BEIT HAKEREM
REMEDIATION OPTIONS APPRAISAL

1. INTRODUCTION

Ramboll UK Ltd (Ramboll) is acting as a subconsultant (International Consultant) to LDD (Local Consultant) in its delivery of remediation advice relating to the Environmental Services Company (ESC, the ultimate Client) regarding the IMI Beit Hakerem project.

Ramboll would be acting as the International Consultant, and LDD as the Local Consultant. Ramboll (formerly Environ) and LDD have worked closely together on numerous ground contamination projects in Israel and have a proven track record of joint successful and delivery of complex technical solutions. A Memorandum of Understanding exists between the two companies, dated 19th July 2018.

In this report, where joint LDD and Ramboll assessments and recommendations are being described, this will be presented as 'LDD-Ramboll'.

The IMI Beit Hakerem site is a 40 dunam (4 hectare) area adjacent to the Beit Hakerem neighbourhood in Jerusalem. The site was formerly occupied by Israel Military Industries (IMI) between 1951 and 1997 and was used as a factory for the manufacture of metal products. The former manufacturing activities at the site utilised organic solvents, which has led to ground contamination. It is understood that the site was closed and decommissioned in the late 1990s and is now intended for unrestricted redevelopment. Numerous environmental surveys have been undertaken at the site, including of soil, soil gas, and groundwater. The soil profile has been described as being mostly karst bedrock (overlain by overburden soils up to 6m deep); the groundwater is greater than 100m deep. The main contaminants at the site include chlorinated organic compounds, TCE and PCE.

1.1 Objectives, Scope, and report layout

The objectives of this project are to provide remediation advice to ESC regarding the IMI Beit Hakerem site. Specifically, the scope of works is defined as follows:

- **Chapter 1 - Review of the Conceptual Site Model (CSM) for Beit Hakerem and provision of case studies for three similar projects** from around the world, presenting the type and concentration of contaminant, treatment, remediation targets attained, timelines, and project budget.
- **Chapter 2 - Consideration of remediation options** to treat pollution and prevent its spread in soil gas and groundwater to include the advantages and disadvantages of each option in terms of execution costs, timeframes, effectivity, reliability, feasibility, etc. The assessment also includes environmental, regulatory and statutory considerations. The options are anticipated to be consistent with those discussed in the literature review in Chapter 1 above, subject to site specific issues identified through a review of the CSM.
- **Chapter 3 - The examination of construction options** at the site with an emphasis on basements and combining treatment systems with the buildings at the site. The examination will be carried out in light of the rehabilitation alternatives presented in Chapter 1, including an examination of the effects of construction on the site and its surroundings, such as sealing the surface soil and excavation (pumping / suction of pollution from the buildings in the area).
- **Chapter 4 - Recommendation of the preferred remediation strategy** and outline for moving forward.
- **Chapter 5 - Preparation of a Work Plan** to execute the recommended remediation strategy including detailed plan for a pilot, examination whether additional surveys are required within the site or outside of the site, timeframes and approximate cost ranges.

This report comprises Chapters 1-5 of the Project and corresponding appendices. The report is structured according to the scope of work above and each chapter includes a contents page and introduction for easy navigation.

BEIT HAKEREM
REMEDIATION OPTIONS APPRAISAL: CHAPTER 1 (LITERATURE REVIEW)

BEIT HAKEREM
CHAPTER 1 (LITERATURE REVIEW)

Project No.	**1620007286**
Issue No.	**04**
Date	**27/07/2020**
Made by	**Hannah Lewis (Ramboll) & Allison Busgang (LDD)**
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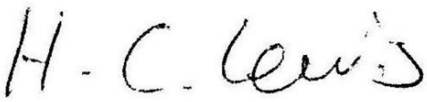
Approved by	**Hannah Lewis (Ramboll)**



Made by:

Checked/Approved by:

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Version Control Log

Revision	Date	Made by	Checked by	Approved by	Description
01	14/02/20	HL/AB	RB	HL	First Issue
02	19/02/20	HL/AB	RB	HL	Revised report following LDD comments.
03	17/05/20	HL/AB	-	-	Response to client comments (tracked changes)
04	27/07/20	HL/AB	MP	HL	Final Report

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CONTENTS

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This document forms 'Chapter 1' of the project and presents the literature review of three case studies together with LDD-Ramboll's interpretation of the CSM for the IMI Beit Hakerem site, including the assumed remedial targets that will be carried forward to the Remediation Options Assessment (to be undertaken in Chapter 2).

1.2 Report Layout

This report comprises Chapter 1 of the Project and following this Introduction is structured as follows:

- **Sections 2 & 3**: describes the site, its former use and its environmental setting and presents a summary of previous investigations. The information in these sections is a summary of site survey information presented in the Dekonta's May 2018 CSM report[1] for the site and of subsequent LDD surveys at the site.
- **Section 4:** summarises LDD-Ramboll's current understanding of the Conceptual Site Model (CSM) as prepared by Dekonta and provides an update following LDD's 2018-2019 investigations.
- **Section 5**: provides LDD-Ramboll's assumptions that we propose to use as a basis for the future Remediation Options Assessment (ROA).
- **Section 6:** presents LDD-Ramboll's understandings of the remediation objectives and target concentrations.
- **Sections 7-9:** present Ramboll's three literature reviews.

[1] Dekonta, Risk Assessment for the Beit Ha'kerem Site, Conceptual Site Model 2017, Revised version May 2018, ref. 117116, dated 2nd May 2018.

2. SITE SUMMARY AND SETTING

2.1 Site Description

IMI Beit-HaKerem site is a former manufacturing facility located in Western Jerusalem, in the Beit Hakerem City District. Between 1951 and 1997, IMI (Israeli Military Industries, presently IMI Systems) operated its 'Netz' facility at the site; this facility has since been relocated.

The site has an area of approximately 4 hectares; however, the extent of the original IMI plant is believed to extend beyond this (to approximately 7 hectares). It is understood that the original south-western part of the plant has already been redeveloped as of 1991 and is currently occupied by residential properties.

Surrounding Area

The site is located in a largely residential area, surrounded by the residential houses of Bet Ha´Kerem and Ramat Ha´Kerem.

Development Plans

The site is intended to be redeveloped for unrestricted re-use. No building plans have yet been approved but the ultimate plan should eventually include residences and commercial centres.

2.1.1 Site History

The former manufacturing facility at the site was operational between the years of 1951 and 1997, and produced different metal products for the security industries of Israel, including warheads and fuses.

The production processes in the different departments were complex and included cutting, assembling, metal processing, colouring and decolouring, welding, surface treatments and electrical wiring machines.

As a result of the different production activities, the facility also handled explosives, solvents, alkaline materials, metals and chemicals generating dangerous waste. Furthermore, some of the buildings at the site included asbestos and there was also use of oils and fuels. There is also understood to have been a wastewater treatment plant (WWTP), likely to have been located in the southern part of the site

After the production was fully ceased in 1997, the site buildings were demolished (except for a few retaining walls), and the site remains undeveloped. It is reported that all underground structures were removed during the demolition works, albeit with some drainage infrastructure remaining that serves properties offsite are understood to remain in-situ.

2.1.2 Site Geology

Regional Geology

The site is located in the recharge zone of the Mountain Aquifer (which is the most important Israeli source of the natural drinking water). Groundwater of this aquifer is present in fractured and karstified rocks of the Cenomanian Judea Group that consists of dolomite and limestone with some thin marl and clay layers. The Mountain Aquifer exists as two main sub-aquifers: the Upper and the Lower sub-aquifers, which are separated by marl and clay associated with the Moza Formation (marl, clay and some limestone).

Site Geology

The entire site is covered with artificial soil composed of reworked limestone sands and gravels or reworked superficial deposits. Its thickness expands to nearly 10 m in the low-lying eastern and southern sections of the site. Fluvial sediments have also been encountered across the eastern fringe of the site, with a maximum recorded thickness of 6 m.

These reworked and superficial deposits are underlain by the Kefar Sha'ul Formation (part of the Judea Group), which consists of well-bedded limestone, chalk and some marl.

2.1.3 Hydrogeology

Overview

In the site area, the depth to groundwater is approximately 100 m in case of the Upper Cenomanian aquifer and some 277 m in the case of the Lower Cenomanian aquifer. Both aquifers are unconfined here.

The site is located very close to the regional watershed divide of the Mountain aquifer from where water flows to the west or to the east. The groundwater surface in the area of the divide is flat with seasonal fluctuations in the order of meters. The watershed divide line cannot be considered as a fully static sharp line; there is a possibility of the general groundwater outflow from the site being towards both the eastern and western flanks of the Mountain aquifer(s).

However, based on date from on-site and nearby monitoring wells, groundwater in the close vicinity of the site was reported to flow to the south–south-east.

There are no permanent or semi-permanent surface water streams at the site or in its wider site surroundings.

2.1.4 Groundwater Levels

There are four monitoring wells on-site which target the Upper sub aquifer; groundwater levels in these wells are presented in Section 3.4.2 (Ramboll Table 3.2).

There are understood to be no Lower Aquifer wells on the site (although it is understood that one is planned); the nearest is 1.7km south of the site. Reported groundwater levels in the Lower Aquifer are typically 300-500 m a.s.l (above sea level)*. The large variations in groundwater levels in the Lower Aquifer have been attributed to the fact that these wells are used for abstraction purposes. It is reported that the maximum values could be quite close to the static water levels.*

3. PREVIOUS GROUND INVESTIGATIONS

There have been various stages of ground investigation between 1998 and 2019, undertaken by a number of different consultancies. Most of these investigations were focused on soil gas.

- Section 3.1 of this report presents the findings of previous surveys that were undertaken in 1997-2010. These historic surveys were summarised within a Phase 1 Review undertaken by LDD in 2013 and are listed below:
  - Royale Ordinance Division Survey (1997 – 1998)
  - BAE general assessment and Soil Survey (1998 – 2000)
  - IMI, Subsequent removal of soil from hot spots (2000)
  - LDD Active Soil Gas Survey (2001)
  - (unnamed author), Soil Gas Survey (2002),
  - MoEP Survey of VOC Emissions to Houses in Surroundings (2003),
  - Ludan Soil Gas Survey and Indoor Air Survey (2007 – 2010)
  - Windex Field Survey for Heavy Metals by XRF (2010)
- Section 3.2 of this report summarises the findings of a substantial on-site (passive and active) soil gas survey, and also a survey of heavy metals in soils, which was undertaken by LDD in 2013
- Section 3.3 of this report summarises the findings of a soil gas survey that focused on off-site residential areas, which was undertaken by Windex in 2015
- Section 3.4 summarises a groundwater investigation performed by Etgar engineering in 2017. A zonal soil gas survey was also undertaken by Etgar to assess the soil gas concentration at depth within the bedrock; the results of the zonal soil gas survey are summarised in Section 3.5 of this report.

The surveys listed above are summarised within the Dekonta CSM report. Since that report was written, additional soil and soil gas surveys have been undertaken by LDD (performed in 2018-2019). The latest LDD soil and soil gas surveys are presented in Section 3.6 of this report. Based on the results of the soil surveys, LDD has recommended removal of hotspots of contaminated soil within the 'overburden soils' (to approximately 6.5m depth) in areas where the Tier 1 risk based target levels have been exceeded.

3.1 1997-2010 Investigations

A desk-based Phase 1 review undertaken in 2013 by LDD summarises the results and findings of the earlier phases of investigation, highlights of which are provided below.

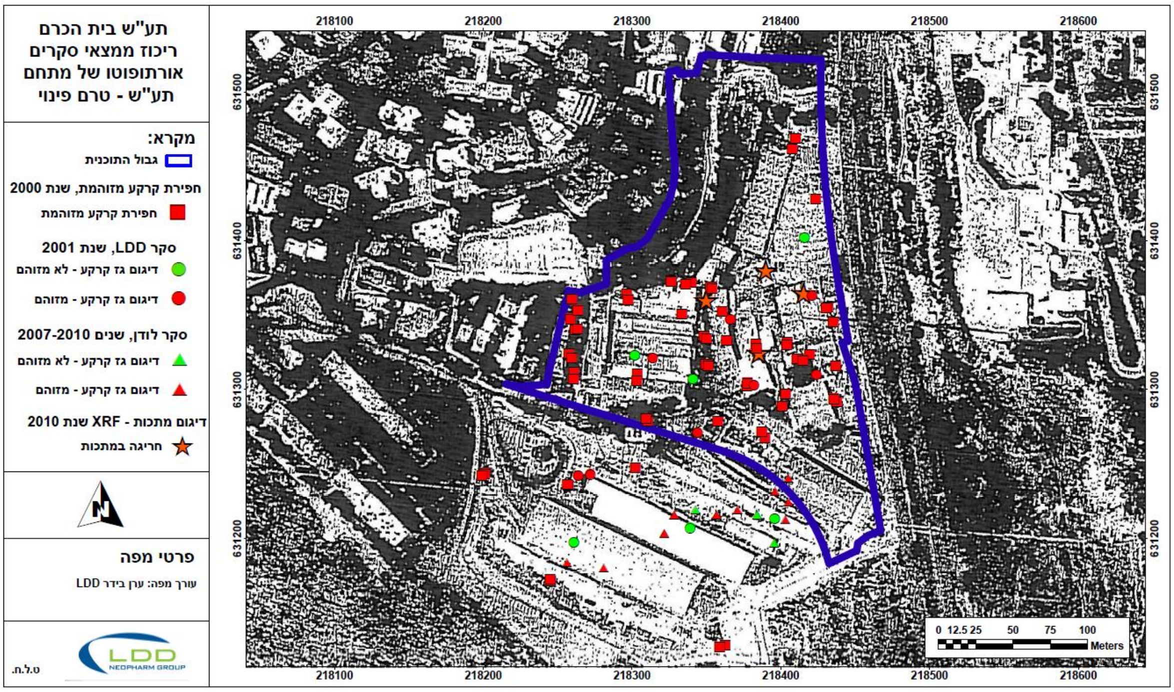
The 1998-2000 BAE investigations identified hotspots of shallow contamination (VOCs, fuel components, heavy metals, and organic halogens) which it was recommended be remediated (by excavation and off-site disposal). Ramboll Figure 1 below shows the location of the resultant contaminated soil excavations; approximately 4,450 tons of soil was excavated from 27 different locations.

The Dekonta CSM also produced figures which summarised the findings (exceedances of screening levels[2]) of the 1997-2010 investigation; Ramboll Figure 1 depicts these using a historical photograph of the site as a base-plan. The soil gas surveys summarised in Ramboll Figure 1 include both on-site and off-site locations, with multiple exceedances detected off-site as well as on-site.

[2] It is unclear what screening levels were used.

Ramboll Figure 1 – Location of Contaminated Soil Excavations pre-2019 *(Figure 10 of the May 2018 Dekonta CSM report)*

Ramboll Figure 2 – Summary of pre-2010 soil and soil gas survey findings *(Figure 15 of the May 2018 Dekonta CSM report)*



3.2 2013 Soil Gas Surveys (LDD)

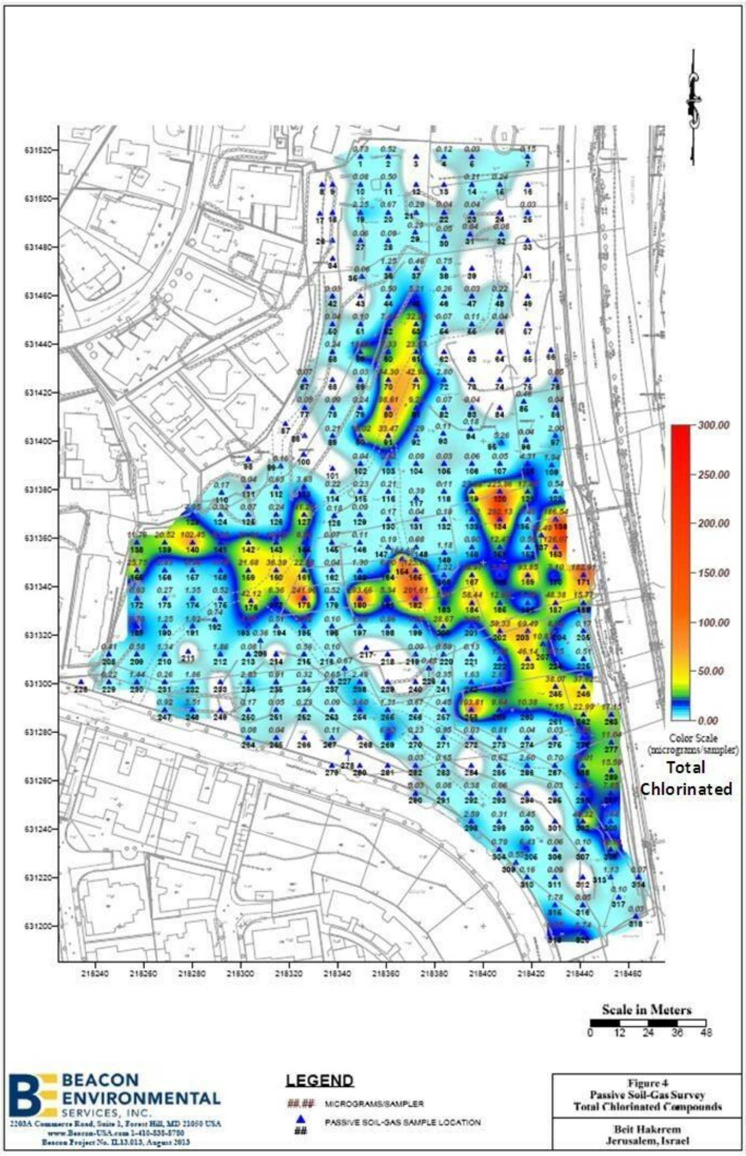
3.2.1 Passive Soil Gas Sampling

The passive soil gas sampling comprised the installation of 320 Beacon samplers across a 11.5x11.5 m grid at approximately 1.5m depth (these being left in the ground for 14 days). According to the findings, there are three main areas of contamination at the site:

- At the eastern border of the site, near the former WWTP (~0.8 ha);
- At the centre of the northern part of the site, not previously investigated (~0.1 ha);
- In the south-west of the site, where a deep excavation of contaminated soil was undertaken in 2000 (~0.3 ha).

Ramboll Figure 3 below shows the distribution of total chlorinated compounds. Separate figures were produced (not included in this report) indicating PCE and TCE distribution, which showed a similar pattern. *The passive sampling results provide valuable data about the spatial spread of chlorinated solvent contamination and possible source areas, but cannot be used for quantitative interpretation. See active soil survey results summarised in the section below.*

Ramboll Figure 3 – Summary of 2013 Passive Soil Gas Survey *(Figure 17 of the May 2018 Dekonta CSM report)*



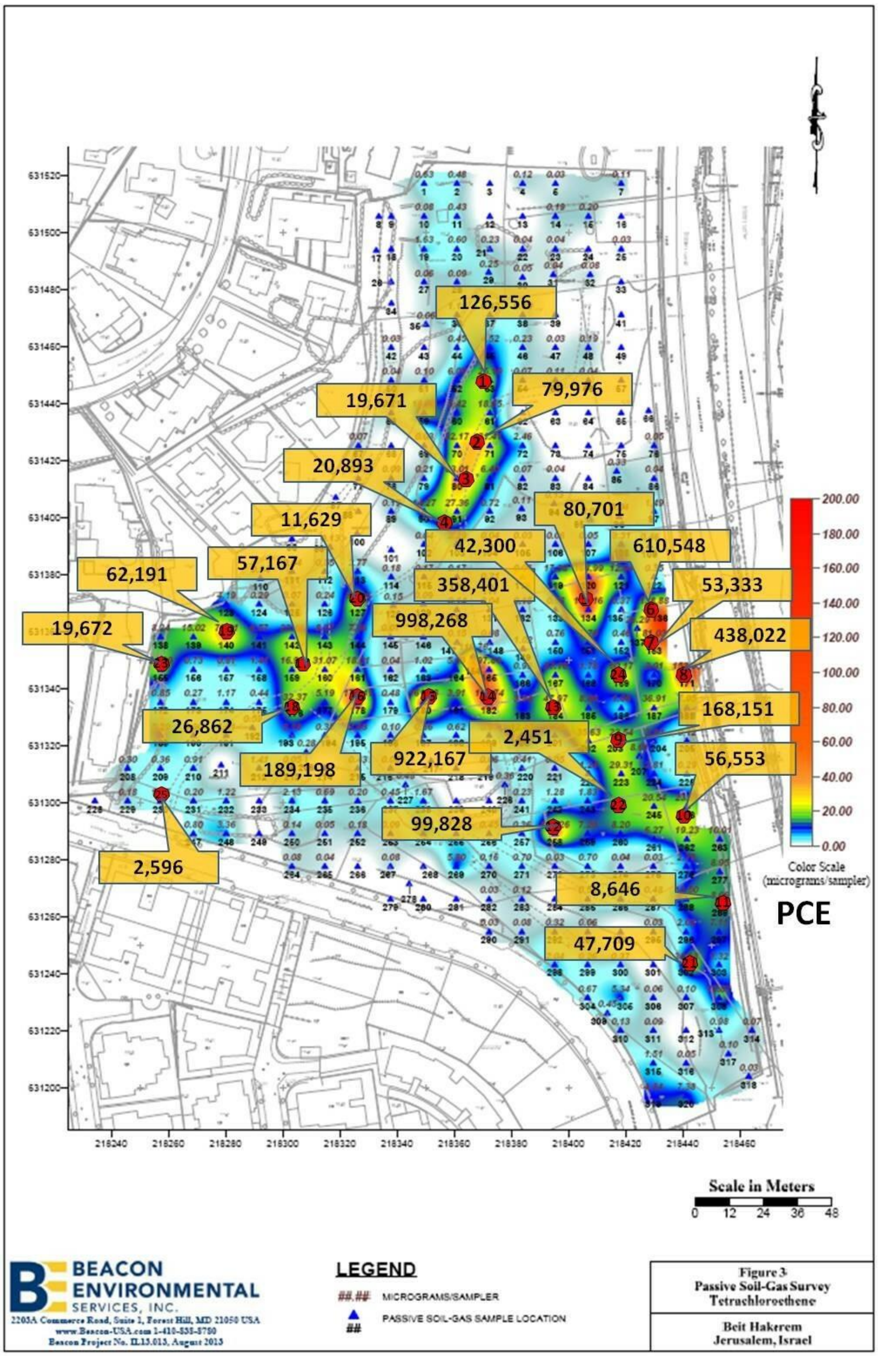
3.2.2 Active Soil Gas Survey

LDD undertook an active[3] soil gas survey in 2013 as the follow-up to the passive survey, which comprised 25 sampling points (1.5m below ground level).

