Assessment of Natural Source Zone Depletion (NSZD) as a Corrective Action Management Option

Buffalo Narrows Fire Protection Base, Saskatchewan

Part 1. Development of the LNAPL Conceptual Site Model

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18 October 2023

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Outline

- Background and Setting
- Nature of the Problem
- Requirements for Assessing NSZD
- Geology and Hydrogeology
- LNAPL Characteristics and Behaviour
- Dissolved Phase Characteristics and Behaviour
- Vapour Phase Characteristics and Behaviour
- Assessment of NSZD as a Corrective Action Option

Background

Site Use and History

- Air Tanker base for forest fire fighting
- Aircraft fueling and water/chemical loading
- Excavation in the east apron area in 2015 identified impacted soils between the fuel tanks and the aviation gasoline hose reel, and an investigation was requested.

Location and Setting

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BUFFALO NARROWS FOREST PROTECTION GROUNDWATER MONITORING 2023

PROJECT LOCATION: BUFFALO NARROWS AIRPORT, BUFFALO NARROWS, SK

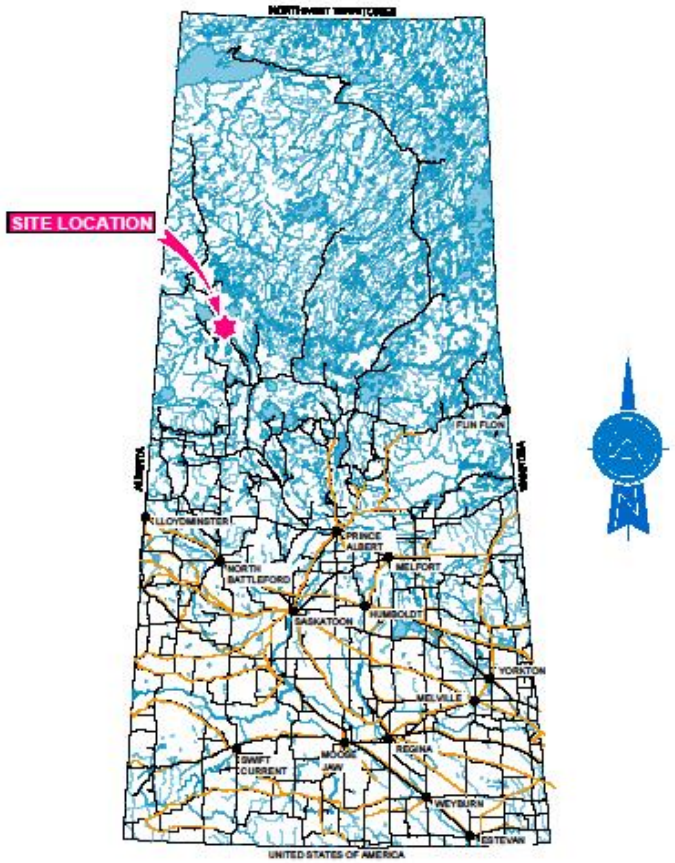


IMAGE COURTESY OF: GOOGLE EARTH PRO

ENGINEER	CLIENT	TITLE	FIG No.
Clifton	SASKATCHEWAN PUBLIC SAFETY AGENCY	SITE LOCATION PLAN	01
		DATE 2023-9-22 / PROJECT No. 82420.13	

A:\Projects\Saskatoon\82420.13 Buffalo Narrows\82420.13 - 01 Site Location Plan.dwg, 09/22/2023 10:07:48 AM

Views SE and SW

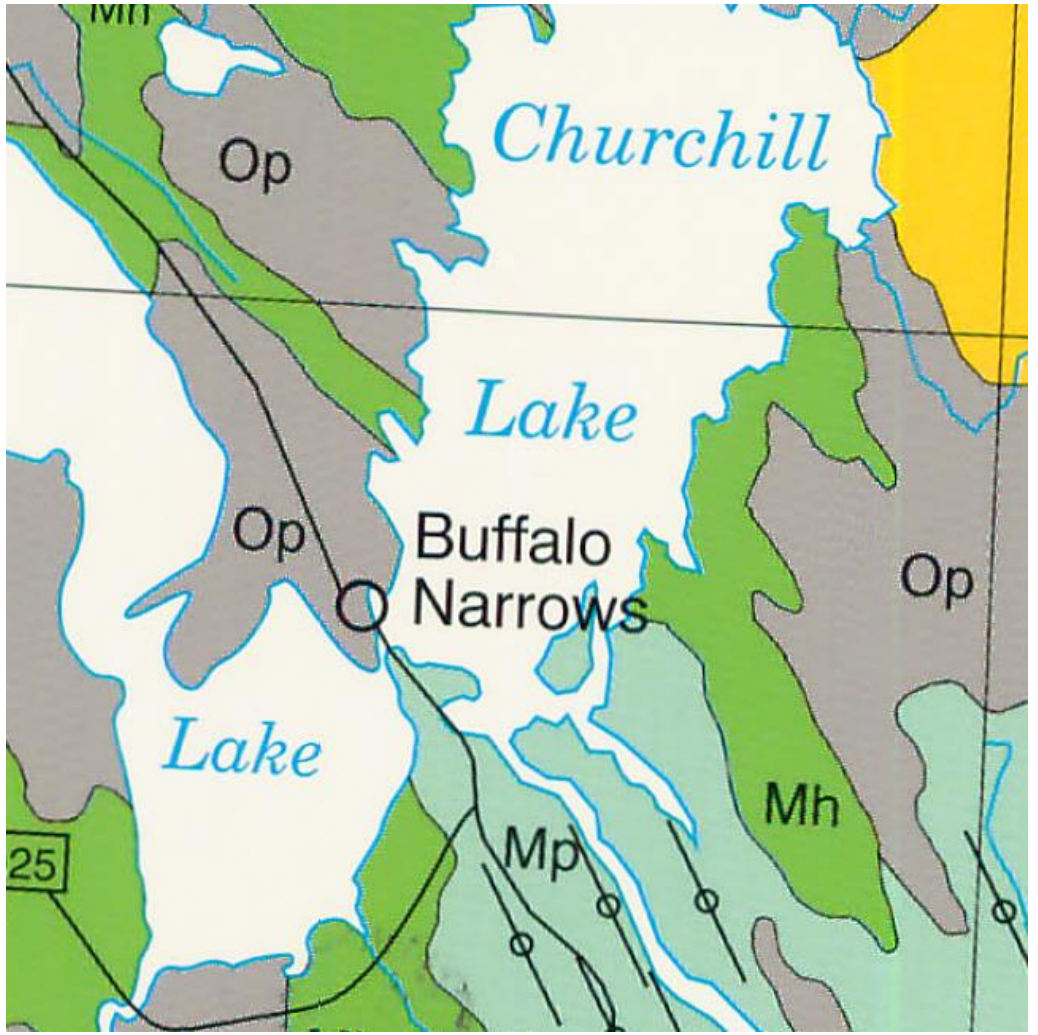
Distance to wetland approx. 250m

Views NE and NW

Distance to Churchill Lake approx. 450m

Regional Geology

- Surficial Geology Map of Saskatchewan (1997): Moraine Plain - Till consisting of unsorted mixtures of boulders, gravel, sand, silt and clay, etc etc.
- Saskatchewan GeoAtlas polygon of the area is labelled as “morainal drumlinoid”
- Roadside observations along Hwy 155 indicate surface soils in the area are sandy
- Glacial environment with extensive shallow sands



Nature of the Problem

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Nature of the Problem

- Soil and groundwater are impacted by a petroleum hydrocarbons, with light non-aqueous phase liquids observed in the subsurface
- A Corrective Action Plan to manage these impacts is required by the Ministry of the Environment
- The site is relatively remote, and traditional management options are a challenge to manage and may result in increased public safety and environmental risks.
- Do natural processes provide a potential solution?

Requirements for Assessing NSZD

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Is NSZD a possible option for site management?

Maybe, if

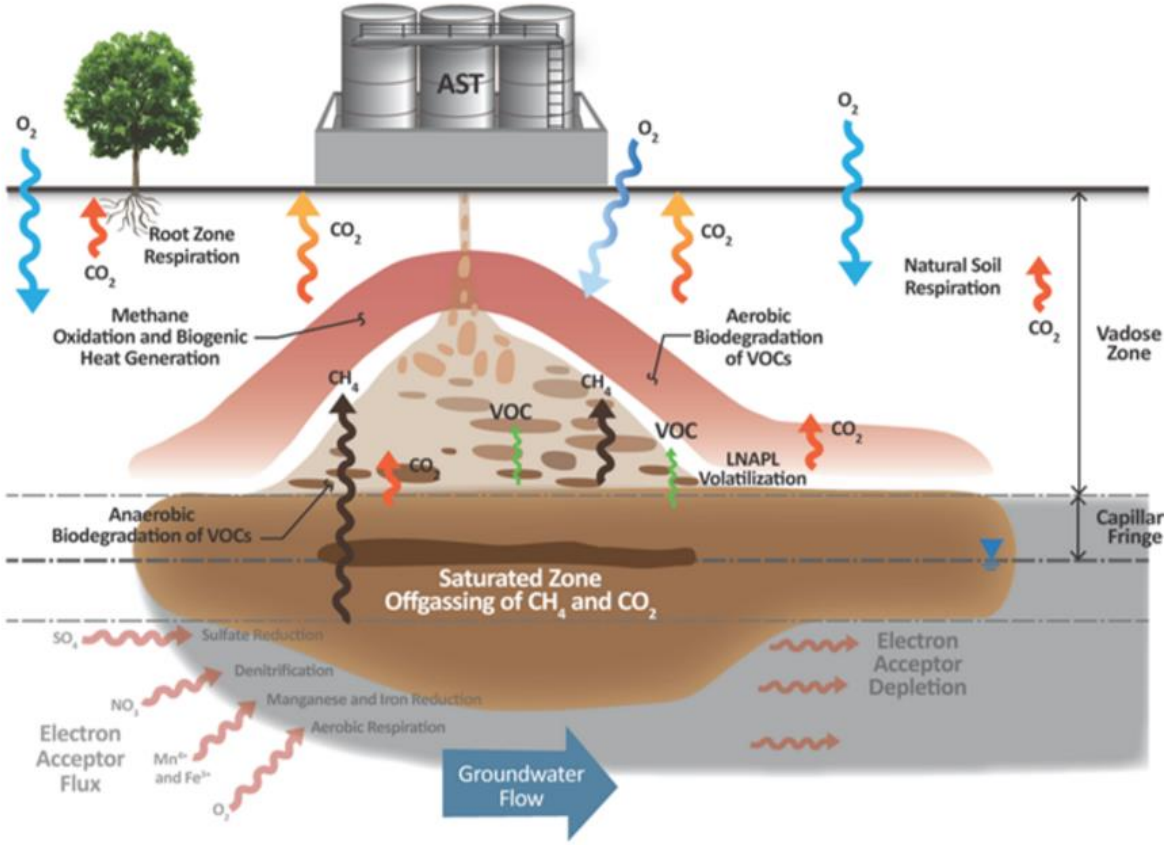
- Source zone is delineated and stable.
- Dissolved phase is delineated and stable.
- Exposure pathway/receptor relationships are not present, or can be managed.
- Existence of biodegradation in the vapour and dissolved phases can be demonstrated.
- Timeframe is acceptable (lots of time….).

But

- Site-specific limitations may exist (soil permeability, vadose zone moisture content, depth of contamination, climate, etc).
- A solid understanding of the LNAPL and constituent chemicals of concern is required.
- Accurate background information is required.
- Reasonable depletion rates and projected time to compliance is required.
- Regulatory acceptance is key.

In short, we need a solid Conceptual Site Model.

- Geology
- Hydrogeology
- LNAPL composition, distribution, and behaviour
- Dissolved phase distribution and behaviour
- Vapour phase distribution and behaviour



