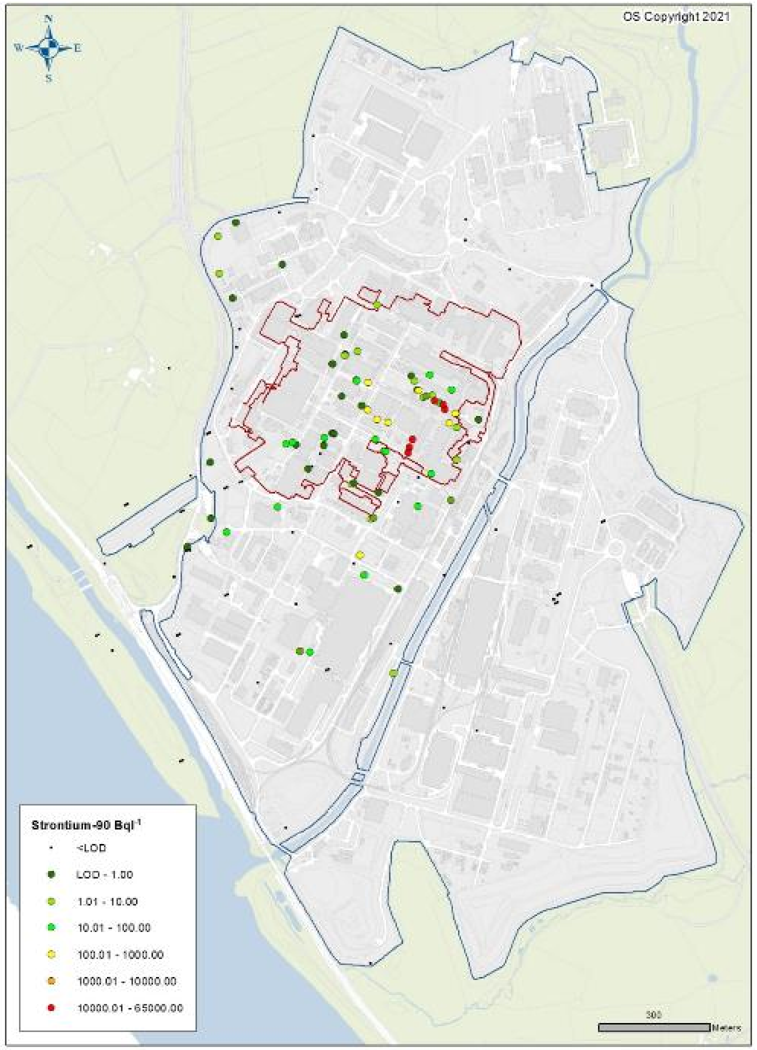




Contamination distribution

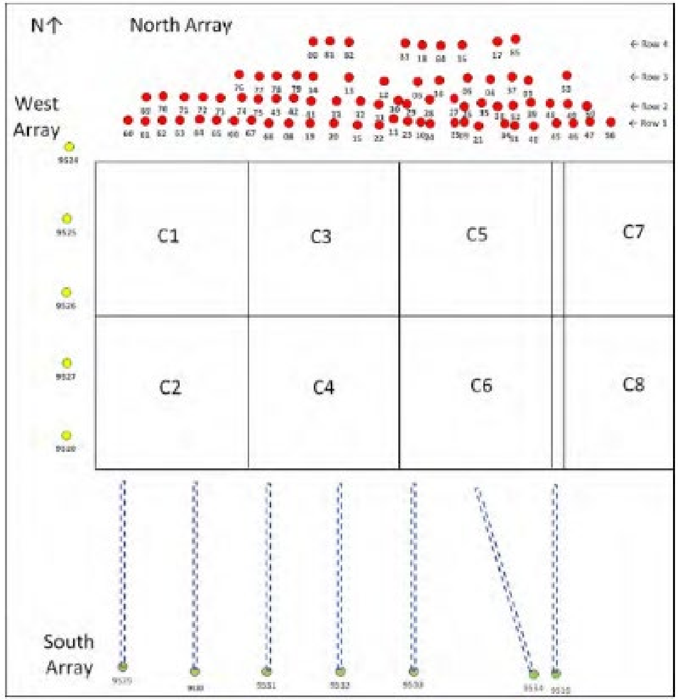
- Total Beta & Sr-90 show greatest activity in vicinity of historic leaks (MSSS & HALES)
- Distributions reflect migration of historic MSSS leak and other sources
- See: Sellafield Ltd environmental and safety reports - GOV.UK (www.gov.uk)

