

NAPL In The UK Context, Does it Matter?

**Site Investigation, Risk Assessment
& Remediation of NAPL at a Site in
Grangemouth**

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Introduction

- **Site investigation found an area of site with complex NAPL mix:**
 - **Petroleum hydrocarbons**
 - **Chlorobenzene**
 - **Nitrobenzene**
 - **Other VOCs, SVOCs with DNAPL**
- **Risk assessment showed low risks but DNAPL required remediation.**
- **Remediation design:**
 - **Short time period in very low permeability stratum**
 - **365 remedial wells**
 - **Remediation and regulatory sign off in 17.5 weeks**

Development Outline

- 215,000 tpa Energy from Waste Plant (EfW)
- 2 ha site adjacent to off-site chemical works (organic dyes)
- Site itself was a former chemical works
- ‘Flat’ land at 5 mOD, 2.5 km from Firth of Forth
- ‘Standard’ planning conditions associated with ground to be discharged including approval of:
 - Phase 1 SI
 - Phase 2 SI
 - Remediation Strategy
 - Etc
- Initial “geotechnical” SI carried out by others.

Initial Geotechnical SI

Factual report only - completed late 2016 by others

- 5 No. Cable percussive with rotary follow on to 43.5 m
- 2 No. Rotary open holes continued by rotary coring to 50 m
- 15 No. dynamic sample holes to 5 m with SPTs
- 7 No. shallow monitoring wells; 2 deep/39 m wells
- 15 No. Trial pits/trenches
- Chemical - 26 samples tested, only one had 'elevated TPH'
- Geotechnical laboratory testing
- Two attempts at one borehole terminated due to *“high visual and olfactory contamination (hydrocarbon).”*
Contamination was not tested.

Site Investigation – Specified by Civils Consultant

TENDER REQUIREMENTS

- Phase 1 Desk Study
- 5 No. Cable percussive with rotary follow on to bedrock !
- 5 No. dynamic sample holes to 5 m with SPTs
- 8 No. shallow monitoring wells
- 5 No. CPT to refusal
- 15 No. Trial pits/trenches
- Geophysics – Seismic survey across site
- Chemical (40 samples) & geotechnical laboratory testing
- Interpretative report
- Draft report to be completed in 6 weeks from award

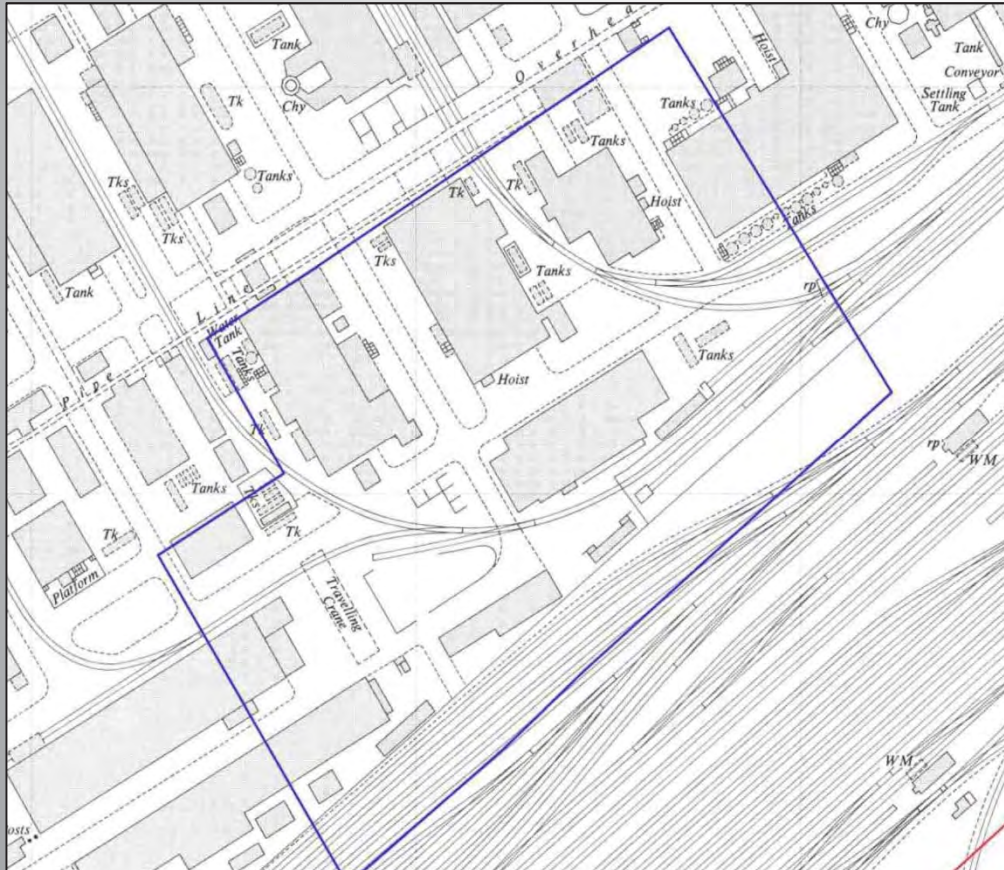
Site Investigation – TerraConsult Alternative Tender

LOWER COST BY £15k – PROGRAMME CERTAINTY

- **Phase 1 Desk Study**
- **5 No. Rotary wireline boreholes to 50 m (rock >60 m) !**
- **5 No. dynamic sample holes to 7 m with SPTs**
- **11 No. monitoring wells – 3 deep & 8 shallow**
- **5 No. CPT to refusal**
- **15 No. Trial pits/trenches**
- **Geophysics – Magnetic & electromagnetic (EM31)**
- **Chemical (52 samples) & geotechnical laboratory testing**
- **Interpretative report**
- **Draft report to be completed in 6 weeks from award**

Phase 1 Desk Study

- **Historic maps & environmental searches**
 - **1915 – Railway sidings in south of site**
 - **1938 – 2015 Dye works with railway sidings**
 - **2016 – Demolition**