Samples were analysed for wide range of organic compounds, however chlorinated aliphatic hydrocarbons (CAH) were the primary the contaminants of concern (COCs).

The PCE results from the active soil gas survey have been overlain over the image showing the PCE results of the passive soil gas survey; this image is presented as Ramboll Figure 4.

Ramboll Figure 4 – Summary of 2013 Active Soil Gas Survey for PCE *(Figure 20 of the May 2018 Dekonta CSM report)*



[3] Active drawing of soil gas by pumping into canisters.

A summary of the CAHs are presented in Ramboll Table 3.1 below. It was concluded that PCE was the primary pollutant; TCE, c-1,2DCE and VC were used as PCE degradation indicators. Increased concentrations of other hydrocarbons were present, but less frequent and not as elevated as the CAHs (albeit some still exceeding IRBCA2014 Residential Threshold Values). Ramboll Table 3.1 also includes also analytical results for benzene and naphthalene (as indicators for BTEX and PAH contamination).

LDD also undertook a survey for metals in 2013 (not discussed further in this document).

Ramboll Table 3.1 – Results of Active Soil Gas Survey 2013 (*'Table 6' from the May 2018 Dekonta CSM report*)

Beit HaKerem - Acctive Soil Gas Survey 2013

Borehole	Sampling depth m	Benzne mg/m3	Naphta-lene mg/m3	Vinyl chloride	Cis-1,2-Dichloro ethene mg/m3	Tetrachlo roethylene mg/m3	Trichloro ethylene mg/m3	SUM of CAHs mg/m3	Ratio of PCE to sum of CAHs
SG-1	1,5	0,027	0,008	ND	0,00	127	1,08	128	1,0
SG-2	1,5	0,019	0,000	ND	0,01	80	4,44	86	0,9
SG-3	1,25	0,007	0,015	ND	0,00	20	0,010	20	1,0
SG-4	1,1	0,005	0,016	ND	0,00	21	0,02	21	1,0
SG-5	1,5	0,011	0,011	ND	5,35	81	41,07	129	0,6
SG-6	1,5	ND	0,000	ND	0,11	611	0,58	626	1,0
SG-7	1,5	0,009	0,013	ND	6,52	53	22,55	83	0,6
SG-8	1,5	ND	0,000	ND	4,31	438	35,12	479	0,9
SG-9	1,2	0,010	0,000	ND	7,07	168	20,39	196	0,9
SG-10	1,5	ND	0,000	ND	0,74	57	17,21	75	0,8
SG-11	1,5	0,044	0,000	ND	0,00	9	1,08	10	0,9
SG-12	1,4	ND	0,000	ND	5,35	100	22,39	128	0,8
SG-13	1,5	ND	0,000	ND	2,51	358	17,75	379	0,9
SG-14	1,5	ND	0,000	ND	8,43	998	30,89	1038	1,0
SG-15	1,3	ND	0,000	ND	0,52	922	102,64	1026	0,9
SG-16	1,5	0,023	0,000	ND	7,89	189	24,75	224	0,8
SG-17	1,5	0,009	0,010	ND	0,00	57	0,54	60	1,0
SG-18	1,5	ND	0,021	ND	0,00	27	0,31	27	1,0
SG-19	1,5	0,278	0,027	ND	0,03	62	3,55	66	0,9
SG-20	1,5	ND	0,012	ND	0,00	12	0,07	12	1,0
SG-21	1,5	0,018	0,000	ND	0,00	44	1,41	47	0,9
SG-22	1,2	ND	0,000	ND	0,00	2	0,15	3	0,9
SG-23	1,5	0,003	0,035	0,012	0,00	20	0,10	20	1,0
SG-24	1,5	0,080	0,000	ND	1,10	42	7,56	51	0,8
SG-25	1,5	ND	0,000	0,003	0,00	3	0.05	3	1,0
IRBCA 2014 residential		0,0404	0,0093	0,0173	-	1,210	0,077		

3.3 Windex Offsite Soil Vapour Survey (Residential Areas)

Windex undertook a soil gas survey of chlorinated hydrocarbons in residential areas in the vicinity of the site (over 3 rounds in August, October and November 2015). The survey comprised sampling of 30 soil gas boreholes spaced at intervals of approximately 50 m; four indoor air samples were also collected (over 24hrs from polythene tents) from locations close to known pollution centres.

- The survey identified elevated concentrations of PCE (up to a maximum concentration of 15,287 µg/L) and TCE (generally in tens of µg/L, (in the first round TCE was detected at 1,099 µg/L in one location)).
- Benzene was also detected in soil gas up to a maximum concentration of 25 µg/L during the first round and concentrations of chloroform and bromodichloromethane were also locally elevated.

The results were compared with the following screening levels:

- indoor/air tent with Clean Air Act (2008) and Almog screening values;
- soil gas with New Jersey screening levels (2013).

In case of indoor air, it was stated that only the screening value for methylene chloride (i.e. dichloromethane) 7.2 µg/m^3 was slightly exceeded at 2 sampling points.

Ramboll Figure 5 below presents the results of the soil gas and environmental/indoor air sampling.

Ramboll Figure 5 – Summary of the results of the Windex 2015 soil gas survey *(Figure 23 of the May 2018 Dekonta CSM report)*

מפת קידוחים מצורפת לחוד בקנ״מ מקורי . מפה זו להמחשה בלבד.

3.4 Groundwater Investigation (2017)

In 2017, Etgar engineering company undertook a groundwater survey. The company drilled and installed 3 new monitoring wells at the site: IMI Beit HaKarem 1, 2, and 3. LDD-Ramboll is aware of a fourth monitoring well at the site. Information regarding the fourth well not shown in this report.

The monitoring wells were drilled into the Upper sub-aquifer (120 - 123 m depth) and were positioned close to the hotspots of chlorinated hydrocarbons identified in LDD's 2013 passive soil gas survey (locations shown on Ramboll Figure 6 below).

Ramboll Figure 6 – Location of Etgar 2017 groundwater monitoring wells *(Figure 25 of the May 2018 Dekonta CSM report)*

תרשים 9: מיקום קידוחי הניטור תע"ש בית הכרם עם גבי תצ"א של אזור המתחם.

3.4.1 Soil / Rock Sampling

During drilling, PID[4] monitoring of rock samples was undertaken every 2m. The samples with the highest PID readings were reported to have been taken for laboratory analyses of VOCs. All results of laboratory VOC analyses were below detection limit[5].

In addition to the groundwater monitoring (presented below), Etgar also undertook a soil survey ('zonal active sampling), which is discussed in Section 2.3.2.

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[4] A PID (photoionization detector) is a field instrument used to provide an indication of the presence of VOCs.

[5] It is considered that the drilling method (dry 'down the hole' drilling using pressurized air) or sampling methodology could be the reason for the lack of VOC detections in the rock sample analysis.

3.4.2 Groundwater Monitoring

Information regarding groundwater levels recorded during drilling and sampling is presented in Table 3.2 below. As discussed in Section 2.1.3 of this report, flow direction was reported by Etgar to be in a south-south-easterly direction.

Ramboll Table 3.2 – On-site Groundwater Levels from Etgar 2017 Investigation *('Table 1' from the May 2018 Dekonta CSM report)*

	New wells to the Upper subaquifer				
Well	Depth	well logs		sampling	
		SWL depth	SWL a.s.l	SWL depth	SWL a.s.l
IMI Beit HaKerem 1	120 m	97.48	635.53	98.73	634.28
IMI Beit HaKerem 2	120 m	98.34	635.53	99.13	634.74
IMI Beit HaKerem 3	123 m	99.90	635.14	100.02	635.02
Remark: data on SWL may not be accurate - it is not specified in the original source if groundwater depths were measured from the well-head or from the terrain.					

Data relating to the physical and chemical parameters (and sampling depths) are presented in Ramboll Table 3.3 below. Information concerning basic chemical parameters is presented in Ramboll Table 3.4, using the units of mg/L[6].

Ramboll Table 3.3 – Physical-Chemical Parameters of Groundwater from Etgar 2017 Investigation ('Table 8' from the May 2018 Dekonta CSM report*)*

עומק מפלס	PH	EC (ms)	TURB (ntu)	DO (mg/l)	Temp (C)	Sal %	ORP	קידוח
98.73	6.97	1.02	15	4.38	20.7	0.04	101	**בית הכרם 1**
99.13	7.06	0.945	0	3.36	20.2	0.4	132	**בית הכרם 2**
100.02	7.12	0.992	0	4.1	20.7	0.04	118	**בית הכרם 3**

טבלה 6: מדידת פרמטרים של מי התהום באתר לאחר התייצבות.

Ramboll Table 3.4 – Basic Chemistry Parameters of Groundwater from Etgar 2017 Investigation *('Table 11' from the May 2018 Dekonta CSM report)*

תקן מי שתיה (מג"ל)	תע"ש בית הכרם 3		תע"ש בית הכרם 2		תע"ש בית הכרם 1		שם של מקור המים
-	שאיבה	ביילר	שאיבה	ביילר	שאיבה	ביילר	סוג מקור מים
-	30/04	24/04	27/04	24/04	27/04	30/03	תאריך דיגום
-	53.5	55.3	50.3	51.7	52.7	52.1	Na
-	1.7	2.2	2.1	2.8	1.0	2.4	K
-	27.1	27.7	24.3	24.6	27.7	28.2	Mg
-	129.1	132.2	126.0	128.6	128.5	128.5	Ca
400	99.7	-	89.1	-	106.9	110.5	Cl
	0.35	-	0.29	-	0.33	0.36	Br
250	46.0	-	39.8	-	37.4	40.1	SO4
	385.0	-	389.0	-	389.0	-	HCO3
70	54.6	-	35.4	-	32.9	31.4	NO3
-	797.1	217.4	756.5	207.7	776.5	393.5	TDS

טבלה 10: סיכום ממצאי דיגום מי תהום. ריכוזים ביחידות של מ"ג\ל.

[6] LDD has noted that there is a typo in this table, and that the data presented is in mg/L, not µg/L.

3.4.3 Groundwater Analysis

Groundwater samples were collected from the three new wells using both pump and bailer methods. The samples were submitted for laboratory analysis for heavy metals, explosives and chlorinated aliphatic hydrocarbons and the results were compared (by Etgar) against the Israel Drinking Water Standards (IDWS).

It was stated by Etgar that:

- chromium exceeded the drinking water standard;
- the explosives analysed for (HMX, RDX, TNT, DNT, PETN, NQ, TNB) were below the laboratory method detection limit;
- four chlorinated aliphatic hydrocarbons were detected in concentrations exceeding the drinking water standards: 1,1-DCE, TCE and PCE. 1,2-cis-DCE.

The results of the chlorinated hydrocarbon analysis are presented in Table 3.5 below.

Ramboll Table 3.5 – Concentrations of chlorinated hydrocarbons in groundwater (in µg/L) from Etgar 2017 Investigation *('Table 10' from the May 2018 Dekonta CSM report)*

Water source name	IMI Beit HaKerem 1		IMI Beit HaKerem 2		IMI Beit HaKerem 3		Drinking water standard
Sampling method	Bailer	Pumping	Bailer	Pumping	Bailer	Pumping	-
Date of sampling	30/3	27/4	24/4	27/4	24/4	30/4	
cis 1,2 dichloroethene	**550**	**123**	**215**	**170**	34	44	50
1,1-Dichloroethane	ND	ND	4	ND	ND	ND	-
1,1-Dichloroethene	**40**	**21**	**40**	**31**	**27**	**22**	10
1,1,1-Trichloroethane	ND	ND	6	6	ND	ND	200
Trichloroethylene	**522**	**212**	**805**	**690**	**297**	**251**	20
Tetrachloroethylene	**2 765**	**1 292**	**3 930**	**4 046**	**1 675**	**1 445**	10

3.5 Zonal Soil Vapour

A zonal soil gas survey in 2017 was undertaken alongside Etgar's groundwater investigation (discussed in Section 3.4 above).

Three rounds of sampling were undertaken by Etgar (using active sampling); soil gas samples were taken from:

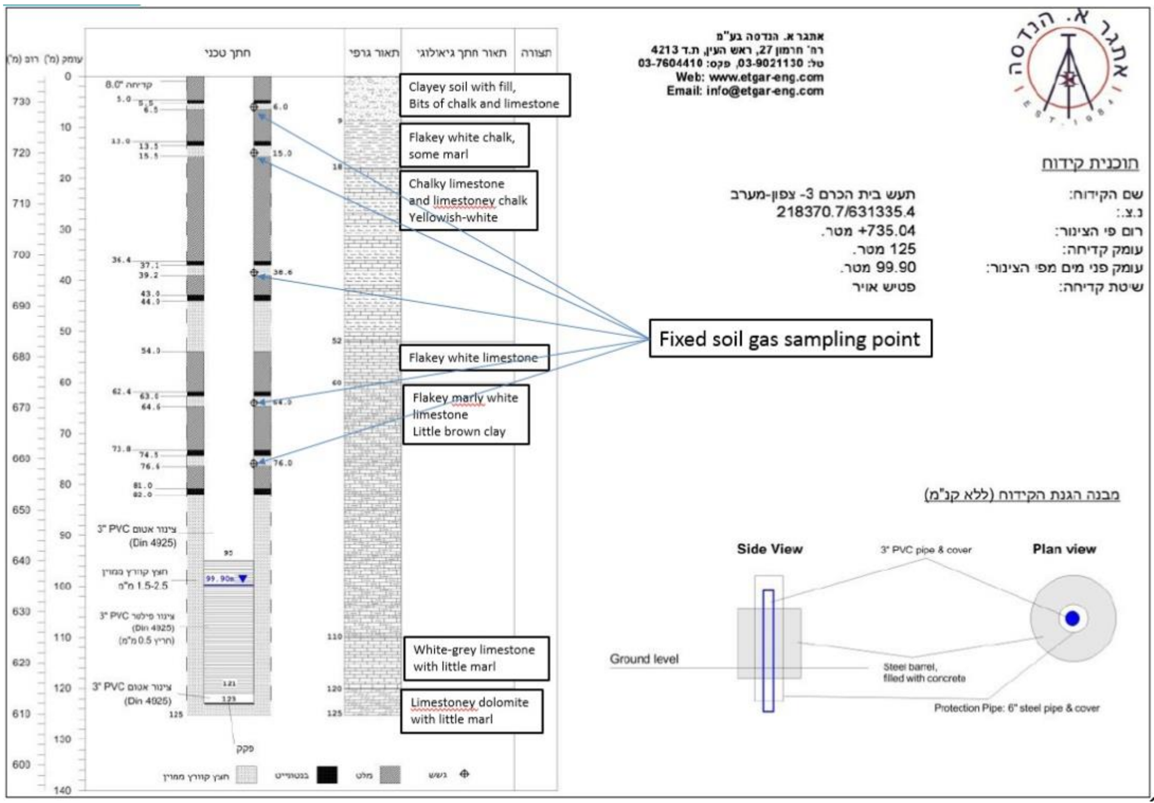
- IMI Beit Hakerem 1 at 30m bgl
- IMI Beit Hakerem 3 at multiple depths (6, 15, 38, 64, and 76 m);

LDD has provided the following diagram (from Etgar) which shows the borehole installation, soil profile and sampling depths (presented overleaf as Ramboll Figure 7).

The results of the analysis from each of the three sampling rounds are presented in the Dekonta CSM (Tables 13-15 of the Dekonta CSM report). The results of the final (September 2017) Etgar monitoring round are provided in Ramboll Table 3.6 overleaf.

Ramboll Figure 8 (further below) shows the vertical distribution of the zonal soil gas sampling results; the information in Ramboll Figure 8 is understood to have been derived (by Etgar / Dekonta) from the zonal sampling undertaken in 2017 (i.e. Tables 13-15 of the May 2018 Dekonta CSM report). Elevated concentrations of chlorinated organic compounds were found at all depths. Generally speaking, higher concentrations were found in the upper soil profile (the upper 10m). Generally lower concentrations were detected at depth, albeit a notable increase was detected at the 38m depth sampling point. Additionally, concentrations at the deepest depth of 76m also showed an increase above those detected at 64m. *It is noted that this sampling* *does not extend all the way to the water table (which is approximately 100m below ground level); it cannot be ruled out that contamination concentrations increase further with depth.*

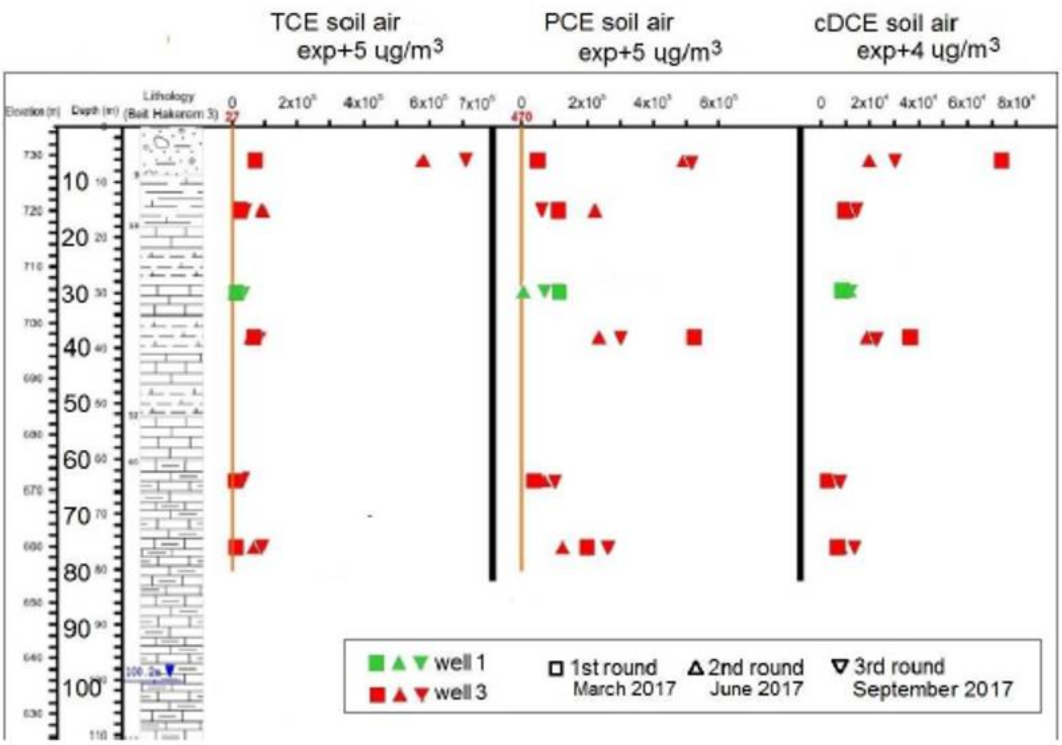
Ramboll Figure 7 – Summary of Etgar 2017 borehole installation, soil profile and zonal soil gas sampling depths *(provided by LDD)*



Ramboll Table 3.6 – March 2017 Zonal Soil Gas Survey Results (µg/m^3) *('Table 15' from the May 2018 Dekonta CSM report)*

	IMI Beit…1	IMI Beit HaKerem 3					
	IMI Beit HaKerem 1	IMI Beit HaKerem 3 - 76	IMI Beit HaKerem 3 - 64	IMI Beit HaKerem 3 - 39	IMI Beit HaKerem 3 - 15	IMI Beit HaKerem 3 - 6	Standard residence area
Date	Sep. 27	Sep. 27	Sep. 27	Sep. 27	Sep. 27	Sep. 27	-
Sampling depth (m)	29.9	76	64	38.6	15	6	-
1,1,1-TCA	1,834.71	392.85	410.31	11,010.66	2,596.73	109,133.23	260,000
1,1,2-TCA	ND	ND	ND	202.97	ND	ND	27
1,1-DCA	1219.53	474.36	213.7	663.78	365.48	1269.27	76
1,1-DCE	9,439.15	17,752.02	7,732.51	7,002.16	3,348.74	47,202.31	10,000
1,2-DCA	ND	ND	ND	157.04	937.3	ND	20
1,3 butadiene	ND	ND	ND	ND	ND	ND	11
Benzene	166.23	141.85	123.96	ND	40	145.68	16
Carbon tetrachloride	ND	ND	ND	ND	ND	2,793.35	31
Chloroform	92.18	117.18	ND	191.4	309.7	2,105.35	24
Cis-1,2-DCE	13,904.64	15,223.94	8,564.36	20,820.91	10,667.35	30,952.23	-
Cyclohexane	146.67	ND	ND	ND	21.75	1252.95	310,000
Ethylbenzene	ND	ND	ND	ND	ND	ND	49
Hexane	ND	ND	ND	ND	ND	10,993.95	36,000
Methylene chloride	34.98	ND	ND	ND	27.72	ND	4,800
Propene	ND	119.79	150.42	ND	ND	229.94	-
PCE	65,824	265,725	132,802	290,419	67,917	507,624	470
Toluene	75.07	239.68	319.57	113.06	796.38	8,761.04	260,000
Trans-1,2DCE	1,842.53	423.46	254.55	339.4	ND	1,173.63	3,100
TCE	33,674	96,687	45,578	62,972	37,468	707,546	27
Vinyl chloride	8,792.33	151.33	89.47	61.35	199.94	71.57	13
	µg/m^3						

Ramboll Figure 8 – Zonal active soil gas sampling results (2017): vertical distribution *(Figure 26 of the May 2018 Dekonta CSM report)*



3.5.1 Etgar Conclusions

Etgar concluded that:

1. *Groundwater monitoring: chlorinated organic mixtures were found in concentrations exceeding threshold values both in the 'unsaturated; and saturated zones. In the upper groundwater there were high concentrations of PCE, TCE and DCE. Furthermore, high concentrations of chromium were found in monitoring wells IMI Beit HaKerem 2 and 3.*
2. *Soil gas: main pollutants identified were PCE, TCE and DCE.*
3. *No VOCs were identified in soil samples. However, this could be as a result of the drilling method used.*
4. *Several pollutants, such as VC, benzene and chloroform, were identified in soil gas but not in the groundwater.*

3.6 LDD Active soil gas and soil survey:

Subsequent to the Dekonta CSM (and therefore not discussed in the CSM report), LDD performed additional soil and active soil gas surveys in 2018 and 2019.