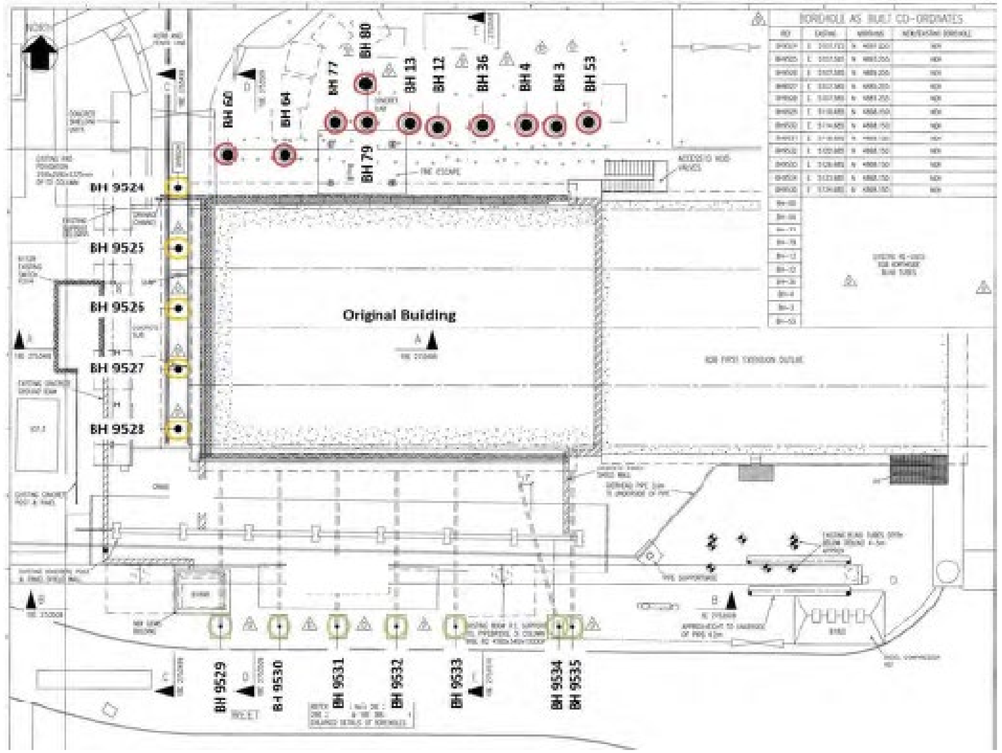




Blind Tube Monitoring

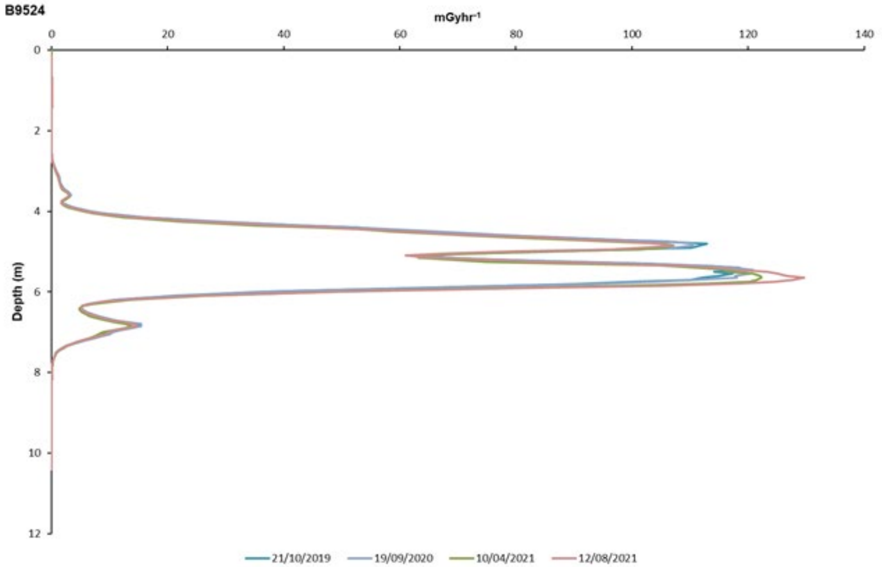
- Blind tubes installed around OB in 1970's (north side) and 2015 (south and west side)
- 'Closed' monitoring boreholes to ca.11m bgl – gross gamma measurements





