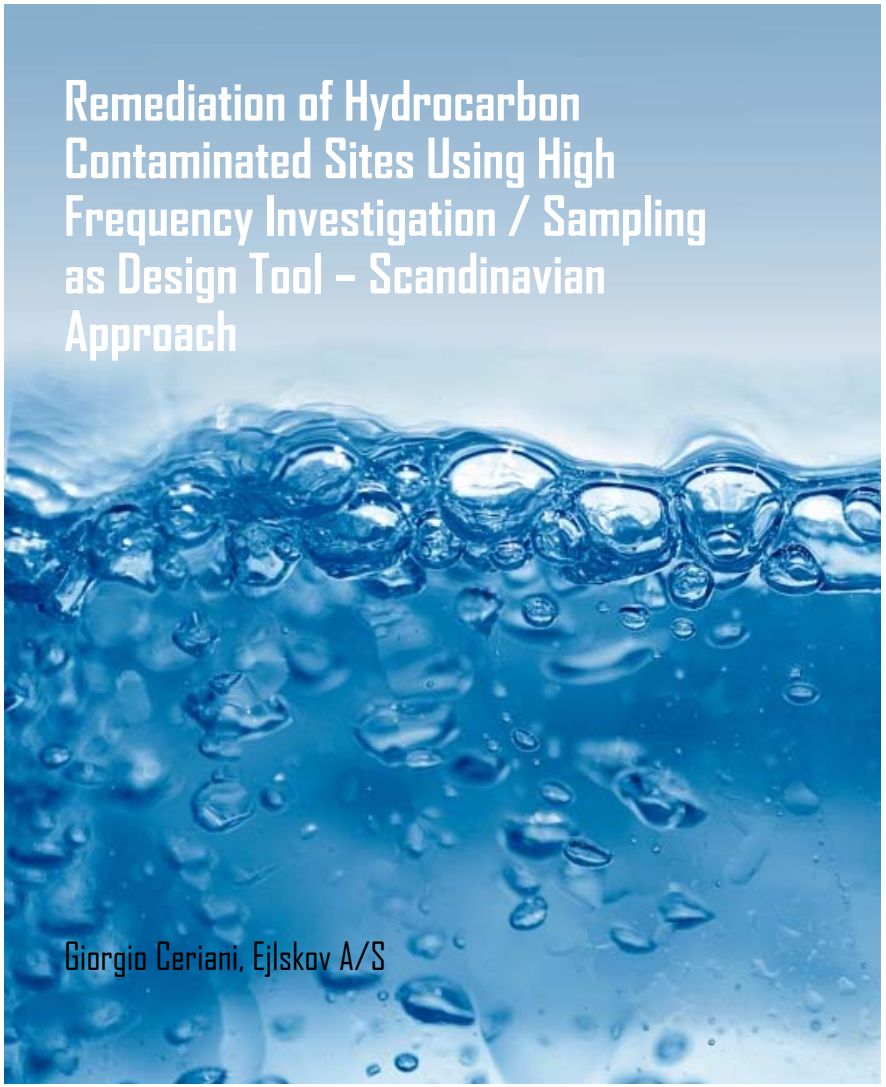

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Lessons Learned and Case Studies

Presentation Layout / Agenda

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PART ONE

- Remedial Design Characterization (RDC)
  Conceptual Introduction
    Why, When, How?
- Desk Study
    Data evaluation and 3D Modeling
- RDC Lessons Learned

PART TWO

- Remediation Technology – Trap & Treat®
- Remediation Results – Case Studies
- Remediation Works - Lessons Learned

RDC Conceptual Introduction (1)

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WHY

- Collect sufficient and relevant data (qualitative) to define the actual area/volume to be treated
- Narrow down to the maximum extent possible data gaps in the Conceptual Site Model (CSM)
- Collect high frequency soil data (quantitative) to estimate actual soil contaminant mass (3D distribution)
- Remove uncertainties related to remediation works extent (need to, how much, how long)

&

WHEN

- Need to assess to a high level of certainty the contaminant mass distrubution (pre-, post-Risk Assessment)
- Insufficient data are available (saturated soil data missing)
- Client is keen in limiting the risks associated to the remediation works implementation
- Client wants a performance based / time based guarantee on the remediation works

RDC Conceptual Introduction (2)

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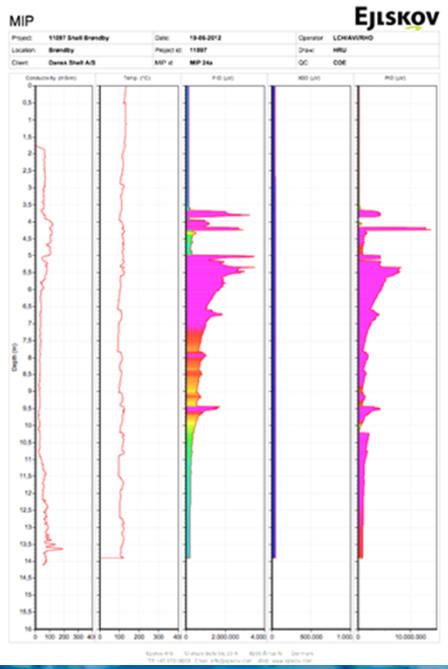
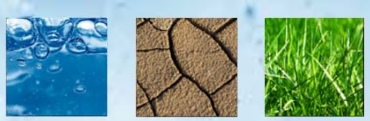


HOW

- High Resolution Tools (i.e. MIP, LIF)
- Assess real time data and modify RDC strategy
- Collect relevant / high frequency soil samples
- Conduct Screen Point Sampling / Install Cluster Wells



Importance of High Frequency Data

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Ejlskov A/S , 16064, Kvistgård CRT

Soil Criteria Class	Sample ID	Prøvedybde	Dry Matter	C6H6-C10	C10-C15	C15-C20	C20-C35	Sum (C10-C20)	Sum (C6H6-C35)
		m bgl	%	mg/kg ts.	mg/kg ts.	mg/kg ts.	mg/kg ts.	mg/kg ts.	mg/kg ts.
Klasse 4	MIP 07 SC	3,75	85	210	4900	5600	3300	10000	14000
Klasse 4	MIP 07 SC	4,0	85	280	4000	4400	2200	8400	11000
Klasse 4	MIP 07 SC	4,25	92	120	2400	2600	1400	5000	6500
Klasse 4	MIP 07 SC	4,5	92	160	3200	3500	2100	6700	9000
Klasse 4	MIP 07 SC	4,75	92	130	2600	2900	1500	5400	7000
Klasse 4	MIP 07 SC	5,0	92	200	3200	4600	2000	7800	10000
Klasse 4	MIP 07 SC	5,25	96	650	7300	8000	4200	15000	20000
Klasse 4	MIP 07 SC	5,5	96	110	1400	1400	610	2800	3500
Klasse 4	MIP 07 SC	5,75	96	9,4	480	260	110	740	860
Klasse 4	MIP 07 SC	6,0	96	14	500	140	57	630	700
Klasse 4	MIP 07 SC	6,25	95	590	11000	1100	370	12000	13000
Klasse 4	MIP 07 SC	6,5	95	290	4700	240	100	4900	5300
Klasse 3	MIP 07 SC	6,75	95	< 2	79	7,0	< 20	86	86
Klasse 4	MIP 07 SC	7,0	95	510	8200	1300	590	9500	11000
Klasse 4	MIP 07 SC	7,25	94	62	1400	250	110	1700	1800
Klasse 0	MIP 07 SC	7,5	94	< 2	< 5	< 5	< 20	#	#
Klasse 0	MIP 07 SC	7,75	94	< 2	< 5	< 5	< 20	#	#
Klasse 0	MIP 07 SC	8	94	< 2	< 5	< 5	< 20	#	#
Klasse 0	MIP 07 SC	8,25	90	< 2	< 5	< 5	< 20	#	#
Klasse 0	MIP 07 SC	8,5	90	< 2	< 5	< 5	< 20	#	#
Klasse 0	MIP 07 SC	8,75	90	< 2	< 5	< 5	< 20	#	#
Klasse 0	MIP 07 SC	9,0	90	< 2	< 5	< 5	< 20	#	#
Klasse 0	MIP 07 SC	9,25	98	< 2	< 5	< 5	< 20	#	#
Klasse 0	MIP 07 SC	9,5	98	< 2	< 5	< 5	< 20	#	#
Klasse 0	MIP 07 SC	9,75	98	< 2	< 5	< 5	< 20	#	#
Klasse 4	MIP 09 SC	5,0	92	12	1100	2500	1600	3600	5200
Klasse 3	MIP 09 SC	5,25	95	< 2	6,5	18	< 20	24	24
Klasse 3	MIP 09 SC	5,5	95	< 2	7,3	16	< 20	23	23
Klasse 4	MIP 09 SC	5,75	97	61	3700	5700	3700	9400	13000
Klasse 4	MIP 09 SC	6,0	97	65	3500	5100	3300	8600	12000
Klasse 3	MIP 09 SC	6,25	96	< 2	46	41	< 20	88	88
Klasse 4	MIP 09 SC	6,5	96	100	2500	2000	860	4500	5400
Klasse 4	MIP 09 SC	6,75	95	260	4800	5100	3000	9900	13000
Klasse 4	MIP 09 SC	7,0	97	8,5	420	440	190	860	1100
Klasse 0	MIP 09 SC	7,25	95	< 2	< 5	< 5	< 20	#	#
Klasse 0	MIP 09 SC	7,5	95	< 2	< 5	< 5	< 20	#	#
Klasse 0	MIP 09 SC	7,75	95	< 2	< 5	< 5	< 20	#	#
Klasse 0	MIP 09 SC	8,0	95	< 2	< 5	< 5	< 20	#	#
Klasse 0	MIP 09 SC	8,25	90	< 2	< 5	< 5	< 20	#	#
Klasse 0	MIP 09 SC	8,5	90	< 2	< 5	< 5	< 20	#	#
Klasse 0	MIP 09 SC	8,75	90	< 2	< 5	< 5	< 20	#	#
Klasse 0	MIP 09 SC	9,0	90	< 2	< 5	< 5	< 20	#	#
Klasse 0	MIP 09 SC	9,25	91	< 2	< 5	< 5	< 20	#	#
Klasse 0	MIP 09 SC	9,5	91	< 2	< 5	< 5	< 20	#	#