3.6.1 LDD 2018-2019 Soil Survey

LDD's 2018 investigation included 103 soil borings, to depths between 0.5-6.0 m; i.e. within the soil overburden, not the bedrock (the site investigation grid was developed by others, but is understood to have been based on previous site investigation findings). LDD subsequently undertook an additional 61 soil borings in 2019 for delineation purposes.

A plan showing the soil boring locations is provided as Ramboll Figure 9 below.

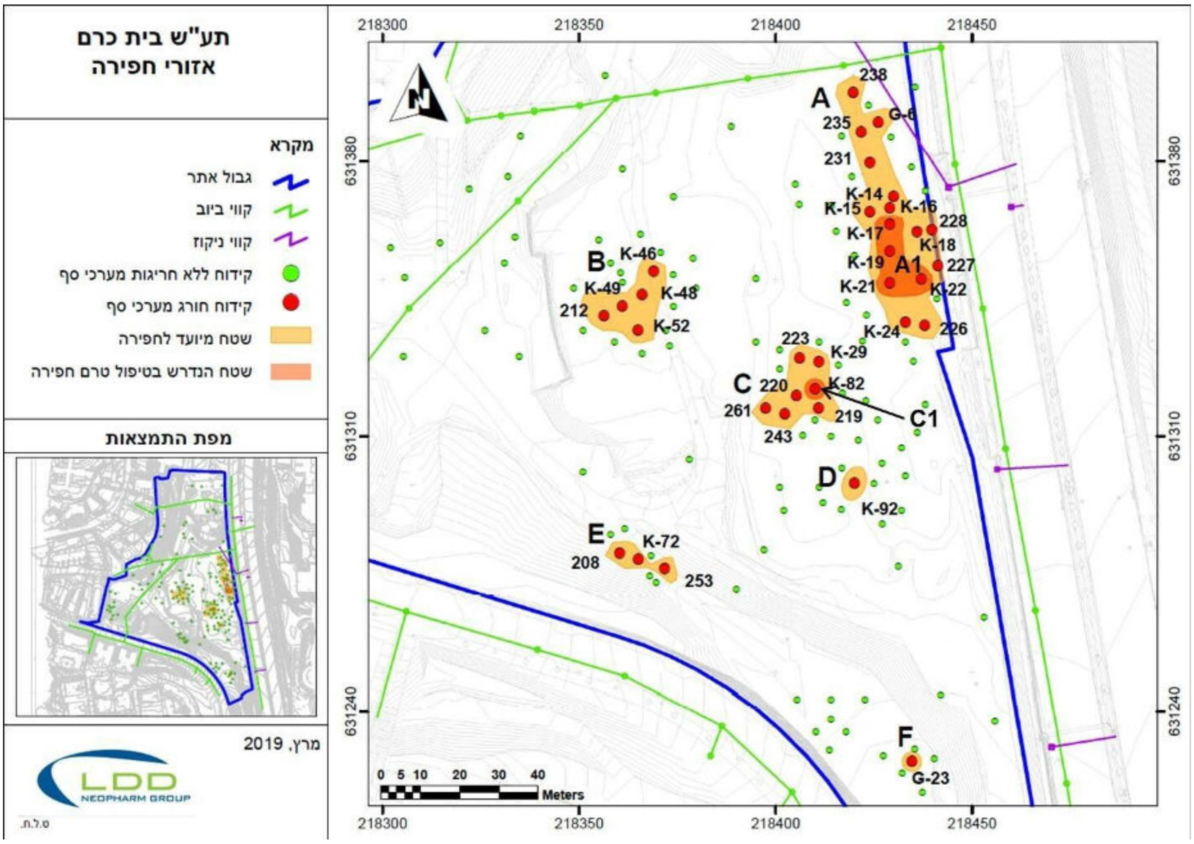
LDD compared the soil results against the IRBCA 2018 Tier 1 risk based target levels (RBTLs), and summarised the results of its soil survey as follows:

- High concentrations of VOCs were detected, including TCE, PCE, cis-1,2 DCE, 1,1,1-trichloroethylene, and 1,2,4-trimethylbenzene,
- Elevated concentrations of naphthalene, TPH, and lead were also detected

LDD has indicated that the Tier 1 RBTL exceedances were present only in certain parts of the site (as hotspots); across the majority of the site, the soil results were reported by LDD to be below the Tier 1 levels. The soil Tier 1 exceedances are shown on Ramboll Figure 9 below.

Based on the soil survey results, LDD has recommended the excavation of soil to address the hotspots of VOCs identified. The excavations are proposed to be to a maximum depth of 6.5m (i.e. to target the overburden soils, but not the underlying karstic rock) within the overburden. Ramboll Figure 9 also shows the areas of soil that are proposed to be excavated. These works are planned for 2020, but have not yet been completed.

Ramboll Figure 9 – LDD 2018-2019 Soil Survey: Findings and proposed areas for excavation *(Figure provided by LDD)*



3.6.2 LDD 2018-2019 Soil Gas Survey

In addition to the soil survey discussed above, LDD also undertook an additional active soil gas survey, which included the collection of samples from 54 locations at depths ranging from 1.0-3.0 m below ground level.

The soil gas survey sampling locations and a summary of analysis results (exceedances of 2019 Tier 1 residential limits) are presented in Ramboll Figure 10 below.

To summarise, the results of the active soil gas survey indicated high concentrations of chlorinated organic solvents and fuel components.

LDD notes that elevated soil gas concentrations (of chlorinated solvents) have been detected across the site, including at some locations where elevated concentrations of the same contaminants were not detected in soil samples taken from the same locations.

The presence of contamination in soil gas but not soil (in some parts of the site) indicates that contamination within the underlying bedrock is likely to be a major contributor towards the detected soil gas concentrations.

3.6.3 Zonal Soil Gas Sampling

LDD also collected additional soil gas samples (via active sampling) from the zonal gas sampling points installed by Etgar (see Section 3.5 above).

Similar to the previous Etgar sampling, elevated concentrations of chlorinated solvents were detected at all depths sampled, with a similar depth distribution to that previously. The highest concentrations detected were of tetrachloroethylene (PCE); elevated concentrations of its daughter products (including trichloroethene (TCE) and vinyl chloride (VC)) were also detected.

The highest concentrations of contaminants were typically detected TBH-3 at 15m depth or 6m depth, however very elevated concentrations were also detected in the deepest sampling point (76m). It is noted that the highest concentration of VC was detected in a different borehole (TBH-1), at 38m.

Ramboll Table 3.7 – LDD 2018-19 Zonal Active Sampling Data (in µg/m^3) *(Table provided by LDD).*

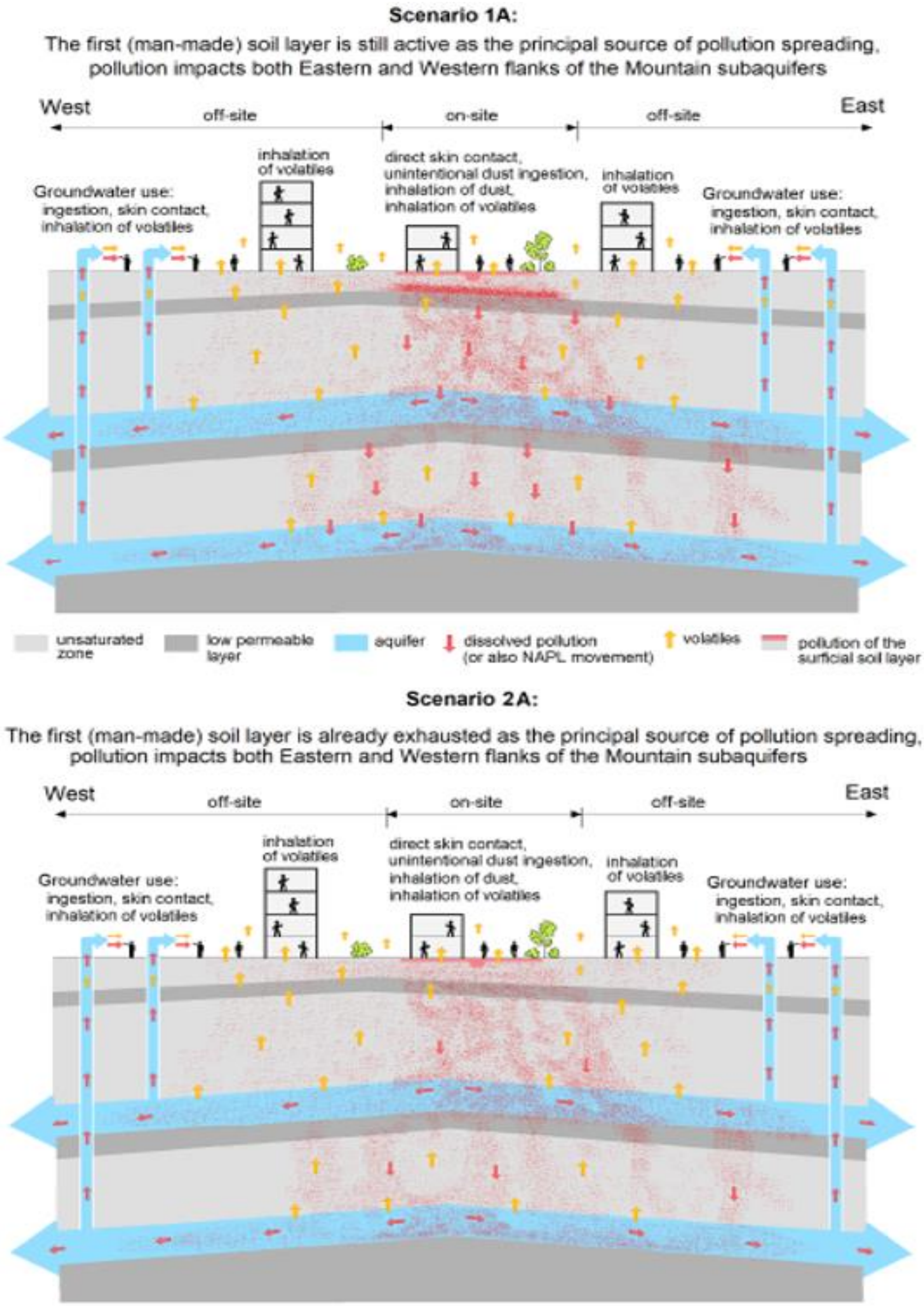
IRBCA Tier 1	NJ 2013	76 -3 באר (TBH-3- 76)	64 -3 באר (TBH-3- 64)	38 - 3 באר (TBH-3 -38)	29 - 1 באר (TBH-1 -29)	15 - 3 באר (TBH-3 -15)	6 - 3 באר (TBH-3 6)	well
		5511	5542	4596B	5504	4071H	4357	canister #
		76.0	64.0	38.0	29.0	15.0	6.0	sampling depth (m)
		2.8.18	2.8.18	2.8.18	2.8.18	2.8.18	2.8.18	sampling date
695,000	260,000	709.31	868.63	8,991.31	3,321.75	3,753.88	228,241.53	1,1,1-Trichloroethane
23.1	27	ND	ND	708.76	ND	ND	ND	1,1,2-Trichloroethane
234	76	1,253.08	639.49	930.5	2,088.47	1,445.74	4,472.41	1,1-Dichloroethane
-	10,000	43,825.73	37,080.51	6,956.56	41,212.02	46,985.03	58,326.07	1,1-Dichloroethene
38	20	ND	ND	198.73	ND	1,816.49	7,199.16	1,2-Dichloroethane
4,310,000	1,600,000	ND	ND	61.05	ND	ND	ND	Acetone
130	16	250.47	217.25	ND	203.19	ND	ND	Benzene
16.3	24	236.66	132.8	229.48	ND	513.64	5,579.76	Chloroform
-	-	35,369.22	25,409.19	18,190.15	86,959.98	43,061.29	87,801.35	Cis-1,2-Dichloroethene
97,300	36,000	ND	ND	48.29	ND	ND	39,703.27	Hexane
-	245.8	31.46	<24.58	70.79	26.55	<24.58	<24.58	Isopropyl Alcohol
-	-	148.01	135.62	121.68	96.38	144.57	966.9	Propene
2,100	470	743,421.95	706,720.07	391,011.48	718,334.56	1,247,763.50	184,872.69	Tetrachloroethylene
30,000	260,000	376.85	355.75	1,069.13	191.44	2,356.08	6,714.74	Toluene
-	3,100	1,281.48	1,191.08	802.91	2,935.67	1,302.10	ND	Trans-1,2-Dichloroethene
200	27	234,230.14	164,173.25	58,330.76	140,176.10	254,680.59	215,826.55	Trichloroethylene
85.1	13	414.1	480.56	50.1	54,743.24	477.5	75.15	Vinyl Chloride

4. SUMMARY OF DEKONTA CSM AND UPDTAE

The existing CSM (Conceptual Site Model) report (produced by Dakona from May 2018) identified a number of uncertainties, specifically relating to the nature of the sources and pathways. As a result, several CSM scenarios were produced by Dekonta.

Scenario 1A, presented below assumes that there is still an ongoing pollution source within the shallow overburden soils, whereas Scenario 2A assumes that contamination within the overburden has been exhausted as a pollution source, and instead contamination within the underlying bedrock is now the primary source.

Ramboll Figure 10 – Dekonta CSM images or Scenarios 1A and 2A *(taken from the Dekonta May 2018 CSM report)*



4.1 Update and Comments regarding Dekonta CSM Uncertainties

The table below lists the uncertainties presented in Table 25 of the Dekonta CSM, and provides an update on these (for example whether further clarification has been provided by LDD's 2018-2019 survey). Where these have not been updated, an assessment has been made as to whether the original CSM uncertainty identified by Dekonta is relevant to LDD-Ramboll's planned remediation options appraisal).

Table 4.1 – Update on Dekonta CSM Uncertainties

<table>
<tr><th colspan="2">Uncertainty Identified by Dekonta</th><th>Update and Relevance to LDD-Ramboll Remediation Options Appraisal (ROA)</th></tr>
<tr><td>1</td><td>Insufficient delineation of area(s) with unacceptable risks from emission of volatiles from soil.
Information on concentrations of soil air pollutants are only from the central and southern parts of the site and from its southern surroundings. Most of these data from the site are too old.</td><td>LDD undertook additional investigation in 2018-2019 which included a soil survey and an active soil gas survey, and delineation of hotspots in soil.</td></tr>
<tr><td>2</td><td>Proportion among the close-to-the surface soil layer, deeper unsaturated zone and groundwater on emissions of volatiles from underground.</td><td>LDD's 2018-2019 investigation included soil and active soil gas sampling.
• Whilst some hotspots of soil contamination were identified in the overburden soils, these are intended for remediation by excavation (planned for 2020), thus removing the ongoing soil.
• However elevated soil gas samples were detected across a much wider area of the site (despite elevated soil concentrations not being detected). This indicates that contamination within the deeper bedrock is likely to be a significant contributor to the shallow soil gas contamination detected.</td></tr>
<tr><td>3</td><td>Impact of some other site contaminants apart from chlorinated solvents on soil air pollution.</td><td>LDD has confirmed that its active soil gas investigation includes analysis of 42 VOCs including BTEX and CAHs. LDD has confirmed that many contaminants were not detected at concentrations above laboratory limits of detection, and are therefore not discussed in LDD's report.</td></tr>
<tr><td>4</td><td>Source of soil air pollution in the southern site vicinity, its connection with the site pollution of the same kind.</td><td>LDD-Ramboll has not seen data which clearly demonstrates whether the elevated soil gas concentrations detected off-site to the south are a result of shallow hotspots of contamination, or deeper contamination within the bedrock.
This point remains an uncertainty, and is relevant to future.</td></tr>
<tr><td>5</td><td>The reach of pollution of the eastern flank of the Upper Mountain aquifer further in the southern and south-eastern direction.</td><td rowspan="3">This has not yet been confirmed.
However LDD-Ramboll's remediation options appraisal will focus on soil vapour (including considering elevated concentrations in groundwater as a source of soil vapour). The direction of regional groundwater flow within the Upper aquifer and the potential for impact to the Lower Aquifer are therefore not directly relevant to LDD-Ramboll's ROA.</td></tr>
<tr><td>6</td><td>Potential spreading of pollution from the site to the Western flank of the Mountain aquifer.</td></tr>
<tr><td>7</td><td>Potential impact of pollution from the site to the Lower Mountain aquifer.</td></tr>
</table>

Table 4.1 – Update on Dekonta CSM Uncertainties		
		It is noted that Dekonta also considered the CSM scenario of the groundwater only flowing towards the eastern mountain flank (Dekonta Figure 1b and 2b), instead of towards both flanks as shown above. Dalkonta Figures 1b and 2b and the direction of groundwater are not discussed here further.
8	The role of the close-to-the surface pollution as the potential source of continuing further descent of organic pollution downward, to the Mountain aquifer(s)	The upcoming remediation hotspot excavations at the site is intended to remove close-to-surface potential contaminant sources . *LDD has noted that there will be some remaining concentrations of VOCs (generally speaking in the 100-200 mg/kg range). The highest concentration to remain being 600 mg/kg TCE & 475 mg/kg PCE directly adjacent to the areas to be excavated.*
9	Impact of some other site contaminants apart from chlorinated solvents on pollution of groundwater beneath the site.	LDD-Ramboll's remediation options appraisal will focus on chlorinated solvents within the karstic bedrock. Whilst it is important for ESC to understand the nature of other contaminants at the site, this is not directly relevant to LDD-Ramboll's ROA.
10	Possibility of the Cr VI occurrence	
11	Origin of the Arsenic increased concentrations	

5. ASSUMPTIONS FOR THE REMEDIATION OPTIONS ASSESSMENT

LDD and Ramboll have reviewed the existing Dekonta CSM and the summarised Site Survey information to develop our understanding of the contamination issues at the site, what are the requirements for remediation and the basis on which the Remediation Options Assessment (ROA) should be undertaken.