Geology and Hydrogeology

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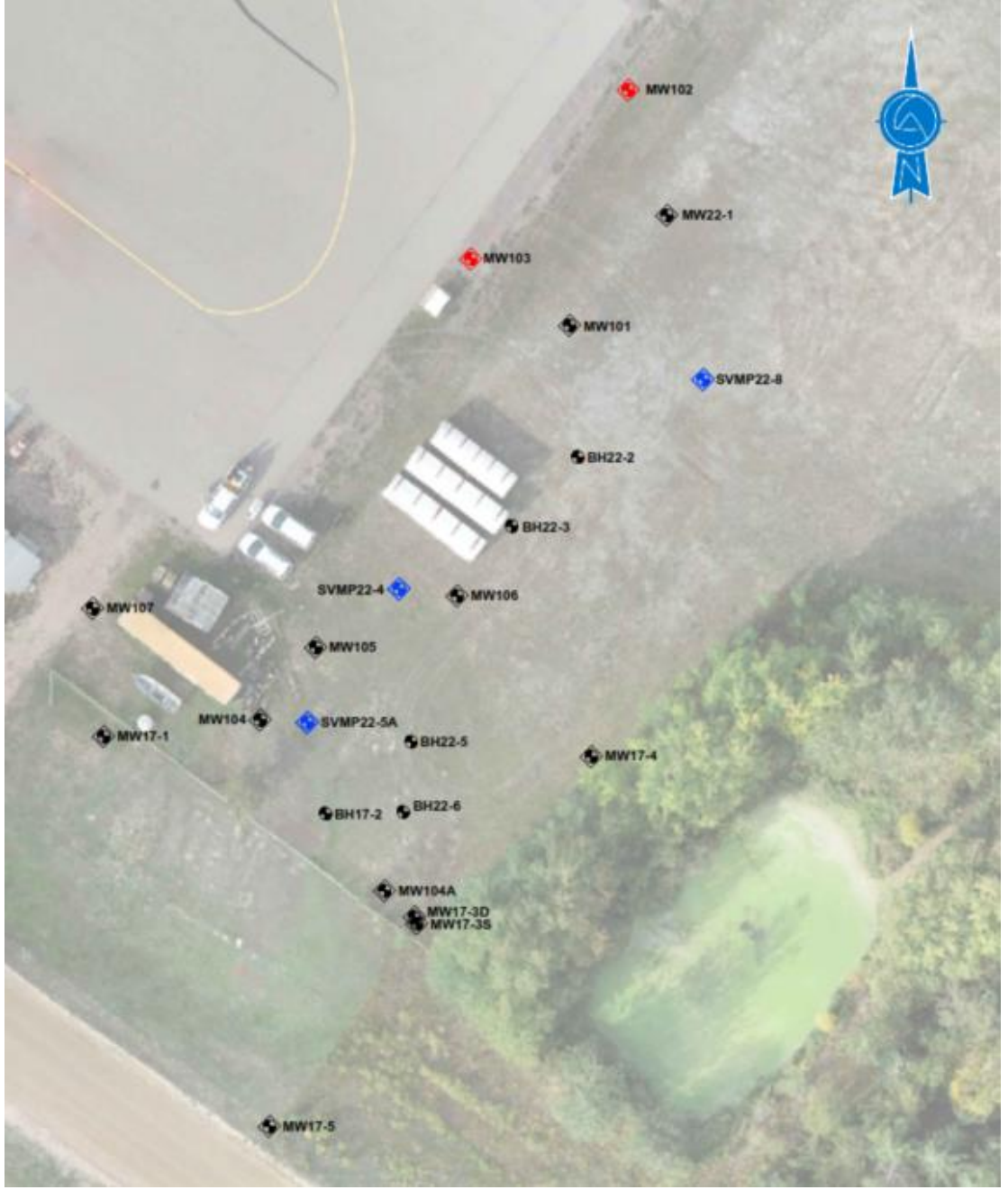
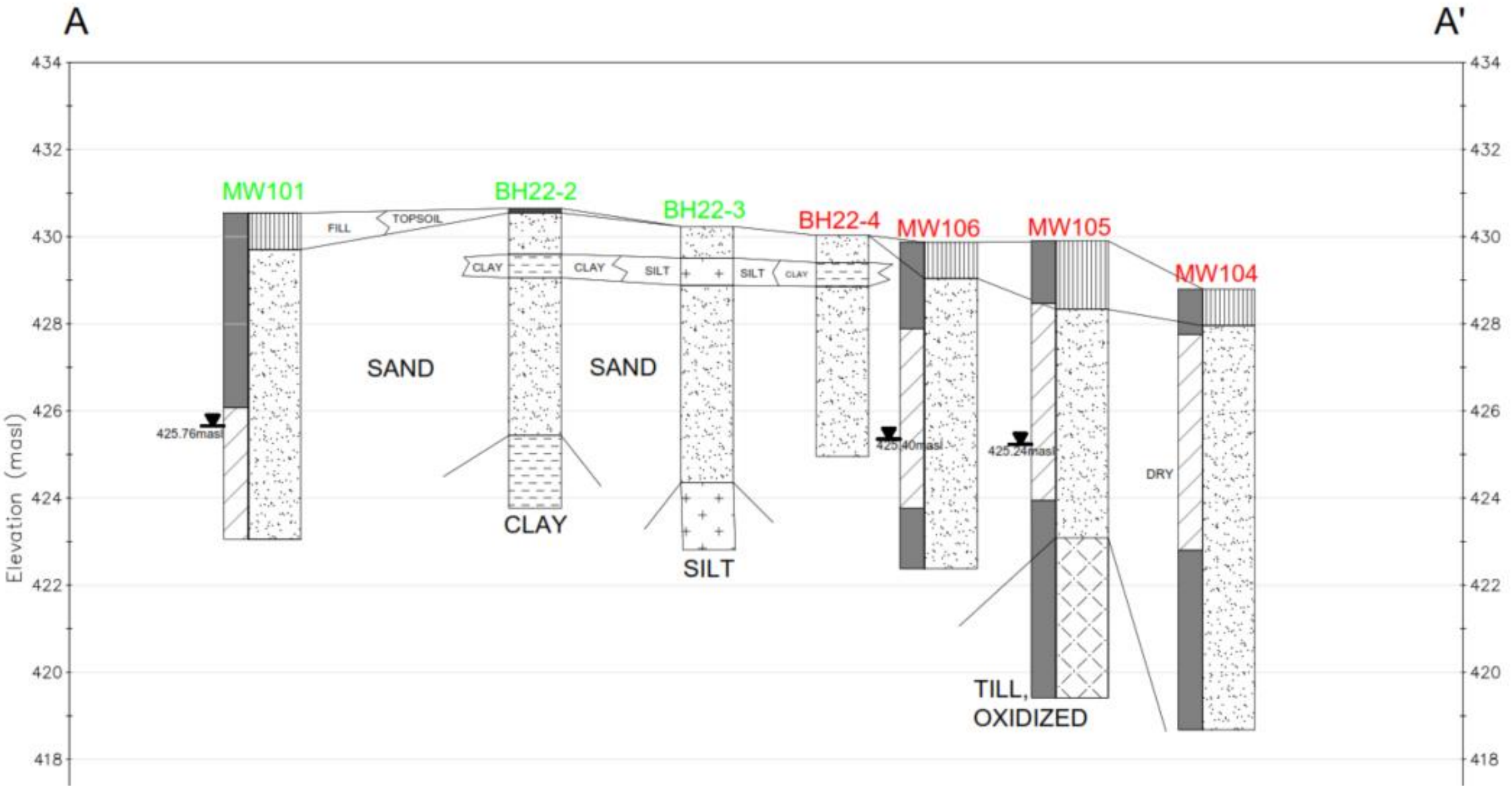
Borehole and Well Locations

- 22 boreholes, wells and nested vapour points installed in 2015, 2017, and 2022.
- Average depth of investigation is 7 m.
- Maximum depth of investigation is 11.5 m
- Depth to water ranges from 3.6 m to 5.4 m.
- Soil is primarily silty sand (SM) overlying till.
- Moisture content in the upper 4m averages around 9% (by weight)





North-South Cross-section

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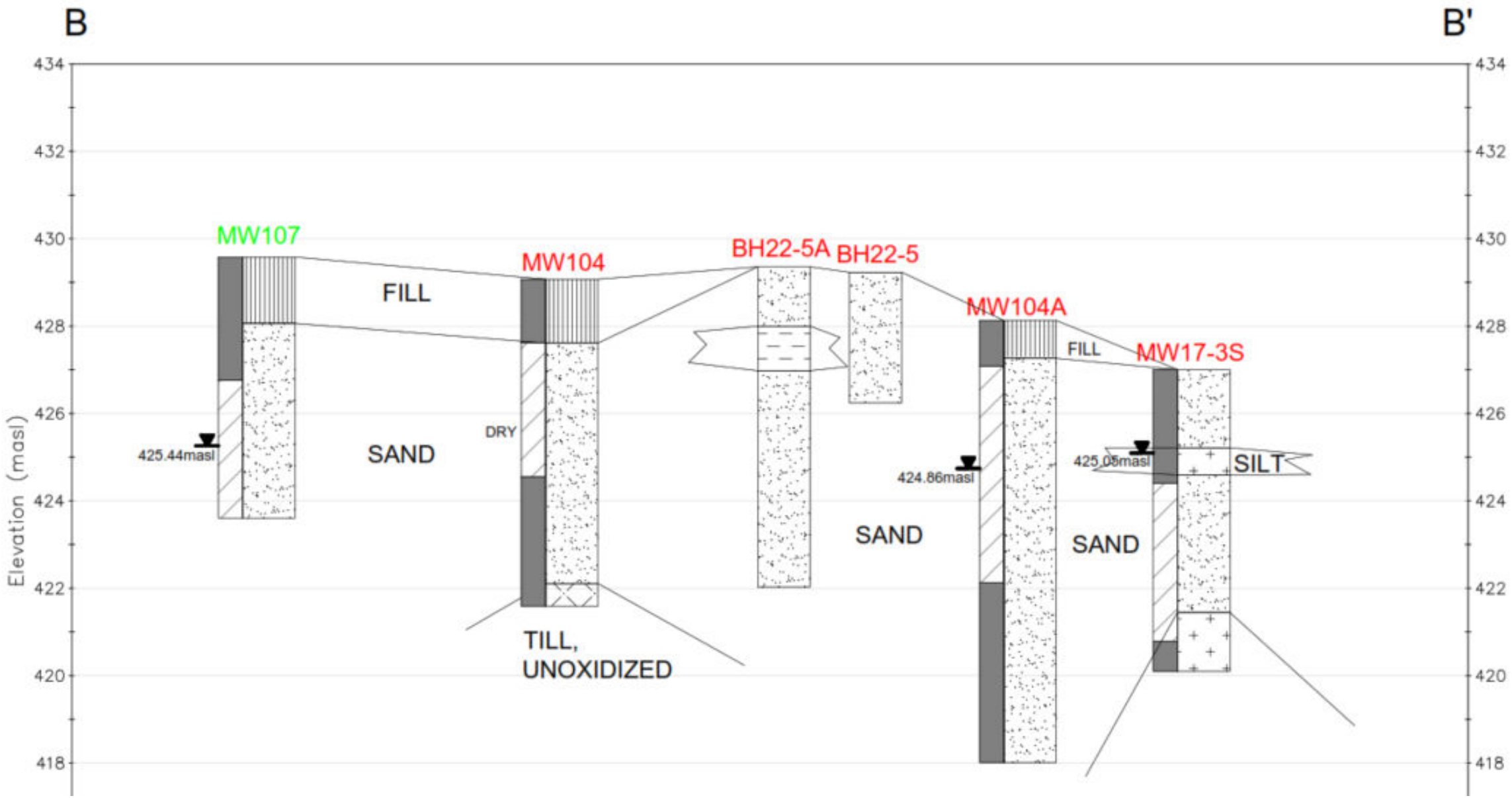

West-East Cross-section

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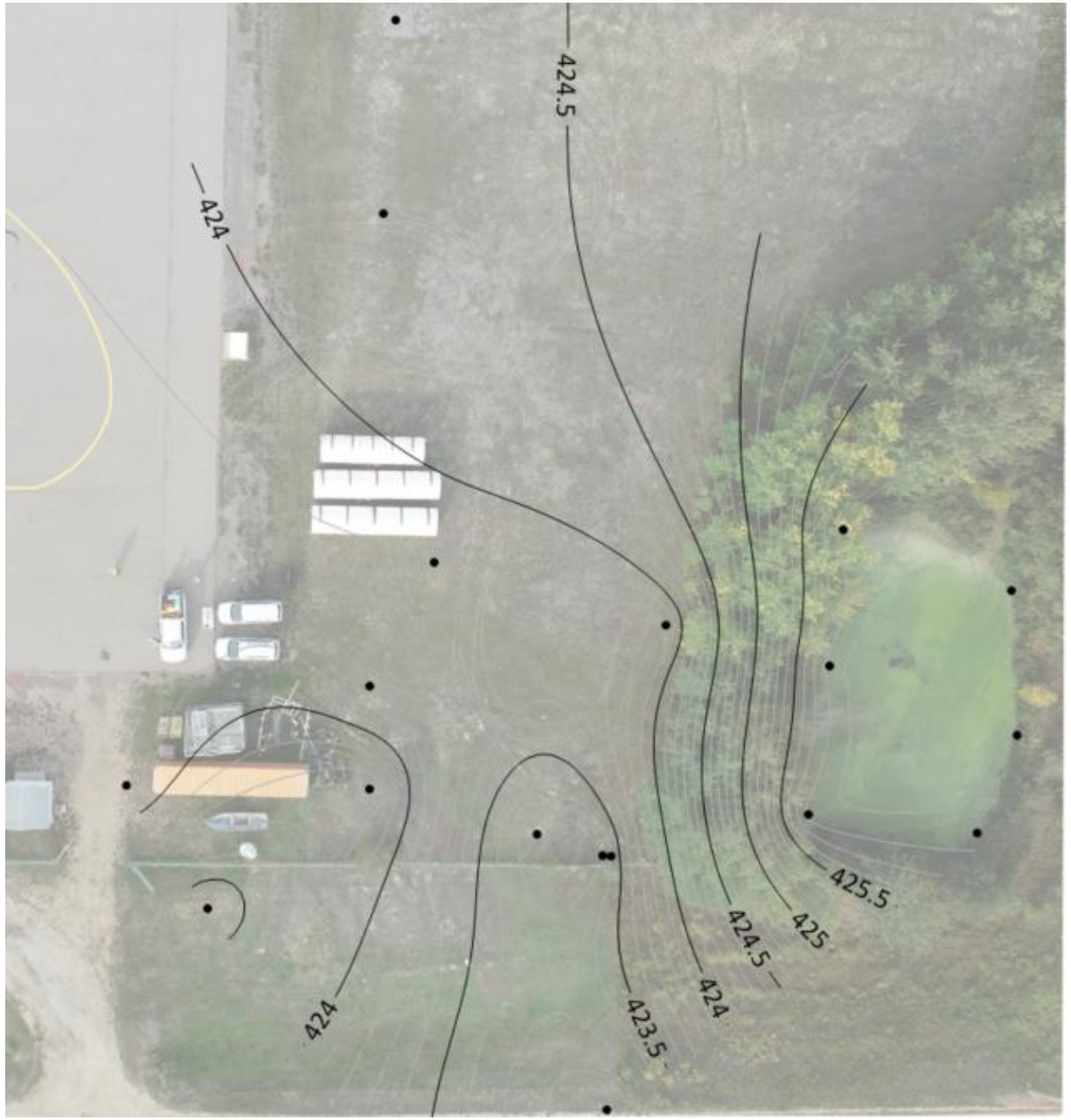
Groundwater Flow

- Generally from northwest to southeast
- Pond influences shallow groundwater flow
- Measured hydraulic conductivity ranged from $1x10^{-6}$ m/s to $3x10^{-7}$ m/s
- Horizontal gradient of about 0.02
- Vertical gradient of about 0.03 downward
- Advective velocity in the order of 1 - 2 m/year



LNAPL Characteristics and Behaviour

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LNAPL Characteristics and Behaviour

- Sheens and high COPC concentrations (*e.g.,* near solubility limits) have been observed over the course of site monitoring since 2015, and the presence of LNAPL has been suspected.
- In May 2021, LNAPL was encountered during sampling of well MW104A. LNAPL was not observed with the interface probe….
- Not observed in any wells in 2022 and June 2023, but.