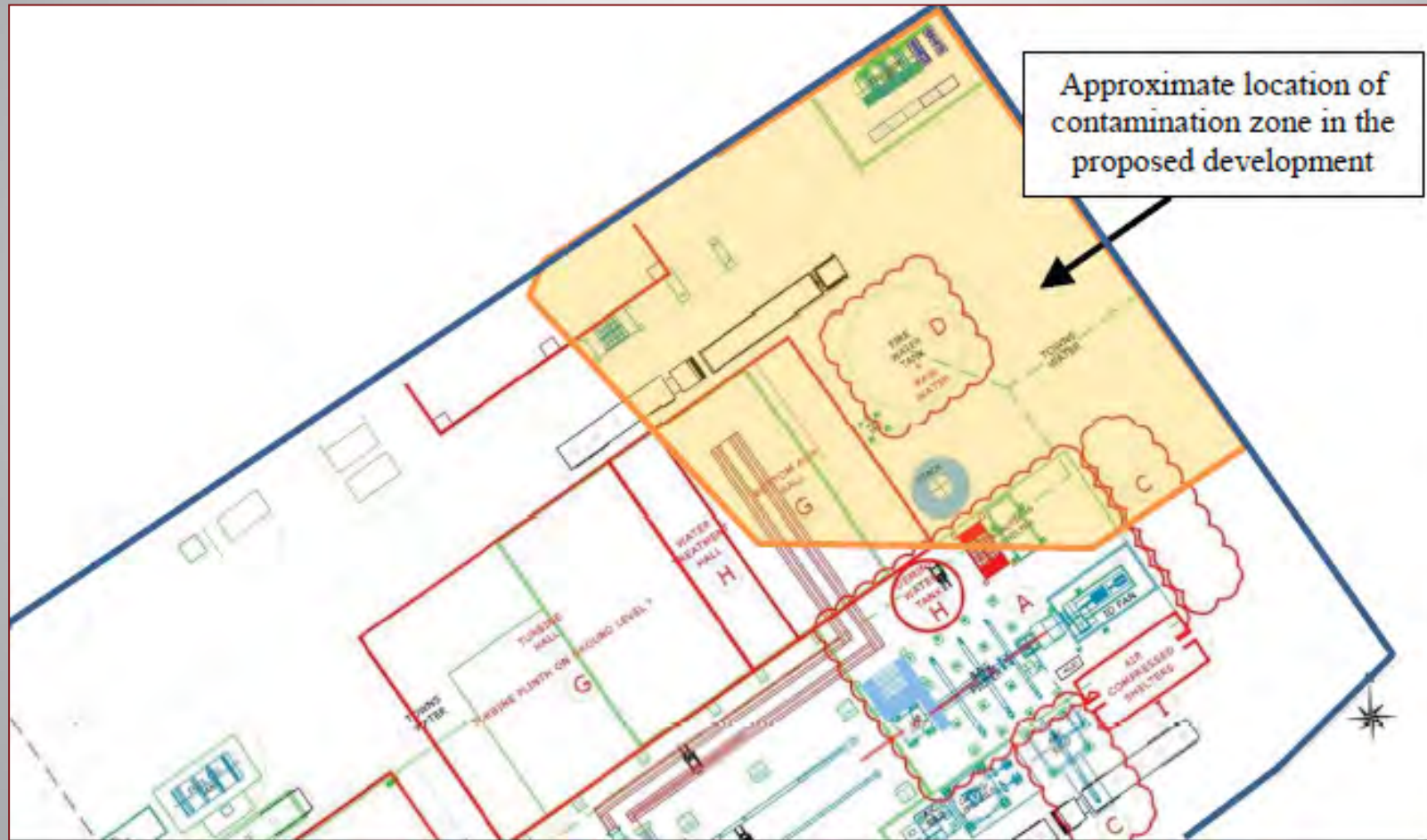


Phase 1 Geology Based on Existing SI

Stratum	Description	Thickness (m)	Depth to Base (m)
Made Ground	Dark brown to black clayed SAND & GRAVEL	0.50 – 1.70	0.50 – 1.70
Made Ground	Very soft to stiff, brown/grey, slightly sandy, gravelly CLAY.	0.50 – 2.10	1.00 – 3.80
Tidal Flat Deposits	Very soft to firm, brown/grey, slightly sandy CLAY/silty CLAY	25.40 – 35.00	26.50 – 37.00
Glacial Till	Firm to very stiff, brown/grey, gravelly, silty CLAY with rare cobbles.	30 m ?	~ 60 m ?
Bedrock	Carboniferous SANDSTONE.		
Groundwater	~0.50 m depth		

Phase 1 Desk Study

- Assess 2016 SI - Carry out 6 No. extra dynamic sample holes in area of visual and odorous contamination



Initial Risk Assessment – July 2017

- 80% of site very low concentrations of contaminants.
- 20% of site in northern corner elevated soil concentrations:
 - Petroleum hydrocarbons,
 - Chlorobenzene & dichlorobenzenes
 - Nitrobenzene
 - Other VOCs, SVOCs with DNAPL
- Elevated concentrations in upper 6 to 7 m only.
- At 6 to 7 m bed of firm clay appeared to be limiting depth of contamination.
- Shallow groundwater at 0.5 to 1.0 m depth, very shallow gradient of 0.0077 to north.
- Deep groundwater (>35 m depth) is artesian

Initial Risk Assessment – July 2017

Shallow groundwater – two rounds of testing:

- Maximum concentrations in northern corner:

- Chlorobenzene: 32,000 µg/l
- Dichlorobenzenes: 4,100 µg/l
- Nitrobenzene: 420,000 µg/l
- Analine: 60,000 µg/l
- Aromatic C₁₀-C₁₂ : 850,000 µg/l
- Other VOCs, SVOCs with DNAPL