This section of the report presents LDD-Ramboll's understanding of the site and contamination status, and defines the assumptions that will be carried forward to the ROA.

It is noted that some uncertainties about the site remain; we understand that the client team has reviewed the below assumptions (in bold italics) and that they are in agreement with the approach that will be taken.

There are some instances where we have identified specific studies, additional investigations, or information that we consider could either confirm the below assumptions or could help refine the ROA. These are presented in red text for ease of reference. *It should be noted that this is not an exhaustive list of additional investigation that may be needed in the future, e.g. to inform future detailed remediation design.*

5.1 Nature and Distribution of On-Site Contaminant Source.

1. Areas of elevated soil contamination have been identified within the overburden soils; these have been delineated and defined, and are intended for remediation by excavation (planned for 2020). ***For the purpose of the ROA, it will be assumed that these hotspots will have been removed prior to the commencement of the remediation of the deeper bedrock. No consideration of remedial actions relating to the overburden soils will be included within the ROA.***
2. It cannot be ruled out that there are additional hotspots of shallow contamination within the overburden that were not detected by LDD's soil survey. ***LDD-Ramboll assumes that there would be a watching brief for unexpected contamination during future construction works, and if further shallow hotspots are identified, it is assumed these will be excavated, thereby removing the source.***
3. Elevated soil gas samples were detected across a much wider area of the site than the above mentioned hotspots (despite elevated soil concentrations not being detected in those areas). This indicates that contamination within the deeper bedrock is likely to be a significant contributor to the shallow soil gas detections. ***The ROA will therefore focus on evaluating remediation options for contamination within the karstic bedrock, rather than an ongoing source within the overburden soils, it being assumed that such sources are no longer present or will be removed as part of the proposed excavation works***.
4. The zonal soil gas survey results indicate that soil gas concentrations of chlorinated solvents are elevated throughout the unsaturated zone (until at least 76m depth below current ground levels). However, soil gas samples have been collected at this depth at only one location (IMI Beit Hakerem 3); it is therefore not known if similarly elevated soil gas concentrations are present to similar (or greater) depth across the remainder of the site, or what depth-distribution pattern exists. ***For the purpose of the ROA, we propose to make the conservative assumption that elevated soil gas concentrations are present throughout the entire unsaturated zone (i.e. to approx. 100m depth) across the treatment area.***

- The extent of soil gas contamination at depth is one of the key variables that could significantly affect the remediation cost (and therefore the outcome of the ROA). Additionally, in terms of soil gas risk to residents and site users, the benefit (e.g. the extent of risk reduction) that could be achieved by the remediation decreases with depth. We recommend that further investigation is undertaken to assess the extent of contamination at depth within the unsaturated zone

5. As noted above, soil gas samples at depth within the bedrock have only been collected at one location (IMI Beit Hakerem 3); the lateral extent of the bedrock affected by elevated soil gas is not known. There is however more information about the shallower overburden soils, and LDD has identified an area of hotspot where the shallow soils are most impacted (see Section 3.6 and Figure 9). Whilst the overburden soils will not be the subject of this ROA, the known hotspot areas in the shallow soils could used as an indicator of where deeper contamination is more likely to be encountered. ***Specifically, we propose to assume that: the lateral extent of the area to be impacted will comprise the area of the hotspots identified by LDD as requiring excavation), multiplied by x2.5 to reflect a 'buffer zone' and as an arbitrary assumption to reflect possible lateral migration at depth. LDD has confirmed that the area of the 'overburden' hotspots requiring remediation is 1,479m2; which multiplied by x2.5, would be an assumed remediation area of 3,697.5 m²^{2}.***

   - As noted above, further investigation to characterise the extent of contamination within the bedrock (both laterally and vertically) is strongly recommended.

6. Given the relatively low concentrations of PCE & TCE in the groundwater compared to those found in the soil gas and the great depth to groundwater at the site and the thickness of the unsaturated zone (>100m), LDD-Ramboll considers it unlikely that contamination within the groundwater would be significantly contributing towards the soil vapour concentrations detected at more shallow depths on site. ***It is therefore proposed that the ROA focuses on technologies to remediate contamination with the unsaturated part of the karstic bedrock (rather than remediation of the groundwater).***

   - Risk assessment / contaminant modelling could be undertaken to assess whether contaminant concentrations in the Upper Aquifer are likely to be a significant source of the elevated soil gas concentrations, particularly at shallow doubt. Such work is outside the scope of LDD-Ramboll's current remediation support, but could provide further confidence in the CSM, and support the basis of the technical assumptions underpinning the ROA and associated recommendations.
   - In our estimation, treatment of the source of the contamination at the site may also lead to an indirect reduction in the concentrations of pollutants outside the site boundary. It is emphasized that this is only an assumption and therefore further tests will be required both in the field of investigation and in examining the applicability of the remediation methods.

5.2 Nature of On-site Soil Gas Receptors

The site is currently vacant, but is intended for residential development. Ramboll understands that the development plans for the site have not yet been defined.

7. It is understood that similar residential developments in Israel have included large basements (e.g. including several stories of below ground carparking). ***For the purpose of the ROA we will assume that the remediation will need to target the entire thickness of the unsaturated zone within the karstic bedrock (but not the overburden soils).***

   - However, if the client is able to provide information about likely basement depths and an outline development plan / layout in advance of us commencing the ROA, this may help refine the output of the ROA and the associated remediation recommendations. *Based on client discussions, it is understood this information will not be available in advance of the ROA.*

5.3 Offsite Considerations (offsite contaminant sources and neighbouring residents)

As discussed in Section 3.3 of this report, elevated soil gas concentrations have been detected in residential areas off-site to the south. Elevated concentrations of chlorinated solvents have also been detected within buildings.

8. LDD-Ramboll does not consider that ROA of contaminant sources outside of the current site boundary are part of this scope of works. Additionally, LDD-Ramboll has not seen data which clearly demonstrate whether the off-site elevated soil gas concentrations are as a result of shallow hotspots of contamination, or deeper contamination within the bedrock. Construction information for these buildings is not currently known (e.g. presence of basements; presence of soil vapour membrane). Additionally, there are likely to be access constraints within built up areas, which could affect the appropriateness of the different remediation methodologies. I.e. there is currently insufficient information to undertake a ROA of source areas outside of the site boundary. ***For these reasons, LDD-Ramboll does not propose to consider active remediation within off-site areas as part of this ROA.***
9. The existing off-site residential receptors to the south are also a potential receptor for contamination within the main-site boundary (i.e. soil gas on the subject site could potentially migrate offsite).
   - The client and regulator should ensure that the risk assessment for the site (not seen by LDD-Ramboll) adequately considers the risk to offsite receptors from soil gas onsite, and that this pathway has been taken into consideration in the risk assessment when deriving the target concentrations for the site.
   - *Also, please refer to Section 5.6 of this report for LDD-Ramboll assumptions about remediation targets for the ROA.*

5.4 Risk to Groundwater Receptors

Groundwater data (discussed in Section 3 above) indicate that the groundwater beneath the site has been impacted by chlorinated solvents. Indeed, similar contaminants have also been detected at public drinking water abstraction wells that are located some >1km from the site (albeit it is not known whether these detections are confirmed as being associated with the Beit Hakerem site).

10. We understand that the Israel Water Authority (IWA) has not yet issued instructions on whether active treatment of groundwater at the Beit Hakerem site is required. Should on-site remediation be deemed necessary by the IWA to protect groundwater resources, it is not known what target concentrations in groundwater would need to be achieved. ***For these reasons, we understand that the Client does not require the ROA to consider remediation of groundwater (in terms of risks to surface watercourses or abstraction wells). See LDD-Ramboll comments in Section 5.1 (point 6) regarding the likelihood of deep groundwater being a significant source of soil gas.***

5.5 Pathways

The bedrock underlying the site is karst and so is assumed to have a well-developed secondary porosity (fractures). The extent of fractures, and the location of major fractures could affect how contamination has moved around the site, both in terms of the original spread of contamination following the primary release, and also in terms of how soil gas moves beneath the site.

11. LDD-Ramboll has not been provided with detailed site specific information about the nature and location of the fractures. We understand that the three deep (Etgar) boreholes on the site were drilled using a rotary (air flush) method, and we are not aware that any down-hole investigation of fractures was undertaken. ***As such, LDD-Ramboll's ROA will make generalist assumptions about the physical properties of the bedrock, including the likely presence of fractures, but will not include consideration of site specific fracture information, as such records are not available.***
    - If further investigation is planned at the site, Ramboll considers it would be useful if more information was collected about the nature and location of fractures in the bedrock.
        - Investigations to further characterise the bedrock should comprise the drilling of sufficient boreholes to provide sufficient coverage across the potentially impacted area, including collection of rock cores and borehole geophysics.
        - (Such information could also be collected alongside future remediation pilot trials to help inform the detailed remediation design, although this may only be of relevance to the area covered by the trial rather than the entire volume of rock requiring remediation).

6. REMEDIATION TARGETS

It is understood that an IRBCA[7] risk assessment has been undertaken for the site by Dekonta which has been submitted to the Ministry of Environmental Protection (MoEP). LDD-Ramboll has not seen a copy of this risk assessment (albeit the Dekonta CSM which supports the technical basis of the risk assessment has been provided, and is discussed in Sections 3 and 4 of this report).

We understand that the IRBCA risk assessment has not yet been approved by the relevant regulators (MoEP or the IWA). As such, site specific remediation targets concentrations have not yet been agreed with the regulators.

In the absence of site specific remediation criteria, LDD-Ramboll understands that ESC would like the ROA to be based on the IRBCA 'Tier 1' RBTLs (risk based target levels). Our understanding of the remediation targets and requirements is presented in Sections 6.1-6.3 below.

- As per the presentation approach used in Section 5 of this report***, LDD-Ramboll assumptions that are proposed to be carried forward to the ROA are presented in bold italics,*** continuing the numbered bullets presented in Section 5. LDD-Ramboll Recommendations are provided in red text.

The remediation targets and objectives outlined below were discuss and agreed during a call on 6th January 2020 which was attended by representatives from LDD-Ramboll[8] and by Mati Caspi of ESC and Noam Fonia of MoEP.

6.1 Soil Gas Tier 1 RBTLs

The Tier 1 RBTL's for Soil Gas (for a residential use) are presented in Table 6.1. The contaminants of concern (CoCs) shown in the table reflect the Tier 1 RBTL exceedances identified by LDD in its latest zonal active sampling (undertaken in 2018/2019). Table 6.1 also presents the maximum contaminant concentrations detected by LDD during its zonal soil gas sampling.

Adapted Tier 1 RBTLs to account for Vapour Membranes

We understand that the MoEP is typically satisfied for the soil gas risks to new buildings to be mitigated by the installation of vapour barriers (membranes) if the detected soil gas concentrations are less than three orders of magnitude the Tier 1 RBTL.

At the Beit Hakerem site, the existing soil gas concentrations are higher than 3 orders of magnitude the Tier 1 RBTLs. Therefore, vapour membranes alone will not be sufficient mitigation at this site and additional remediation is required.

12. Ramboll understands that, if active remediation reduces the soil gas concentrations to below 3 orders of magnitude higher than the Tier 1 RBTLs, this would be sufficient to allow the development of Beit Hakerem to proceed as long as vapour barriers are installed in the future residential buildings. ***LDD-Ramboll therefore proposes to undertake its ROA based on the target of achieving 3 orders of magnitude the IRBCA Tier 1 RBTL, not the Tier 1 RBTL itself.***
13. There are existing residential areas surrounding the site, and it is unlikely that the existing buildings in those areas comprise gas protection measures. ***LDD-Ramboll therefore understands that Tier 1 RBTLs for residential use are required to be achieved at the site boundary.***

–

[7] Israel Risk Based Corrective Action

[8] Hannah Lewis, Richard Bewley, Jeff Levesque and Paul Hare of Ramboll; and Allison Busgang and Ori Zvikelsky of LDD.

Table 6.1 – Soil Gas Tier 1 RBTLs			
Contaminant of Concern	**Max. Concentration detected by LDD zonal sampling (µg/m3)**	**IRBCA Tier 1 RBTL for Residential Use (µg/m3)**	**3 orders of magnitude IRBCA Tier 1 RBTL for Residential Use* (µg/m3)**
1,1,2-trichloroethane	708.76 (38m)	23.1	**10,000**
1,1-dichloroethane	4,472.41 (6m)	234	**100,000**
1,1-dichloroethene	58,326.07 (6m)	27,809	**10,000,000**
1,2-dichloroethane	7,199.16 (6m)	38	**10,000**
Benzene	250.47 (76m)	130	**100,000**
Chloroform	5,579.76 (6m)	16.3	**10,000**
Tetrachloroethylene (PCE)	1,247,763.50 (15m)	2,100	**1,000,000**
Trichloroethylene (TCE)	254,680.59 (15m)	200	**100,000**
Vinyl Chloride (VC)	54,743.24 (29m)	85.1	**10,000**

*Calculation based on the clarification from MoEP to LDD regarding exceptions in soil gas tests above 3 orders of magnitude dated 29/01/2020

6.2 Soil and Groundwater RBTLs

LDD-Ramboll understand that there are no numeric remedial target values for the contaminants within the soil or groundwater. The objective of the remediation is therefore to reduce soil gas concentrations of the contaminants of concern to the remediation targets as set out in Table 6.1 above.

It is recognised that elevated soil (rock) and groundwater concentrations of volatile compounds, such as the contaminants of concern, will result in elevated soil gas concentrations. Therefore the remediation approach should consider these media in terms of a potential soil gas source, but focus primarily on the rock, based on previous discussions in this report. *Note the assumption made in Section 5.1 (Item 4) about groundwater as a potential source.*

6.2.1 Remediation Timescales and Phasing

LDD-Ramboll has not been provided with fixed remediation timescales that are required to be achieved. However, given that the site is intended for residential development, the redevelopment schedule could be an important consideration/evaluation factor for remedial alternatives).

One of the remediation concepts that LDD-Ramboll proposes to consider in the future ROA is the option of using short-term engineering controls intended to meet remedial objectives (soil gas Tier I criteria, for example) in shallower soils. There may be a somewhat different/longer-term approach for addressing soil gas in deeper soils. This two-staged approach could potentially be used to promote expedited site redevelopment and structures installation in the upper 10-20m; i.e. if the remediation criteria are achieved in the shallower parts of the bedrock, this could enable development of the site whilst remediation of the contamination at greater depths is ongoing.

This possible option of implementing a two-stage approach was discussed during the call between LDD-Ramboll, ESC and MoEP on 6th January 2020. ***ESC and MoEP confirmed during the call that they were not in principle against selecting a two stage approach, and agreed that this merited further consideration as part of the ROA.***

7. RAMBOLL CASE STUDY 1: TCE SUPERFUND SITE (SVE), MALVERN, USA

7.1 Background:

The Malvern TCE Superfund Site is a 2 hectare (5-acre) partially wooded area in East Whiteland Township, Chester County, Pennsylvania, USA. Solvent reclamation activities historically took place that the site. These activities had resulted in the release of tetrachloroethene (PCE) trichloroethene (TCE) and other solvents into the ground.

The geology of the site can be summarised as follows:

- site overburden soils generally consisting of silts/clays to depths ranging to 15-18 m (50-60 ft) below ground surface (bgs); underlain by
- fractured dolomite/limestone bedrock, encountered at depths generally ranging from 13-18 m (45-60 ft) bgs.

Perched water zones were encountered within the overburden soils. The groundwater table within the bedrock was encountered at approximately 24-28 m (80-90 ft) bgs.

The former use of the site had resulted in contamination of the soil and groundwater across much of the 2 hectare property, with chlorinated VOC (CVOC). Elevated contaminant concentrations had been detected in both overburden soils and within the bedrock groundwater. Contaminant concentrations in the soil ranged as high as 1,000 mg/kg PCE and 1,1,1-TCA. (Soil gas monitoring was not undertaken).

No site redevelopment was planned, however there were regulatory requirements for remediation. The main driver for remediation was risk to drinking water supply; therefore the remediation criteria were developed based on drinking water consumption.

Both soil and groundwater were addressed in the remediation. The following table represents the soil remediation criteria (Record of Decision Soil Clean-up Standards (ROD SCS)) for the various constituents of concern (COCs) for the remedial action, based on the findings from historical Site investigations.

COC	1997 ROD SCS (mg/kg)
1,1,1-TCA	4.5
PCE	1.22
TCE	0.7
1,1-DCE	0.05
1,1-DCA	0.39
Vinyl Chloride	0.01
Methylene Chloride	0.5

The future Site use was planned to continue as commercial/industrial (i.e. to remain consistent with historic Site use). The Site is located in close proximity to a residential neighbourhood located downgradient from the property, so protection of these downgradient/nearby receptors (prevention of consumption of impacted groundwater as drinking water) was a key consideration in the remedial action planning/design.

7.2 Remediation Approach

The ground investigation, which informed the remediation was undertaken by a third party. The soil survey to characterise the site and delineate the extent of contamination within the SVE treatment area comprised over 50 soil borings, with soil sampling undertaken at several depth intervals within each boring in order to provide vertical characterization of the soil impacts. In addition to the soil borings, there are dozens of groundwater monitoring wells at the site

The remediation was led by OBG, a part of Ramboll. Ramboll's work involved the construction and operation of the remediation system. The remediation project included:

- demolition of an existing manufacturing facility;
- construction of a 0.8 hectare (2-acre) cap over the area of the demolished facility (to eliminate the potential for direct contact by site users/occupants with impacted soils);
- installation of a soil vapor extraction (SVE) system in an area that was previously used as a drum disposal area; and
- continuing operation and maintenance and monitoring services.

In addition to the SVE system installation and operation, Ramboll designed and constructed an accelerated in situ bioremediation (AISB) groundwater remedy in the fractured bedrock aquifer, which has been in operation since 2010. *In addition to the remediation work described above, OBG designed and constructed an accelerated in situ biormediation (AISB) groundwater remedy in the fractured bedrock aquifer, which has been in operation since 2010. This is not directly relevant to remediation of the unsaturated zone, however information about this element of the remediation is presented in Section 7.5 below.*

7.2.1 SVE system Selection

SVE was selected as a remedial technology for the Malvern site for the treatment of VOC impacts in vadose zone soils. The primary objective of the SVE system was to reduce the potential for continued migration of contaminants in overburden site soils to groundwater.

SVE is described as follows:

- SVE technology entails the extraction of air/vapor from subsurface soils in the vadose zone as a means of removing VOC impacts from the soils.
- Deployment of the technology generally includes the installation of vapor extraction wells screened in the vadose zone. Above-grade extraction piping then connects the extraction wells to above-grade treatment equipment at a centralized location.
- The SVE treatment equipment typically includes vacuum blowers which, when operated, allow air/vapor to be extracted from the vadose zone soils via the network of extraction wells. The blowers convey extracted air/vapor to treatment equipment (typically granular activated carbon vessels) prior to discharge of extracted air to the atmosphere.

The SVE remedy implementation included the SVE extraction wells and treatment system installation; SVE system operation, performance evaluation, and optimization; and system shutdown/closure.