Ejlskov A/S , 16064, Kvistgård CRT

Soil Criteria Class	Sample ID	Prøvedybde	Dry Matter	C6H6-C10	C10-C15	C15-C20	C20-C35	Sum (C10-C20)	Sum (C6H6-C35)
		m bgl	%	mg/kg ts.	mg/kg ts.	mg/kg ts.	mg/kg ts.	mg/kg ts.	mg/kg ts.
Klasse 0	MIP 10 SC	2,5	89	< 2	< 5	< 5	< 20	#	#
Klasse 0	MIP 10 SC	3,5	96	< 2	< 5	< 5	< 20	#	#
Klasse 0	MIP 10 SC	4,5	98	< 2	< 5	< 5	< 20	#	#
Klasse 0	MIP 10 SC	5,0	96	< 2	< 5	< 5	< 20	#	#
Klasse 0	MIP 10 SC	5,5	96	< 2	< 5	< 5	< 20	#	#
Klasse 0	MIP 10 SC	6,0	98	< 2	< 5	< 5	< 20	#	#
Klasse 0	MIP 10 SC	6,25	98	< 2	< 5	< 5	< 20	#	#
Klasse 0	MIP 10 SC	6,5	98	< 2	< 5	< 5	< 20	#	#
Klasse 0	MIP 10 SC	6,75	98	< 2	< 5	< 5	< 20	#	#
Klasse 0	MIP 10 SC	7,0	93	< 2	< 5	< 5	< 20	#	#
Klasse 0	MIP 10 SC	7,25	93	< 2	< 5	< 5	< 20	#	#
Klasse 0	MIP 10 SC	7,5	93	< 2	< 5	< 5	< 20	#	#
Klasse 0	MIP 10 SC	7,75	93	< 2	< 5	< 5	< 20	#	#
Klasse 0	MIP 10 SC	8,0	96	< 2	< 5	< 5	< 20	#	#
Klasse 0	MIP 10 SC	8,25	90	< 2	< 5	< 5	< 20	#	#
Klasse 0	MIP 10 SC	8,5	90	< 2	< 5	< 5	< 20	#	#
Klasse 0	MIP 10 SC	8,75	90	< 2	< 5	< 5	< 20	#	#
Klasse 0	MIP 10 SC	9,0	90	< 2	< 5	< 5	< 20	#	#
Klasse 0	MIP 10 SC	9,25	90	< 2	< 5	< 5	< 20	#	#
Klasse 0	MIP 10 SC	9,5	90	< 2	< 5	< 5	< 20	#	#
Klasse 0	MIP 10 SC	9,75	90	< 2	< 5	< 5	< 20	#	#
Klasse 0	MIP 10 SC	10,0	91	< 2	< 5	< 5	< 20	#	#
Klasse 0	MIP 10 SC	10,25	91	< 2	< 5	< 5	< 20	#	#
Klasse 0	MIP 10 SC	10,5	90	< 2	< 5	< 5	< 20	#	#
Klasse 0	MIP 10 SC	10,75	90	< 2	< 5	< 5	< 20	#	#
Klasse 0	MIP 10 SC	11,0	90	< 2	< 5	< 5	< 20	#	#
Klasse 0	SC-01	4,0	74	< 2	< 5	< 5	< 20	#	#
Klasse 4	SC-01	4,5	74	< 2	9,0	5,2	140	14	150
Klasse 4	SC-01	6,0	87	29	760	880	410	1600	2100
Klasse 2	SC-01	6,5	87	< 2	28	45	23	73	96
Klasse 4	SC-01	7,0	94	3,6	140	170	82	310	400
Klasse 4	SC-01	7,5	92	430	8200	8600	4000	17000	21000
Klasse 4	SC-01	7,75	92	340	5200	5500	2400	11000	13000
Klasse 4	SC-01	8,0	90	390	8500	9300	4500	18000	23000
Klasse 4	SC-01	8,25	90	360	8700	11000	5000	20000	25000
Klasse 4	SC-01	8,5	90	61	1600	2300	1000	3900	5000
Klasse 4	SC-01	8,75	88	92	5700	7800	3600	13000	17000
Klasse 4	SC-01	9,0	88	< 2	8,5	14	< 20	22	22
Klasse 3	SC-01	9,25	88	< 2	7,2	11	< 20	19	19
Klasse 0	SC-01	9,5	91	< 2	< 5	< 5	< 20	#	#
Klasse 0	SC-01	9,75	91	< 2	< 5	< 5	< 20	#	#
Klasse 0	SC-02	4,0	64	< 4	< 10	< 10	49	#	49
Klasse 4	SC-02	4,5	83	< 2	170	740	650	910	1600
Klasse 4	SC-02	5,5	83	70	1200	750	700	2000	2700
Klasse 4	SC-02	6,5	91	130	3200	770	660	4000	4800
Klasse 4	SC-02	7,5	96	7,8	270	34	30	310	350
Klasse 0	SC-02	7,75	96	< 2	< 5	< 5	< 20	#	#
Klasse 4	SC-02	8,0	96	89	1300	110	39	1400	1500
Klasse 4	SC-02	8,25	97	230	3900	1800	730	5700	6600
Klasse 0	SC-02	8,5	97	< 2	36	16	< 20	52	52
Klasse 0	SC-02	8,75	97	< 2	< 5	< 5	< 20	#	#
Klasse 0	SC-02	9,0	97	< 2	< 5	< 5	< 20	#	#
Klasse 0	SC-02	9,25	97	< 2	< 5	< 5	< 20	#	#
Klasse 0	SC-02	9,5	94	< 2	< 5	< 5	< 20	#	#
Klasse 0	SC-02	9,75	94	< 2	< 5	< 5	< 20	#	#

Conceptual Site Model (Pre RDC)

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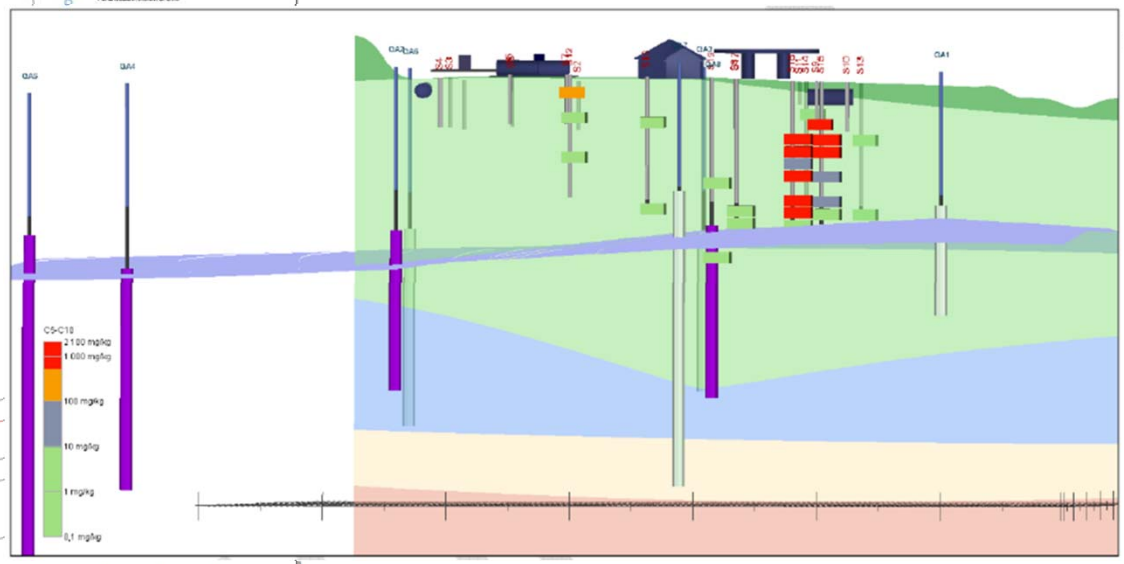
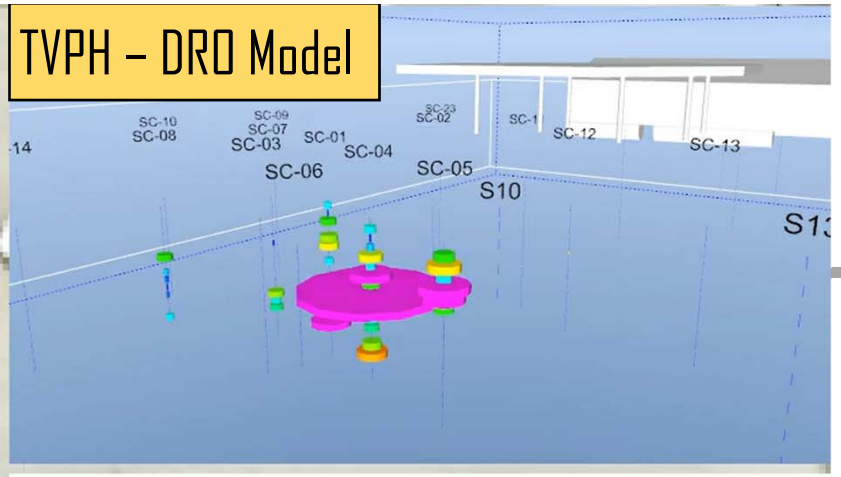
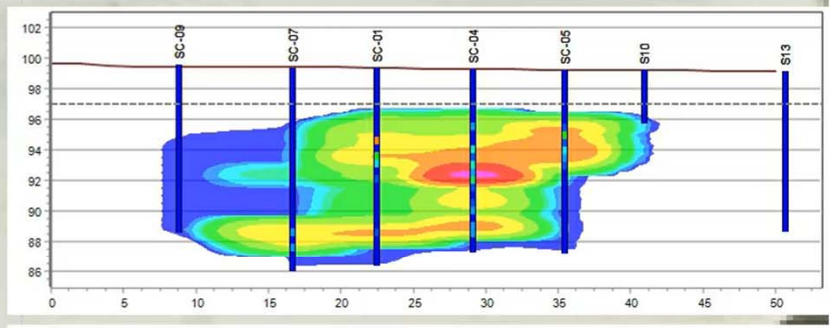
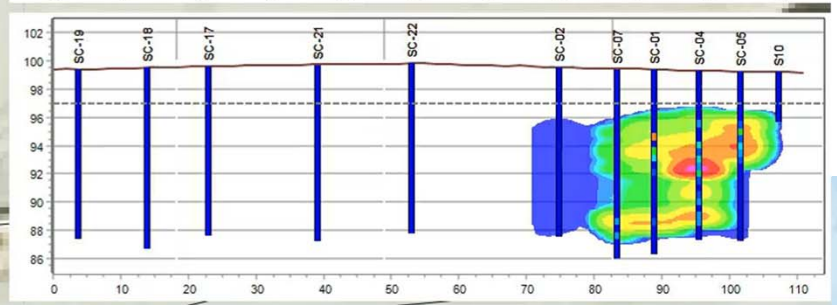