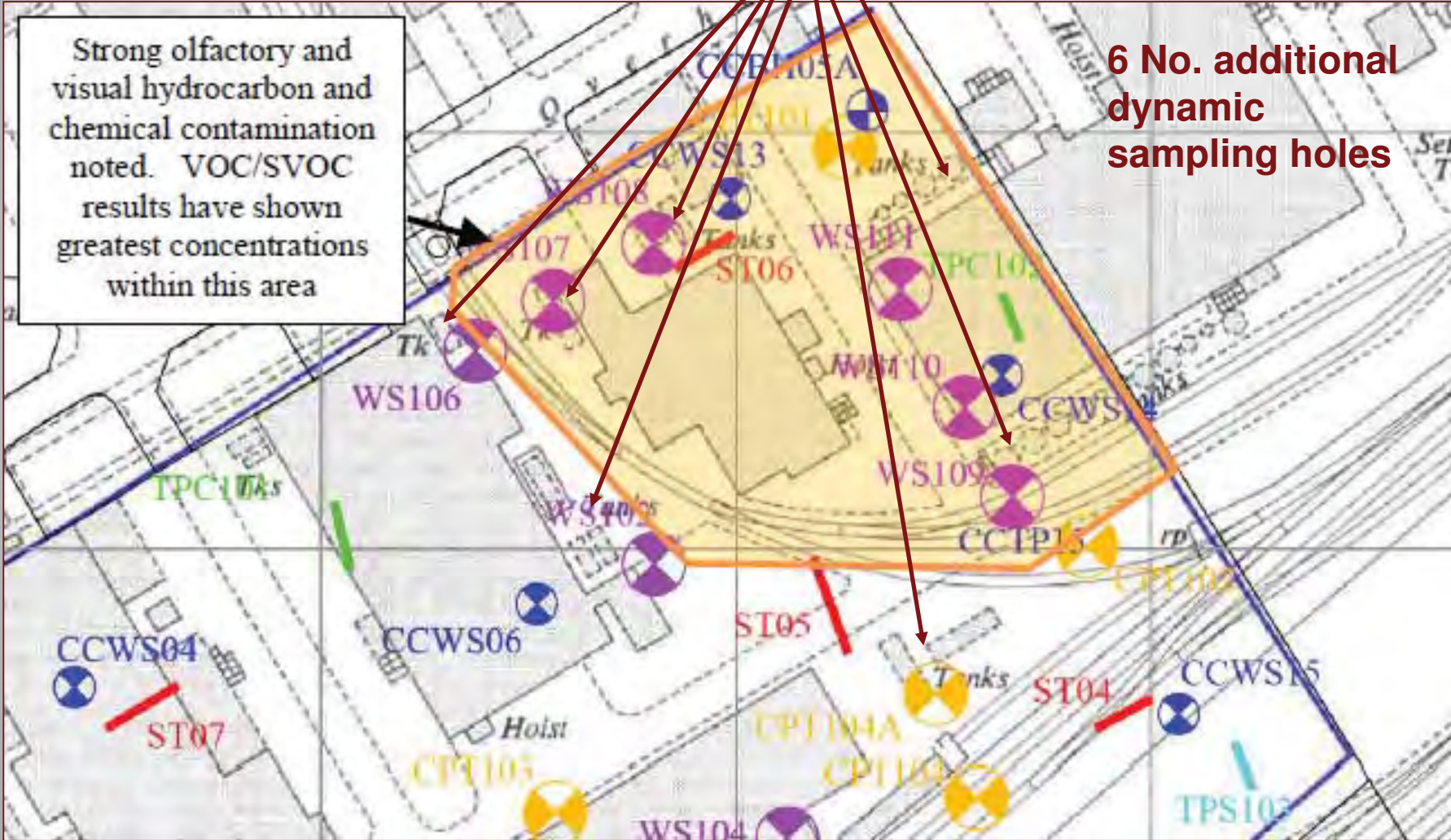
- NAPL present

- Low risk to the water environment:

- Nearest surface water feature River Carron >1 km.
- Sandstone aquifer 60 m depth not at risk: > 50 m low permeability clay and artesian groundwater

Area of Contamination from 2016 & 2017 SI

Tanks



Site Investigation – Further SI July & Sept 2018

- **2017 Investigation report recommended:**
 - **Further site investigation to delineate tanks**
 - **DQRA**
- **July 2018: 12 (18) No. holes to 7 to 8 m with monitoring wells:**
 - **6 pairs of holes in north with 4 m and 7 m wells**
 - **6 holes around other former tanks across rest of site**
- **Sept 2018: 17 holes with monitoring wells to 8 m to improve delineation**
- **Groundwater sampling & testing in July & September 2018**
- **Improve CSM & Update Remediation Strategy**

Site Investigation – Further SI July 2018

- DQRA
 - Hydraulic gradient: 0.007
 - Hydraulic conductivity: 3×10^{-5} m/day (3.5×10^{-10} m/s)
 - Compliance points 50 & 250 m (River Carron >1 km)
- Travel time: Chlorobenzene to 50 m is 0.5 million years
- Travel time for other principal contaminants is longer
- Very low risk
- SEPA policy: all free product to be removed irrespective of risk
- Remediation required