7.2.2 SVE System Installation

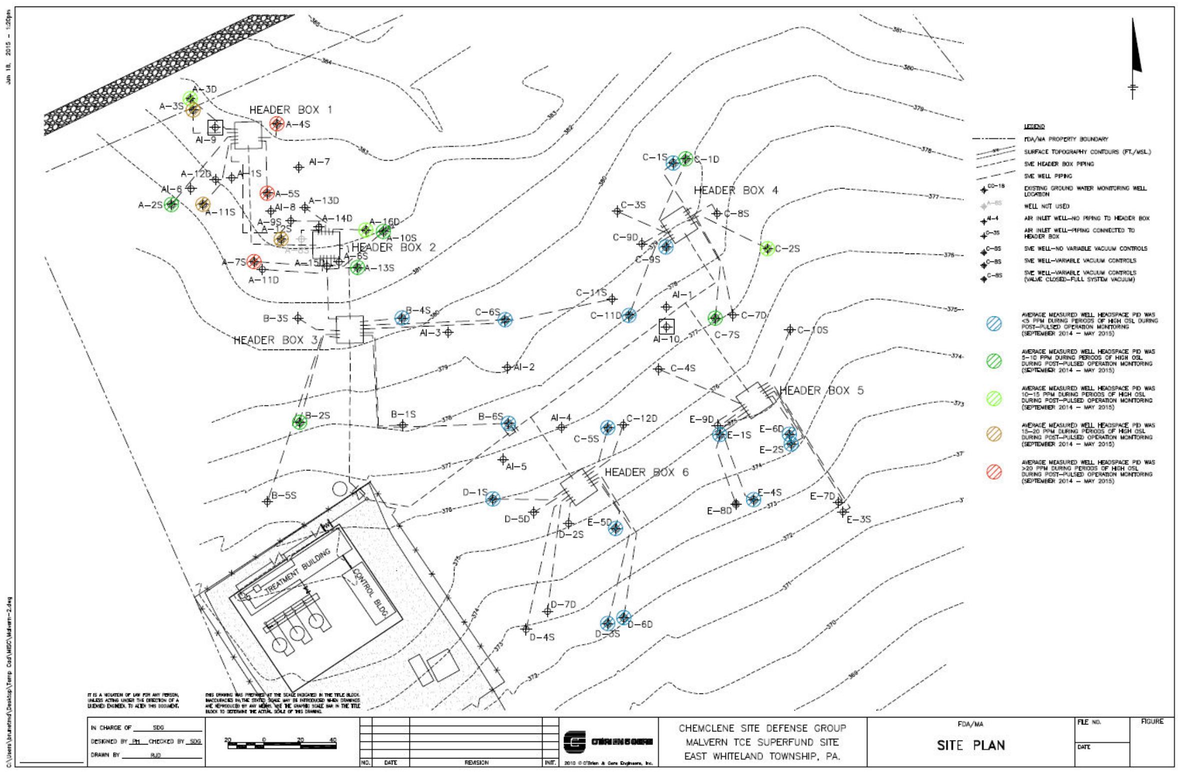
OBG (Part of Ramboll) completed the SVE system installation in December 2005. The system installed was completed in approximately 6 months, and can be summarised as follows:

- The system covered an area of approximately 0.5 hectare (1 acre) and included 55 vapor extraction wells installed at spacings of approximately 1.5-12 m (5-40 ft), representing an overall treatment volume of approximately 23,000 cubic meters (30,000 cubic yards)
- The depth of the SVE extraction wells was in the range of 3-14 m (10-50 ft) bgs (average depth of approximately 6-8 m (20-25 ft bgs), within the overburden soil.
- The SVE wells were manifolded to the above-grade treatment system equipment, which comprised:

- vacuum blowers for air/vapor extraction;
- moisture-separator equipment for removal of entrained liquids from the air stream; and
- two 1,000-lb vapor-phase granular activated carbon (GAC) vessels installed in series for removal of volatile organic compounds from the extracted air. Air monitoring for permit compliance was conducted by continuous monitoring of total VOCs via a hydrocarbon gas analyser, at interstitial ports in system piping located upstream, between and downstream from the GAC vessels

- The overall sizing of the blowers/system airflow was approximately 1,500 standard cubic feet per minute (approx. 2,548 m^3/hr).
- The SVE system equipment was located on a concrete pad (approximately 40-feet by 40-feet in size). The equipment included the GAC vessels, connecting piping, storage buildings for the system equipment. The equipment pad was provided with perimeter chain link fencing for site security. A 4,160 volt, 3-phase electrical service was installed to provide system power.

Ramboll Figure 12 - Layout of SVE Wells and System for Malvern Superfund site (Ramboll Case Study 1)



Ramboll Figure 12 - Photo of SVE system equipment installation for the Malvern Superfund site (Ramboll Case Study 1)

7.2.3 SVE System Operation

Ramboll completed the system start-up activities, and conducted the system operation/maintenance and monitoring activities, as summarised below. (Detail about the logistics for the remediation, including electricity supply, are detailed in Section 7.2.2 above).

- The SVE system operations were conducted from December 2005 through August 2014.
- Ramboll undertook and arranged equipment maintenance, data collection, monthly progress reports, and regular system adjustments.
- In addition Ramboll conducted several system optimization studies and implemented system upgrades to enhance VOC mass removal. These included:
  - pulsed operations approach (in which SVE system operations were cycled on and off and soil gas measurements were collected in SVE wells to evaluate and compare soil gas concentrations during operational and non-operational periods);
  - air injection enhancements (in which air was injected into the subsurface in selected areas to enhance air movement in the subsurface and evaluate whether an increase in VOC mass removal would be achieved); and
  - vacuum/influence testing (in which the radius of vacuum influence at selected SVE wells was tested during the system operations to confirm that the targeted soil areas were being treated).

  These operational adjustments allowed the system operations to be customized to the site-specific conditions (e.g. varying the amount of vacuum to minimize the entrainment of water into the system, and thereby enhancing air flow from the extraction wells). The findings from the active air injection and pulsed operations testing were used to support the decision to shut down the SVE system due to asymptotic removal conditions.

7.2.4 SVE System Costs and Timescales

The system construction costs were estimated between $3-4M (the system was installed as part of a larger remediation project which included groundwater treatment, and so some of the installation/construction costs were shared between the two systems).

Operations costs varied between $200-300K per year.

- O&M costs were relatively consistent over the operations period, and did not vary with concentration reductions.

The SVE operations commenced in December 2005 and the overall operations period was estimated to take approximately 4-5 years (in addition to the construction period of 6 months, discussed above).

No “pilot” testing was undertaken as part of this project, but field design testing typically requires 6 months to plan and implement. The 4-5 year estimated treatment period included associated system testing, plus approximately 1 year of modified/non-continuous operations prior to shut-down.

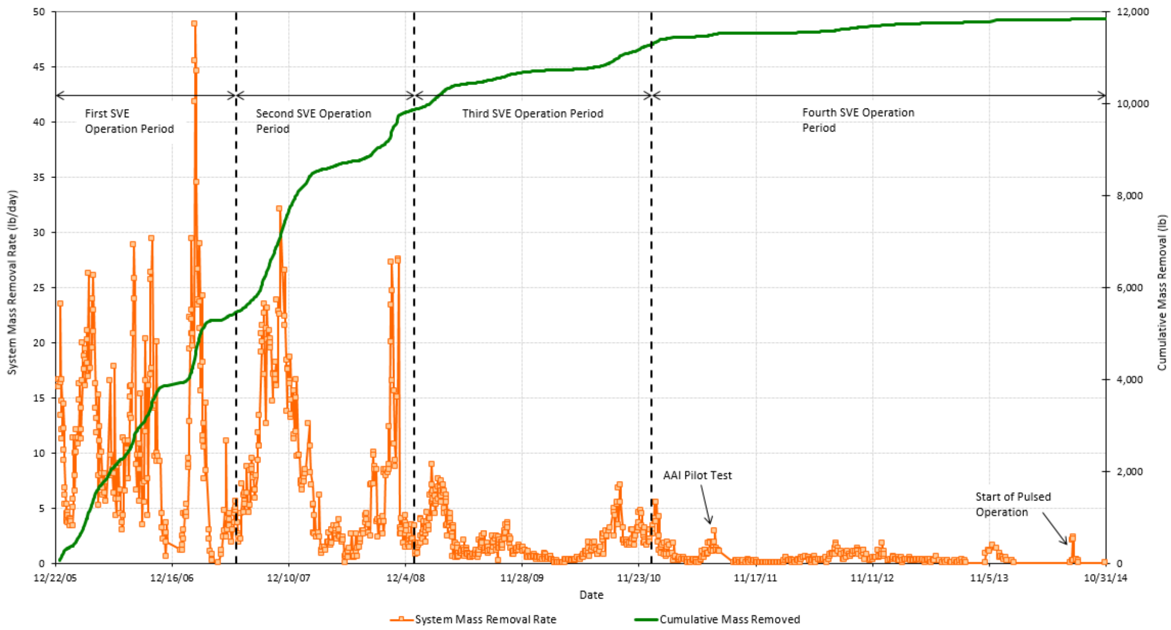
7.3 Outcome

Based on the observed system-wide asymptotic mass flux, the SVE system was shut down in August 2014 (i.e. the remediation end point was determined based on achieving an asymptote, rather than by re-sampling of soils to assess whether the ROD SCS (as presented in Section 7.1) had been achieved).

The SVE system was therefore operational for approximately 9 years (rather than the 4-5 years originally estimated). The differences in the timeframe for the SVE system largely stem from issues related to high groundwater at the site and the presence of low-permeability soils (silts/clays) within the treatment zones – i.e. challenging subsurface conditions.

The estimated total VOC mass removed by the SVE system was approximately 5,350 kg (11,800 pounds). Although the numerical soil remedial targets were not achieved (final soil concentrations remained elevated, generally in the range of 10-1,000 mg/kg), Regulatory approval for system shut-down was obtained based on the demonstration of asymptotic mass flux from the treatment zone. To recap, the main driver for this remediation was to mitigate the risk to drinking water supply (from a potential ongoing source in the unsaturated zone). However, the regulators also required that any future buildings at the site be installed with soil vapor mitigation systems.

Ramboll Figure 13 - Graph showing SVE mass removal rate over time at Malvern Superfund site (Ramboll Case Study 1)



7.4 Lessons Learnt

Several lessons were learned from this project:

- One of the main take-aways was that a thorough understanding of the site-specific groundwater characteristics (in this case the presence of perched zones of groundwater) is critical for successful SVE system design and operation. *As noted above, the presence of shallow groundwater contributed to a longer remediation timescale.*
- Also, due to the heterogeneous nature of the soil, the installation of variable vacuum control on each well was effective in improving the performance of the system. *As noted above, Ramboll was able to enhance the air flow from extraction wells and minimise water uptake in the system by varying the amount of vacuum.*

These lessons will be useful in the implementation of future SVE systems.

7.5 Applicability to Beit Hakerem Site

The Beit Hakerem project has some key similarities to the Malvern site, including the presence of heterogeneous subsurface conditions, where the lessons learned from the Malvern site can be applied towards developing an effective remedial approach.

It is noted that the Beit Hakerem site has a significantly deeper vadose zone requiring treatment (including bedrock), so some adaptation of the remedial approach used for the Malvern site would be required. As a general statement, the implementation of remediation in bedrock settings tends to increase the costs and timeframes, but the magnitude of the cost/schedule impacts is determined on a case-by-case basis.

In addition, the Beit Hakerem site is located in a region with a drier climate, so soil moisture conditions may be more favourable to the application of SVE as a remedial technology for the site.

7.6 Treatment of Groundwater - Accelerated In Situ Bioremediation (AISB) at Malvern Superfund Site (Ramboll Case Study 1)

7.6.1 Microcosm Study

Prior to start up of the full scale AISB system Ramboll conducted a laboratory microcosm study to support the AISB optimization process. The microcosm study plan was developed to specifically address the challenge of incomplete biodegradation of volatile organic compounds (VOCs) observed during the prior field testing (conducted by others). The incomplete process was originally attributed to microbial inhibition associated with the high concentration, complex VOC mixture. However, Ramboll's microcosm study data indicated excess electron donor (primarily methanol) used during the prior pilot test had created a toxic environment for the dechlorinating microorganisms in the groundwater. This observation, borne out of the microcosm study, was key to understanding microbial dechlorination inhibition in the site groundwater and to reviving the feasibility of the AISB remedy.

Ramboll also conducted a groundwater pH study, initially using laboratory titration experiments and subsequently, in the field using a manual anoxic subsurface delivery system designed and constructed at the site in response to potentially inhibitory pH conditions observed in site groundwater during the monthly AISB monitoring.

7.6.2 Pilot Study

OBG completed a 3.5-year AISB field pilot study. Based on interim results from the concurrent microcosm study discussed above, OBG adjusted the pilot program to improve groundwater conditions for the dechlorinating organisms. The results from the pilot test indicated dechlorination of 90% of the TCE, cis-1,2-dichloroethene (cDCE), and vinyl chloride (VC) to ethene, and 1,1,1-trichloroethane (1,1,1-TCA) dechlorination to chloroethane. Remedy Change

Based on OBG's successful pilot study, USEPA changed its Record of Decision (ROD) from extraction and treatment of groundwater via air stripping followed by carbon adsorption and reinjection of the treated water to AISB using a recirculation method from "pump and treat". This change resulted in more effective treatment of the chlorinated VOCs with a shorter remedial timeframe relating to a higher cost saving to the client when compared to the pumping option.

7.6.3 Design, Construction and Start-Up

The design, construction, and start-up phases for the full scale AISB system were approved by the USEPA and completed by OBG within a 16-month period. The full-scale setup consisted of an automated "biorecirculation" system where groundwater is extracted through five groundwater wells into a mixing tank and amended with lactate and nutrients. This water is re-injected through seven injection wells into the groundwater TCE source area. Enhanced attenuation / monitored natural attenuation (MNA) was the remedial approach to address the groundwater down gradient and beyond the AISB treatment zone.

The full scale system consisted of a central anaerobic amendment mixing tank connecting seven injection and five extraction wells with sodium lactate as the electron donor, and mineral nutrients to supply ammonia and phosphate that are metered into the tank.

Bioaugmentation of the groundwater with Bioremediation Consulting Inc.'s (BCI) TCE/1,1,1-TCA degrading culture was performed to grow and distribute the culture within the treatment area. After five years of continuous operation, the AISB system achieved dechlorination of TCE/1,1,1-TCA to end products at down gradient extraction wells. On average, parent CVOC concentrations were reduced

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Bioaugmentation of the groundwater with Bioremediation Consulting Inc.'s (BCI) TCE/1,1,1-TCA degrading culture was performed to grow and distribute the culture within the treatment area. After five years of continuous operation, the AISB system achieved dechlorination of TCE/1,1,1-TCA to end products at down gradient extraction wells. On average, parent CVOC concentrations were reduced by 87% (1,1,1-TCA) to 99% (PCE and TCE) in full-scale AISB treatment areas. Additionally, the source area wells demonstrated a high ratio of end products (e.g., ethene) to parent or intermediate compounds.

7.6.5 Diagnostic Testing

After achieving complete in situ reductive dechlorination (IRD) of high concentrations of TCE, cDCE and 1,1,1-TCA to end-products within two years, challenges posed by variable groundwater flow conditions and precipitation/ biofouling on well screens resulted in the near complete loss of in situ electron donor concentrations. As a result, additional diagnostic testing and well rehabilitation efforts were employed to restore biostimulation, confirm the robustness of the dehalorespiring culture, and restore in-situ reductive dehalogenation (IRD) rates. Adjustments in system operations were made to optimize the distribution of electron donor and mineral nutrients and to enhance the rate of dechlorination.

7.6.6 AISB Performance

The AISB system met performance objectives and design expectations in terms of flow and amendment distribution, as documented throughout the six years of operation. AISB remediation efforts have demonstrated success at achieving complete dechlorination of TCE to ethene and reductive dechlorination of TCA to chloroethane several monitoring points at various times throughout the operating period.

Based on the source area percent reductions in groundwater parent CVOC concentrations, AISB treatment and natural attenuation processes in the MPA to date has potentially reduced the residual source mass by as much as 86 to 90%.

The groundwater CVOC data from the pre-AISB period through March 2016 clearly demonstrate that AISB remedial actions and MNA processes have significantly decreased CVOC concentrations over time in the MPA core source area and downgradient plume area.

7.6.7 Enhanced Monitored Natural Attenuation (CVOCs and 1,4-dioxane)

The downgradient dissolved phase plume is being remediated by natural attenuation consistent with the ROD and enhanced by source remediation. Based on the AISB pilot study and operation results to date, bioremediation provides control of the CVOCs in the source area and effectively limits further migration of the CVOC plume from the source area by reducing the source mass and CVOC concentrations. AISB treatment of the source area enhances the attenuation of the CVOC plume, and together with natural attenuation, reduces the extent of the CVOC plume. Pumping and reinjection of groundwater is employed to optimize the distribution of organic donor/nutrients and remediation of the potential and core source plume area. The system is expected to reduce the CVOC mass flux from the source area to the extent that attenuation processes will prevent the potential further migration and ultimately remediation of the CVOC plume. The groundwater MNA performance monitoring data for Site VOCs demonstrates declining trends in CVOCs, including 1,4-dioxane, and significant spatial attenuation of VOC concentrations approaching Maximum Contaminant Levels (MCLs) in the farthest monitoring wells from the source area.

8. RAMBOLL CASE STUDY 2: IN-SITU THERMAL REMEDIATION, NEW JERSEY, USA

8.1 Background

OBG (now part of Ramboll) provided remediation support at an industrial facility in New Jersey, USA, where ground contamination with chlorinated solvents had been identified. The site had previously been used for the manufacture of pipe fittings and couplings.

Tetrachloroethene (PCE) and to a lesser degree trichloroethene (TCE) had been identified as Constituents of Concern (COCs) at the site, with soil concentrations in the range of 1-100 mg/kg (soil gas was not sampled).

The geology of the site comprised:

- low-permeability silts with zones of perched groundwater, underlain by;
- fractured carbonate bedrock, which was encountered at approximately 15-18 m (50-60 ft) bgs.

The area of the vadose soil footprint that required treatment was approximately 464 m^2 (5,000 square feet), spanning to depths up to 15-22 m (50-70 feet), representing an overall treatment volume of approximately 5,000 cubic yards, or approximately 3800m^3) below ground surface (i.e. into the upper portions of the bedrock zone, where the groundwater table was first encountered).

8.2 Remediation Approach

Ramboll conducted a remedial investigation, provided remediation selection/design, then undertook permitting, and third party implementation support for the remediation project.

The conceptual remedial approach entailed treatment/removal of the PCE-impacted soils in the vadose zone. The objective of the vadose zone treatment was to promote natural attenuation of PCE impacts in the underlying bedrock groundwater. There was a soil remediation target was <0.1 mg/kg of PCE.

8.2.1 Selection of ISTR

Due to the low permeability conditions in the vadose zone, and based on the soil clean up goal for PCE, conventional soil vapor extraction (SVE) was not considered viable to address the PCE impacts in these soils.

In-situ thermal remediation (ISTR) was selected for the area of concern due to the enhanced VOC removal offered by heating of the soils targeted for treatment. The ISTR treatment zone encompassed both overburden soils and the upper portions of the bedrock zone.

8.2.2 ISTR System Installation

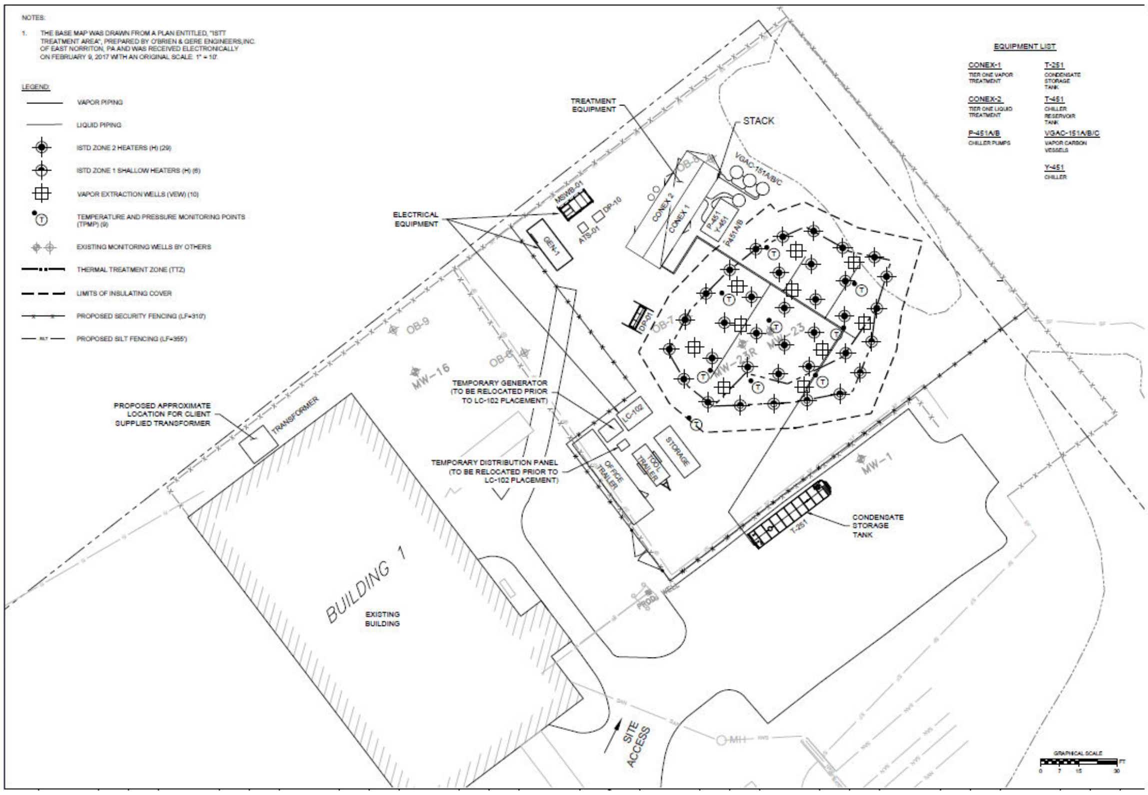
The ISTR approach employed the use of sonic drilling techniques, which allowed for the installation of heating well-field into the upper portions of the limestone bedrock, providing an effective heating of the full extent of the overlying vadose zone soils, as well as the upper portions of the bedrock.

Shallow soils with a high total organic content (up to 2.5m (8 ft) bgs) were removed due to the potential for interference in the extraction of VOCs. Liquids and vapours generated by the ISTR treatment were treated by above-grade treatment equipment in accordance with applicable permit requirements.