LNAPL Characteristics and Behaviour

- LNAPL was again encountered during sampling of well MW104A in Sept 23.
- Water levels at the site are at the lowest since monitoring began.
- LNAPL has not been observed in any other wells.
- Not migrating (source has been removed), probably not mobile (only flows into well when water level is lowered), and likely residual.

LNAPL = 100LL Aviation Gasoline

LNAPL = 100LL Aviation Gasoline

Dissolved Phase Characteristics and Behaviour

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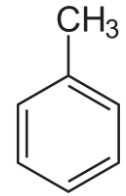
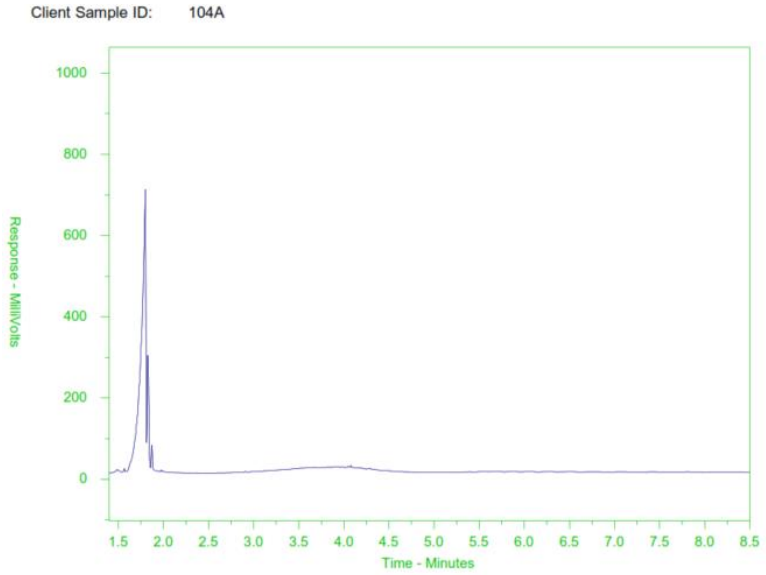
Toluene is the significant COC

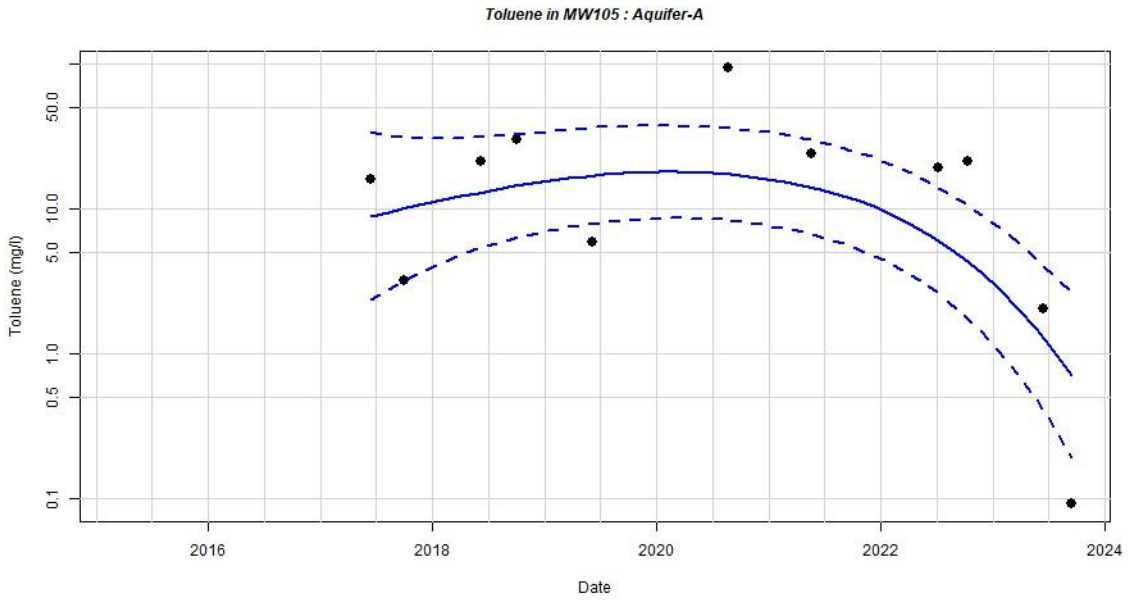


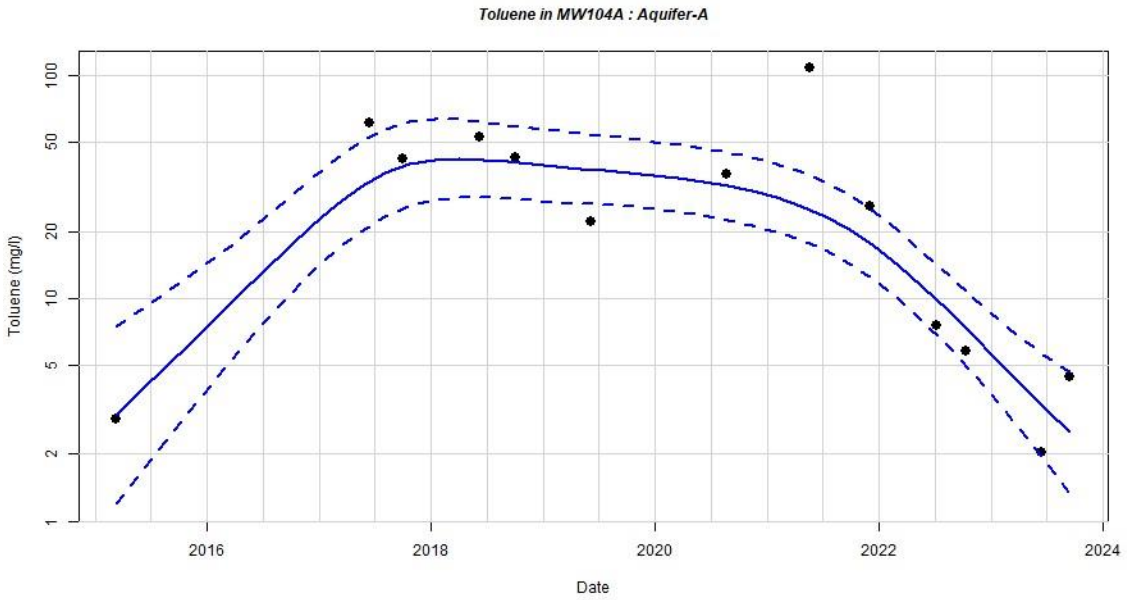
- Toluene has the highest relative concentrations and the highest magnitude of exceedance
- Relatively high mobility in soil/groundwater

Parameter		Benzene	Toluene	Ethylbenzene	Xylenes	PHC F1	PHC F2	Lead
SEQG[1]		0.005	0.021	0.14	0.09	2.2	1.1	0.01
MW105	14-Jun-17	0.0091	16	<0.00040	0.0083	27	6.9	0.021
	28-Sep-17	0.0031	3.2	<0.00040	0.0064	8.2	16	0.095
	5-Jun-18	0.014	21	<0.00040	0.015	35	10	0.083
	3-Oct-18	0.0072	30	0.00054	0.021	41	5.1	0.052
	5-Jun-19	0.0033	5.8	<0.00040	0.0057	14	15	0.041
	19-Aug-20	0.0224	93.1	0.00085	0.0243	360	7.7	0.0794
	19-May-21	0.101	23.8	<0.00050	0.0159	1430	45.3	0.0947
	7-Jul-22	0.0136	19	<0.00050	0.0137	28.9	41.1	0.0763
	12-Oct-22	0.0139	21.3	<0.00050	0.0115	21.4	9.19	0.111
	13-Jun-23	0.00226	2.03	<0.00050	0.00307	12.9	2.8	0.135
	12-Sep-23	0.00408	0.0906	<0.00050	0.103	22.3	23.1	0.104



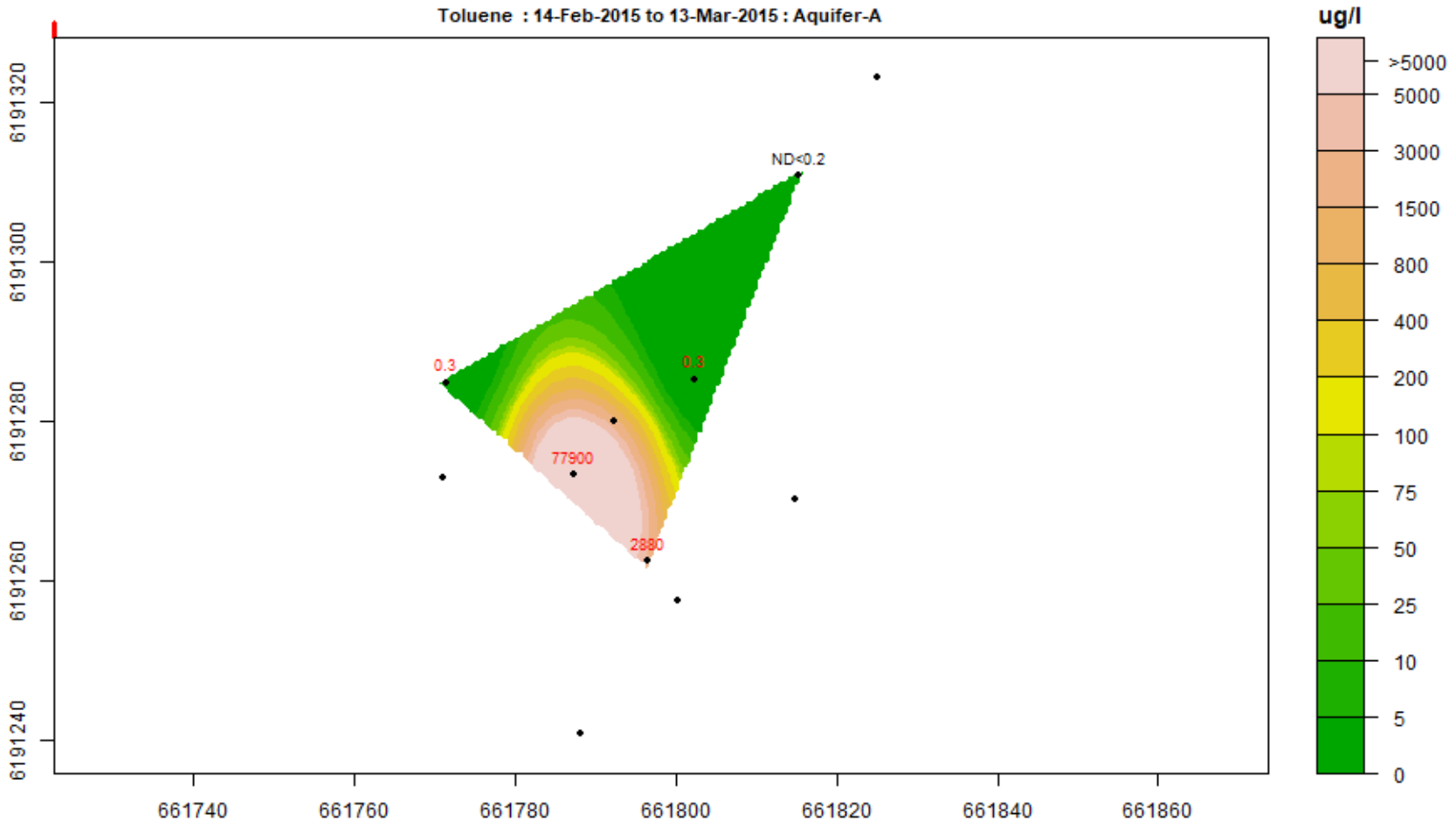
Toluene concentrations within the plume core

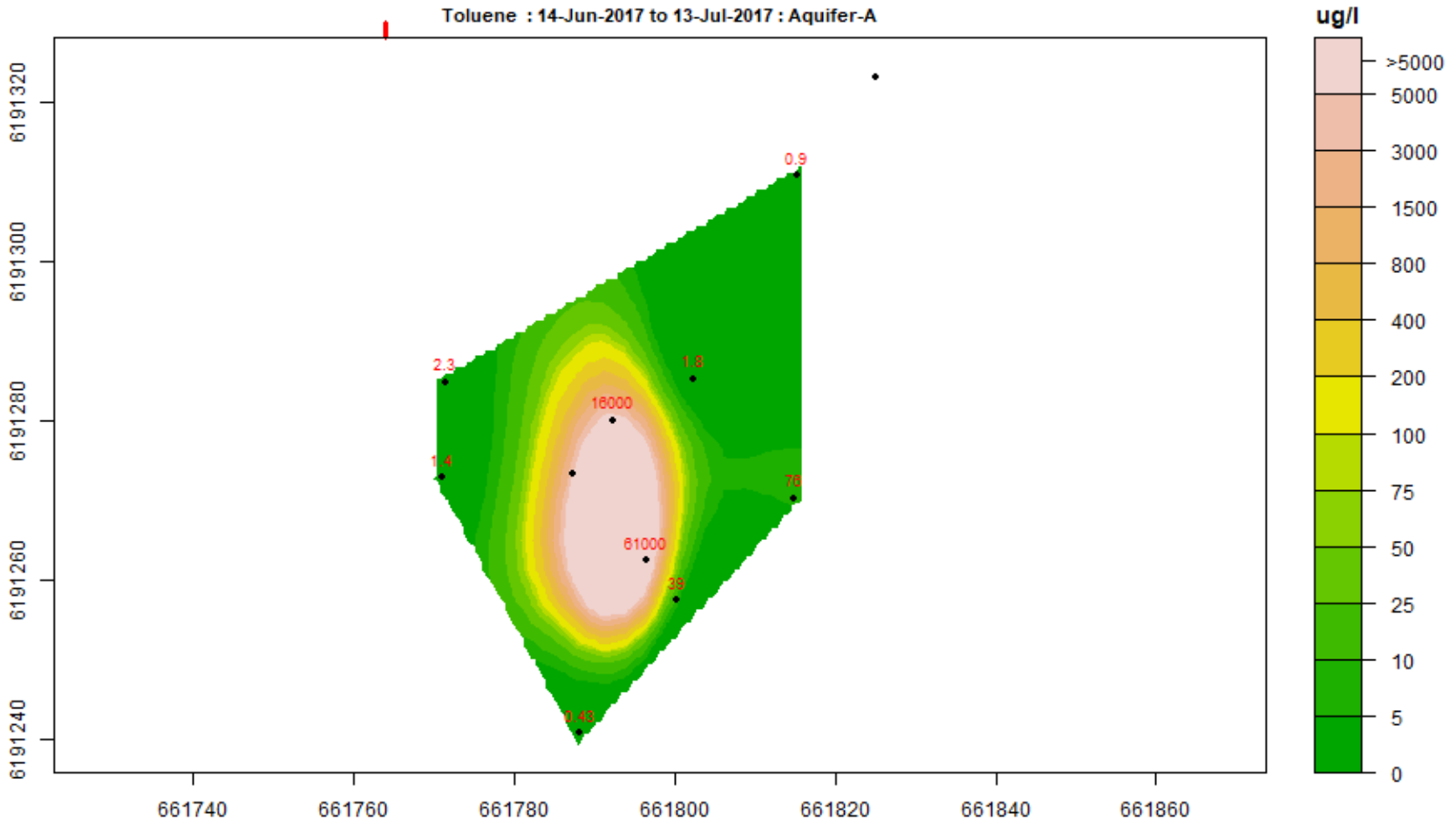




Slug tracer breakthrough curve or biodegradation?