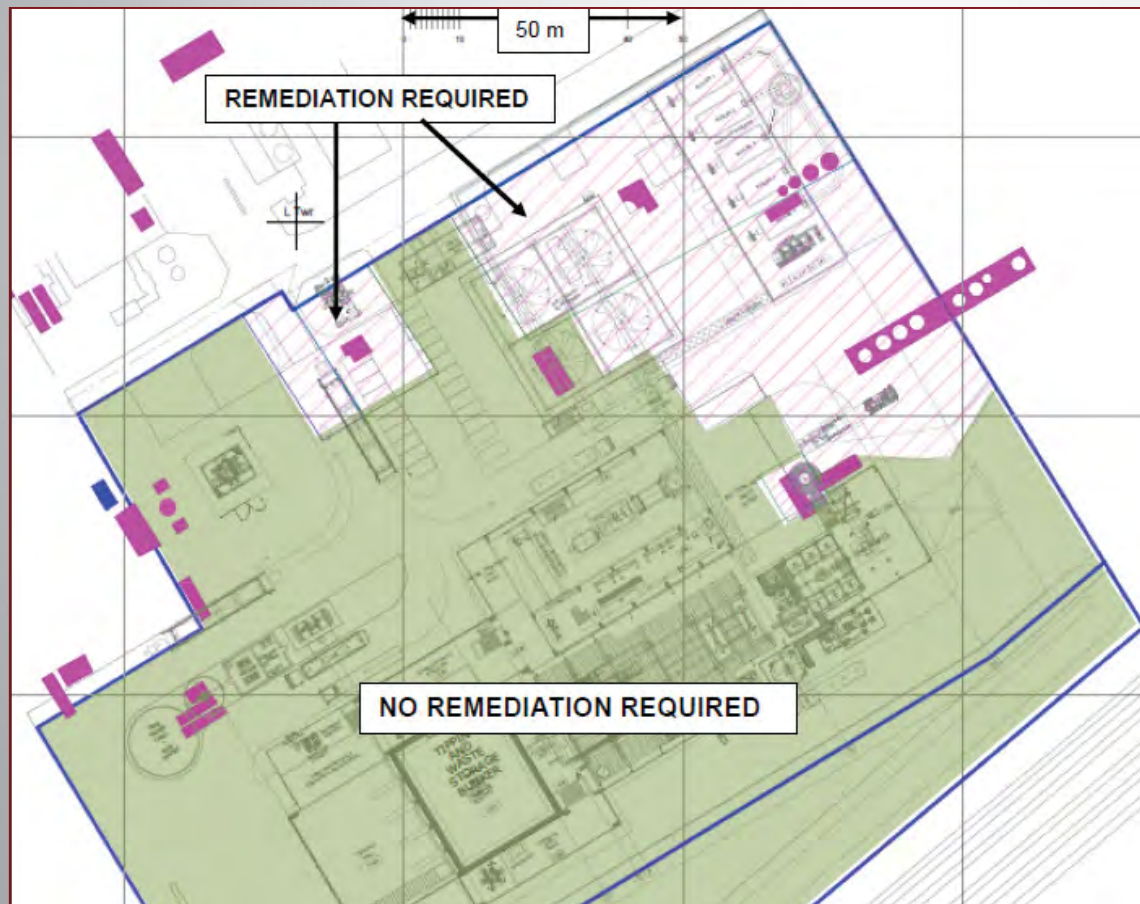
Site Investigation – Remediation Proposal July 2018

- Options appraisal take into account:
 - Low permeability – wells take >4 days to recharge
 - Time for remediation 3 months
 - DNAPL removal difficult
 - Compliance points: 50 m (River Carron >1 km)
- Remediation required – proposed betterment:
 - Pump and removal: 186 wells 3.5 m grid, extract for 1 month
 - Chemical Oxidisation & In Situ Bio-augmentation
- Monitoring & verification

August 2018 SEPA agree to betterment with aim to achieve Remedial Target Values (RTV) but want more SI

Remediation Proposal October 2018

- **SEPA wanted remediation to concentrate on contaminant removal rather than use of chemical oxidants**
- **Pump and removal: 300 wells 3.5 m grid, extraction over 5 weeks.**