OBG (Part of Ramboll) completed the SVE system installation in December 2005 (system installation period of approximately 4 months). The system (which used a thermal conductive heating (TCH) technology) can be summarised as follows:

- The system included approximately 44[9] heater wells and vapor extraction wells installed at spacings of approximately 3 m (15 ft).
- The depth of the heater wells and SVE extraction wells was in the range of 6-20 m (20-70 ft) bgs.
- The SVE wells were manifolded to the above-grade treatment system equipment, which included vacuum extraction blowers and granular activated carbon (GAC) vessels for treatment of extracted air prior to discharge to the atmosphere.
- The above-grade treatment equipment was installed in an approximately 50-foot by 50-foot area adjacent to the well-field. Treatment equipment was housed in two small buildings and three 1,000-lb vapor-phase granular activated carbon (GAC) canisters installed in series provided air emissions treatment, and air permit compliance monitoring was conducted via photo-ionization detector (PID) readings. The extraction blowers for this site were sized at approximately 500 standard cubic feet per minute (approx. 850 m^3/hr). Perimeter chain link fencing was installed for site security.
- A dedicated 1,000-kVA power service drop was furnished to provide power for well-field heating and system operations. A stand-by generator was also provided to provide system back-up power in the event of primary power service interruption.

Ramboll Figure 13 - Layout of ISTR Wells and System for Case Study 2



[9] One or two additional wells were installed beyond the initial design based on site-specific conditions during drilling, but the approximate number of 44 wells is representative of the overall scale of the project

8.2.3 ISTR System Operation

Ramboll provided engineering support and third-party oversight throughout the ISTR implementation.

The ISTR heating operations were conducted over an approximately 6-month period, during which period Ramboll provided the following services:

- review of system operations data to evaluate overall treatment progress;
- performed perimeter air monitoring to evaluate the potential for fugitive emissions from the ISTR well-field (conducted using periodic PID measurements along the work area perimeter); and
- conducted post-treatment soil sampling to confirm that the remedial action treatment objectives were attained, as described below.

See also information in Section 8.2.2 above regarding air monitoring.

SVE System Costs and Timescales

The total cost of this remediation was originally estimated to be $3,100,000. The ISTR operations were planned to be completed within approximately 6 months.

8.3 Outcome

The remediation project was completed on-budget, and within the 6-month time period that was originally envisaged.

Ramboll collected hot soil treatment verification samples upon treatment completion. The soil clean-up objective (<0.1 mg/kg of PCE) was attained in all samples.

Ramboll also conducted communications with the regulator (New Jersey Department of Environmental Protection) and undertook post-remediation reporting as required to document the successful completion of the remediation in accordance with regulatory requirements.

The estimated total VOC mass removed by the ISTR system was approximately 68kg (150 pounds).

8.4 Lessons Learnt

There were several lessons learnt from this project. One major lesson was experienced from working in a karst environment.

- Features such as troughs or sinks in the overburden/bedrock interface were identified during this project at the time of ISTR wellfield installation.
- Based on this finding, drilling/well installation adjustments had to be made during the drilling activities. If there had been a better understanding of the subsurface prior to this stage, it would have proved to be beneficial. This knowledge can help guide future investigations.

The takeaway from this is to consider the utilization of surface geophysics techniques to map the highly variable subsurface terrain prior to ISTR design.

8.5 Applicability to Beit Hakerem Site

The remedial approach for the Beit Hakerem project is likely to include remedy implementation in a heterogeneous fractured bedrock environment (similar to the variable bedrock conditions described in the above case study). Therefore, some of the key lessons learned relative to subsurface characterization and technology deployment will be highly applicable to the Beit Hakerem remedy selection/design.

The main difference between work in soils vs. karstic bedrock would be the type of drilling techniques used for the well-field installation. For this project, sonic drilling techniques were used since the lower portion of the treatment zone was installed into karstic bedrock, and similar drilling techniques would be contemplated for use at the Beit Hakerem site.

9. RAMBOLL CASE STUDY 3: SVE AND BIOVENTING, VIRGINIA USA

9.1 Background:

The site is an industrial facility, located in Virginia, USA. The site is located in a complex karst environment, on the bank of river that serves as a public water drinking water supply. The area surrounding the facility is residential and agricultural

The site was constructed in 1940 for the chemical manufacture of pharmaceuticals. The site was originally selected for this use because of an extremely productive groundwater aquifer that could supply water to support the manufacturing processes. Groundwater contamination was identified soon after production started in 1941. The manufacturing operations at the site are currently undergoing a transformation from chemical to biological processes, with significant changes in infrastructure, and reduction in the demand for water.

9.1.1 Contaminants of Concern and Target Levels

There are a wide range of organic contaminants present in soil and groundwater at the site.

- Soil contamination encompasses approximately 10 hectares (25 acres) spread over 5 separate areas of concern (AOC), and extends to a depth of up to 18m (60 feet) below ground level.
- Groundwater contamination is primarily within the karst bedrock, and encompasses an area of more than 25 hectares (60 acres) across the site to a depth of up to approximately 90m (300 feet). The presence of groundwater within the overburden is limited, however it is contaminated in the areas where it is present (approximately 2.5 hectares (6 acres)).
- The primary contaminants of concern are benzene, chlorobenzene, toluene, xylene, and alpha picoline.
  - Contaminant concentrations were detected in the range of up to parts per 10,000 in both soil and groundwater (100,000-999,999 ppb range). Soil gas concentrations were detected up to 10,000 ppm.
  - Chlorinated volatile organic compounds (CVOCs) such as carbon tetrachloride, trichloroethylene, and methylene chloride have been identified in limited areas of the site, with concentrations up to parts per 100,000 (10,000-99,999 ppb range).

9.1.2 Remediation Objectives

Through a happy accident, groundwater abstraction at the site has contained the majority of the contaminant plume in the bedrock groundwater (i.e. the 'hydraulic containment' action of the on-site groundwater abstraction well has mitigated the migration of contaminants offsite towards the river and towards privately-owned water supply wells). As a consequence, the site has been able to negotiate a more flexible approach to investigation and remediation of contaminant source areas within the soil.

- The overall remedial action goal for the site is to reduce the concentration of contaminants of concern in the bedrock groundwater to achieve the groundwater clean-up levels (GCLs) established for the site, and return the bedrock groundwater to is maximum beneficial use.
- In support of this, the remedial action objectives for the soil are to reduce the flux of contaminants to bedrock groundwater to the extent practical within the limits of the specified remediation technology, which is soil vapor extraction, and bioventing. There are no specific cleanup levels for soil or soil gas. Instead, the objectives have been to undertake the

remediation treatment to the limits of the specified technology (i.e. to achieve asymptotic conditions).

9.2 Remediation Approach

9.2.1 Selected Technology and Approach

The approach selected for the remediation of the soil in one approximately 2.5 hectare (6-acre) area of the site (AOC South) is soil vapor extraction (SVE) and bioventing. As background:

- bioventing is an in situ remediation technology that encourages the biodegradation of organic constituents in the unsaturated zone by microorganisms. Oxygen is delivered to the subsurface via bioventing wells, to encourage the biodegradation.
- An overview of SVE is provided in Section 7.2.1 above, as part of the Malvern case study.

These technologies were selected because:

- Pilot-testing indicated that SVE was very effective at rapidly removing highly volatile compounds such as benzene, xylene, and CVOCs, particularly in areas where high concentrations of these constituents could limit the effectiveness of bioventing.
- Pilot testing of bioventing indicated it was effective at treating the compounds that were less volatile.
- Both SVE and bioventing were able to address a broad area of the overburden, and could be used to address contamination beneath the extensive surface infrastructure at the site.

The original design of the remediation system called for implementation of SVE first, to reduce high concentrations of volatiles. This was to be followed by bioventing to remove the less volatile contaminants. This approach was approved by the regulatory agency, and the system was constructed; however, prior to final implementation of the remedy, the client eliminated soil vapor extraction as an option, because of air permitting limitations[10] for the site, and bioventing is the only technology that has been implemented at full scale.

9.2.2 Description of Implementation

The remedial action has been implemented in phases.

- Initially, a pilot study was performed using both SVE and bioventing through a series of wells in a limited area (approximately 0.4 hectare / 1 acre) to an average depth of around 10m (35 feet) below surface.
- Following the pilot study, Phase 1 implementation included 12 vertical wells, and a single, 215m (700-foot) long horizontal well over an area of approximately 2.8 hectares / 7 acres.
  - The horizontal well was targeted to level out at a depth immediately above the top of bedrock (approximately 10-12m (35-40 feet) below surface) with a screen 90m (300 feet long). The intent was to avoid intersecting any bedrock pinnacles, to avoid the potential of intersecting a fracture or void that could cause short-circuiting, and prevent even distribution of the airflow.
  - With extensive infrastructure overlying the phase 1 area, the system was operated using gentle, intermittent pulses of air, to prevent the surface emission of organic vapors.

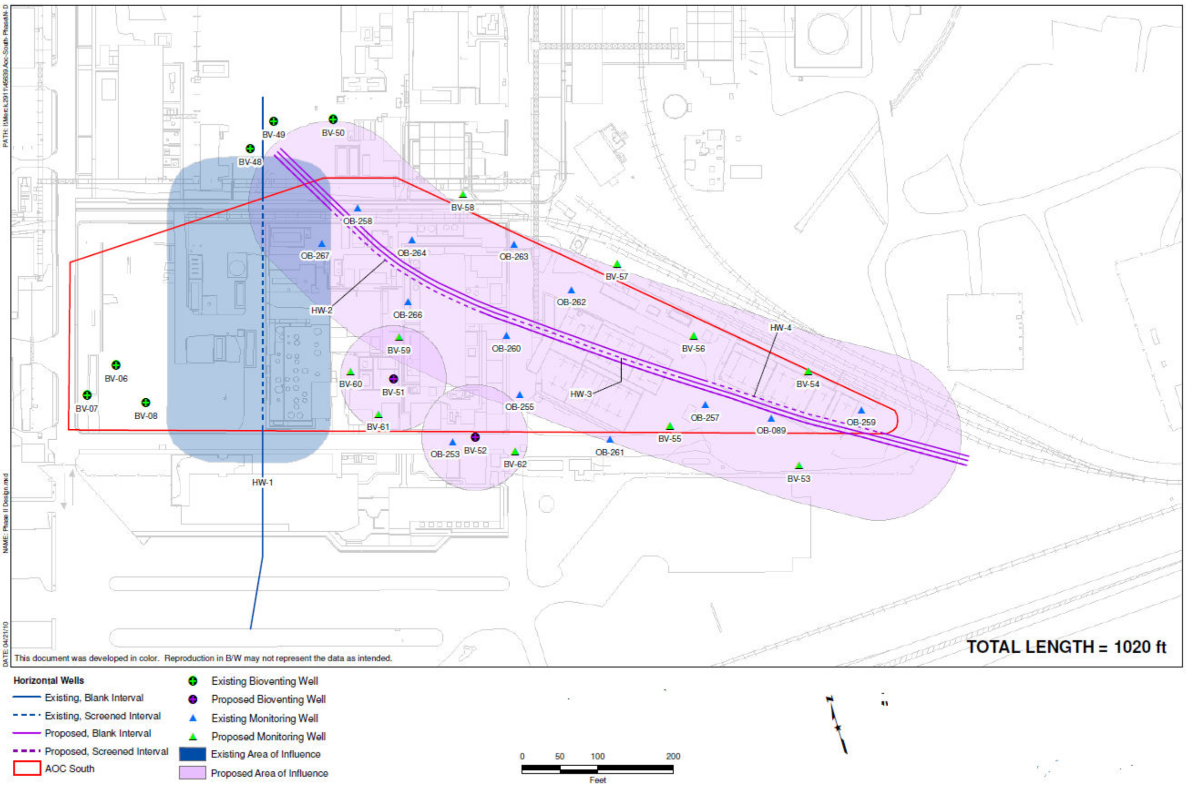
[10] The client had recently had other unrelated air emissions issues. The client was very close to their total allowed emissions limit, and did not want to risk going over because of the SVE system. Even with emission controls, the regulations in Virginia based the limit on the potential to emit, and not the actual emissions. Given all of these issues, the client elected to forego SVE, and simply work with a slower remedial technology. Recently, processes at the site have changed, there is added capacity in the air permit, and the client has suggested that perhaps SVE is an option in some areas where bioventing has been particularly slow to reduce contaminant mass.

Extensive surface and subsurface monitoring was performed to verify that there were no emissions.

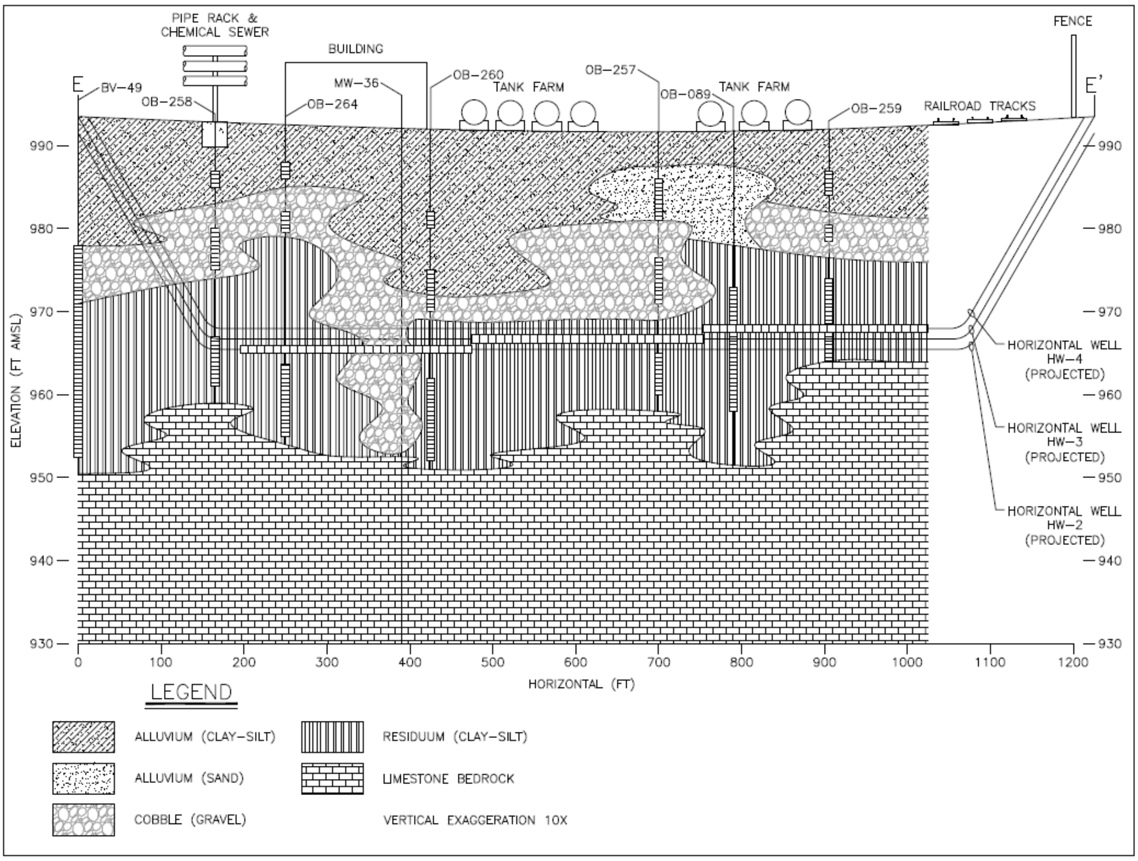
- Operation of the Phase 1 system over a period of approximately 2 years demonstrated that the horizontal well had the greatest area of effect, and was more effective than vertical wells for treatment of the unsaturated soil.
- Furthermore, the use of horizontal wells was found to be less than half the cost of vertical wells because of the significant cost of construction for pipelines to serve the vertical wells.
- The horizontal wells pump air at approximately 50 cubic feet per minute (approx. 85 m^3 per hour). The flow rates of the vertical wells varies, but is typically around 5 cubic feet per minute (approx. 8.5m^3 per hour). These flow levels have prevented surface emission of VOCs.
- The treatment system was constructed in two seatrain containers located adjacent to each other. One contained the blowers and control system, and the second contained granular activated carbon filters for the effluent air, and a steam regeneration unit that then discharged the condensate to a thermal oxidizer associate with one of the manufacturing processes at the Site. Electrical connections were made directly to the the plant utility system. Piping to the wells was run below ground where possible, and on existing pipe racks through process areas where trenching was not practical.

- The Phase 2 system was designed to include three, 3-inch diameter horizontal wells installed in a single 335m (1,100-foot) borehole to address contamination across the remaining 1.6 hectares / 4 acres of the treatment area.
  - The wells were constructed with 350 screens that were set at different intervals in the borehole, with each screen separated by approximately 9m (30 feet).
  - This was done to allow a greater range of control over the system, and to limit the potential for failure if a portion of the screened interval intersected a void or conduit that could short-circuit the airflow and prevent a broader distribution of oxygen.
  - In fact, a bedrock pinnacle with a void was identified during the drilling, and a 12m (40-foot) section of one of three screens was replaced with blank casing to prevent short circuiting. This modification was successful, and allowed use of all three screens.

Ramboll Figure 14 - Layout of Horizontal and Vertical Bioventing Wells for Case Study 3



Ramboll Figure 15 – Horizonal Well Design Cross Section from Case Study 3



9.2.3 Anticipated Cost and Timescales

The cost for installation of the Phase II system was approximately $ 1.2 million USD. This includes the installation of the horizontal wells ($ 750,000), vertical wells ($ 100,000) and piping.

The operation and maintenance costs for the entire system have varied, but average approximately $ 100,000 USD per year. The Phase 2 system has been in operation since 2011, and was initially projected to operate for 5-7 years.

9.3 Outcome

The system has been promoted bioremediation in the overburden soil and has been effective in reducing the mass of contaminants in the overburden soil.

Initially, it produced vigorous bioremediation in the overburden soil, although the rate of biodegradation has decreased significantly over time. This has been attributed to the depletion of nutrients (nitrogen and phosphorous) which has impacted the rate of biological activity. The system had been designed to use SVE first to remove the majority of the contaminant mass, and then use bioventing to degrade the more recalcitrant compounds. Because bioventing has been used throughout, the depletion of nutrients has been more pronounced.

The system was initially projected to operate for 5-7 years, however with the elimination of SVE as a remediation technology (see Section 9.2.1 above), this timeframe is no longer valid. The system has already been in operation for 10 years, and has still not achieved remedial objectives (treatment to the limits of the selected technology) in all areas, although it continues to reduce the contaminant mass in the overburden soil.

9.4 Lessons Learned

Overall, the remediation system has been effective in promoting bioremediation in the overburden soil. The system would have been far more effective if SVE could have been implemented, and would likely have achieved the remedial objectives throughout the treatment area by this time.

The regulatory agency has been completely satisfied with the system, and despite the fact that remedial objectives have not been achieved in all areas, would likely allow shutdown, if the client wished to do so. The client has elected to continue with bioventing given that it still produces reductions in the contaminant mass. Recently, changes in the manufacturing processes at the Site have produced significant reductions in the amount of VOCs emitted, and it may be that SVE can be used to address recalcitrant areas that have not met remedial objectives.

9.5 Applicability to Beit Hakerem Site

The system described in this case study was not installed into bedrock (targeting to immediately above the bedrock).

- This was because, within the bedrock, contamination within groundwater was the primary concern at this site, and the groundwater was already being addressed via containment through groundwater extraction (see Section 9.2.1 above).
- There is no reason, however, that SVE/bioventing with horizontal wells could not be effectively applied within the bedrock. In fact, Ramboll is currently evaluating the installation of a groundwater recirculation system at the site of this case study, which would make use of horizontal wells to facilitate the distribution of a chemical oxidant, and reach areas beneath a closed, hazardous waste landfill.

While the approach described in this case study was not focused on the treatment of CVOCs, it is clear that SVE could be very effective for these constituents. Furthermore, although less common, there have been case studies[11] that demonstrate the effectiveness of bioventing to remediate CVOCs in the unsaturated zone. For example, by cometabolic bioventing, or by creating a low oxygen environment within the unsaturated zone that is conducive to the in-situ bioremediation of CVOCs (albeit, it should be noted that this is a fairly novel technology which is currently not commonly implemented).

[11] This includes a case-study by the U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response Technology Innovation Office on 'Cometabolic Bioventing at Building 719, Dover Air Force Base, Dover, Delaware', dated March 2000.

10. REPORT QUALIFICATIONS

10.1 General Limitations and Reliance

This report has been prepared by Ramboll UK Limited ("Ramboll") exclusively for the intended use by LDD Advanced Technologies (the "client") in accordance with the agreement (proposal reference number LQ1620007286_01), dated 25th July 2019 between Ramboll and the client defining, among others, the purpose, the scope and the terms and conditions for the services. No other warranty, expressed or implied, is made as to the professional advice included in this report or in respect of any matters outside the agreed scope of the services or the purpose for which the report and the associated agreed scope were intended or any other services provided by Ramboll.