Plume Extent over Time




Toluene : 14-Jun-2017 to 13-Jul-2017 : Aquifer-A
ug/l
>5000
5000
3000
1500
800
400
200
100
75
50
25
10
5
0
0.9
2.3
1.8
16000
1.4
76
61000
39
0.43
6191320
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661780
661800
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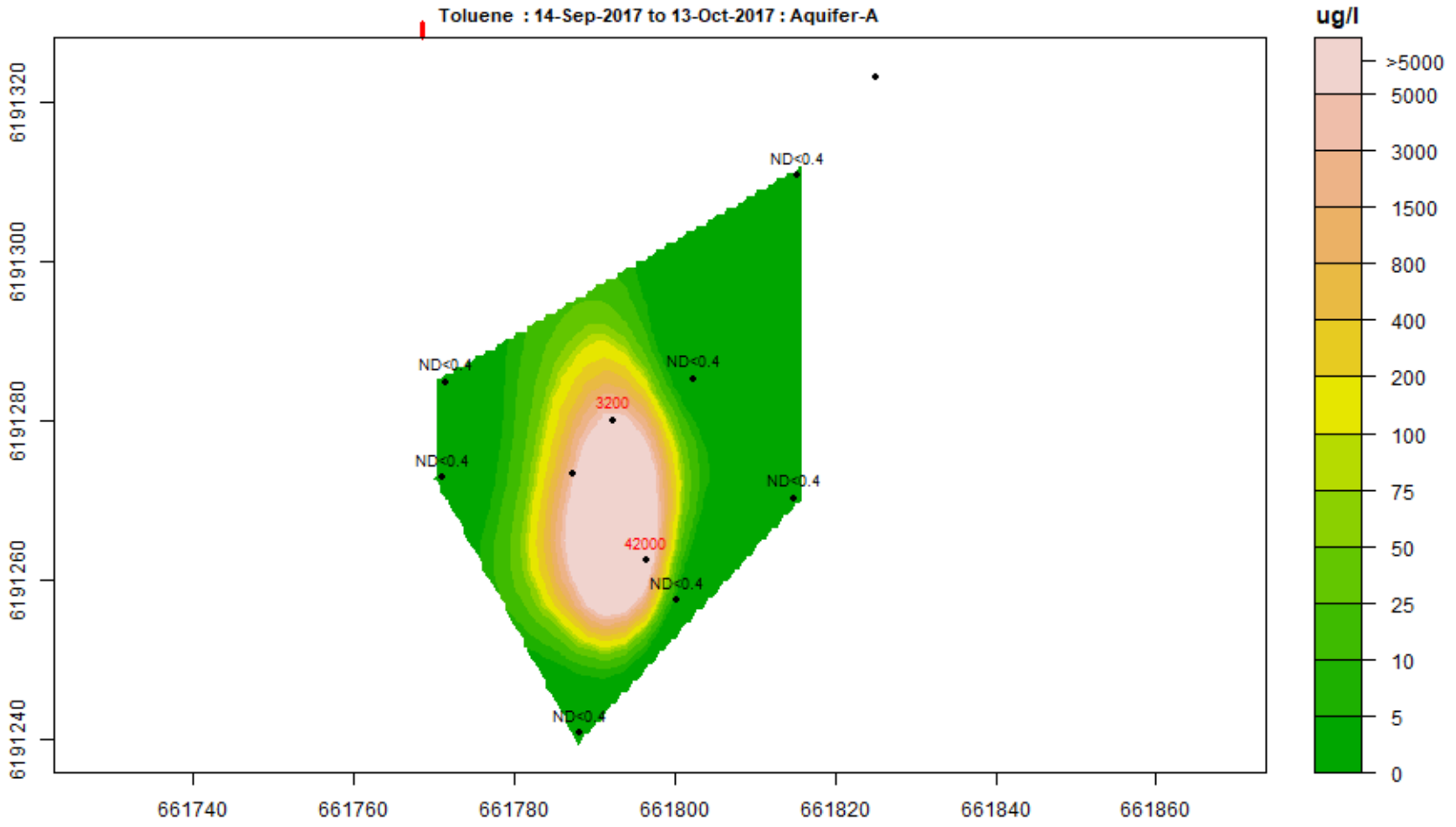
661840
661860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ug/l
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10
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ND<0.4
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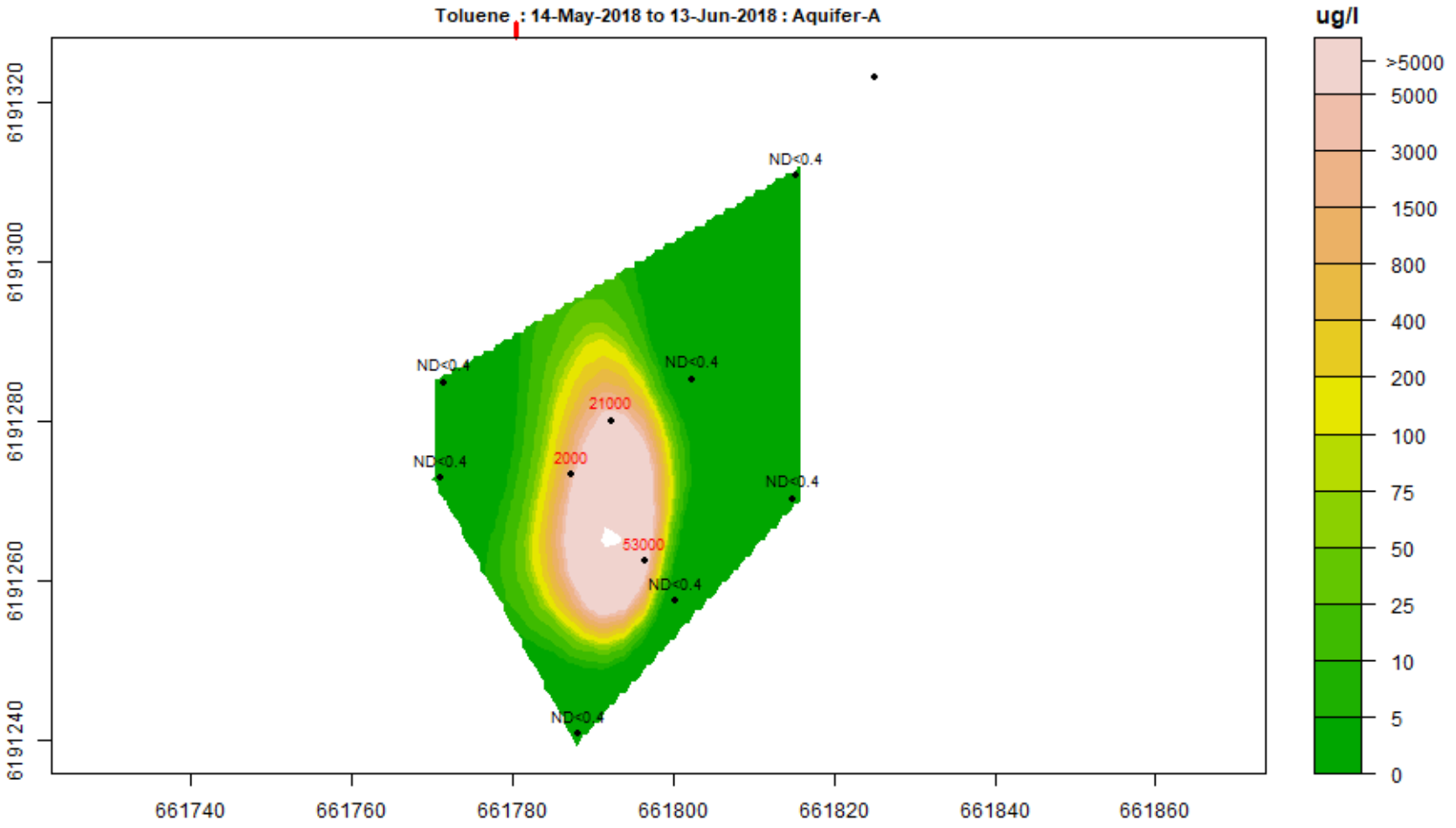
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ug/l
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100
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10
5
0
6191320
6191300
6191280
6191260
6191240
661740
661760
661780
661800
661820
661840
661860
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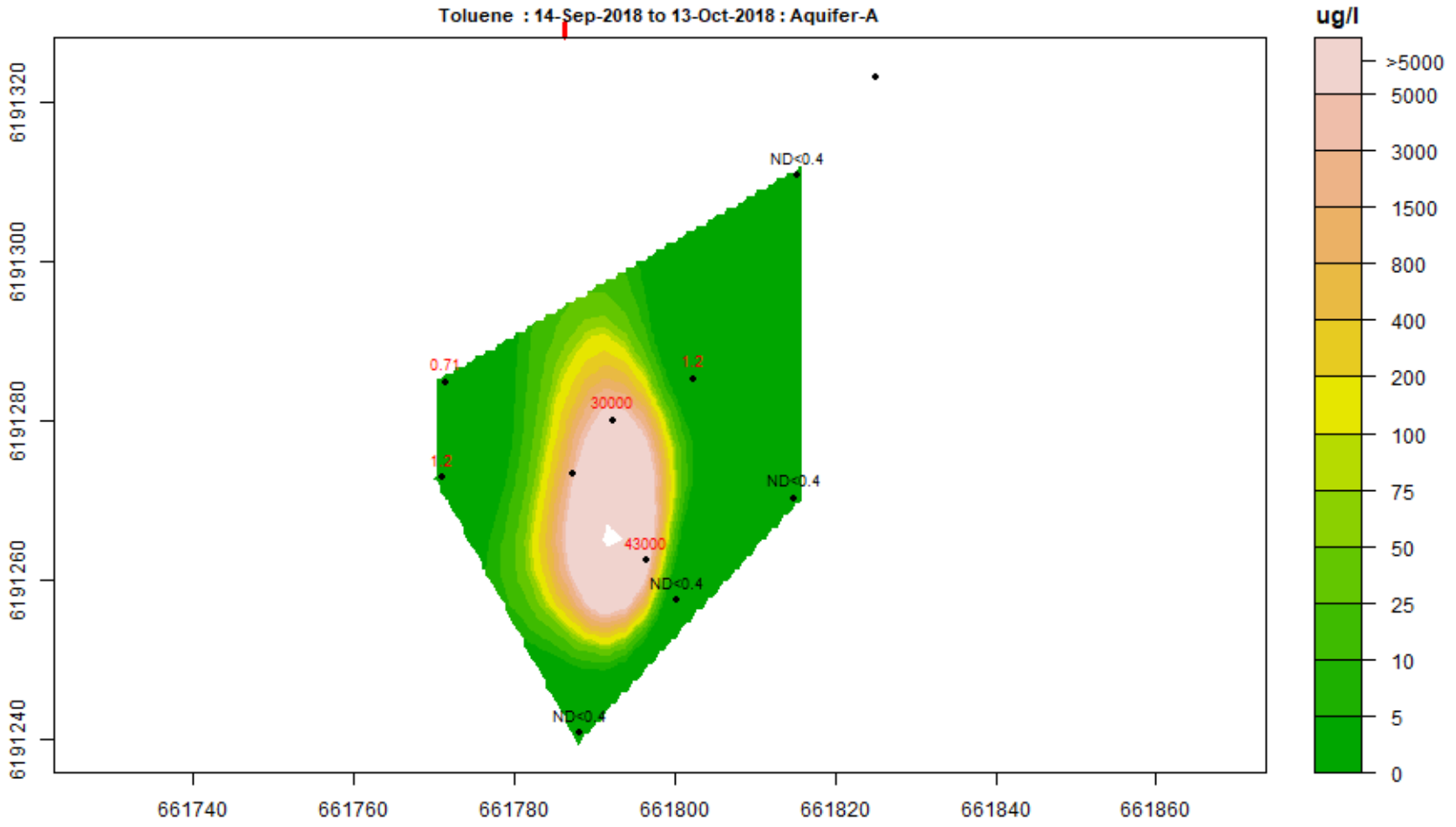
Toluene : 14-Sep-2018 to 13-Oct-2018 : Aquifer-A
ug/l
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400
200
100
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10
5
0
ND<0.4
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1.2
30000
1.2
ND<0.4
43000
ND<0.4
ND<0.4
6191320
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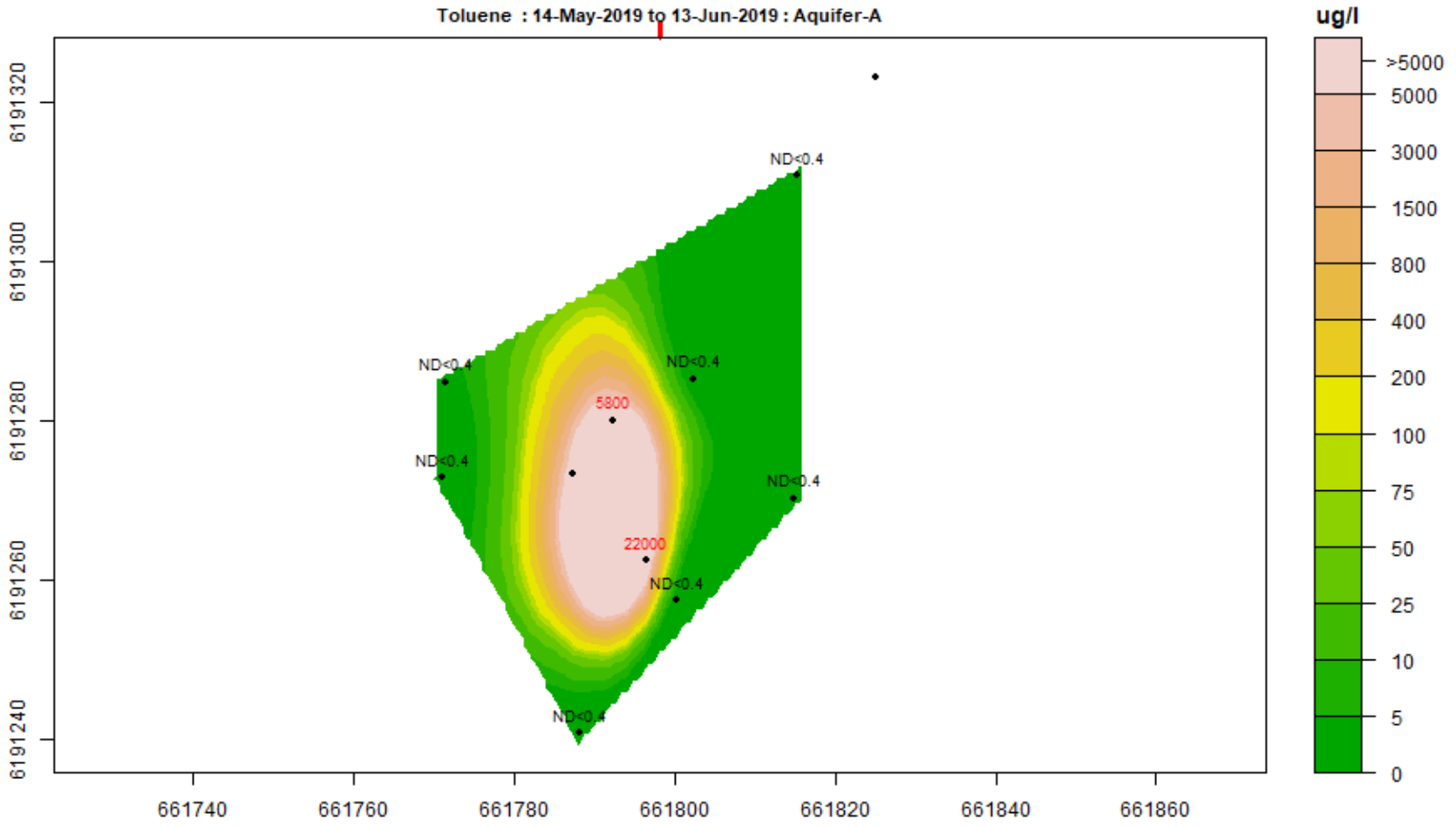