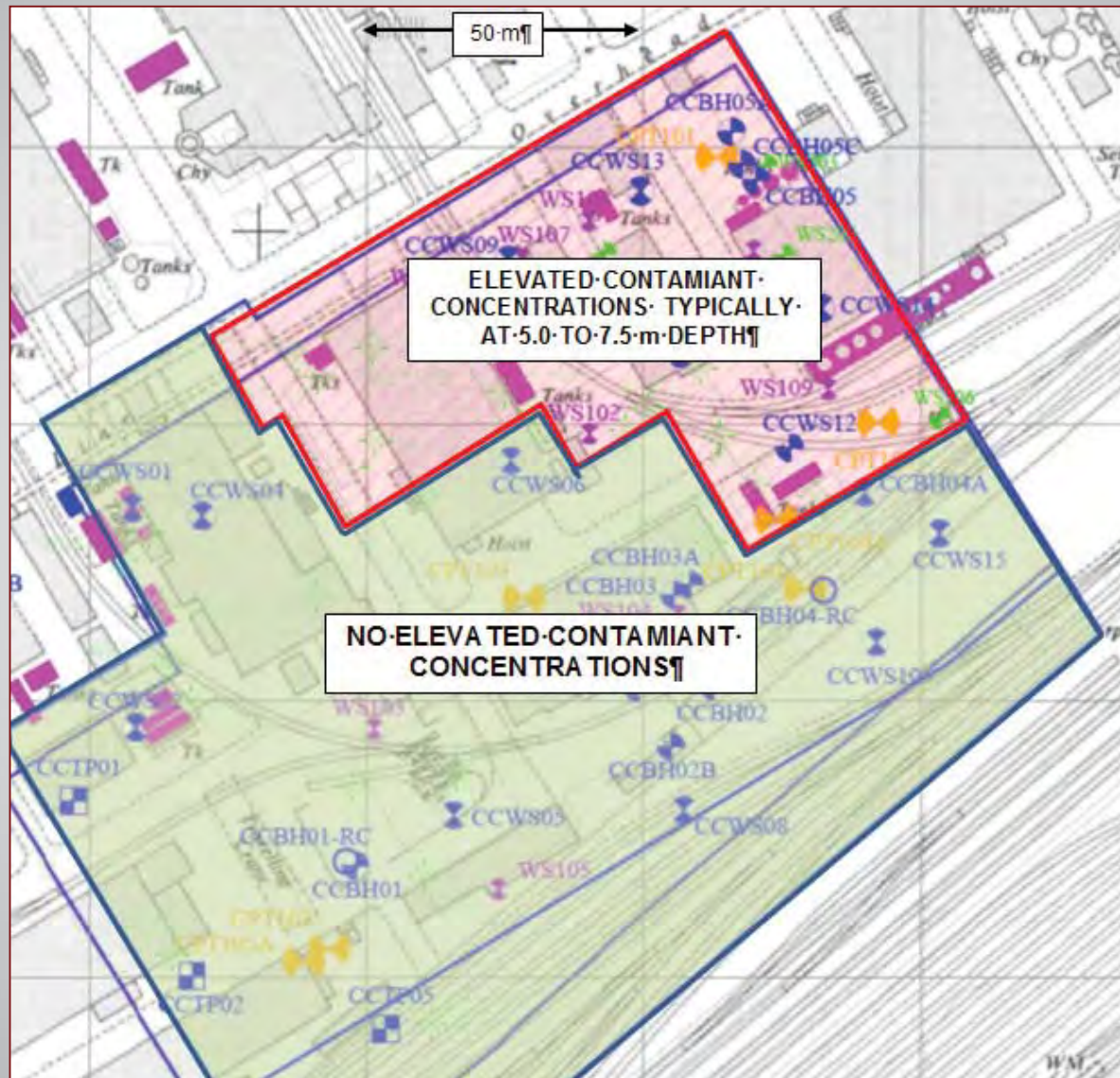


- **Remediation area 1.6 times larger and double the estimated liquid removal**
- **No chemical oxidisation & In Situ Bio-augmentation proposed**

Remediation Proposal 3rd December 2018

- **After further SEPA comments:**
 - **Increased remediation area further**
 - **Agree to betterment on an agreed scope of works**
 - **Increase number of wells & increase estimated liquid removal volume**
 - **Requested chemical oxidisation & In Situ Bio-augmentation to be reinstated**
- **Remediation:**
 - **Install further 355 remediation wells to 7.6 m on 4 m grid & 12 monitoring wells**
 - **Dual Phase Vapour Extraction extraction over 9 weeks**
 - **Two injection rounds chemical oxidisation & In Situ Bio-augmentation.**
- **Monitoring & verification.**

Remediation Proposal 3rd December 2018



Monitoring Plan

Four rounds of Verification Monitoring will be carried out:

- Round 1: During well installation - baseline**
- Round 2: After minimum of 3 weeks of DPVE extraction**
- Round 3: Towards End of DPVE (minimum of 6 weeks extraction)**
- Round 4: Two weeks post second chemox injection**

The verification reporting will be in three stages:

- Interim Report 1: After Monitoring Rounds 1 and 2.**
- Interim Report 2: After Monitoring Round 3.**
- Main Groundwater Verification Report on completion.**
- SEPA agree to phased sign off.**

Remediation - Well Installation By TerraConsult

- 355 remediation wells & 12 monitoring wells to 8 m.
- 3 week programme – up to dynamic sampling 6 rigs



Remediation - Well Installation



Remediation – DPVE by Geo2

- Ten rounds of extraction from each well



- 4 days to recharge each well



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Chemox by Geo2

- Each remediation well injected twice
- Each well 2 x 25 L of 5 % Klozur (MSDS Ref no. 7775-27-1-12) – 20 m³ total injection.
- Solution contained Sodium Persulfate, Sodium Peroxydisulfate and Disodium Peroxydisulfate.



Remediation Key Dates

- **SEPA approval of remediation strategy 6th December 2018**
- **Instruction 15th December 2018 – Contract Award Jan 19!**

- **Well installation 9th to 26th January 2019.**

- **Dual Phase Vapour Extraction (DPVE) – 10 rounds:
30th January to 22nd March 2019**

- **Chemox Injection:**
 - **Round 1: 27th March to 1st April 2019**
 - **Round 2 : 1st to 3rd April 2019**

Remediation Key Dates

- **Instruction 15th December 2018.**
- **Well installation 9th to 26th January 2019.**
 - Baseline/Round 1: 31st January 2019**
- **Dual Phase Vapour Extraction (DPVE) – 10 rounds**
 - 30th January to 22nd March 2019**
 - VR1 Wells & Round 1/2**
 - 26th February 2019**
 - VR2 Round 3**
 - 20th March 2019**
- **Chemox Injection**
 - **Round 1: 27th March to 1st April 2019**
 - **Round 2 : 1st April to 3rd April 2019**
 - Round 4: 23rd April 2019 – Only 3 weeks after injection**
 - VR3 Round 4 30th April 2019**

Remediation Key Dates

- Instruction 15th December 2018.
- Well installation 9th to 26th January 2019.