TVPH – DRO Model







RDC as a Remedation Tool - Why

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- Added value for long term project planning and budgeting
  - High frequency sampling ⇨ more defined and specific Conceptual Site Model
  - More specific Conceptual Site Model ⇨ more accurate remediation budget
  - More accurate remediation budget ⇨ better defined overall project costs and lifetime

- High frequency sampling advantages
  - Lead to more accurate Risk Assessment ⇨ might rule out the case with no further action
  - Allows for accurate contaminant mass assessment (amount and distribution) ⇨ more accurate (regardless of type of remedial technology) remediation budget and lifetime

- RDC is generally 5-15% of total remediation costs
  - Ejlskov experience of RDC costs are <0.5 - 1€/m3 of investigated soil

PART TWO

Remediation Technology – Trap & Treat®

BOS 200®

Trap & Treat® - Biodegradation of Hydrocarbons

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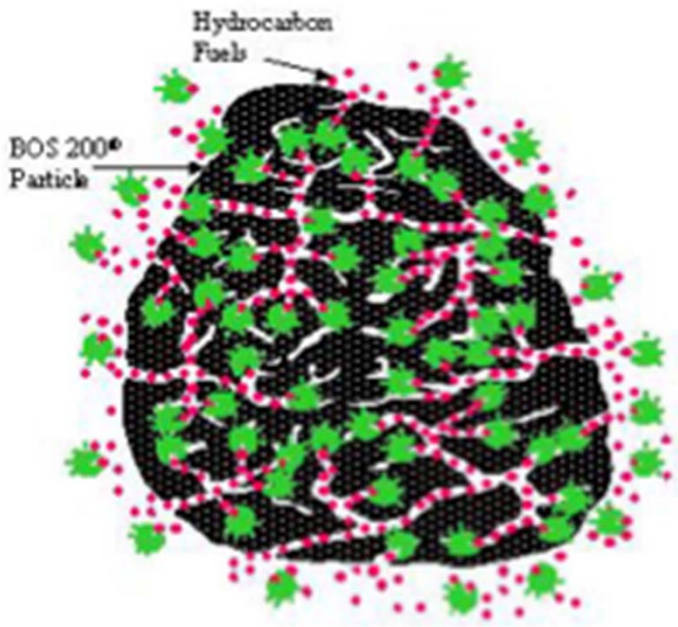
A Carbon/Biological Based Product consisting of;

Activated Carbon Powder mixed with
Calcium Sulfate
Nitrate
Phosphate
Ammonia

Two primary treatment mechanisms take place with BOS 200®:

- First mechanism is the **"Trap":** BOS 200® uses activated carbon to adsorb petroleum hydrocarbons.
- Biodegradation, the **"Treatment"**, is the second mechanism of BOS 200® remediation



Surgical Injection Design

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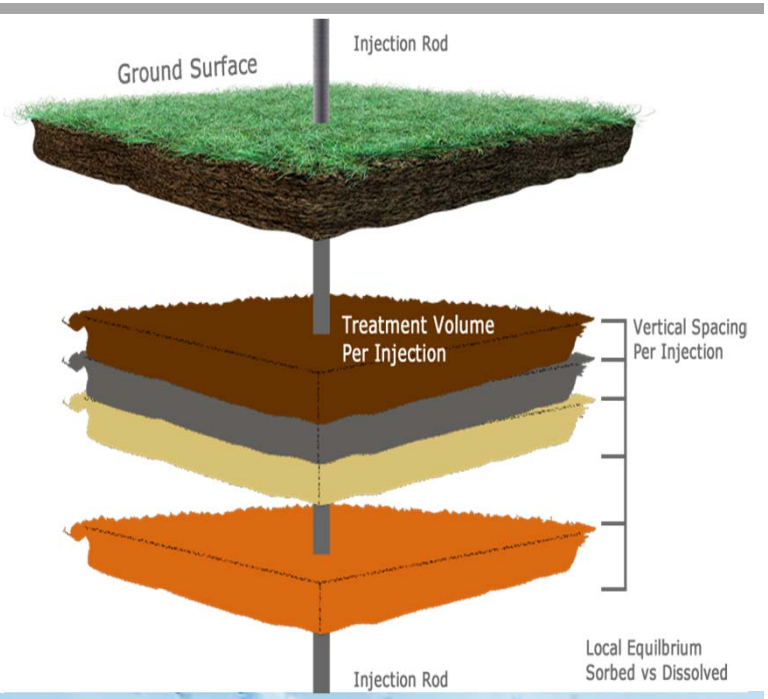
Group 2 (IP1, 5, and 9)
(Data from MIP2 and B-105 used for this Group)

(based on 2.3 m grid spacing) IP-1 and 9			(based on 2.3 m grid spacing) IP-5		
Vertical Inj. Interval (m)	BOS 200 (kg/inj)	Inj. Volume (L)	Vertical Inj. Interval (m)	BOS 200 (kg/inj)	Inj. Volume (L)
			8	22,7	80
8,25	22,7	80			
			8,5	22,7	80
8,75	22,7	80			
			9	22,7	80
9,25	22,7	80			
			9,5	22,7	80
9,75	22,7	80			
			10	13,6	80
10,25	13,6	80			
			10,5	13,6	80
10,75	13,6	80			
			11	9,1	80
11,25	9,1	80			
			11,5	9,1	80
11,75	9,1	80			
			12	34,0	115
12,25	34,0	115			
			12,5	34,0	115
Sub-total (kgs)	170,1			204,1	
Totals (kgs)	340,2			204,1	
Total (kgs) B-200 for Group 2 =		**544,3**			

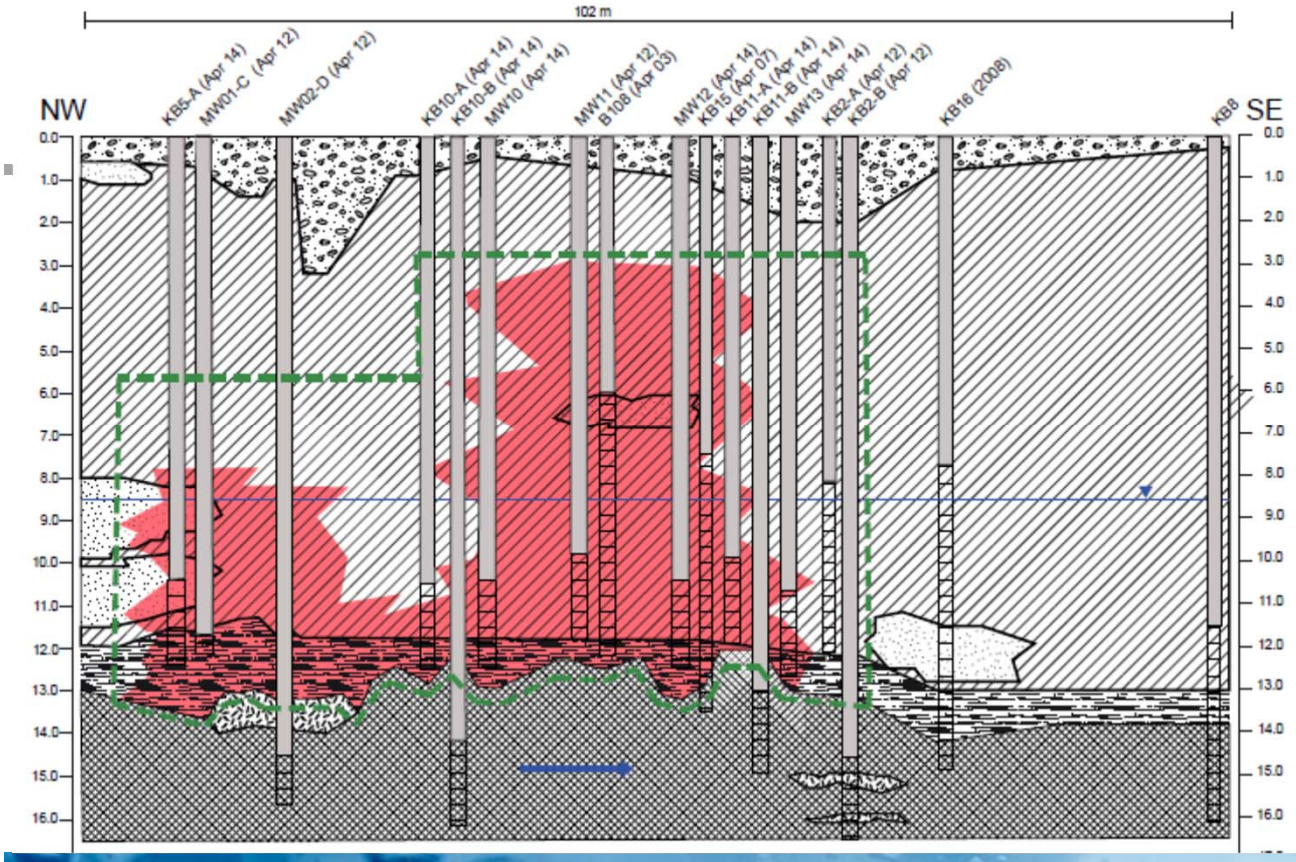
Relevant Data	
TVPH Soil (ppm)	Benzene GW (ppb)
2300	22 600 B-105
500	
2600	
610	22 600
170	No Data
150	
39	
43	
3500	
3500	