Blind Tube Monitoring

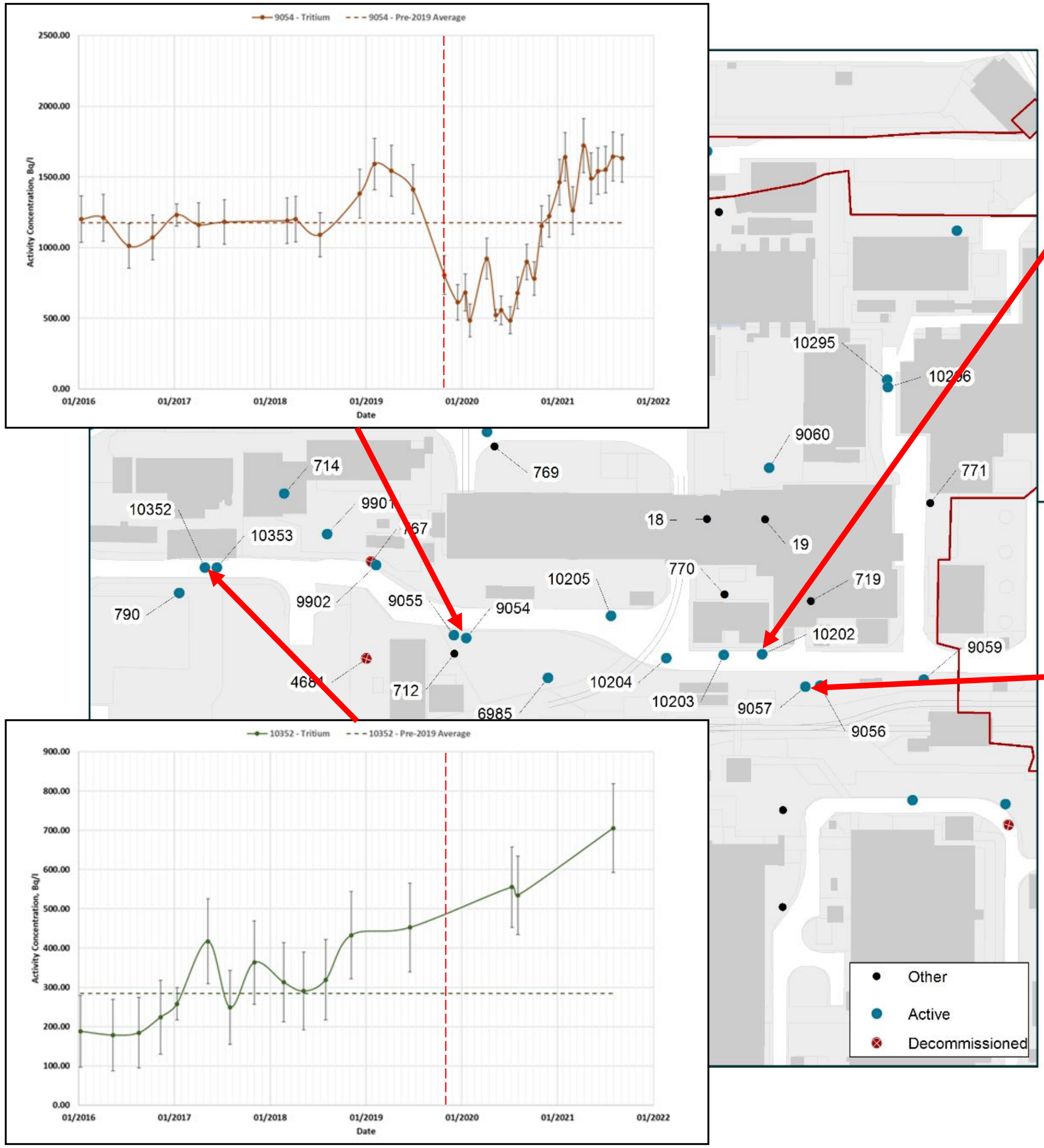
- Routine monitoring allows monitoring of trends – principally Cs-137
- Migration of Sr-90 possibly evident with trends thought to be associated with bremsstrahlung radiation