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ug/l
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5000
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800
400
200
100
75
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25
10
5
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6191300
6191280
6191260
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ND<0.4
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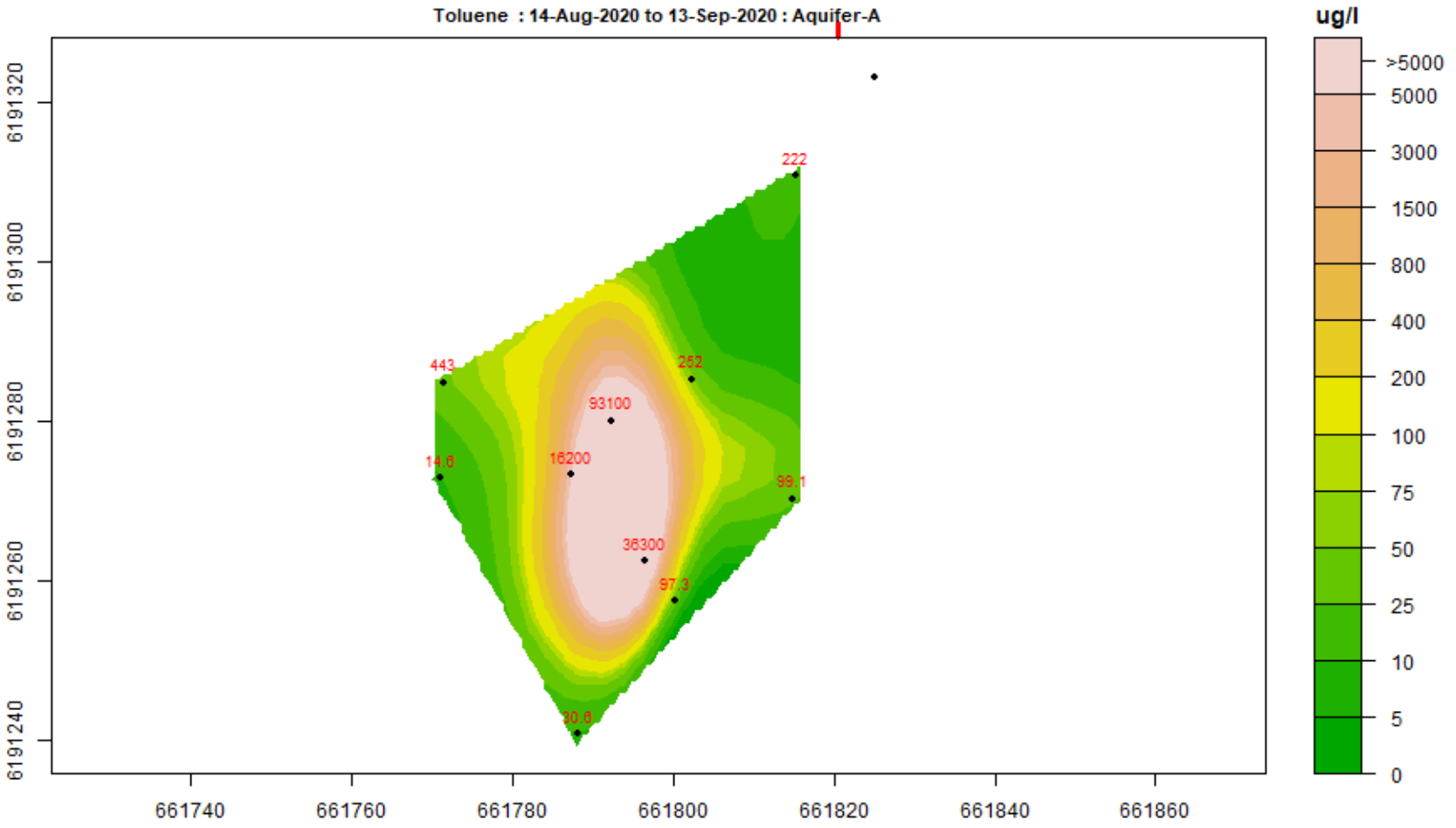
ND<0.4
ND<0.4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ug/l
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1500
800
400
200
100
75
50
25
10
5
0
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6191300
6191280
6191260
6191240
661740
661760
661780
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661860
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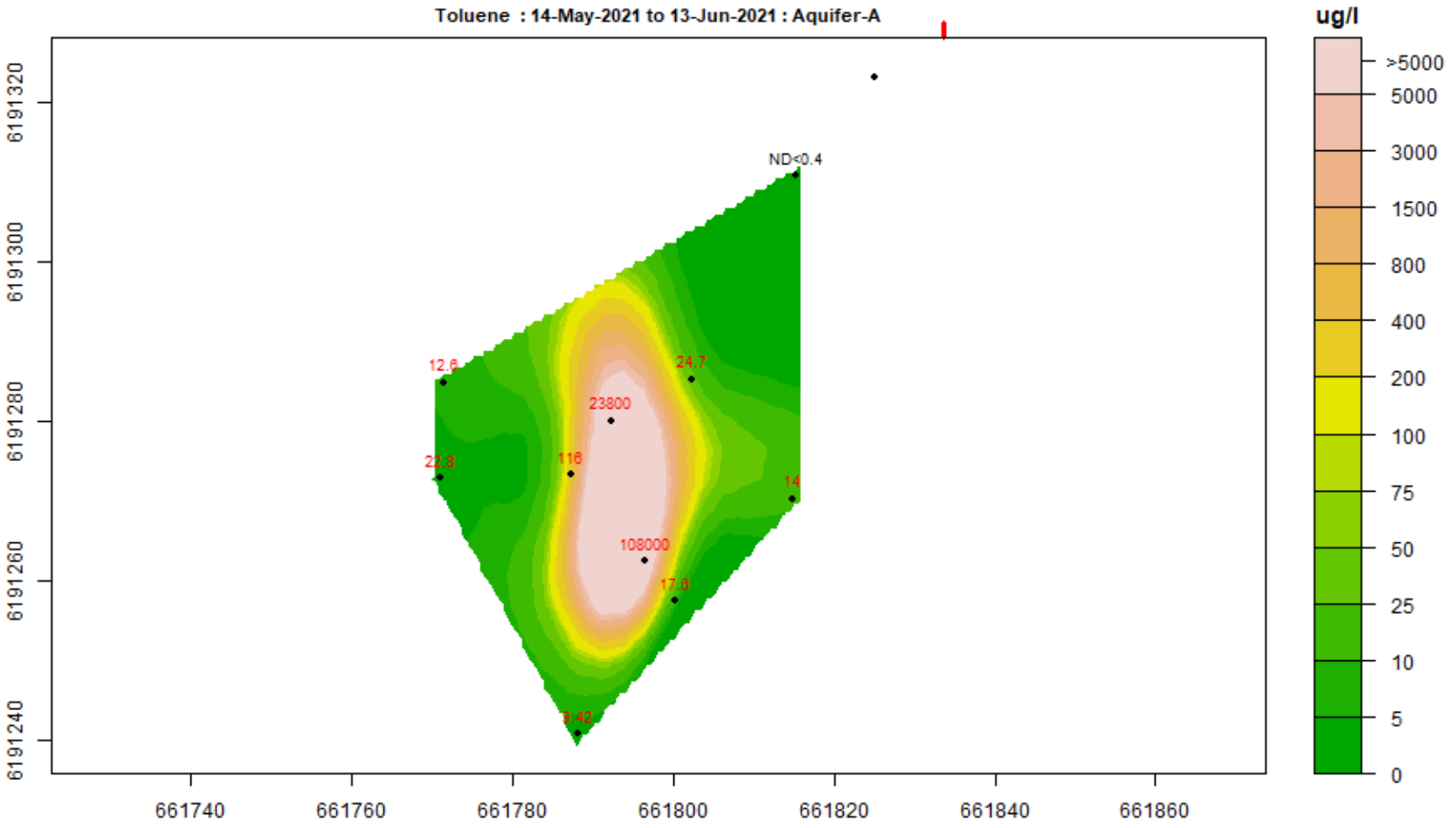
252
93100
14.6
16200
99.1
36300
97.3
30.6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ug/l
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1500
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400
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100
75
50
25
10
5
0
ND<0.4
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22.8
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14
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17.6
6.42