PART TWO – Case Study

Active Retail Station – Copenhagen (Denmark)

Conceptual Site Model (CSM) - 2014



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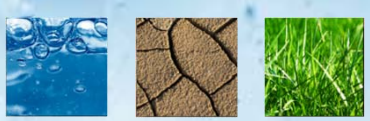
Legend

- Approximate groundwater level
- Groundwater flow
- Fill material
- Moraine clay
- Weathered limestone
- Consolidated deep limestone
- Flint
- Sandy lenses
- Bulk contaminated mass
- BOS 200 zone of injection
- Well
- Screened interval in well



Injection Design and Injection Layout Map

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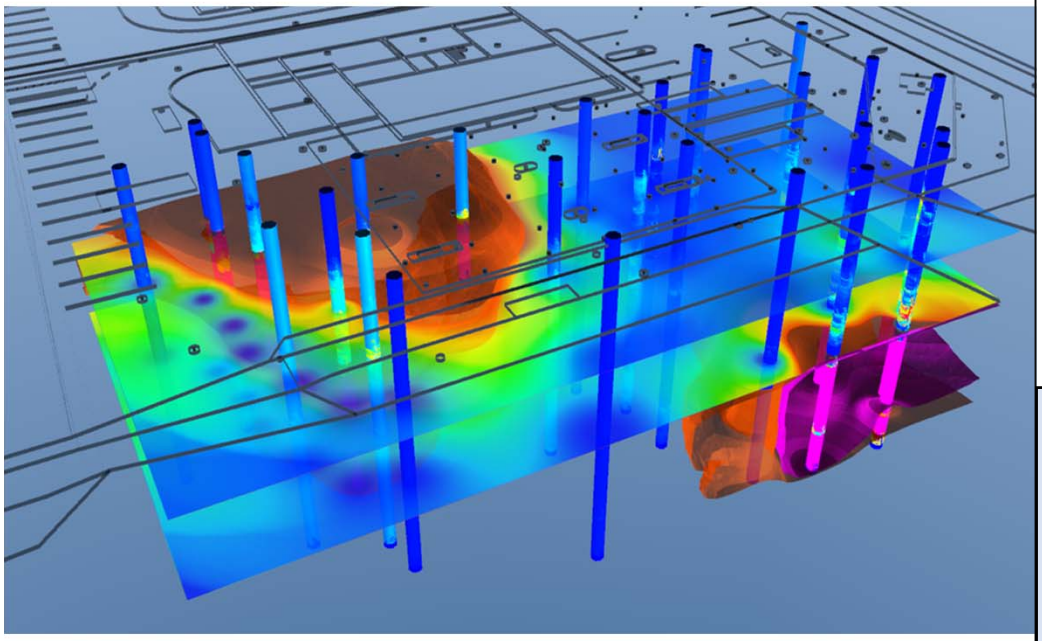
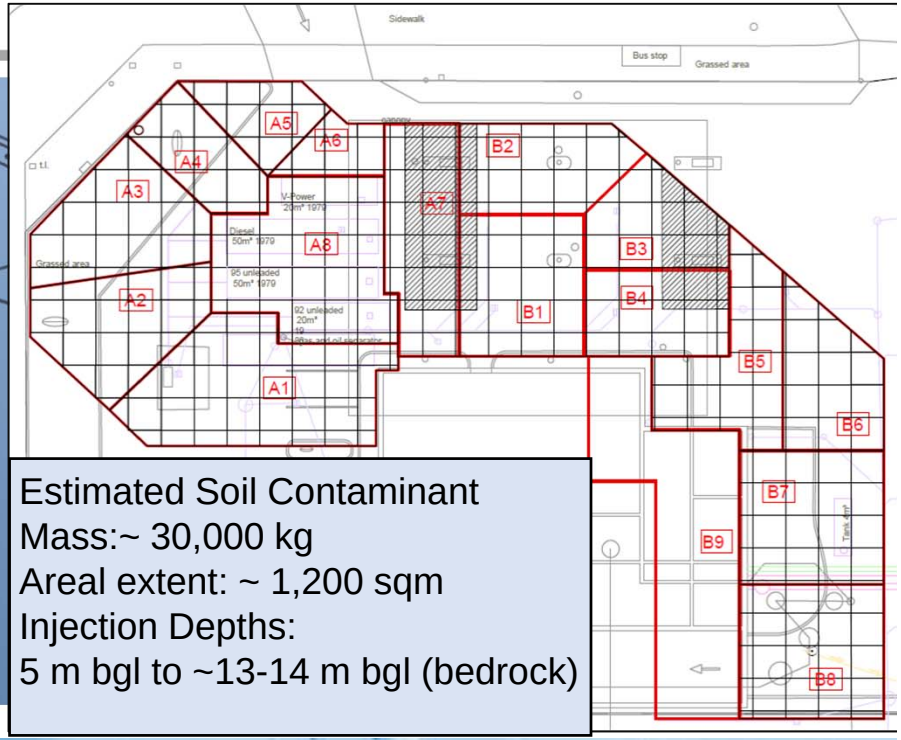
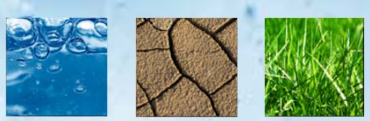
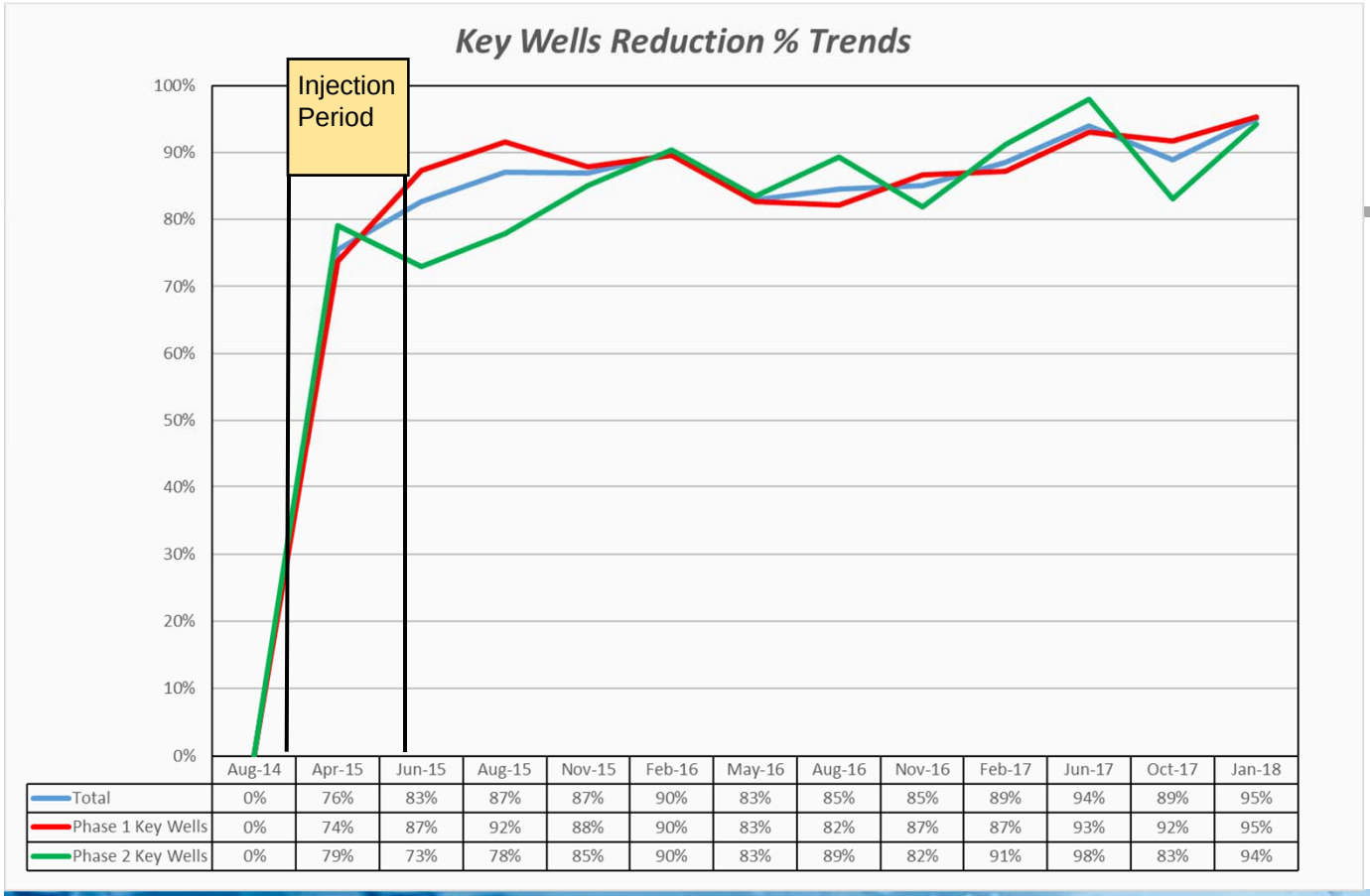