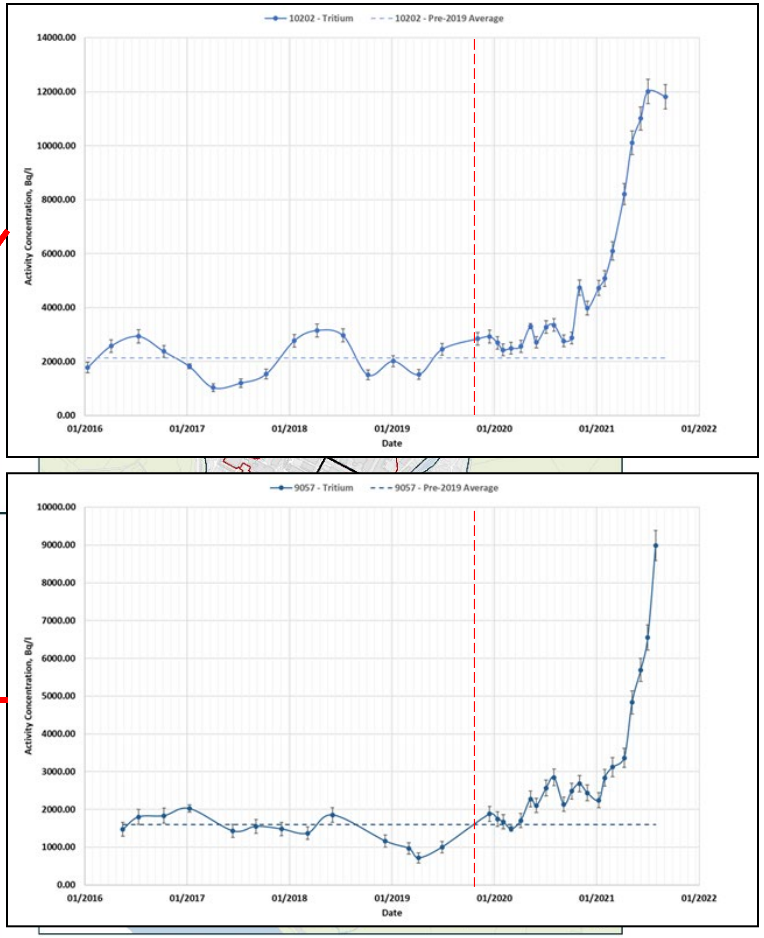


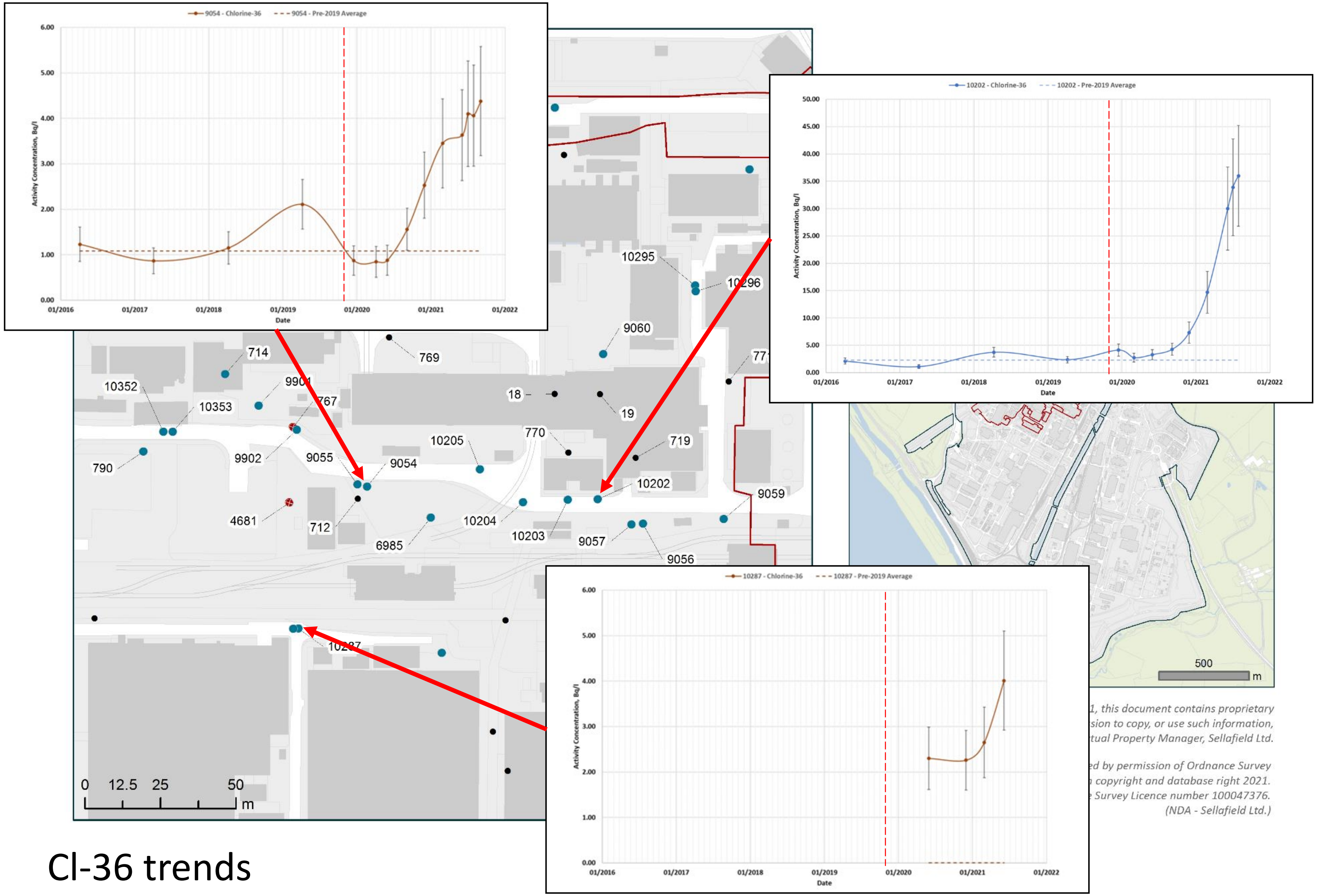
The current leak

- The current leak is starting to show in groundwater
  - H-3 showing upward trend (care in interpretation – multiple H-3 sources)
  - Cl-36 – first definitive marker of silo liquor from current leak in groundwater
  - C-14 starting to show upward trends
- Monitoring frequency and range of analysis increased
  - Approach is in line with Leak to Ground Risk Management Plan – latest version dated 2019
  - Continuing vigilance – monitoring intensity based on observations with changes based on recorded trends