Baseline/Round 1: 31st January 2019

**Verification
Sign-off by SEPA
14th May 2019**

(PVE) – 10 rounds

VR1 Wells & Round 1/2
26th February 2019

VR2 Round 3
20th March 2019

➤ Round 1: 27th March to 1st April 2019

➤ Round 2 : 1st April to 3rd April 2019

Round 4: 23rd April 2019 – Only 3 weeks after injection

VR3 Round 4 30th April 2019

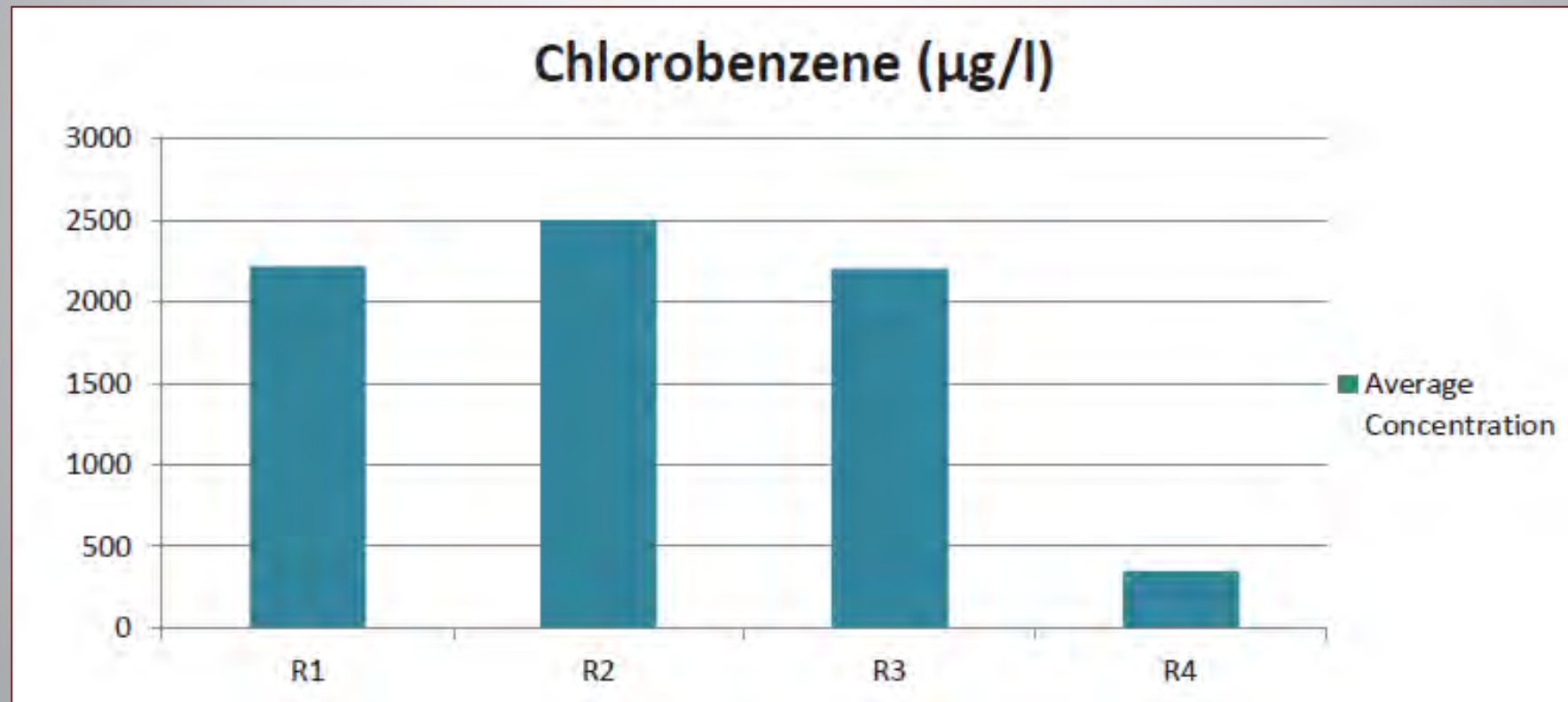
Verification by TerraConsult

Two main approaches to show betterment:

- Concentration in monitoring wells
- Mass of contaminant removed
 - Removal of liquid & vapour by DPVE
 - Chemox injection

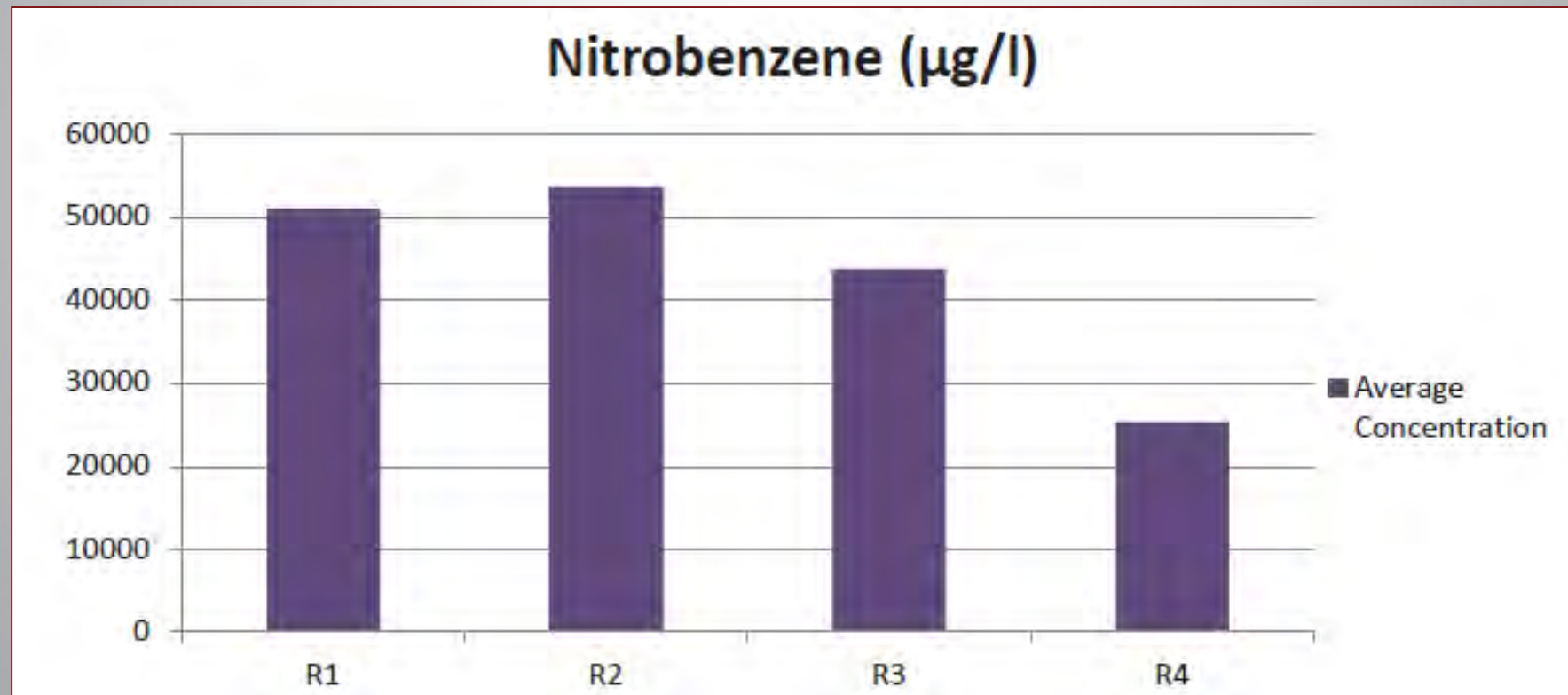
Groundwater Monitoring Results

Chlorobenzene:	Mean Baseline	2,212 µg/l
	Mean Round 4	349 µg/l
	RTC	890 µg/l
	Mean Reduction	98.7 %