Estimated Soil Contaminant Mass:~ 30,000 kg
Areal extent: ~ 1,200 sqm
Injection Depths:
5 m bgl to ~13-14 m bgl (bedrock)





	Aug-14	Apr-15	Jun-15	Aug-15	Nov-15	Feb-16	May-16	Aug-16	Nov-16	Feb-17	Jun-17	Oct-17	Jan-18
Total	0%	76%	83%	87%	87%	90%	83%	85%	85%	89%	94%	89%	95%
Phase 1 Key Wells	0%	74%	87%	92%	88%	90%	83%	82%	87%	87%	93%	92%	95%
Phase 2 Key Wells	0%	79%	73%	78%	85%	90%	83%	89%	82%	91%	98%	83%	94%

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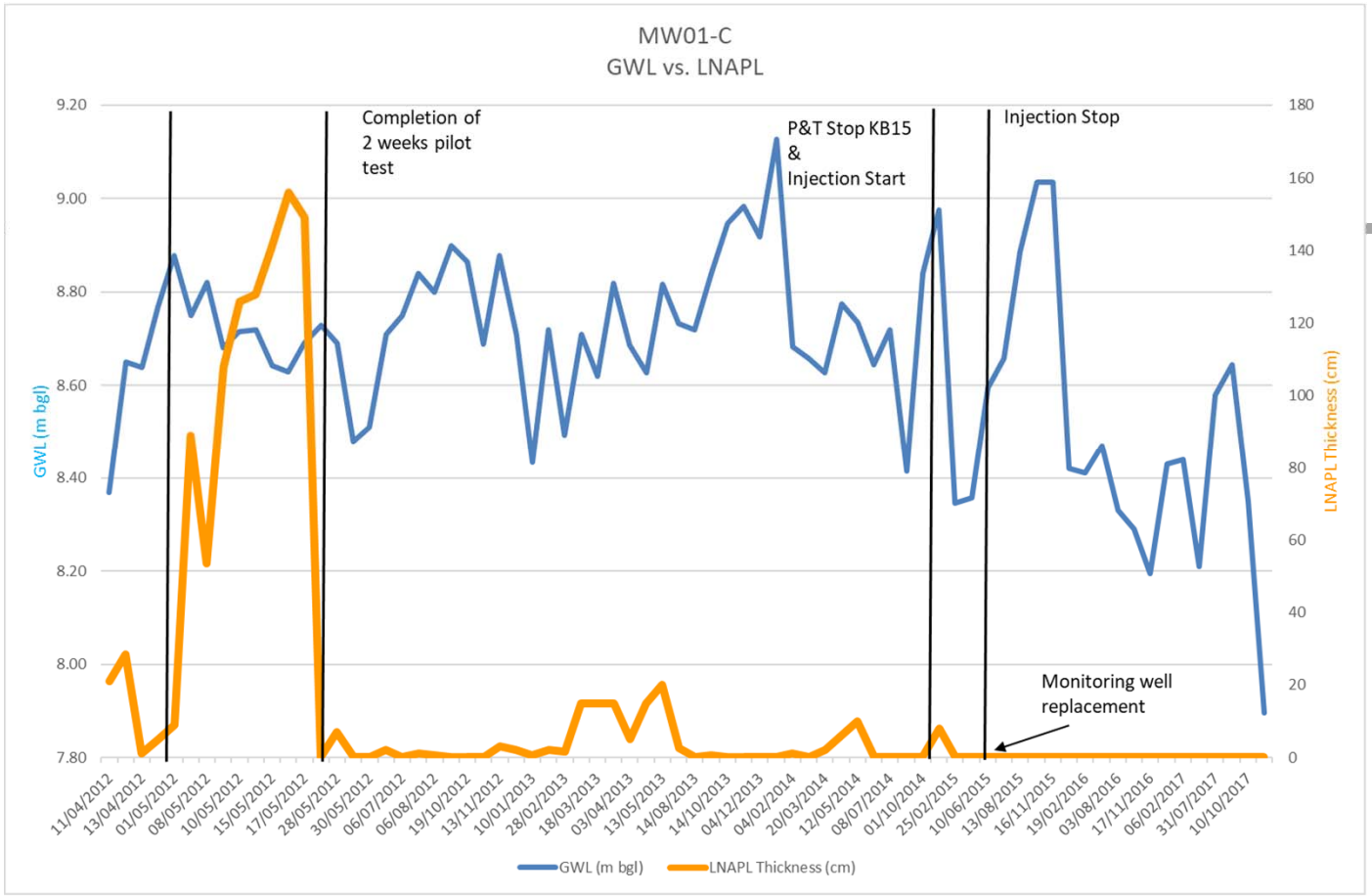
Reduction % variation calculated as:

[(Baseline concentration (Aug 2014) – Current concentration / (Baseline concentration (Aug 2014)]

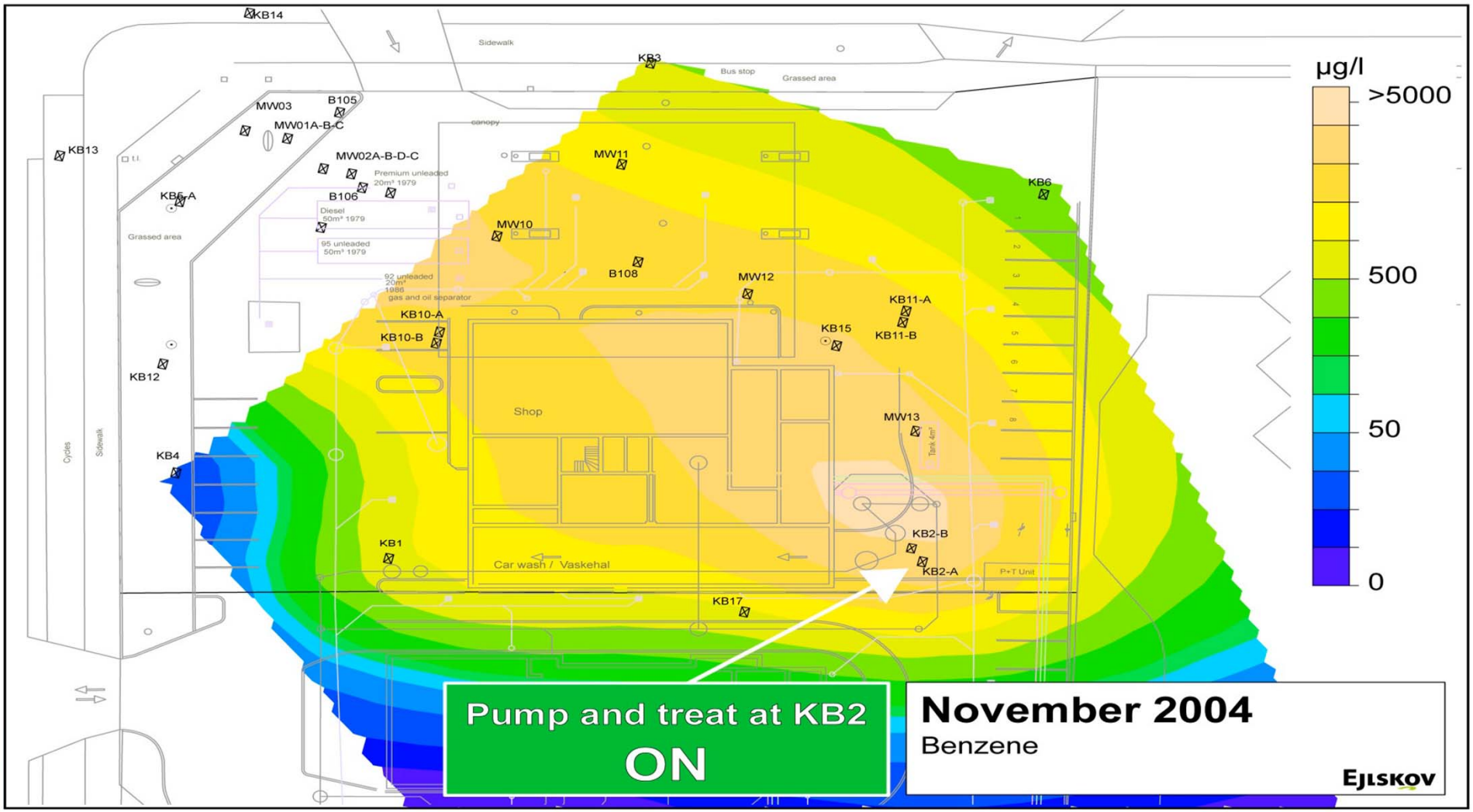
Note – August 2014 concentration baseline is with the pump and treat still running. Therefore the real 2014 baseline is higher.