Tritium trends






9054 - Chlorine-36
9054 - Pre-2019 Average
Activity Concentration, Bq/l
Date
10202 - Chlorine-36
10202 - Pre-2019 Average
10287 - Chlorine-36
10287 - Pre-2019 Average
10295
10296
9060
769
714
10352
10353
767
18
19
770
719
10205
9902
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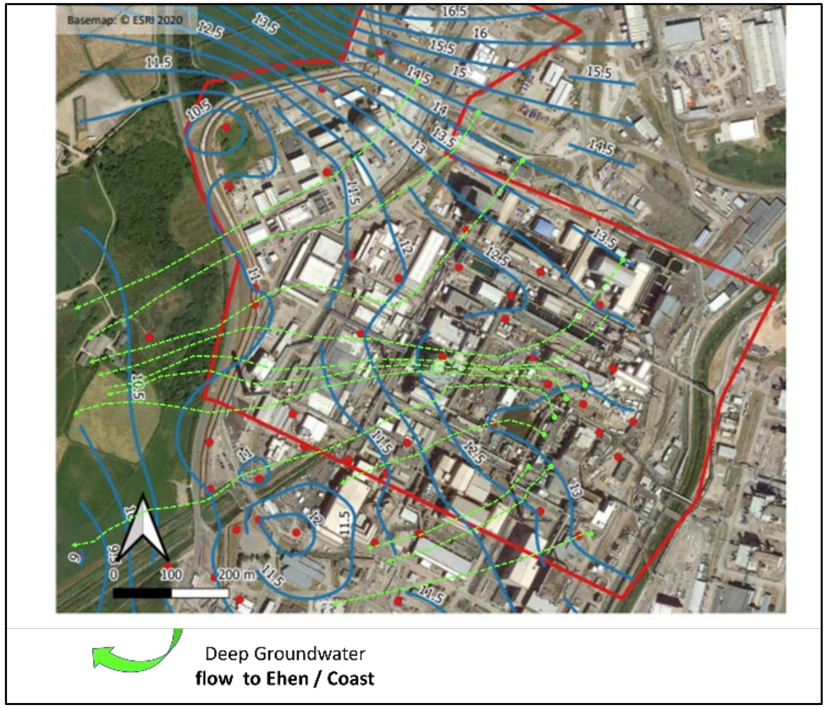
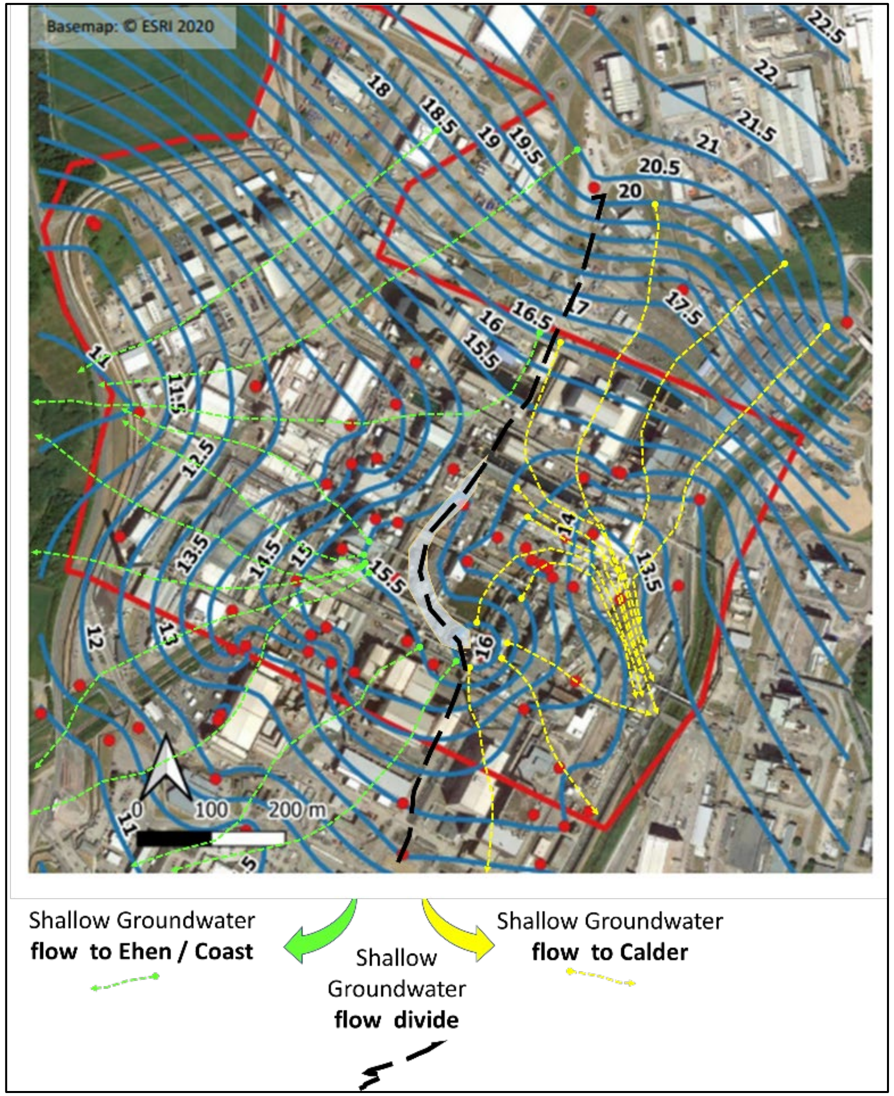
Cl-36 trends