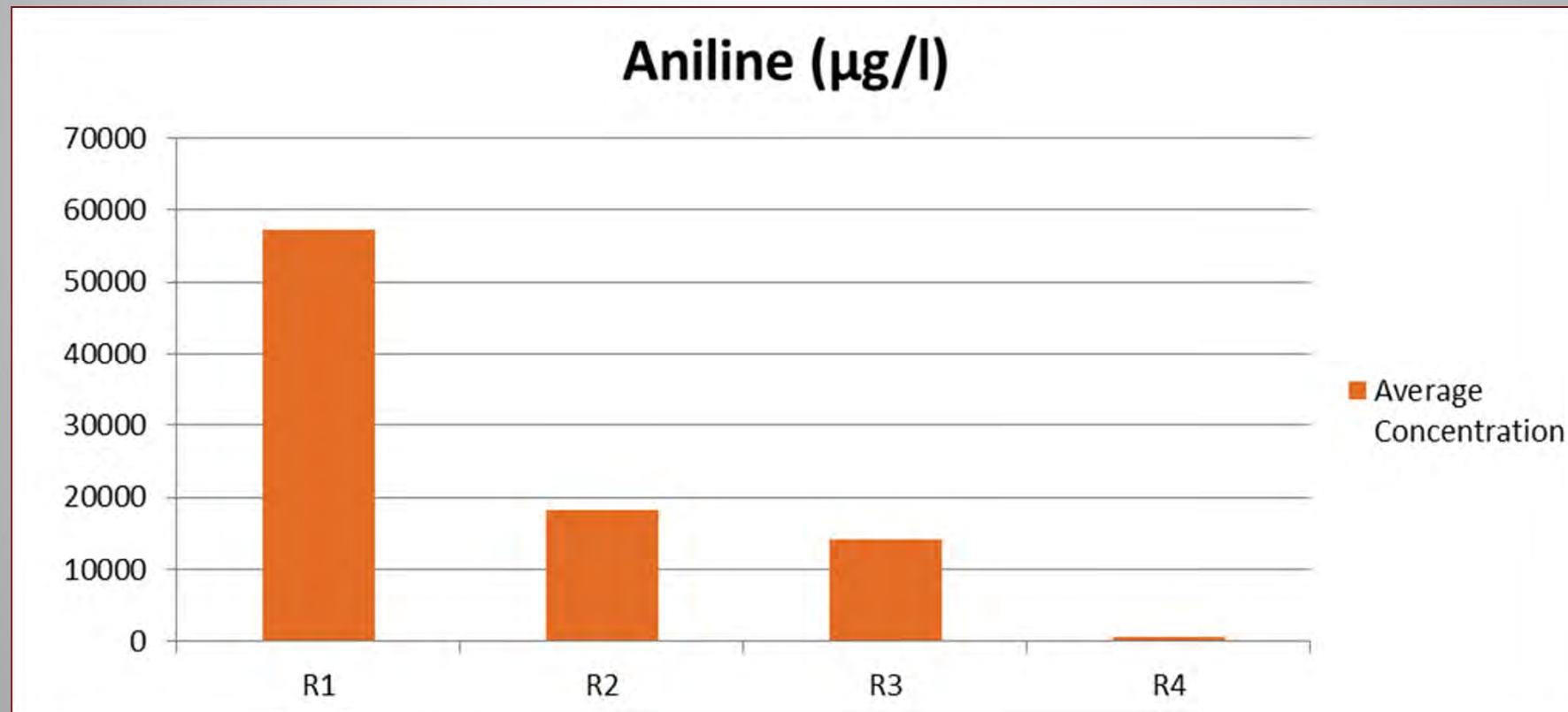
Groundwater Monitoring Results

Nitrobenzene: Mean Baseline	51,007 µg/l
Mean Round 4	25,340 µg/l
RTC	89.9 µg/l
Mean Reduction	50.3 %