MW01-C is screened from 11.65 m bgl to 12.15 m bgl

OBS!!! – LNAPL entering the well 1.5 m below soil saturation level

No LNAPL re-accumulation observed during the past 24 months


KB14
Sidewalk
KB3
Bus stop
Grassed area
µg/l
>5000
500
50
0
MW03
B105
MW01A-B-C
KB13
canopy
MW02A-B-D-C
MW11
Premium unleaded
20m³ 1979
B106
KB6
KB5-A
Diesel
50m³ 1979
MW10
Grassed area
95 unleaded
50m³ 1979
B108
MW12
92 unleaded
20m³
1986
gas and oil separator
KB11-A
KB10-A
KB15
KB10-B
KB11-B
KB12
Shop
MW13
Tank 4m³
Cycles
Sidewalk
KB4
KB2-B
KB1
Car wash / Vaskehal
KB2-A
P+T Unit
KB17
Pump and treat at KB2
ON
November 2004
Benzene
EJLSKOV

PART TWO

Active Retail Station – Lahti (Finland)

Conceptual Site Model – Post Remedial Design March 2015

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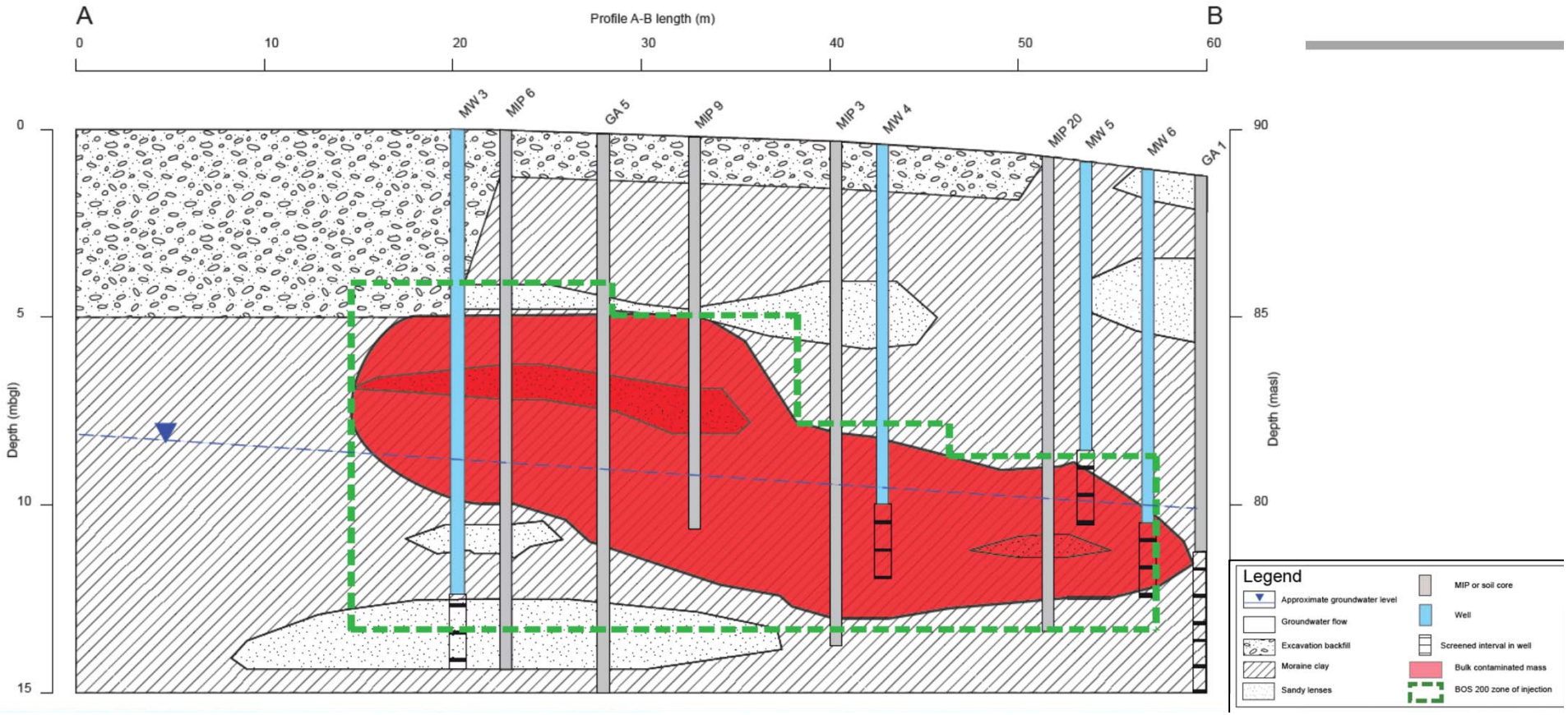

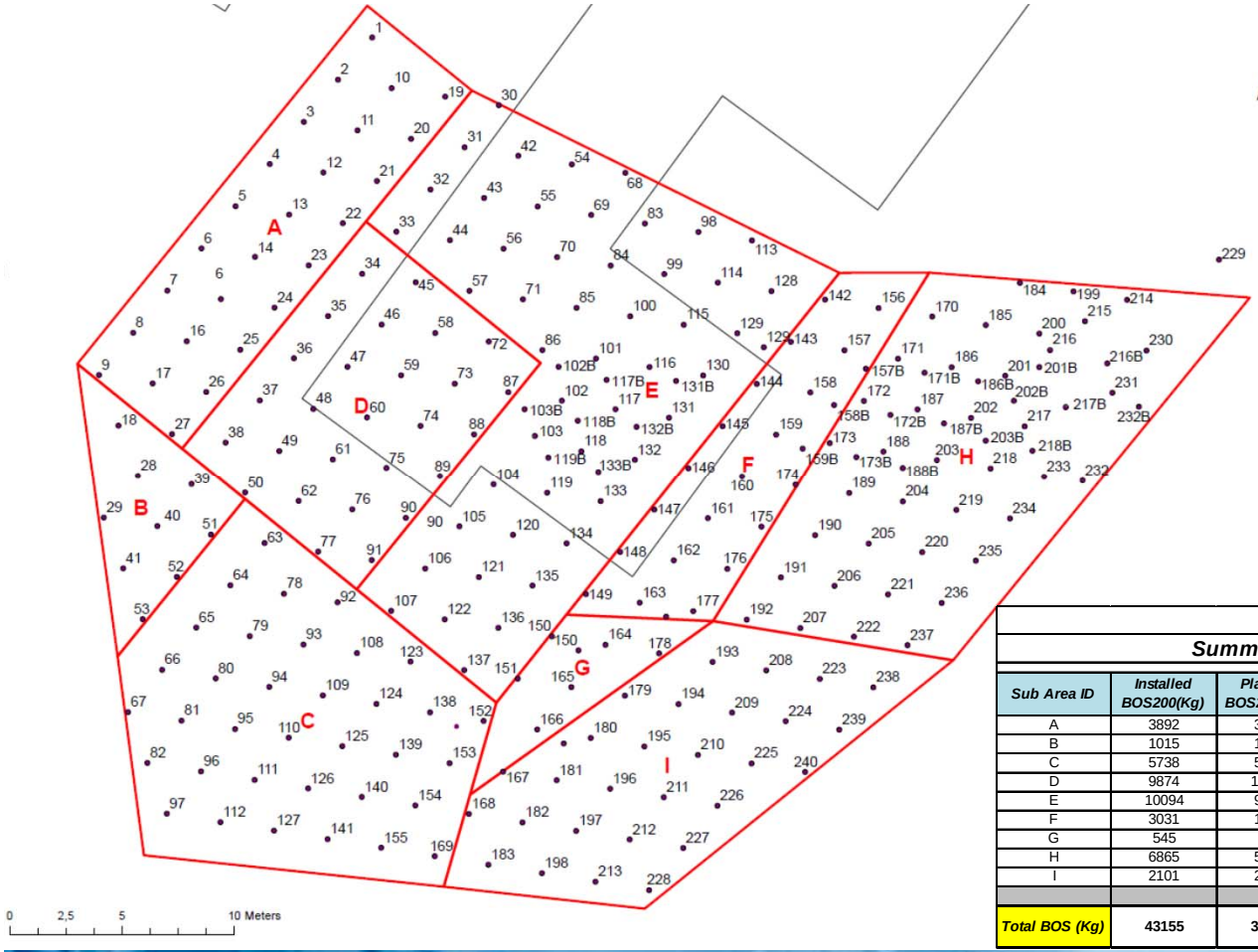

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Injection Points Map

One phase of work was carried out from June to August 2015

Lahti - Hennala Site

Summary of BOS200 Injection Works at 17/08/2015

Sub Area ID	Installed BOS200(Kg)	Planned BOS200 (Kg)	Missing points (Kg)
A	3892	3888	0
B	1015	1018	0
C	5738	5732	0
D	9874	10308	0
E	10094	9410	0
F	3031	1783	0
G	545	446	0
H	6865	5217	0
I	2101	2036	0
Total BOS (Kg)	**43155**	**39838**	**0**

Sub Area ID	Installed Gypsum (Kg)	Planned Gypsum (Kg)	Missing points (Kg)
A	5141	5150	0
B	1536	1534	0
C	7113	7096	0
D	0	0	0
E	2085	1883	0
F	1333	891	0
G	510	446	0
H	2843	2609	0
I	1966	2036	0
Total Gypsum (Kg)	**22528**	**21645**	**0**