The current leak

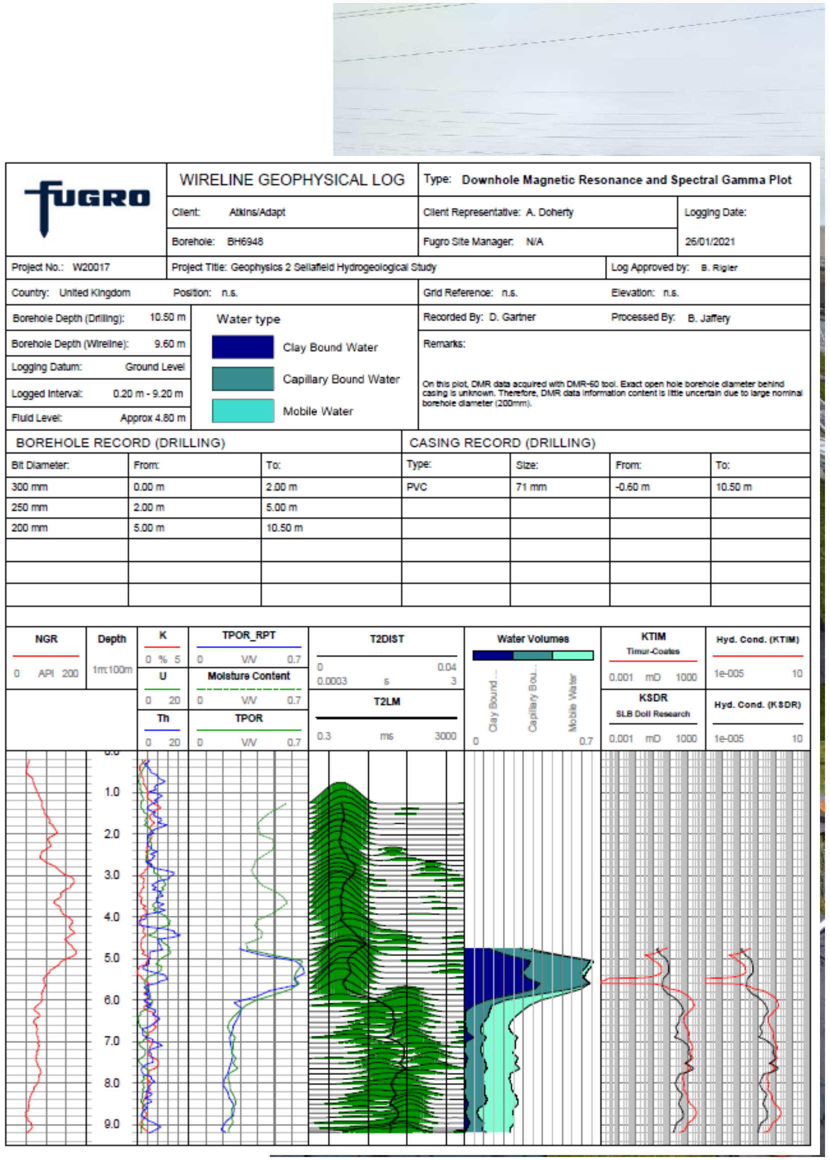
- Migration in deeper groundwater (ca. 30m BGL) in buried channel (SW) – broad flow front, consistent with historic conceptualisation
- Movement in shallow groundwater (ca. 10m BGL) in SE direction – pathway less well understood, poorly addressed in historic work
- Conservative radionuclides (e.g. Cl-36) acting as tracers to aid characterisation
- Further work needed to understand relationship between heads and flows