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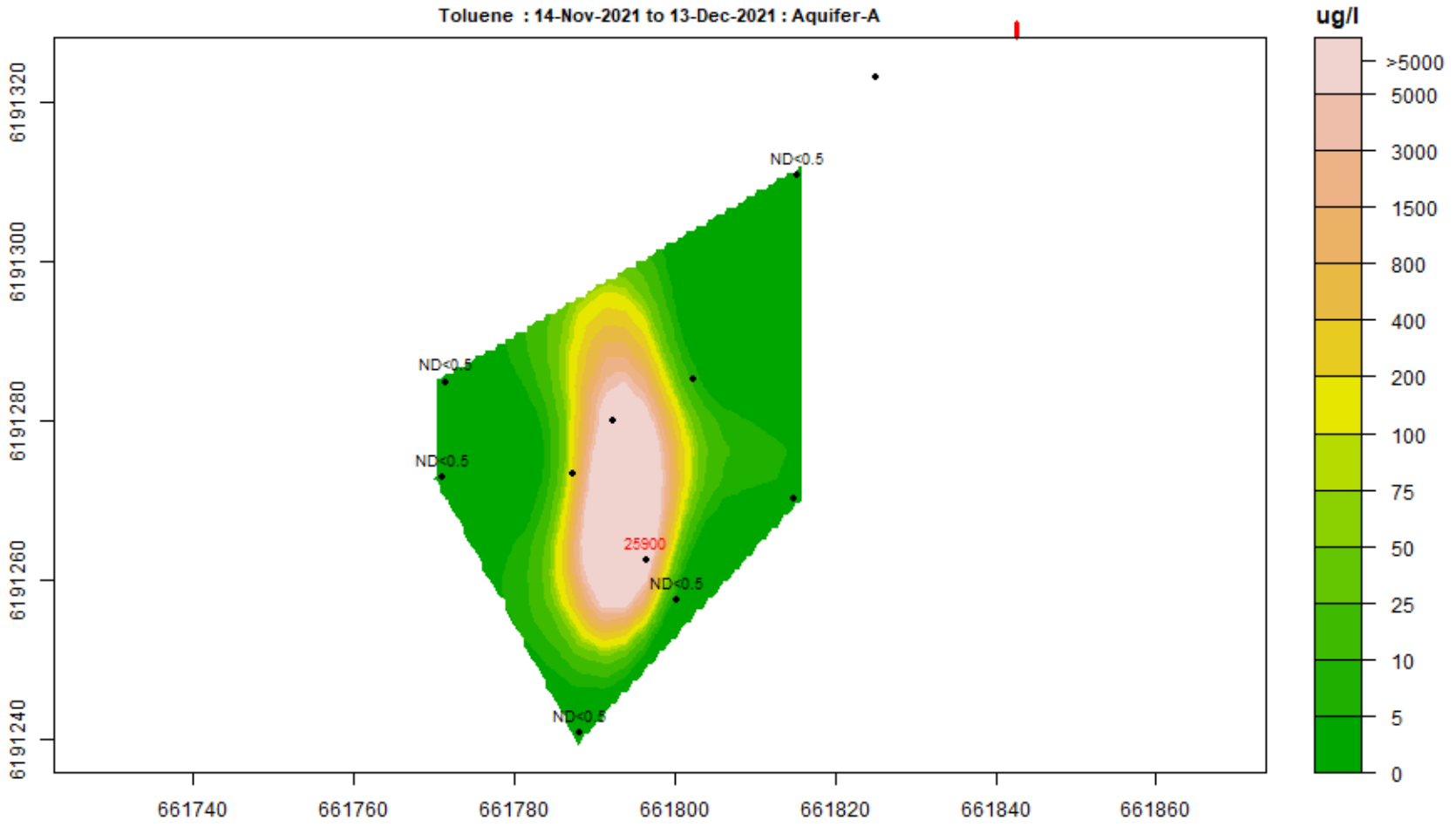
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ug/l
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ND<0.5
ND<0.5
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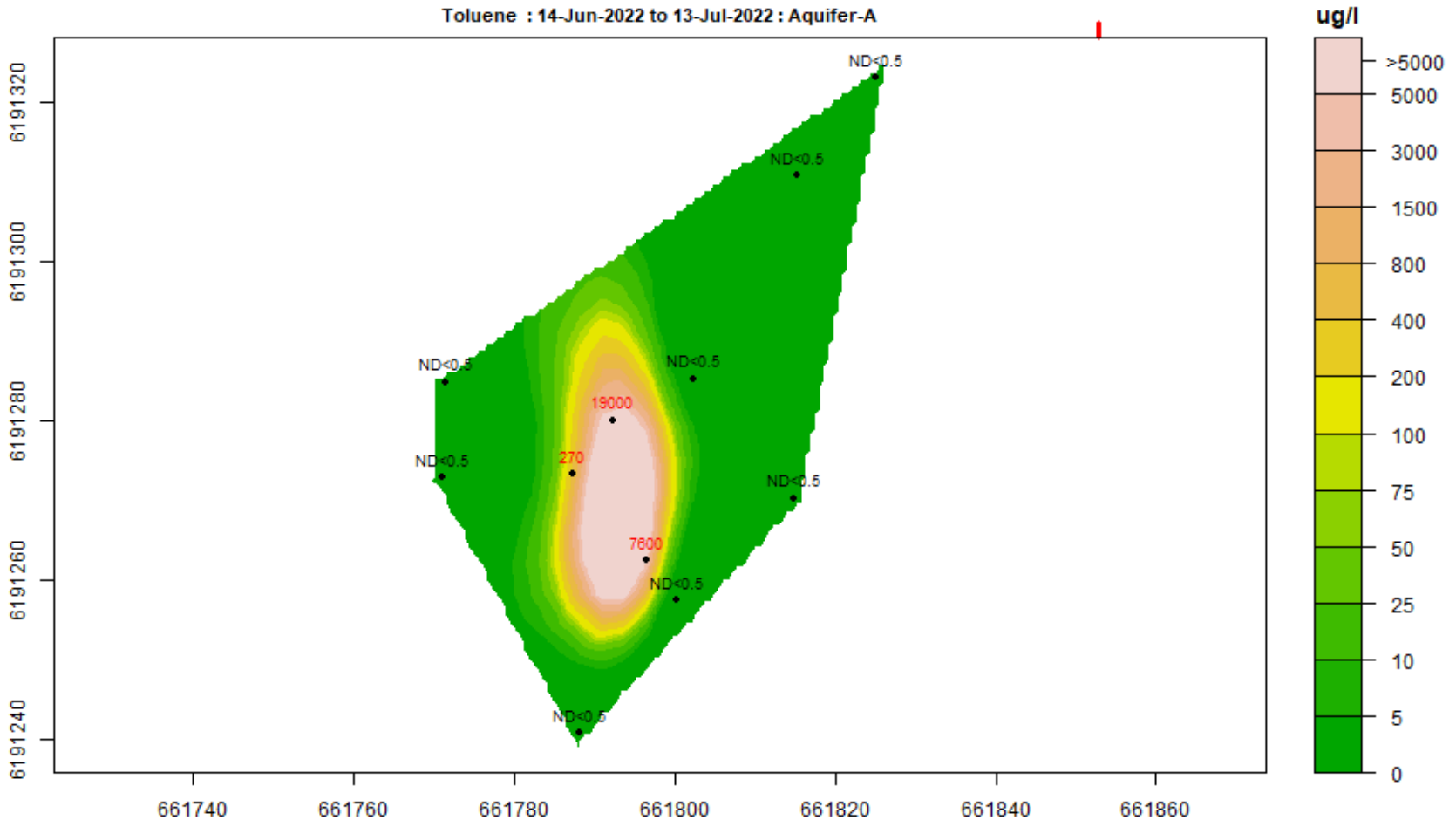
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ug/l
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5000
3000
1500
800
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200
100
75
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25
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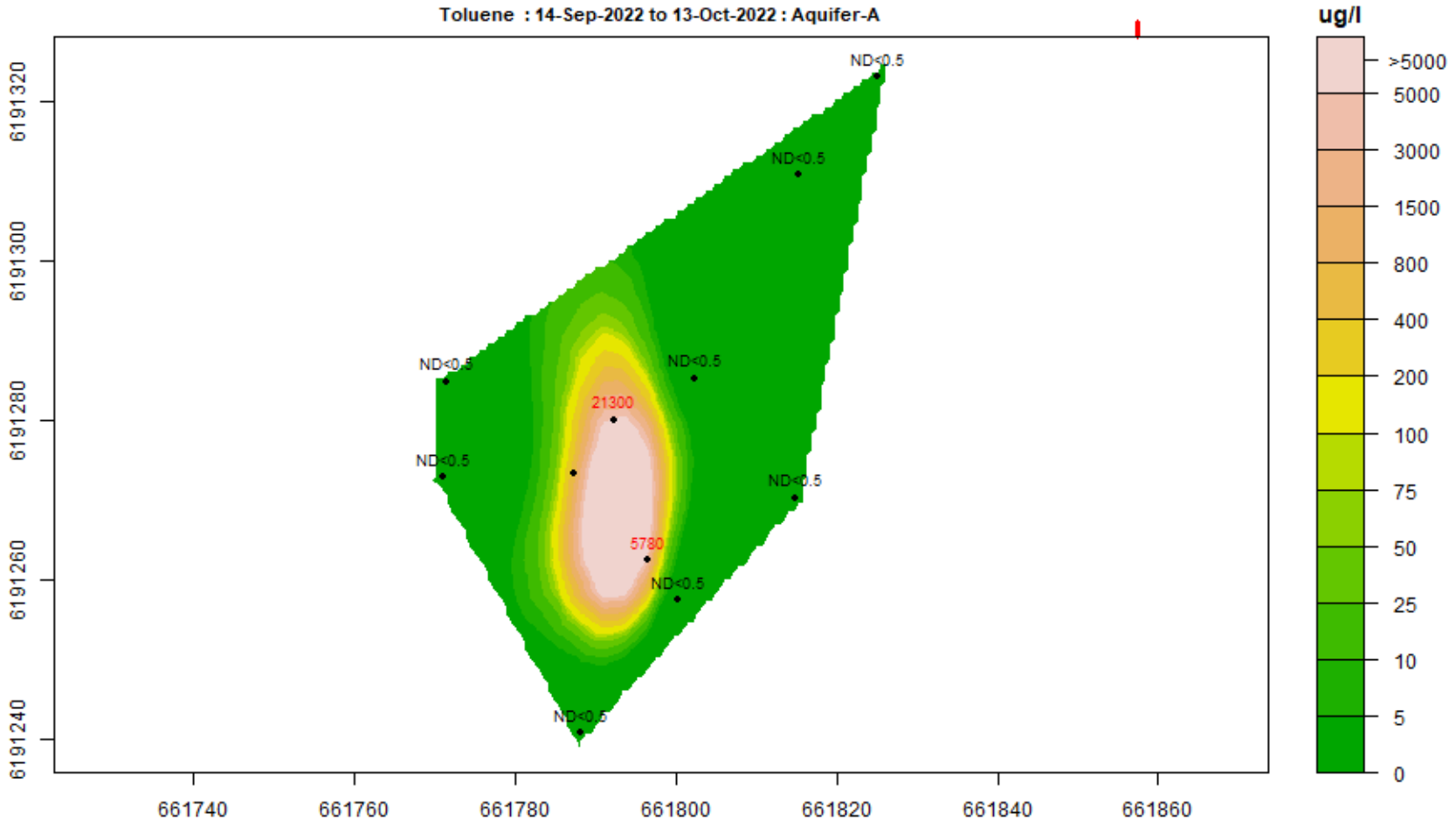
Toluene : 14-Sep-2022 to 13-Oct-2022 : Aquifer-A
ug/l
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5000
3000
1500
800
400
200
100
75
50
25
10
5
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ND<0.5
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ND<0.5
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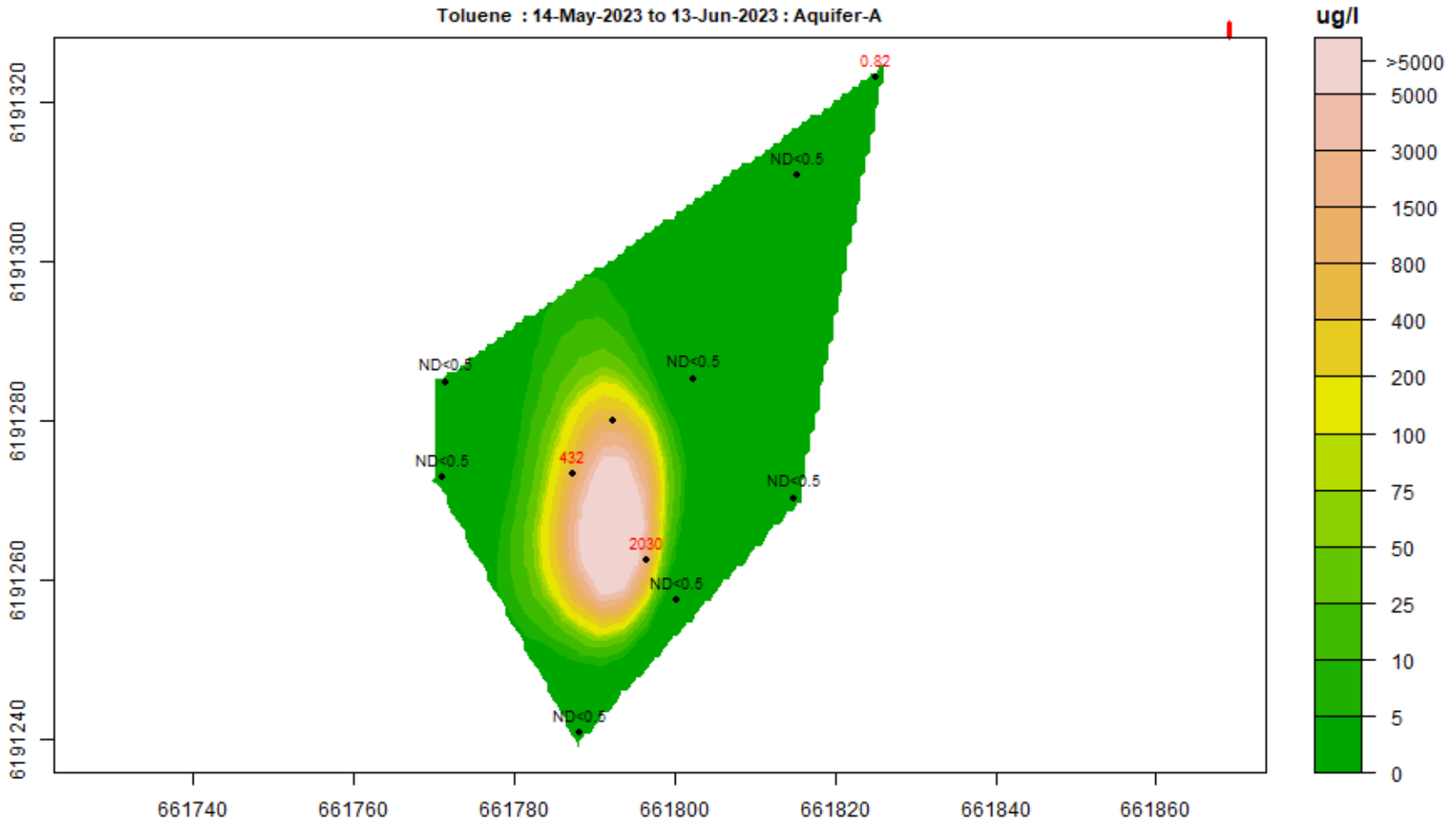
Toluene : 14-May-2023 to 13-Jun-2023 : Aquifer-A
ug/l
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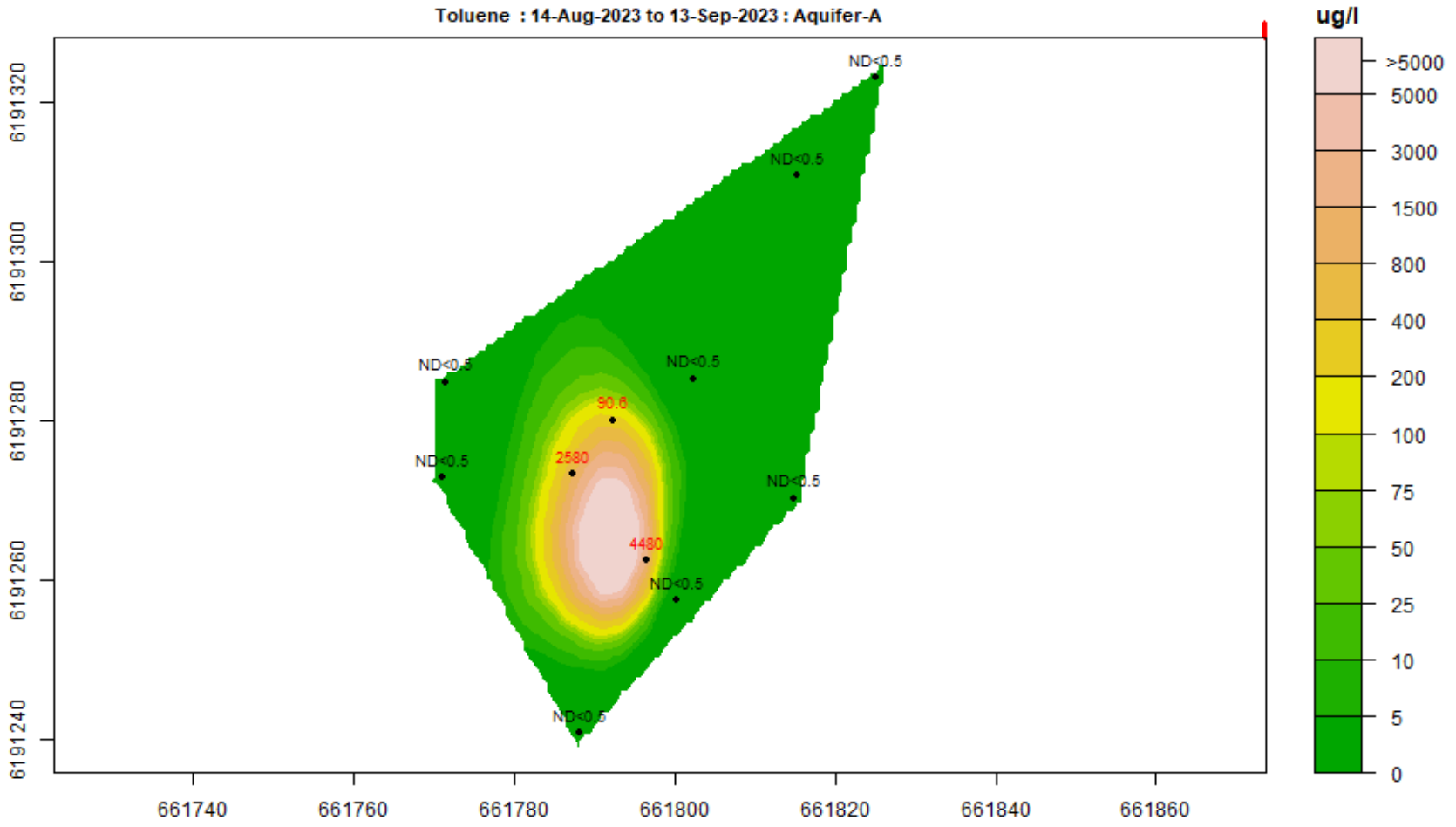
Toluene : 14-Aug-2023 to 13-Sep-2023 : Aquifer-A
ug/l
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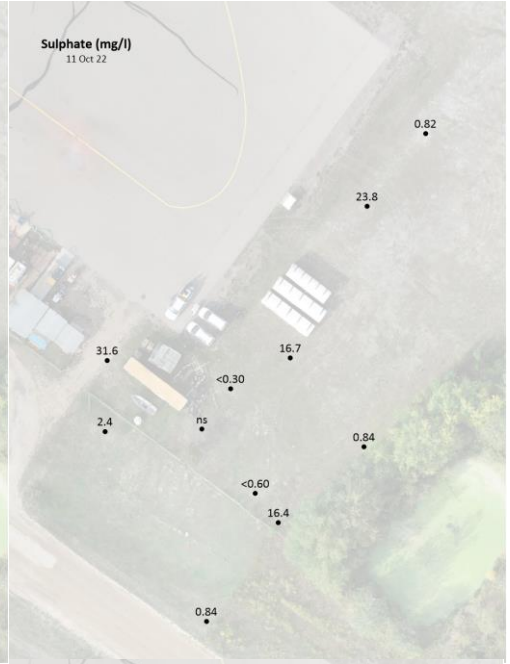
6191280
6191260
6191240
661740
661760
661780
661800
661820
661840
661860