Groundwater Results MW4

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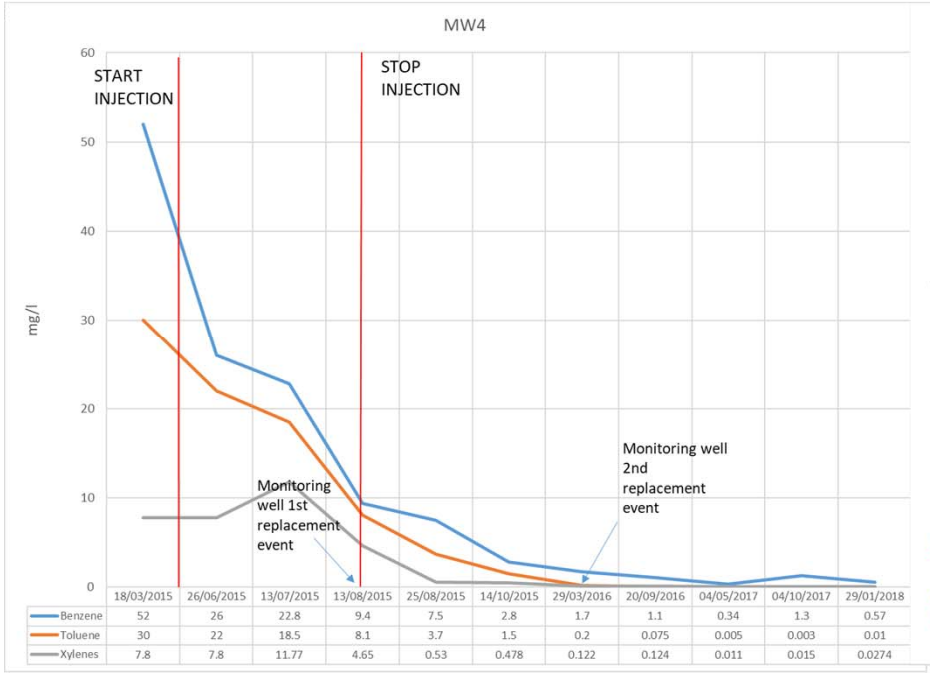
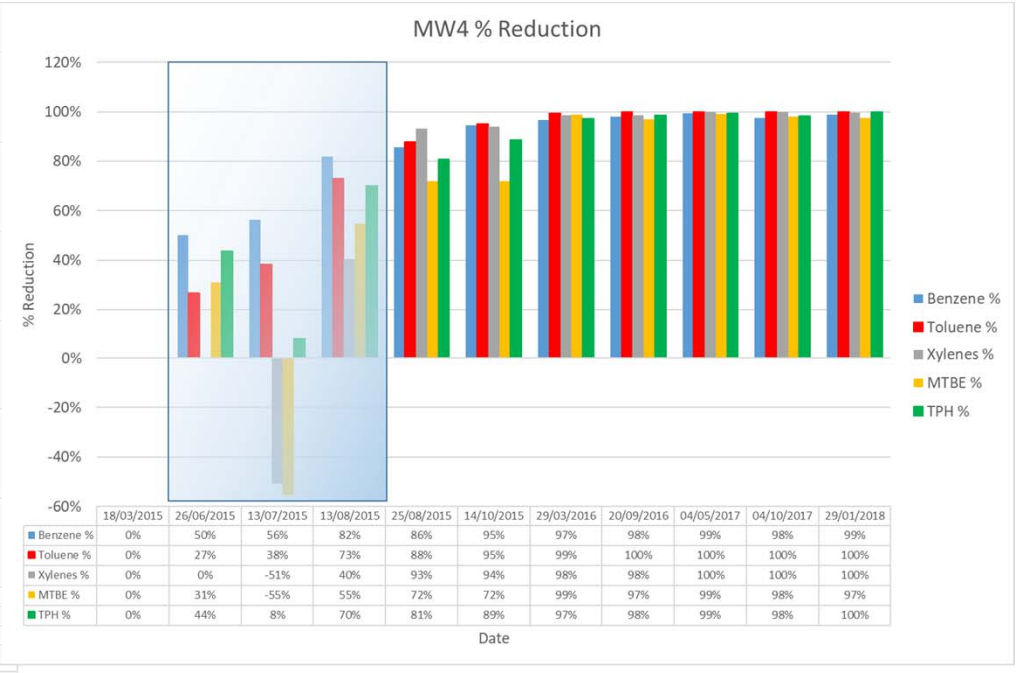


	18/03/2015	26/06/2015	13/07/2015	13/08/2015	25/08/2015	14/10/2015	29/03/2016	20/09/2016	04/05/2017	04/10/2017	29/01/2018
Benzene	52	26	22.8	9.4	7.5	2.8	1.7	1.1	0.34	1.3	0.57
Toluene	30	22	18.5	8.1	3.7	1.5	0.2	0.075	0.005	0.003	0.01
Xylenes	7.8	7.8	11.77	4.65	0.53	0.478	0.122	0.124	0.011	0.015	0.0274



	18/03/2015	26/06/2015	13/07/2015	13/08/2015	25/08/2015	14/10/2015	29/03/2016	20/09/2016	04/05/2017	04/10/2017	29/01/2018
Benzene %	0%	50%	56%	82%	86%	95%	97%	98%	99%	98%	99%
Toluene %	0%	27%	38%	73%	88%	95%	99%	100%	100%	100%	100%
Xylenes %	0%	0%	-51%	40%	93%	94%	98%	98%	100%	100%	100%
MTBE %	0%	31%	-55%	55%	72%	72%	99%	97%	99%	98%	97%
TPH %	0%	44%	8%	70%	81%	89%	97%	98%	99%	98%	100%

Groundwater Results MW5

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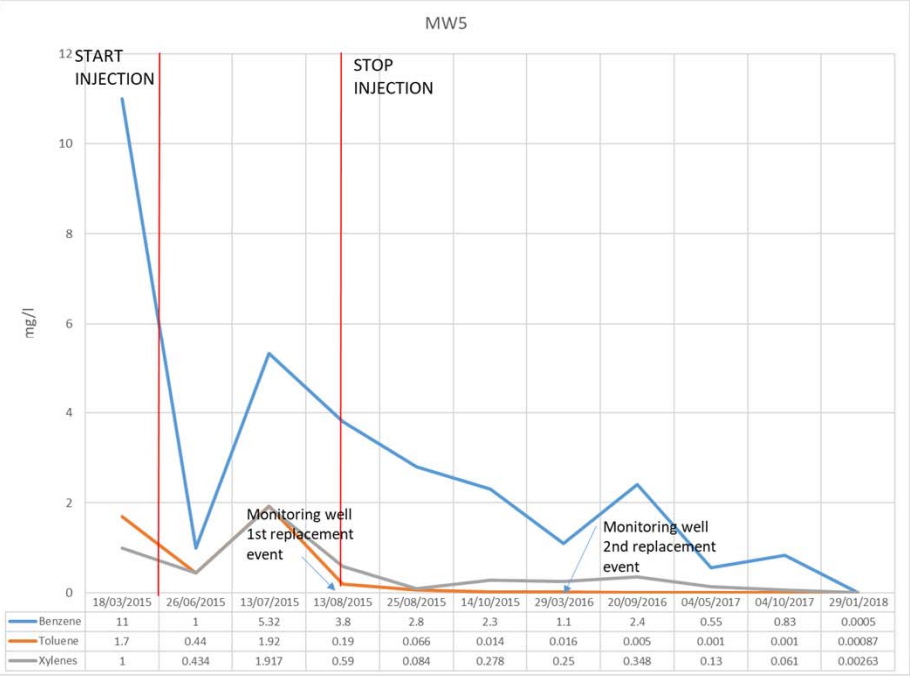
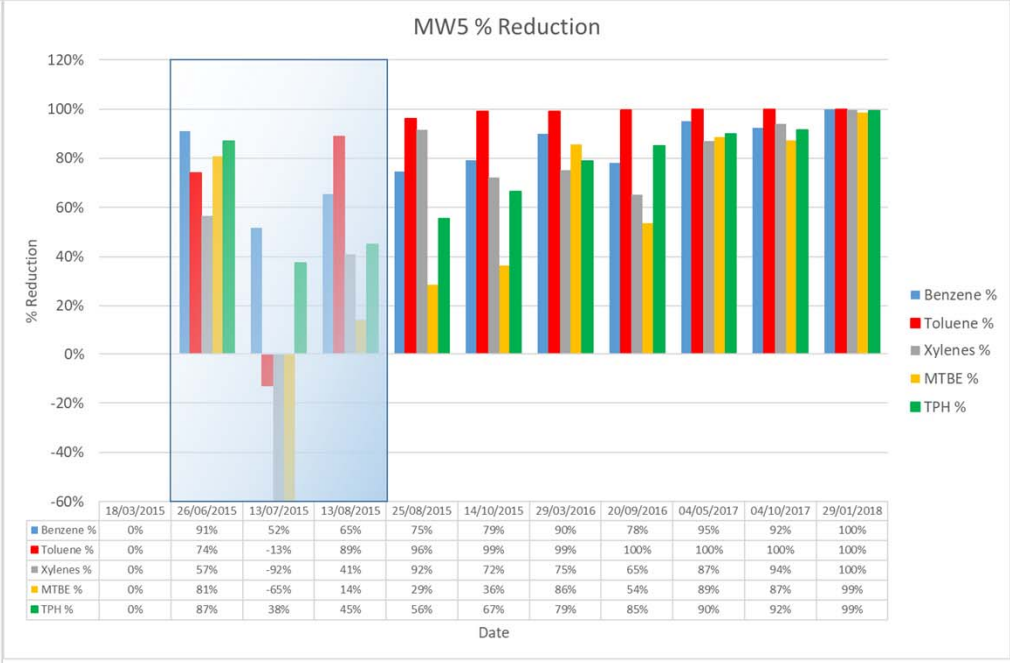


	18/03/2015	26/06/2015	13/07/2015	13/08/2015	25/08/2015	14/10/2015	29/03/2016	20/09/2016	04/05/2017	04/10/2017	29/01/2018
Benzene	11	1	5.32	3.8	2.8	2.3	1.1	2.4	0.55	0.83	0.0005
Toluene	1.7	0.44	1.92	0.19	0.066	0.014	0.016	0.005	0.001	0.001	0.00087
Xylenes	1	0.434	1.917	0.59	0.084	0.278	0.25	0.348	0.13	0.061	0.00263



	18/03/2015	26/06/2015	13/07/2015	13/08/2015	25/08/2015	14/10/2015	29/03/2016	20/09/2016	04/05/2017	04/10/2017	29/01/2018
Benzene %	0%	91%	52%	65%	75%	79%	90%	78%	95%	92%	100%
Toluene %	0%	74%	-13%	89%	96%	99%	99%	100%	100%	100%	100%
Xylenes %	0%	57%	-92%	41%	92%	72%	75%	65%	87%	94%	100%
MTBE %	0%	81%	-65%	14%	29%	36%	86%	54%	89%	87%	99%
TPH %	0%	87%	38%	45%	56%	67%	79%	85%	90%	92%	99%