In preparation of the report and performance of any other services, Ramboll has relied upon information provided by the client. Accordingly, the conclusions in this report are valid only to the extent that the information provided to Ramboll was accurate, complete and available to Ramboll within the reporting schedule.

Ramboll's services are not intended as legal advice, nor an exhaustive review of site conditions and/or compliance. This report and accompanying documents are initial and intended solely for the use and benefit of the client for this purpose only and may not be used by or disclosed to, in whole or in part, any other person without the express written consent of Ramboll. Ramboll neither owes nor accepts any duty to any third party, unless formally agreed by Ramboll through that party entering into, at Ramboll's sole discretion, a written reliance agreement.

Unless otherwise stated in this report, the scope of services, assessment and conclusions made assume that the site will continue to be used for its current purpose and end-use without significant changes either on-site or off-site. Unless stated otherwise, the geological information provided is for general environmental interpretation and should not be used for geotechnical and/or design purposes.

Where assessments of works or forecast costs required to reduce or mitigate the environmental or health and safety liabilities identified in this report are made, such assessments are based upon the information available at the time the work was undertaken and are subject to further studies and information which may become available. Cost forecasts are based upon measures which, in Ramboll's experience, could normally be agreed with the competent authorities (based on international experience) and associated third parties by an experienced practitioner under present legislation and enforcement practice, all parties acting reasonably.

Cost forecasts do not include potential indirect costs (e.g. business loss and interruption, etc.) that may be incurred as part of implementation of any technical measures as enforcement action by the competent authorities. No allowance has been made for changes in prices or exchange rates or changes in any other conditions which may result in price fluctuations in the future, all cost forecasts having been calculated at present day market rates. Unless expressly stated, Ramboll has not discounted (net present value) the expenditure profiles and has not taken account of applicable taxes or cost inflation.

10.2 Scope Limitations and Exceptions of the Assessment

Ramboll has performed this assessment in accordance with the scope of services outlined in our (proposal reference number LQ1620007286_01), dated 25th July 2019.

- The site history, site survey, and conceptual site model (CSM) information presented in this report is based on information provided in third party reports (i.e. Dekonta's Conceptual Site Model report, May 2018; and summaries provided by LDD of its more recent investigations). These third party reports and summaries provided to Ramboll are assumed by Ramboll to be accurate and correct; Ramboll has not collected any first-hand data and has not undertaken a critical review of the data from the original site investigation reports.

- In Sections 5 and 6 of this report, Ramboll has provided a suggested list of assumptions on which the future Remediation Options Appraisal (ROA) would be based. These assumptions have been proposed by Ramboll in response to uncertainties in the site investigation data and because there is not currently an approved risk assessment or site specific target levels for the remediation. It will necessary to make assumptions in order to undertake the ROA; however the client should confirm it is satisfied that the proposed assumptions are appropriate and acceptable, before Ramboll proceeds to the next stage of this assessment.
- As per our proposal LQ1620007286_01, dated 25th July 2019, the ROA will: consider the contamination within the bedrock only (i.e. not the 'overburden' soils); will consider chlorinated solvents only; and will consider treatment of a single source area (or, if multiple source areas, it will be assumed that these have similar characteristics). This scope of these works does not include remediation options appraisal or remediation advice relating to contaminant sources outside of the site boundary.
- Ramboll cannot guarantee what the findings of the Remediation Options Appraisal, outline strategy and Work Plan will be, and does not provide a guarantee of regulatory approval of this work.

BEIT HAKEREM
REMEDIATION OPTIONS APPRAISAL: CHAPTERS 2, 3 AND 4

BEIT HAKEREM
REMEDIATION OPTIONS APPRAISAL: CHAPTERS 2, 3 AND 4

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CONTENTS

APPENDICES

Appendix 1
Remediation Options Applicability Screening

Appendix 2
Remediation Detailed Options Appraisal

1. INTRODUCTION

Ramboll UK Ltd (Ramboll) is acting as a subconsultant (International Consultant) to LDD (Local Consultant) in its delivery of remediation advice relating to the Environmental Services Company (ESC, the ultimate Client) regarding the IMI Beit Hakerem project.

Ramboll would be acting as the International Consultant, and LDD as the Local Consultant. Ramboll (formerly Environ) and LDD have worked closely together on numerous ground contamination projects in Israel and have a proven track record of joint successful delivery of complex technical solutions. A Memorandum of Understanding exists between the two companies, dated 19th July 2018.

In this report, where joint LDD and Ramboll assessments and recommendations are being described, this will be presented as 'LDD-Ramboll'.

The IMI Beit Hakerem site is a 40 dunam (4 hectare) area adjacent to the Beit Hakerem neighbourhood in Jerusalem. The site was formerly occupied by Israel Military Industries (IMI) between 1951 and 1997 and was used as a factory for the manufacture of metal products. The former manufacturing activities at the site utilised organic solvents, which has led to ground contamination. It is understood that the site was closed and decommissioned in the late 1990s and is now intended for unrestricted redevelopment. Numerous environmental surveys have been undertaken at the site, including of soil, soil gas, and groundwater. The soil profile has been described as being mostly karst bedrock (overlain by overburden soils up to 6m deep); the groundwater is greater than 100m deep. The main contaminants at the site include chlorinated organic compounds, TCE and PCE.

1.1 Objectives and Scope

The objectives of this project are to provide remediation advice to ESC regarding the IMI Beit Hakerem site. Specifically, the scope of works is defined as follows:

- **Chapter 1 - Review of the Conceptual Site Model (CSM) for Beit Hakerem and provision of case studies for three similar projects** from around the world, presenting the type and concentration of contaminant, treatment, remediation targets attained, timelines, and project budget.
- **Chapter 2 - Consideration of remediation options** to treat the bedrock contamination, to include the advantages and disadvantages of each option in terms of execution costs, timeframes, effectivity, reliability, feasibility, etc. The assessment also includes environmental, regulatory, and statutory considerations.
- **Chapter 3 - The examination of construction options** at the site with an emphasis on basements and combining treatment systems with the buildings at the site.
- **Chapter 4 - Recommendation of the preferred remediation strategy** and outline for moving forward.
- **Chapter 5 - Preparation of a Work Plan** to execute the recommended remediation strategy including detailed plan for a pilot, examination whether additional surveys are required within the site or outside of the site, timeframes, and approximate cost ranges.

This document forms **'Chapter 2, Chapter 3 and Chapter 4'** of the project and sets out the rationale for the recommended remedial approach, based on our understanding of the Conceptual Site Model and the objectives of the proposed remediation.

1.2 Report Layout

This report comprises **Chapter 2**, **Chapter 3 and Chapter 4** of the overall Project; following this Introduction section, the report is structured as follows:

Chapter 2

- **Section 2** describes the procedure used for identifying the recommended remedial approach.
- **Section 3** sets out our understanding of the Remedial Objectives for the site.
- **Section 4** screens a broad range of remedial options for the bedrock remediation and discusses the key issues driving the screening process in the context of the Conceptual Site Model. From the output of the screening, a short-list of remedial options is presented
- **Section 5** provides a summary of the short-listed remedial options, including outline scope, estimated conceptual costs and likely duration.
- **Section 6** presents a detailed evaluation of the short-listed bedrock remediation options. A preferred remedial approach is then selected, facilitated by a semi-quantitative scoring procedure.

Chapter 3

- **Section 7** discusses how the planned development of the site could interact with the construction phase and how this could influence the bedrock remediation. Vapour intrusion mitigation for future buildings are also discussed in this section.

Chapter 4

- **Section 8:** Presents LDD-Ramboll's overall recommendation for remediation, taking into consideration both the outcome of the detailed evaluation for bedrock remediation and the construction phase considerations.

2. SUMMARY OF APPROACH

Ramboll has taken the following staged approach with regards to the Remediation Options Assessment (ROA) for the bedrock remediation:

- **Task A (see Chapter 1): Review of Conceptual Site Model** - It is Ramboll's experience that the most critical element to a successful remedial strategy is a suitably developed Conceptual Site Model so that the issue requiring remedial action can be fully understood and the purpose of the remediation properly defined. The first task has been to review the existing CSM, with particular emphasis on the nature and distribution of the contamination ***LDD-Ramboll's summary of its review of the CSM is presented in Chapter 1 of the ROA[1];*** *Ramboll's summary in Chapter 1 also includes gaps in the current knowledge of the CSM, and presents the assumptions that have been made for purpose of the ROA.*
- **Chapter 2 - Task B: Review of Remedial objectives** – The Remedial Objectives have been developed based on Ramboll's review of the CSM, and based on subsequent discussion with LDD and ESC. ***The Remedial Objectives are presented in Section 3 of this report.***
- **Chapter 2 - Task C: Selection of the Most Feasible Remediation Options (Tier 1)** - Tier 1 of the assessment process consists of two elements: screening and selection. Screening involves identification of a broad range of techniques that are suitable for treatment of the contaminants in question and then selecting ones that are potentially suitable for application at the site in the light of site-specific characteristics and issues identified in the CSM. These potentially suitable techniques have then been further developed into three specific remedial options for further evaluation. A short description of each short-listed option has been provided, highlighting the outline scope. ***The screening and selection of the most feasible remediation options (Tier 1) is presented in Section 4 and in Appendix 1.***
- **Chapter 2 - Task D: Detailed Evaluation of Options:** A simple semi-quantitative procedure is then used to facilitate evaluation of the short-listed options in order to enable an objective and defensible approach to be adopted. It involves scoring each option against a series of criteria that have been weighted to reflect their relative importance at the site and identifying which option provides the best overall approach. Criteria were identified against which each remediation option was evaluated (the criteria were amended and weighted on a score of 1 to 5 to incorporate specific preferences of ESC). The evaluation was undertaken using a spreadsheet format; each option being evaluated against each of the criteria and a score assigned. The process was undertaken by several scientists and engineers in order to reduce subjectivity and ensure the key aspects of the evaluation process are captured accordingly. The weighted score for each criterion was then calculated and summated for each option, which was then normalised against the maximum achievable total to generate a final percentage score. ***The detailed evaluation of the most feasible remediation options (Tier 2) is presented in Section 5 and in Appendix 2.***
- **Chapter 3 – Consideration of Construction Options:** This section provides a review of construction options to minimize the possibility of soil gas intrusion to on-site and off-site buildings provided there is sufficient evidence that soil gas poses an unacceptable risk to off-site users.
- **Chapter 4 – Recommendation for the Preferred Remediation Strategy**: This section presents LDD-Ramboll's overall recommendation for the remediation strategy and next stages, taking into account the findings and outcome of the previous sections.

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[1] Ramboll UK Ltd, Beit Hakerem, Chapter 1 Literature Review, ref. R16200007286_Chapter 1_01, dared 27th August 2020.

3. REMEDIATION OBJECTIVES

The remedial objectives and associated criteria as set out below are based on the premise that all of the assumptions set out in Sections 5 and 6 of Chapter 1 of the report are applicable.

It should be noted that this report does not discuss the remediation of the overburden (which must be considered by the Client as part of the complete strategy for remediation). It does not discuss clean cover systems, which are likely to be required in landscaped areas to mitigate 'direct contact' pathways.

An appraisal of mitigation systems which should be installed into future buildings (such as vapour barriers or sub-slab depressurisation systems) is provided as part of Chapter 3 (Consideration of Construction Options).

There are two key objectives for the remediation of the Beit-Hakerem site:

3.1 Objective 1: Reduction in Chlorinated Hydrocarbons within the Karstic Bedrock

Objective 1 is to reduce chlorinated hydrocarbons at the site, as measured in soil gas within the karstic bedrock and above the water table, to concentrations that are acceptable for the proposed redevelopment, assuming 'unrestricted' use (i.e. commercial, industrial, residential or landscaped), through fulfilment of the following criteria:

- The achievement of soil gas concentrations within the on-site treatment zone no greater than three orders of magnitude higher than the respective IRBCA 'Tier 1' RBTLs[2] (risk based target levels) for the contaminants of concern based on values prescribed for a residential and recreational use (see Section 3.3 below) on the assumption that these are protective of future site residents subject to the installation of appropriate vapour mitigation system(s) (e.g. vapour barriers, and potentially sub-slab depressurization system) in new buildings to be constructed on the site.
- The treatment of land within the site boundary based on an assumed area of 3,700m^2 (representing the footprint area of the LDD-defined 'hotspots', multiplied by 2.5) and considering that the treatment depth within the unsaturated bedrock extends to approximately 40 m below ground level[3].

3.2 Objective 2: Mitigate Risks to Off-Site Residents from Onsite Contamination

Objective 2 is to mitigate unacceptable risks to off-site residents (or other human receptors) arising from current / future chlorinated hydrocarbons within the site boundary, within the vadose zone, through fulfilment of the following criterion:

- The achievement of soil gas concentrations at applicable parts of the site boundary, no greater than the respective IRBCA 'Tier 1' RBTLs (risk-based target levels) for the contaminants of concern based on values prescribed for a residential use (see Section 3.3 below).
- The applicable parts of the site boundary where treatment is required (for the purpose of this ROA, we have assumed that mitigation would be required around the entire site boundary (i.e. an assumed length of 931m), future surveys and sampling may demonstrate that treatment is not necessary along the entire length of the site boundary, however this is not currently known.

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[2] The IRBCA Tier 1 Residential RBTLs are Israel's most stringent threshold values for soil gas that are suitable for the most sensitive suitable land uses such as residential and recreational use.

[3] The 40m assumed treatment depth was chosen to build the cost estimates for this remediation options appraisal. The pilot trial and further investigation that will be planned as part of 'Chapter 5' will delineate and better define the locations and depths where treatment is required.

3.3 Remediation Target Levels

The relevant IRBCA Tier 1 RBTLs (and the amended three orders of magnitude target that is applicable to this site for the on-site areas) are presented in Table 3.1 below. These are consistent with the values presented in the Chapter 1 report; they are provided again in Table 3.1 of this report for ease of reference.

Table 3.1 – Soil Gas Tier 1 RBTLs

Contaminant of Concern	Max. Concentration detected by LDD zonal sampling (µg/m3)	IRBCA Tier 1 RBTL for Residential Use (µg/m3)	3 orders of magnitude IRBCA Tier 1 RBTL for Residential Use* (µg/m3)
1,1,2-trichloroethane	708.76 (38m)	23.1	**10,000**
1,1-dichloroethane	4,472.41 (6m)	234	**100,000**
1,1-dichloroethene	58,326.07 (6m)	27,809	**10,000,000**
1,2-dichloroethane	7,199.16 (6m)	38	**10,000**
Benzene	250.47 (76m)	130	**100,000**
Chloroform	5,579.76 (6m)	16.3	**10,000**
Tetrachloroethylene (PCE)	1,247,763.50 (15m)	2,100	**1,000,000**
Trichloroethylene (TCE)	254,680.59 (15m)	200	**100,000**
Vinyl Chloride (VC)	54,743.24 (29m)	85.1	**10,000**

*Calculation based on the clarification from MoEP to LDD regarding exceptions in soil gas tests above 3 orders of magnitude dated 29/01/2020

3.4 The Requirement for Groundwater Treatment

As stated in Chapter 1, LDD-Ramboll considers it unlikely that contamination within the groundwater would be significantly contributing towards the soil vapour concentrations detected at more shallow depths on site. Risk assessment / contaminant modelling could be undertaken to assess whether contaminant concentrations in the Upper Aquifer are likely to be a significant source of the elevated soil gas concentrations, particularly at shallow depth. Such work is outside the scope of LDD-Ramboll's current remediation support, but could provide further confidence in the CSM, and support the basis of the technical assumptions underpinning the ROA and associated recommendations. This ROA therefore focuses on technologies to remediate contamination with the unsaturated part of the karstic bedrock (rather than remediation of the groundwater). It is therefore considered that focusing treatment efforts on the unsaturated bedrock rather than the groundwater is likely to be more efficient at reducing the contaminant concentrations in soil gas.

3.5 Consideration of Off-Site Sources of Contamination

There is a third remediation objective which is outside the scope of this assessment. The third objective is to 'mitigate any unacceptable risks to off-site residents (or other human receptors) arising from chlorinated hydrocarbons outside the current boundary site'.

The current scope of the ROA does not extend to contamination that is present outside the current site boundary (either from contamination sources that originate from outside the current site boundary, or contamination which may have originated from the subject site but has previously migrated offsite.). Specifically, the current ROA scope does not include assessment of existing residential areas which have previously been developed on other parts of the former IMI Beit Hakerem site (i.e. outside of the current site boundary).

However, as part of the ROA of the area within the current site boundary, Ramboll has provided a high level opinion on the monitoring and, if required, mitigation of off-site soil gas contamination impacts. This opinion is presented as a brief narrative in Section 8 of this report (i.e. as part of Chapter 4: recommendation for a preferred remediation strategy).

- This opinion has to be tentative in nature based on the paucity of information available, the absence of a clearly defined CSM for the current offsite residential areas and the potential for there to be additional off-site sources of contamination within shallower soils that had previously not been addressed prior to redevelopment.
- There are key data gaps in understanding the extent and severity of the contamination present within the site as have been identified in Section 5 Chapter 1 of the report. The options assessment is therefore made subject to the assumptions previously set out.
- Because of the lack of available information, it is not possible to determine the degree of contamination existing along the boundary of the residential area, e.g. immediately across Begin Street and adjacent to the site. Should this be well in excess of the respective IRBCA 'Tier 1' RBTLs then achievement of these at the site boundary may prove to be difficult to achieve in the longer term.

4. SCREENING OF REMEDIATION TECHNIQUES

This section of the report presents the 'screening phase' of the ROA, which to recap, involves:

- Identification of a broad range of techniques that are suitable for treatment of the contaminants in question, volatile organic compounds (VOCs), namely chlorinated hydrocarbons (CHC).
- Screening of these techniques to identify a short-list of ones that are potentially suitable for application at the site, considering practicability of implementation or other single factor issues ('showstoppers') that immediately rule out their deployment.
- The short-listed techniques are then taken forward for detailed review

4.1 Identification of Remediation Techniques

As outlined in Section 3, the focus of the detailed remediation options assessment (ROA) is on remedial techniques to address the VOC contamination in the unsaturated karstic bedrock. A broad range of techniques are available for remediation in unsaturated karstic bedrock. ***These are set out in Appendix 1.***

The techniques have either been rejected or put forward for further consideration as a result of the assessment detailed in this table. Where there are one or more issues that rule out the effective implementation of the technique, these are identified, while in other cases the technique has been shortlisted as a potential option either as standalone approach or in combination with another.

The option screening process and option selection is driven by the following issues:

- Treatments is restricted to the vadose zone only.
  - A significant number of remedial techniques (mainly in situ techniques) are more suitable for the saturated zone because they rely on the continuum of water within the voids to enable effective transport of reagents – through advection by groundwater flow or in many cases by diffusion. This is particularly the case for most chemically based approaches where direct contact with the contaminant is fundamental and biological ones that are based on the injection of a chemical reagent that diffuses through the medium. Whilst such approaches may have some limited effect in the unsaturated zone, this would have to be dependent on a dense injection network.
- The treatment matrix being karst bedrock rather than soil, and the assumed treatment zone extending to potentially significant depth:
  - Both matrix composition and depth effectively rule out all treatments that would normally be conducted ex situ, on the basis that excavation would be impractical and removal of rock prohibitively costly.
  - Additionally, the deliverability of chemicals and reagents for promotion of either chemically based reactions or biological processes may be impracticable from the standpoint of delivering in a rock matrix, to achieve the appropriate distribution and also because of the potential depth involved: even if delivery at assumed treatment depths of 40m is possible, the degree of control would be very limited.
- The density and location of fractures within the karst is not known
  - Aqueous based fluids that are injected into the rock at a particular point may therefore intersect a fracture by chance or more likely 'daylight' back to the surface along the means of injection.
  - It should also be noted that within the karst bedrock, contamination will exist both within fractures and also the micropores of the rock itself. Once the contamination is removed from the fractures, back-diffusion from within the rock into the fractures will take place

over time: as such any remedial action has to take account of this and operate over a sufficient length of time to avoid contaminant re-bound.

4.2 Selection of Most Feasible Remedial Options (Appendix 1)

4.2.1 On-Site Vadose Zone Treatment - Soil Vapour Extraction (SVE)

From a general review of the techniques available, physically-based in situ extractive approaches appear to hold the greatest potential for mass removal within the unsaturated zone, of which soil vapour extraction (SVE) can operate as a standalone treatment system, or in combination with other techniques such as thermal enhancement. The question of combining these approaches therefore rests upon whether this will confer significant advantages, primarily in achieving the overall remedial objectives more expeditiously and/or with better cost implications (taking longer term operational and monitoring requirements into account).