Dissolved Oxygen (mg/l)
11 Oct 22
7.5
7.4
6.6
6.21
2.1
6.31
ns
5.6
2.9
5.9
6.8

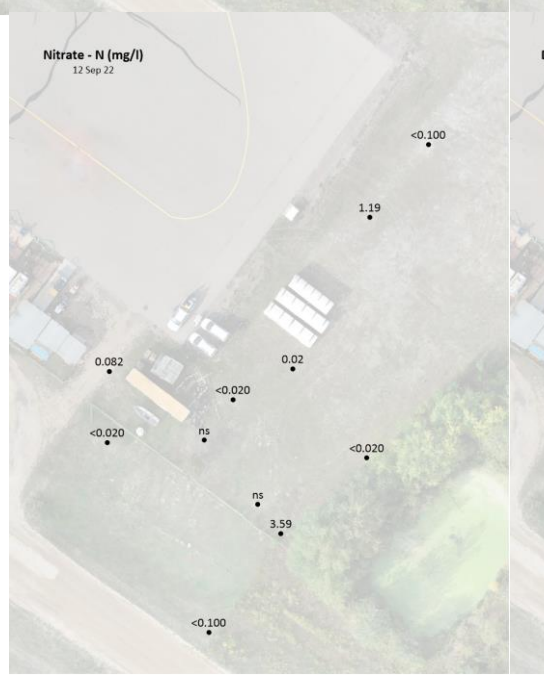

Nitrate - N (mg/l)
11 Oct 22
<0.020
0.288
<0.020
<0.040
<0.020
<0.040
ns
0.049
<0.040
2.48
<0.020

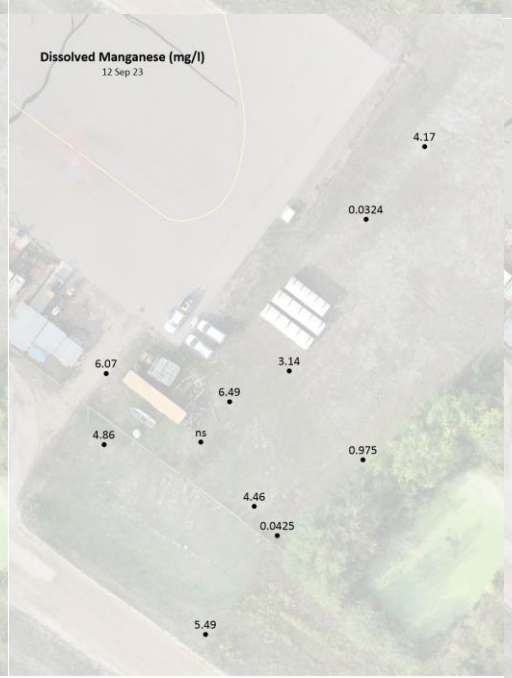

Dissolved Manganese (mg/l)
11 Oct 22
4.62
0.161
6.52
3.99
9.86
3.67
ns
1.04
4.78
0.052
3.86


Dissolved Iron (mg/l)
11 Oct 22
0.537
<0.030
2.43
0.031
7.19
2.57
ns
2.55
0.429
<0.030
0.145


Sulphate (mg/l)
11 Oct 22
0.82
23.8
31.6
16.7
<0.30
2.4
ns
0.84
<0.60
16.4
0.84


PLEASE STAND BY


Nitrate - N (mg/l)
12 Sep 22
<0.100
1.19
0.082
0.02
<0.020
<0.020
ns
<0.020
ns
3.59
<0.100

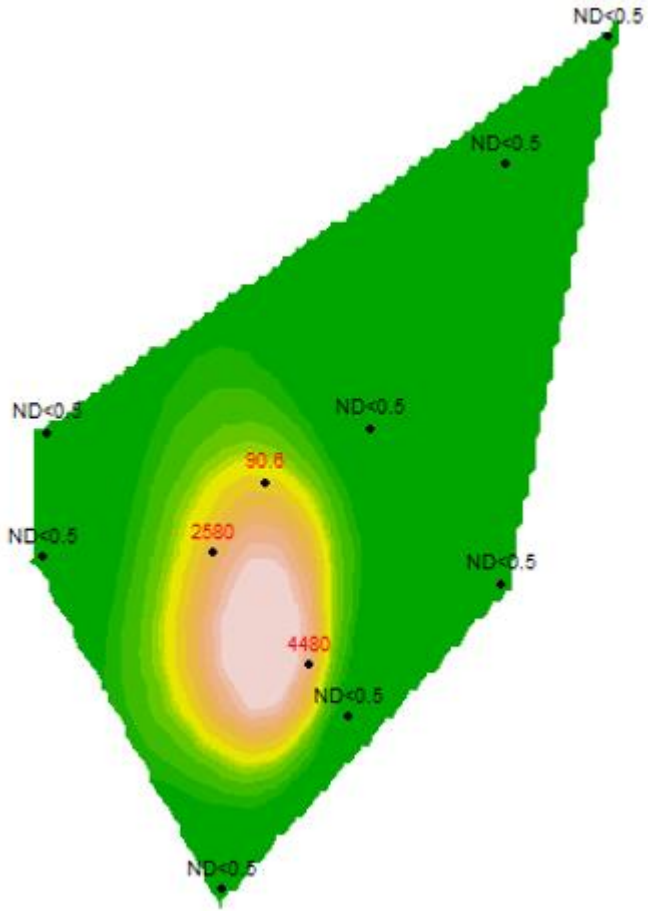

Dissolved Manganese (mg/l)
12 Sep 23
4.17
0.0324
6.07
3.14
6.49
4.86
ns
0.975
4.46
0.0425
5.49


Dissolved Iron (mg/l)
12 Sep 23
1.72
0.055
1.47
9.27
30.8
19.5
ns
6.57
62.7
<0.010
13.2


Sulphate (mg/l)
12 Sep 23
2.22
8.11
22.7
25.4
<0.30
7.69
ns
3.64
ns
17.6
<1.50

Dissolved phase behaviour

- Plume extent appears to be stable or even shrinking (steady-state)
- Dissolved concentrations of toluene appear to be decreasing with the plume
- There is evidence of biodegradation of the dissolved phase (iron and sulphate reduction – going anaerobic).