Groundwater Results MW6

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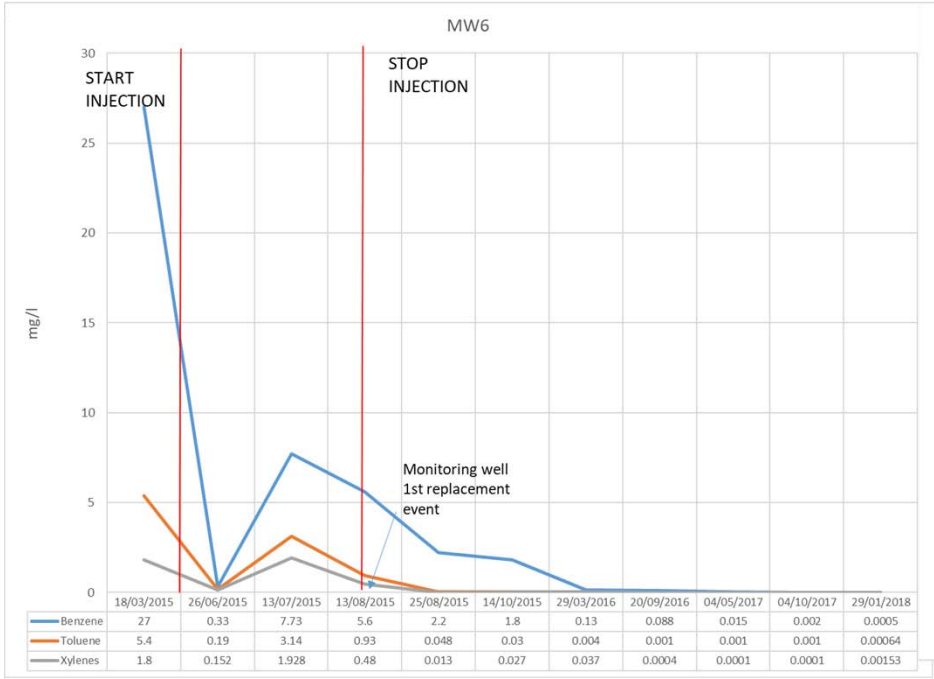
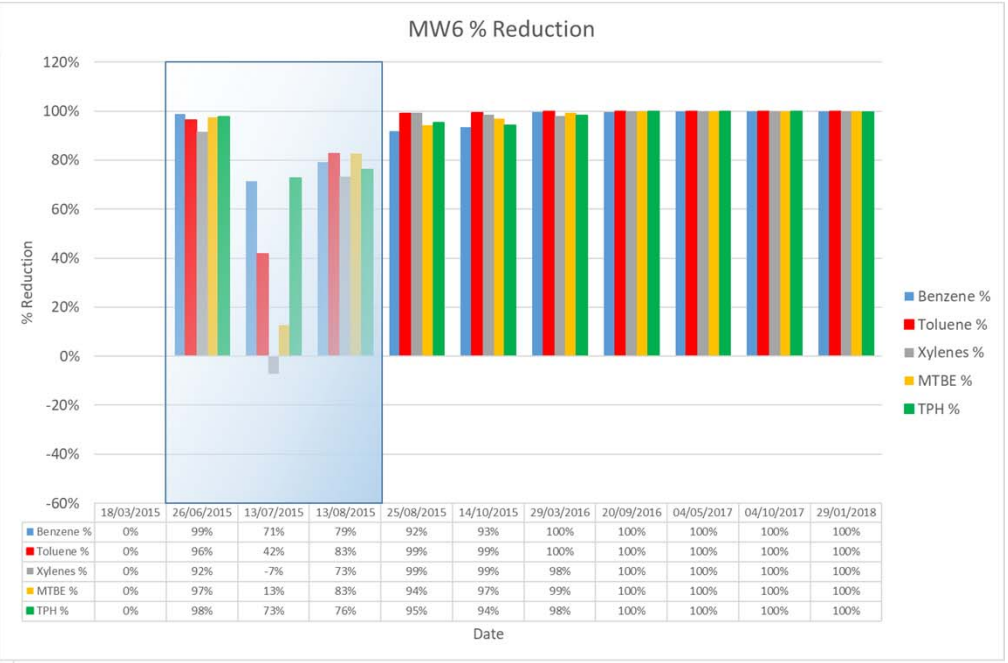
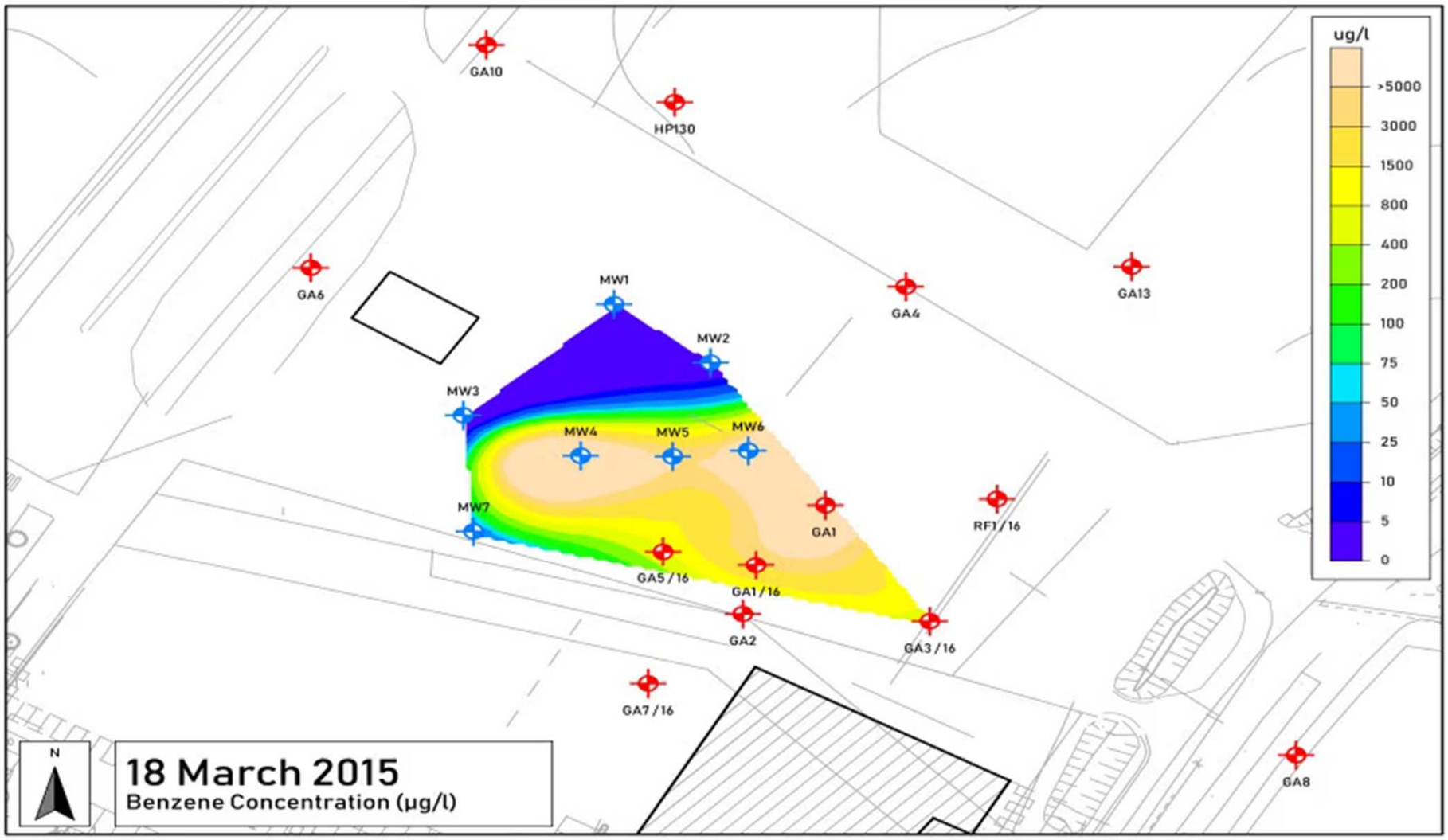


	18/03/2015	26/06/2015	13/07/2015	13/08/2015	25/08/2015	14/10/2015	29/03/2016	20/09/2016	04/05/2017	04/10/2017	29/01/2018
Benzene	27	0.33	7.73	5.6	2.2	1.8	0.13	0.088	0.015	0.002	0.0005
Toluene	5.4	0.19	3.14	0.93	0.048	0.03	0.004	0.001	0.001	0.001	0.00064
Xylenes	1.8	0.152	1.928	0.48	0.013	0.027	0.037	0.0004	0.0001	0.0001	0.00153



	18/03/2015	26/06/2015	13/07/2015	13/08/2015	25/08/2015	14/10/2015	29/03/2016	20/09/2016	04/05/2017	04/10/2017	29/01/2018
Benzene %	0%	99%	71%	79%	92%	93%	100%	100%	100%	100%	100%
Toluene %	0%	96%	42%	83%	99%	99%	100%	100%	100%	100%	100%
Xylenes %	0%	92%	-7%	73%	99%	99%	98%	100%	100%	100%	100%
MTBE %	0%	97%	13%	83%	94%	97%	99%	100%	100%	100%	100%
TPH %	0%	98%	73%	76%	95%	94%	98%	100%	100%	100%	100%


ug/l
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800
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75
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GA10
HP130
GA6
GA4
GA13
MW1
MW2
MW3
MW4
MW5
MW6
MW7
GA1
RF1 / 16
GA5 / 16
GA1 / 16
GA2
GA3 / 16
GA7 / 16
GA8
N
18 March 2015
Benzene Concentration (µg/l)

Remediation Lessons Learned

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- Experienced advantages of conducting a remediation following an RDC
  - Site knowledge such to reflect on less ”unexpected” events during remediation works
  - Risks of leaving untreated zones ”behind” is minimal
  - Management of Change situations can be handled more rationally having a solid CSM (goals of the project are linked to a thorough understanding of the contaminant distribution, migration pathways, etc.)
  - Confindence in signing PBR contracts

- Goals achievement
  - Highly predictable thanks to RDC data and BOS200® efficiency / longevity
  - Validated by post-injection monitoring data (performance assessment)

- Remediation costs using BOS200® after completion of an RDC are in the 45-60 €/ton

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Thank you