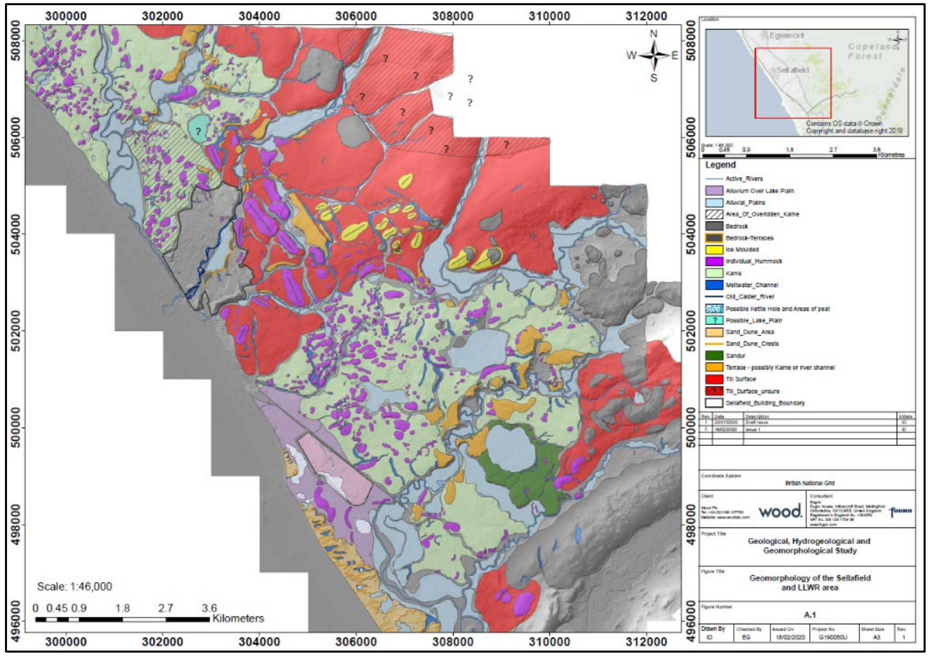
Recent characterisation

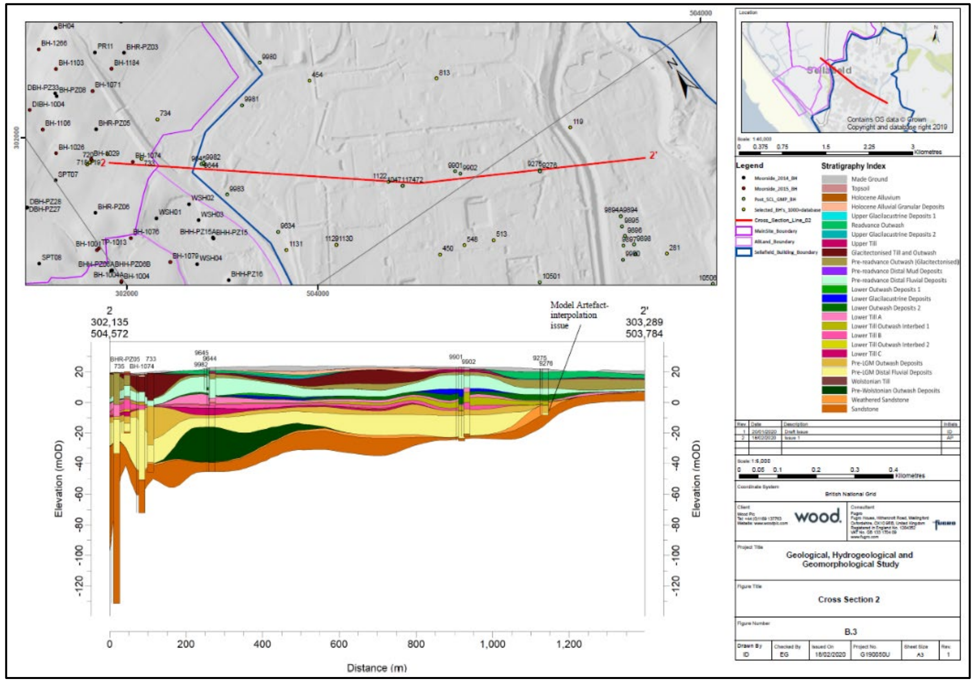
- Geophysics surveys
  - Wireline surveys along SE and western pathways
  - Various techniques, including NMR to estimate K
- Useful additional insights to site geology and hydrogeology
- Notable that estimates of K are lower than suggested by lithological observations
  - Consistent with historic reporting observations



Site wide geological modelling

- Building on work from proposed Moorside development and LLW Repository Ltd., development of an update geological understanding
- Work in progress