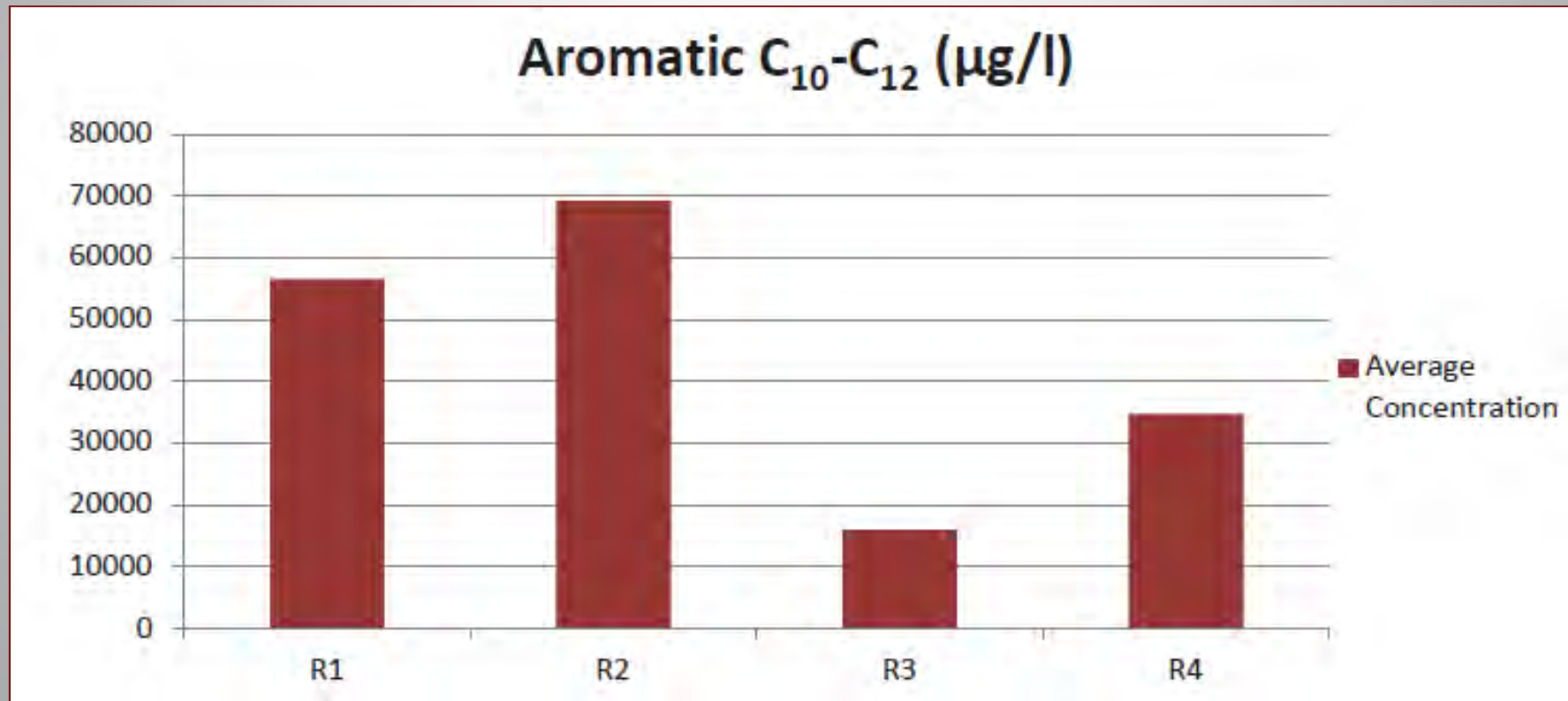
Groundwater Monitoring Results

Aniline:	Mean Baseline	57,359 $\mu\text{g/l}$
	Mean Round 4	726 $\mu\text{g/l}$
	RTC	44 $\mu\text{g/l}$
	Mean Reduction	98.7 %



Groundwater Monitoring Results

Aromatic C₁₀-C₁₂:	Mean Baseline	56,549 µg/l
	Mean Round 4	34,648 µg/l
	RTC	89 µg/l
	Mean Reduction	38.7 %



Groundwater Monitoring Results

Summary:

Mean reduction in groundwater concentrations across the remediation area over 12 weeks:

Benzene	73.1 %
Chlorobenzene	84.2 %
Nitrobenzene	50.3 %
Aniline	98.7 %
Aromatic C₁₀-C₁₂	38.7 %

Mass Removal

Summary: Dual Phase Removal - Liquid:

Volume Pumped 85 m³

Mass of NAPL Removed 232 kg

Determinand	Average Concentration (µg/l)*	Mass Removed (kg)
Chlorobenzene	5,565	0.45
Benzene	1.44	0.00
1,2-Dichlorobenzene	2,892	0.24
1,3-Dichlorobenzene	314	0.02
1,4-Dichlorobenzene	1,831	0.15
Nitrobenzene	789,263	67.1
Aniline	100,072	10.1
Aliphatic C10-C12	2,537	0.18
Aliphatic C12-C16	1,216	0.11
Aliphatic C16-C21	1,592	0.15
Aliphatic C21-C35	553	0.05
Aromatic C10-C12	2,343,496	153.2
Aromatic C12-C16	2,326	0.17
Aromatic C16-C21	2,035	0.15
Aromatic C21-C35	934	0.07

Mass Removal

Summary: Dual Phase Removal – Liquid Removed:

The average concentration in the IBC waste water being higher than the baseline groundwater concentrations – mobilisation of NAPL

Determinand	IBC Collection 1 Average Concentration (µg/l)	Final/6th IBC Collection Average Concentration (µg/l)
Benzene	18	1
Chlorobenzene	2,212	2,263
Nitrobenzene	51,007	877,619
Aniline	57,359	257,388
Aromatic C ₁₀ -C ₁₂	56,549	513,308

Mass Removal

Summary: Dual Phase Removal - Vapour:

Vapour Volume Pumped	84,000 m³
Mass of NAPL Removed	??? kg
Mass of Nitrobenzene Removed	40.14 kg

Mainly Nitrobenzene as this is most prevalent VOC

Limited mass of Chlorobenzene and vapours of other VOCs because their concentrations were >10 times lower and smaller molecular weights

Mass Removal

Summary: All Stages:

Volume Liquid Removed	85 m ³
Volume Air Pumped	84,000 m ³
Mass of Chemox Injected	20 m ³

Determinand	Dual Phase Removal - Liquid (kg)	Dual Phase Removal - Vapour (kg)	Chemox (kg)	Total (kg)
Total	232	40.1	4.3	276.4
Principal Contaminants Removed				
Aromatic C ₁₀ -C ₁₂	153	?	1.3	154.3
Nitrobenzene	67	40.1	2.3	109.4
Aniline	10	-	0.7	10.67
Other NAPLs	2	??	0.01	2.01

Groundwater Monitoring Results

“Final” remedial concentrations would be lower than this due to:

- Low permeability of the Tidal Flat Deposits resulting in limited aquifer penetration of Chemox.**
- The second phase of the Chemox injection is slowly activated and will continue to act on contaminants for up to 3 to 6 months prior to the final groundwater verification sampling.**

Conclusion

Difficult site to remediate due to:

- **Very low permeability of the Tidal Flat Deposits**
- **Complex mix of NAPL**
- **Difficult/short time constraints**

Worked with SEPA to agree strategy for betterment.

Demonstrated significant betterment over 17.5 weeks from commencement to regulatory approval of remediation.



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