Vapour Phase Characteristics and Behaviour

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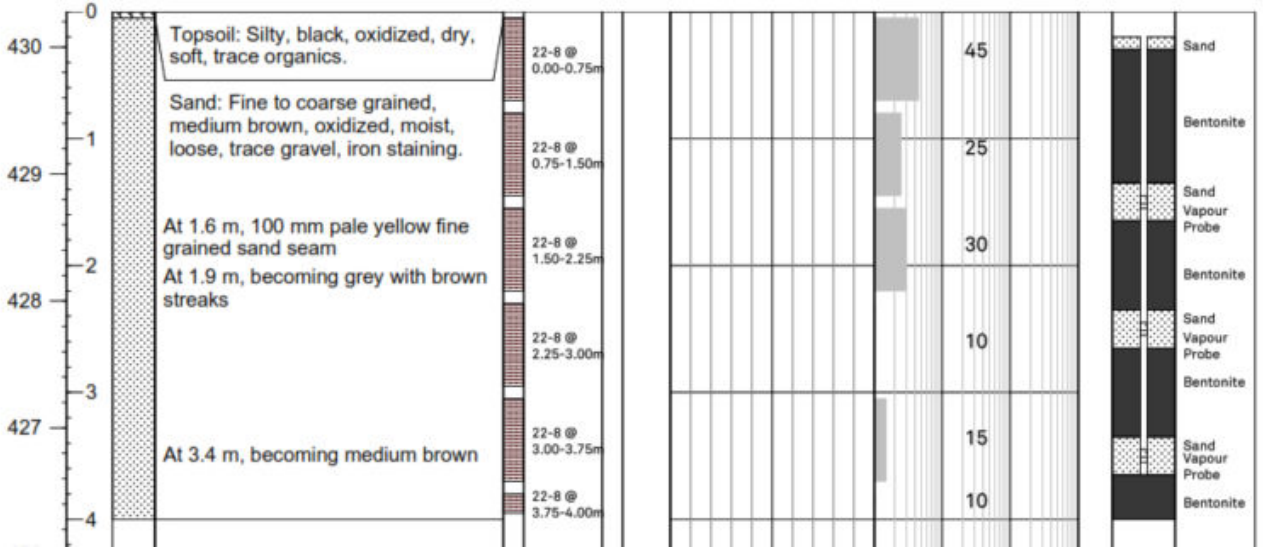
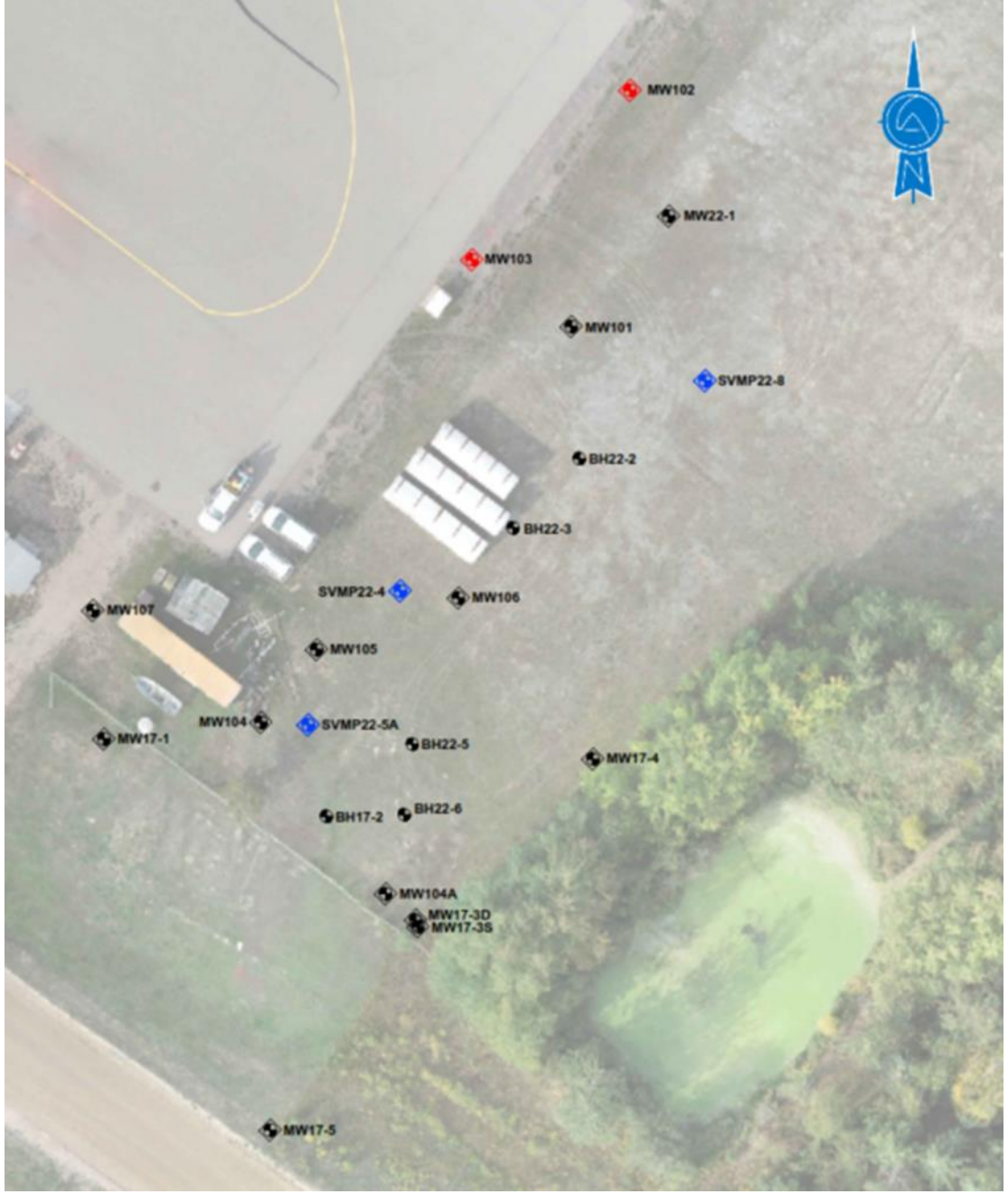
Nested vapour probes

- Three sets of vapour probes
- Two in the plume, one outside the plume
- Three sampling points per nest in the vadose zone.





Vapour behaviour in the vadose zone

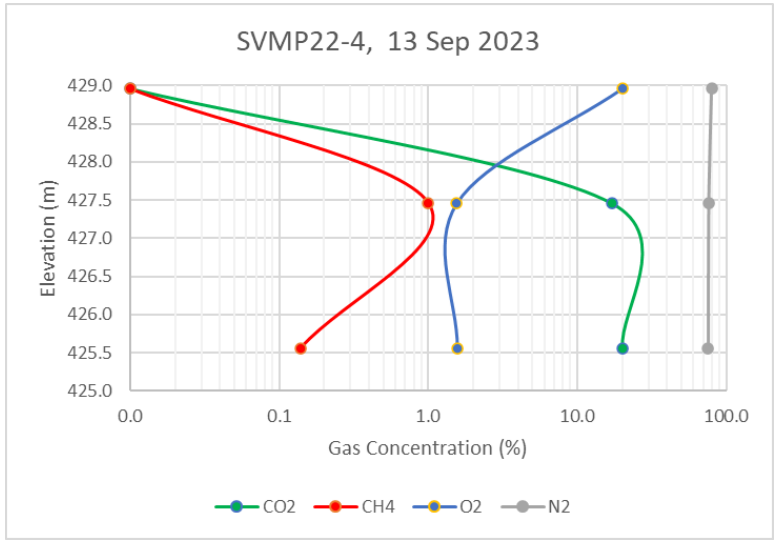
Two processes:

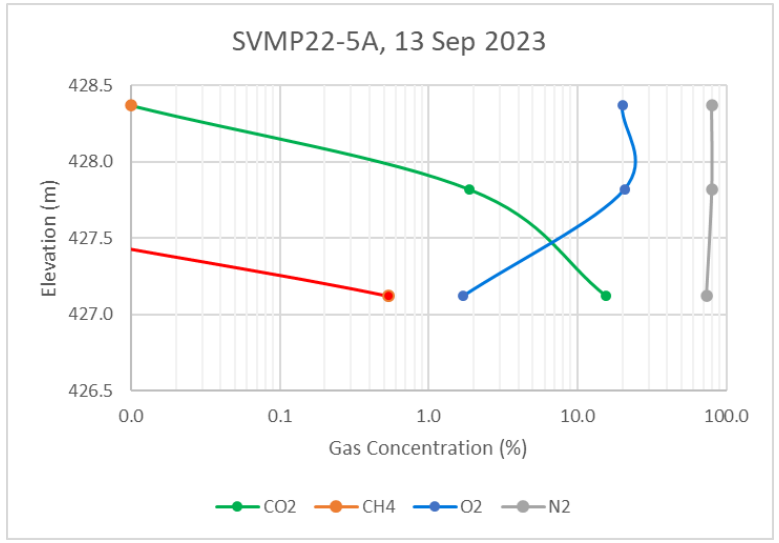
- Methanogenesis

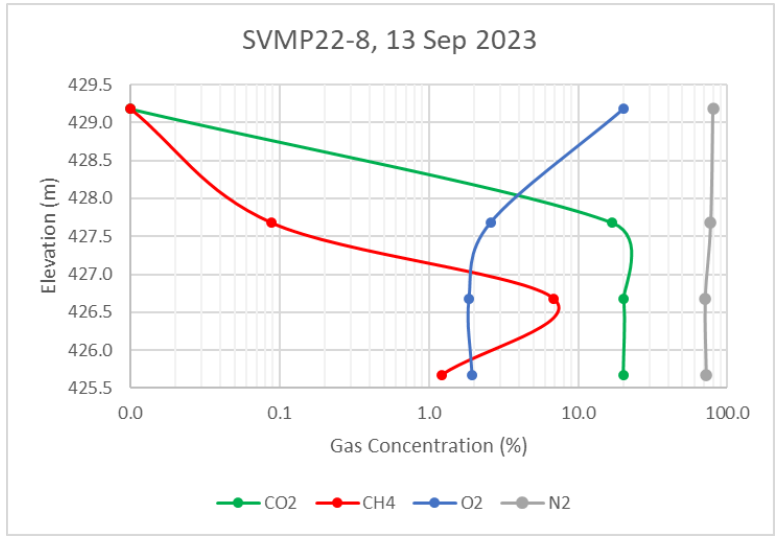
$C_8H_{18} + 3.5\ H_20 \Rightarrow 1.75\ C0_2\ (g) + 6.25\ CH_4\ (g)$

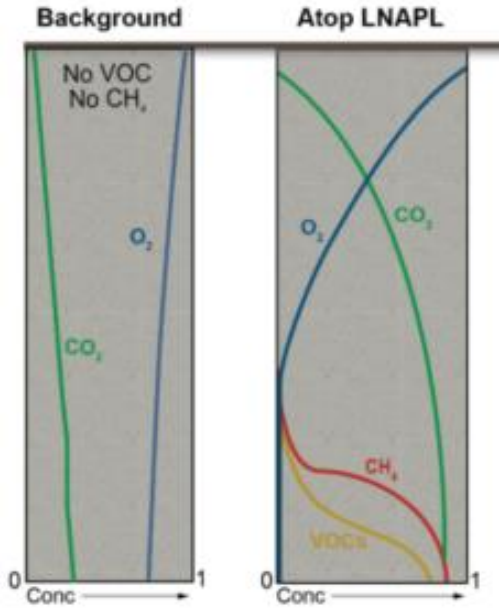
- Methane oxidation

$CH_4 + 2\ 0_2 \Rightarrow C0_2\ (g) + H_20$



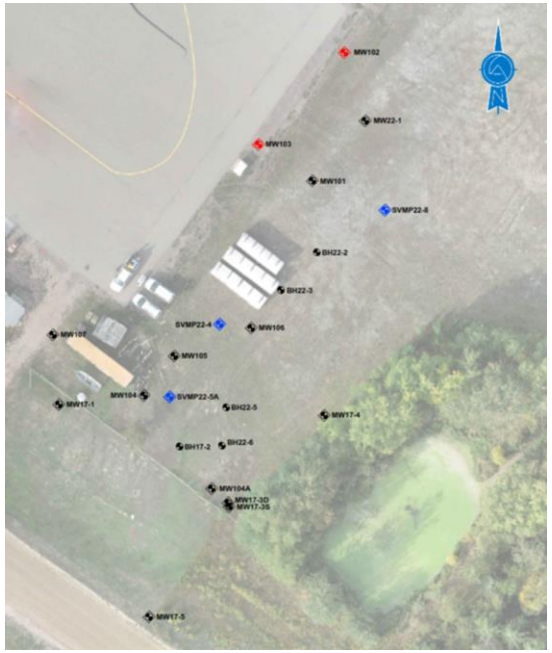






From CRCCare TR44.

- CH_4 is being produced
- $C0_2$ is being produced
- 0_2 is being consumed
- Concentrations at the ground surface are not known
- CH_4 oxidation may not be entirely complete in the vadose zone (needs to be considered in flux estimates)
- We need a good background location
- We need a nest near MW104A



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Conclusions

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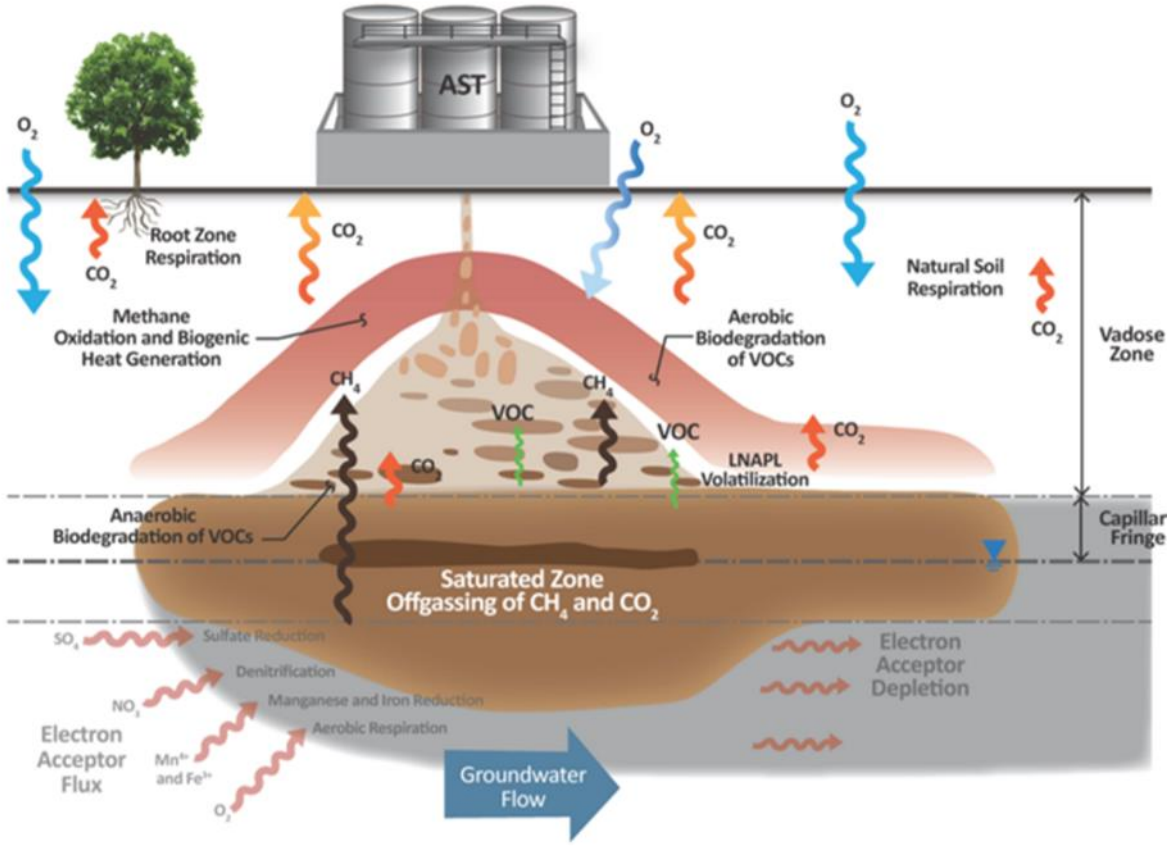
Is NSZD a possible option for site management?

- We have a good CSM.
- Source zone is delineated and appears stable.
- Dissolved phase is delineated and appears stable.
- Biodegradation in the vapour and dissolved phases appears to be active.
- The COC are light and amenable to biodegradation.
- The plume is small and the site is remote.



What's next?

- Estimation of LNAPL volume and mass
- Quantification of CO_2 and CH_4 flux and calculation of depletion rates in the vapour phase (DCC survey)
- Calculation of depletion rates in the dissolved phase
- Estimation of time to compliance
- Just one more well….
- Engagement with SK MOE

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