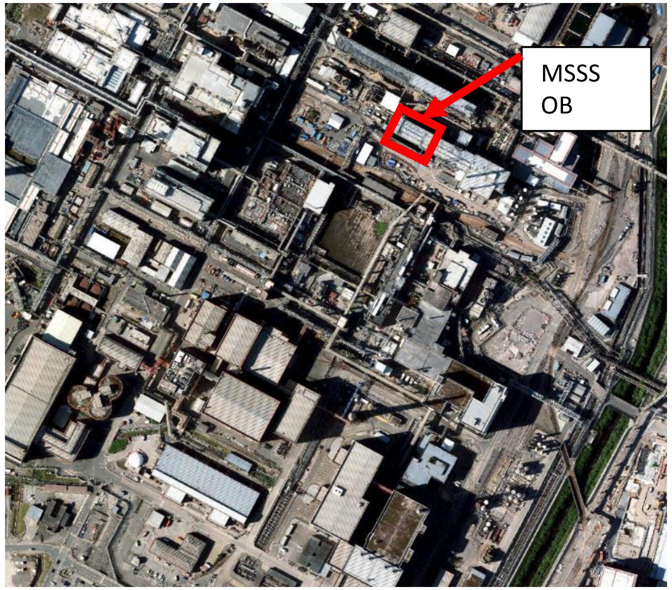


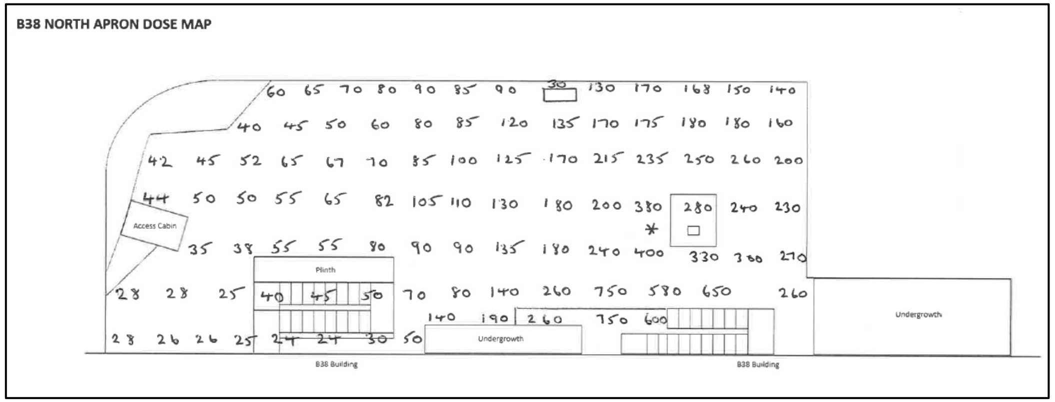
Ongoing work

- DQO study undertaken to cover groundwater monitoring – current arrangements considered to be good, but some gaps identified
  - Filling gaps limited by infrastructure constraints
  - Design needs to consider 3D aspects – lateral & vertical spacing
  - Work underway to design new wells
- Characterisation support to mitigation options development
- Extensive groundwater level logger deployment
- Groundwater monitoring technology review
  - Recommendations on instrumentation
  - Consideration of multi-level sampling systems
    - Solinst 403 CMT recommended

Characterisation challenges

- Access and infrastructure
  - Congestion and buried services across site limits viable locations
- Contamination
  - Worker dose uptake – lots of shine paths & background activity
  - In-ground contamination can present significant challenges
    - Worker dose and waste management (ILW?)

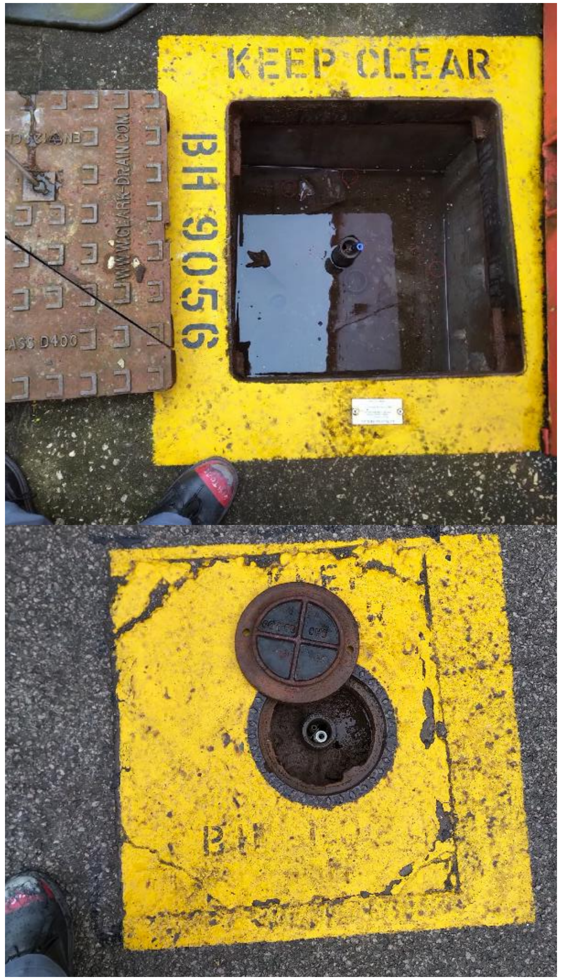




Asset maintenance

- SCLS & SCL&GMP wells are all >10 years old
  - Soakaways require cleaning to prevent flooding
  - New covers required – secure covers and better sealing
- Well condition surveys
  - Do wells need re-developing
- Decommissioning of redundant wells
  - Remove potential liabilities

- Not as exciting as new characterisation – but just as important!



Summary

- Sellafield & MSSS area geology / hydrogeology is complex
- Significant characterisation efforts over the last 40+ years
- Uncertainty remains
- Recent leak behaviour in-line with expectations
- Plans for additional characterisation
  - Improve understanding
  - Support mitigation options development
- Multiple challenges
  - Site congestion
  - Worker dose
  - Waste management

Summary

- Planning for future adverse events
- Maintaining readiness of plans/strategies/management schemes
- Engaging stakeholders to develop and maintain trust and confidence
- Learning on potential mitigations and future clean up strategies

Thanks for Listening