4.2.2 Thermal approaches

In addition to the use of SVE as the primary remedial approach, thermal based technologies could be considered in conjunction with SVE or to enhance SVE effectiveness:

- SVE with Heated Air Injection: SVE can be implemented with heated air injection to enhance VOC removal in certain areas. Due to the additional costs associated with heated air injection, this enhancement could be implemented selectively in areas where higher VOC impacts are expected, or in zones where expedited VOC removal may be desired to promote site redevelopment.
- In situ thermal remediation (ISTR): ISTR entails an SVE system combined with an in-ground network of heating elements or electrodes (often referred to as heater wells). The heater well network provides robust heating of the subsurface formation (typically to targeted temperatures of 100°C). Due to the additional installation and electrical costs associated with ISTR, this technology is typically implemented selectively in areas where higher VOC impacts are expected, or potentially in zones where expedited VOC removal may be desired to promote site redevelopment.

4.3 Mitigation of Off-Site Migration of On-Site Soil Gas Impacts – Soil Vapour Extraction

As described in Section 3.2, an additional objective of the remedial options is the achievement of soil gas concentrations at the site boundary, no greater than the respective IRBCA Residential 'Tier 1' RBTLs for the contaminants of concern. The inclusion of a vapour control system (e.g., linear array of SVE points) in selected locations along the property boundary could be included as part of the remedial options in order to meet this objective. As noted in Section 3.2, for the purpose of this ROA, we have assumed that a vapour control system would be required around the entire site boundary, however future surveys and sampling may demonstrate that this is not necessary along some parts of the site boundary.

4.4 On-Site Receptors Protection - Vapour Mitigation Systems

The inclusion of vapour (soil gas) mitigation systems in on-site buildings enables the adoption of more advantageous target levels as remediation criteria (i.e. three orders of magnitude the IRBCA Tier 1 RBTL), and also provides protection of future on-site receptors (e.g. building occupants) from exposure to residual concentrations of VOCs in soil gas that may remain upon completion of the initial remedial actions. For these reasons, it has been assumed that vapour mitigation systems would be installed in all buildings to be constructed on site; this assumption applies for all of the options evaluated in the ROA.

Additional discussion of vapour mitigation systems installation in conjunction with future site redevelopment is included in Chapter 3 (Section 7) of this report.

4.5 Summary of Remedial Options Included in Detailed Evaluation

To summarise, the remedial options for karstic bedrock that have been taken forward for detailed evaluation are set out below:

Table 4.1: Summary of Remediation Options Included in Detailed Evaluation

Option number	Site treatment to protect on-site
1	SVE
2	SVE with Heated Air Injection
3	In situ thermal remediation (ISTR)
Boundary treatment to protect off-site residents	
4	SVE system to address boundary remedial requirements

The use of vapour mitigation systems is discussed in Section 7 of this report. Vapour mitigation systems are not discussed in the detailed evaluation, which focuses on bedrock remediation only. However construction considerations such as vapour mitigation are discussed in the overall Recommendation for Remediation (presented in Chapter 8).

5. OUTLINE OF SHORT-LISTED FEASIBLE REMEDIAL OPTIONS

This section of the report provides a description of the short-listed options identified in the previous section, three of which (Soil Vapour Extraction, (SVE), SVE with heated air injection and In-Situ Thermal Remediation (ISTR)) are applicable to the source area. The fourth option, also SVE, is discussed in the context of the boundary remedial requirements.

The description for includes a summary of both the installation and operational requirements associated with the four options, which will, for the three associated with the source zone, provide the basis for the comparative assessment performed as part of the detailed evaluation presented in Section 6.

- Sections 5.1-5.3 provide a description of the three shortlisted technology options considered in the detailed evaluation.
- Section 5.4 describes how remediation could be applied to the perimeter boundary.
- Comparative costs are presented in Section 5.5, including an explanation of how these were derived and examples of cost uncertainties.

5.1 Option 1: SVE

A typical SVE system would include a network of vapour extraction wells/points installed in a grid pattern across the treatment zone.

5.1.1 Extraction Wells

The vapour extraction points are constructed as wells, with screened intervals installed at the desired treatment depth(s).

- Screened interval lengths are typically limited to approximately 6m or less to promote uniform air flow along the full screen length, so for deeper treatment zones, nested extraction point clusters with multiple screened intervals may be required to provide effective treatment throughout the full depth of the treatment zone.
- Spacing between extraction points can be as high as 18m-24m. However, given the complexity of the site's subsurface geology (fractured rock with lenses of marl, according to general site subsurface information), a spacing of 6m-9m is assumed at this time.
- Rotosonic or air rotary drilling techniques would likely be used for installation of the points.
- **The assumed treatment zone footprint (3,700m^2) would require approximately 80 vapour extraction point clusters based on a 7-8m spacing assumption**. In addition, dependent upon further design considerations, air inlet wells may be installed between the extraction points to further promote air flow throughout the treatment zone.
- As an indicator, 80 vapour extraction points (installed to a depth of 40m below ground level (bgl)) would be expected to take approximately 8 months to one year[4] to drill using two drilling rigs; **although with multiple drill rigs, this timescale could be substantially shortened**.
- It is typical for 2-inch (approximately 50 mm) diameter vapor extraction points to be used in SVE wells, however it should be noted that specific extraction well diameters should be determined at detailed design stage.

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[4] Based on assumption of approximately 9.1m drilling and installation achieved per day, equating to approximately 4.4 days per well location/cluster (this would allow for 2-3 days drilling plus 1-2 days installation time; it assumes a more complex well installation, comprising 3-4 nested vertical screened intervals, each approximately 10-13m in length; it assumes a 8-10 inch diameter borehole). A further 10% has been added to the total drilling time estimation to include an allowance for typical mechanical/weather delays.

5.1.2 Vapour Extraction Piping Network and Vapour Treatment Equipment

The vapour extraction points are connected to above-grade treatment equipment via a vapour extraction piping network that connects to each extraction well and allows extracted vapours to be conveyed to the treatment equipment.

- The extraction piping network can be installed above-grade, or as a buried network within shallow utility trenches. The extraction piping network is routed back to a central location where the above-grade treatment equipment is installed. The treatment equipment is typically installed within an approximately 18m by 18m area which is fenced for system security.
- Treatment equipment typically includes a knock-out pot (i.e., moisture separator) to remove entrained moisture from extracted vapours, suction fans/blowers used to apply vacuum to the extraction piping to draw vapours from the extraction points, and vapour treatment equipment. Treatment equipment typically includes vapour-phase granular activated carbon (GAC) vessels used for removal of volatile organic compounds (VOCs) from the vapour stream. Two to three vessels are installed in series (or lead-lag) configuration, to provide effective removal of VOCs and equipment redundancy.
- Treated vapours are discharged through a small stack (typically in the region of approximately 6m in height). Note vapour-phase GAC is typically not effective for treating vinyl chloride, and the soil gas data for the site indicate significant concentrations of this compound. Depending upon further design considerations and review of air permitting requirements, impregnated vapour-phase GAC or thermal oxidation equipment can also be considered for treatment of extracted vapours. *The specification and costs for specific air emissions treatment control technologies is a detailed design decision. The choice of specific air emissions control technology is often a function of the overall contaminant mass (which is not known at this time) and the mixture of specific compounds to be treated.*
- Power requirements for SVE systems can vary based on factors such as the number of extraction points, required vacuum/blower sizing, and treatment depth. Subject to further design considerations, the estimated power requirements for the conceptual SVE system described above would be expected in the range of 1 to 2 kVA.

5.1.3 Operation

SVE systems are typically operated for time periods between 2-4 years, but this duration can vary dependent in part upon the complexity of the subsurface formation being treated, the concentrations of constituents present, and the project-specific treatment objectives. Given the complexity of the site geology and relative lack of data regarding the specific extents of subsurface VOC impacts in the vadose zone at this time, an SVE operations period in the range of 5-10 years is assumed at this conceptual planning stage.

System operations data are typically used to evaluate the time at which VOC removal from the subsurface is approaching asymptotic conditions (i.e. the point at which the system has removed as much VOC mass as reasonably feasible given the site conditions, and further system operation would provide negligible additional VOC removal), at which point the system is typically shut down (with regulator approval/concurrence, as required).

5.2 Option 2: SVE with Heated Air Injection

This option would be similar to SVE (Option 1), but would also include the injection of heated air into the subsurface to enhance VOC removal/removal rates. *It should be noted that, although combinations of technologies have not been evaluated as part of this conceptual evaluation, combinations are possible and can be considered as part of detailed design work.*

Vapour Extraction Wells and Heated Air Injection Wells

The extraction points are constructed as wells, with screened intervals installed at the desired treatment depth(s).

- Heated air injection wells are typically closely spaced together (e.g. approximately 4.5 m-6 m spacing/grid), with vapour extraction wells installed between the injection wells. Screened interval lengths are typically limited to approximately 6m or less to promote uniform air flow along the full screen length, so for deeper treatment zones, nested extraction point clusters with multiple screened intervals may be required to provide effective treatment throughout the full depth of the treatment zone.
- Given the complexity of the site's subsurface geology (fractured rock with lenses of marl, according to general site subsurface information), a spacing of approximately 5m is assumed at this time.
- Rotosonic or air rotary drilling techniques would likely be used for installation of the points.
- **The assumed treatment zone footprint (3,700m^2) would require approximately 225 heated air injection point clusters and 225 vapour extraction point clusters based on an approximate 5m spacing assumption**. **Targeted heating temperatures for chlorinated VOCs are typically in the range of 100°C.**
- As an indicator, 225 vapour extraction points (installed to a depth of 40m) would be expected to take approximately 1.6-2 years[5] to drill using two drilling rigs; **although with multiple drill rigs, this timescale could be substantially shortened**. *The difference in timescales between the SVE and this heated based method is based in part on the differences in number/spacing of injection points between the two technologies (80 for SVE vs. 225 for heated air injection). It is also assumed that SVE extraction would require multiple screened intervals/nested screens and accordingly larger borehole diameters to accommodate this installation. Due to the advantages associated with the application of heat to the subsurface, it is assumed that heated air injection and ISTR would not require the "nested" screens approach.*
- Power requirements for heated SVE systems can vary based on factors such as the number(s) of heated air injection/air extraction points, treatment zone size/sequencing, required vacuum/blower sizing, and treatment depth. Subject to further design considerations, the estimated power requirements for the conceptual heated SVE system described above would be expected in the range of 8 to 10 kVA.

5.2.1 Extraction Piping Network and Vapour Treatment Equipment

The vapour extraction points are connected to above-grade treatment equipment via a vapour extraction piping network that connects to each extraction well and allows extracted vapours to be conveyed to the treatment equipment. The vapour extraction piping and vapour treatment equipment would be similar to the SVE option; however, due to the addition of heated air, wells and extraction piping would typically be of steel construction (PVC piping/well materials are typically used for conventional SVE system construction).

The specific sizing of equipment layout areas is a detailed design decision, however in general terms, ISTR equipment layout areas tend to be somewhat larger than SVE equipment layout areas

[5] Based on assumption of approximately 12.2m drilling and installation achieved per day, equating to approximately 3.3 days per well location (this would allow for approximately 2 days of drilling plus 1 day installation time, and assumes a 3-4 inch diameter borehole). A further 10% has been added to the total drilling time estimation to include an allowance for typical mechanical/weather delays.

5.2.2 Operation

A SVE system with heated air injection is estimated to be operated for time periods between 1-2 years, but this duration can vary dependent in part upon the complexity of the subsurface formation being treated, the concentrations of constituents present, and the project-specific treatment objectives. Given the complexity of the site geology and relative lack of data regarding the specific extents of subsurface VOC impacts in the vadose zone at this time, an operations period in the range of 2-3 years is assumed at this conceptual planning stage.

System operations data are typically used to evaluate the time at which VOC removal from the subsurface is approaching asymptotic conditions (i.e., the point at which the system has removed as much VOC mass as reasonably feasible given the site conditions, and further system operation would provide negligible additional VOC removal), similar to conventional SVE system operations as noted above.

Proper fencing around above grade equipment should mitigate risks relating to people accessing the site / treatment area. The approach to fencing required would be similar for either SVE or ISTR – both would entail the use of above-grade vapor recovery piping extending across the treatment area that would require access controls.

The potential risk of mobilising contamination through the application of heat and subsequent impact offsite is also an important consideration. There is considered to be a higher risk of this occurring if the treatment zone is located close to the site boundary. There is also perceived to be a higher risk of contaminants being mobilised, when compared to in-situ thermal remediation (discussed below), due to the injection of heated air (rather than heating in-situ).

In Ramboll's experience, properly designed remedial systems (whether SVE, heated air injection, or ISTR) would not in themselves usually pose significant risks to wildlife. ISTR and heated air injection could potentially be more harmful to surface plants than SVE, depending on specifics of the remedy design (how close heating is conducted to the ground surface, whether a surface cover is required, etc.), but that is not necessarily the case.

As with any in situ approach there may be vegetation disturbance at the locations where the wells are to be installed, and in establishing routes for plant to access these. It is considered that this can be dealt with sensitively, through an impact assessment and establishing appropriate protocols to minimise ecological disturbance. In US projects, temporary impacts to vegetation are typically temporary and are addressed through a vegetative restoration plan (e.g., replanting) following completion of the remedial works.

5.3 Option 3: In-Situ Thermal Remediation

In-situ thermal remediation (ISTR) is a form of heated SVE that entails the installation of heating elements/electrodes ("heater wells") in a grid network within the subsurface, combined with a network of vapour extraction wells. Dynamic heating options are possible for ISTR (or SVE with heated air injection). For ISTR, heat is typically applied until monitoring results indicate that treatment is complete.

5.3.1 Heating Elements/Extraction Wells

The heating elements/electrodes and vapour extraction points are installed similar to wells, with heated/screened intervals installed at the desired treatment depth(s).

- Heating elements and vapour extraction wells are typically installed through the full depth of the treatment zone.
- Spacing between heating elements and vapour extraction wells is typically in the range of 4.5-6 meters.

- Rotosonic or air rotary drilling techniques would likely be used for installation of the points in a bedrock setting.
- **The assumed treatment zone footprint (3,700m^2) would require approximately 225 heating elements based on an approximate 5m spacing assumption**. **Targeted heating temperatures for chlorinated VOCs are typically in the range of 100°C.**
- As an indicator, 225 vapour extraction points (installed to a depth of 40m) would be expected to take approximately 1.6-2 years[6] to drill using two drilling rigs; **although with multiple drill rigs, this timescale could be substantially shortened**.
- ISTR can be implemented using electrical resistance heating (ERH, where electrical current passes between adjacent electrodes in the subsurface to generate the required heating) or via thermal conductive heating (TCH, where electrical current is used to heat the electrode/heater well itself, and heat is transmitted conductively to the surrounding subsurface materials). TCH is typically better adapted for use in vadose zone applications, and is assumed to be the ISTR technology for application at this site; however, it should be noted that the implementation costs for TCH/ERH are relatively comparable.
- Power requirements for ISTR systems can vary based on factors such as the number(s) of heating elements/air extraction points, treatment zone size/sequencing, required vacuum/blower sizing, and treatment depth. Subject to further design considerations, the estimated power requirements for the conceptual ISTR system described above would be expected in the range of 8 to 10 kVA.

5.3.2 Vapour Extraction Piping Network and Vapour Treatment Equipment

The vapour extraction points are connected to above-grade treatment equipment via a vapour extraction piping network that connects to each extraction well and allows extracted vapours to be conveyed to the treatment equipment.

- The extraction piping network can be installed above-grade, or as a buried network within shallow utility trenches. The extraction piping network is routed back to a central location where the above-grade treatment equipment is installed. The treatment equipment is typically installed within an approximately 30m by 30m area which is fenced for system security. Similar to SVE with heated air injection, piping and related materials would be of steel or similar heat-resistant construction (not PVC), due to the temperatures involved.
- Treatment equipment typically includes knock-out pots (i.e., moisture separators) to remove entrained moisture from extracted vapours, suction fans/blowers used to apply vacuum to the extraction piping to draw vapours from the extraction points, and vapour treatment equipment. Treatment equipment typically includes vapour-phase granular activated carbon (GAC) vessels used for removal of volatile organic compounds (VOCs) from the vapour stream. Two to three vessels are installed in series (or lead-lag) configuration, to provide effective removal of VOCs and equipment redundancy.
- Treated vapours are discharged through a small stack (typically in the region of approximately 6m in height). Note that vapour-phase GAC is typically not effective for treating vinyl chloride, and the soil gas data for the site indicate significant concentrations of this compound. Depending upon further design considerations and review of air permitting requirements, impregnated vapour-phase GAC or thermal oxidation equipment can also be considered for treatment of extracted vapours.

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[6] Based on assumption of approximately 12.2m drilling and installation achieved per day, equating to approximately 3.3 days per well location (this would allow for approximately 2 days of drilling plus 1 day installation time, and assumes a 3-4 inch diameter borehole). A further 10% has been added to the total drilling time estimation to include an allowance for typical mechanical/weather delays.

5.3.3 Operation

ISTR systems are typically operated for time periods between 6-9 months, but this duration can vary dependent in part upon the complexity of the subsurface formation being treated, the concentrations of constituents present, and the project-specific treatment objectives. Given the complexity of the site geology and relative lack of data regarding the specific extents of subsurface VOC impacts in the vadose zone at this time, an ISTR operations period in the range of 8-12 months is assumed at this conceptual planning stage.

System operations data are typically used to evaluate the time at which VOC removal from the subsurface is approaching asymptotic conditions (i.e., the point at which the system has removed as much VOC mass as reasonably feasible given the site conditions, and further system operation would provide negligible additional VOC removal), at which point the system is typically shut down (with regulator approval/concurrence as required).

Proper fencing around above grade equipment should mitigate risks relating to people accessing the site.

The potential risk of mobilising contamination through the application of heat and subsequent impact offsite was also discussed. There is considered to be a higher risk of this occurring if the treatment zone is located close to the site boundary. However, ISTR has good track record of maintaining well pressures, thereby reducing potential for migration away from the treatment area.

5.4 Option 4: SVE system to address Boundary Remedial Requirements

As described in Section 3.2, an additional objective of the remedial options is the achievement of soil gas concentrations at the site boundary, no greater than the respective IRBCA ‘Tier 1’ RBTLs (residential use). The inclusion of a vapour control system (e.g., linear arrangement or “wall” of SVE points) in selected locations along the property boundary would be considered as part of the remedial approach in order to meet this objective.

The pilot trial could include the installation of boundary monitoring wells, which could be used to evaluate whether there is potential for the remediation in treatment to bring about a reduction in soil vapour concentrations at the site boundary (albeit the short-term effect at the boundary is likely to be limited by the zone of influence and proximity of the hotspot treatment and extraction wells). It should be noted that, whilst soil gas measurements during and immediately following the pilot trial could offer some insight, the soil gas concentrations could return or ”rebound” some months following the pilot work, dependent upon the mass of contaminants present.

There is currently limited information about the soil vapour conditions at the boundary, particularly at depth. It will be important to undertake further monitoring to better understand the situation and to ensure that remediation / mitigation efforts are appropriately targeted.

5.4.1 Extraction Wells

For the purpose of this conceptual evaluation, SVE treatment along the entire site boundary has been assumed to be required. (Additional data acquisition and review would be necessary to delineate the specific lengths of the border that require treatment). We have therefore assumed that the perimeter SVE system would be installed along the entire site boundary to mitigate off-site migration of on-site soil gas contamination.

Design/construction of the perimeter SVE system and vapour treatment system requirements would be similar to those described for the source area SVE system above:

- The entire site boundary (estimated site perimeter of 931 m) would require approximately 122 extraction point clusters based on this spacing assumption.

- The exact depth(s) of the perimeter SVE extraction points are unknown (and may vary, pending the acquisition of additional data regarding the presence/depths of soil vapour impacts along the site boundary); a perimeter system installation depth of 40m has been assumed.
- As an indicator, 122 vapour extraction points (installed to a depth of 40m) would be expected to take approximately 1-1.5 years[7] to drill using two drilling rigs; **although with multiple drill rigs, this timescale could be substantially shortened**.
- For context, based on the above assumptions, a 300m length of the perimeter SVE system would require approximately 40 vapour extraction point clusters based on a 7-8m spacing assumption.

The SVE system installation approach, extraction piping, and surface treatment equipment requirements would be similar to the source area SVE system description above.

5.4.2 Operations

A key difference in operations approach between the perimeter SVE system and the SVE system within the central portion of the site pertains to the potential operations period. Due to the significantly lower treatment objective for the perimeter systems (i.e., 'Tier I' residential RBTLs), and the concept that prevention of on-site soil vapours from migrating off-site may represent more of a long-term remedial objective, it is likely that the perimeter SVE systems may require longer operations periods than the source area treatment system(s) in the central portion of the site. While the exact operations period for the site is unknown, an assumed operations period of 30 years for the perimeter SVE systems is used for preliminary options evaluation/comparison purposes.

The reason that a longer period of SVE operations has been assumed along the site boundary, compared to the source area treatment, is primarily because the remediation targets at the boundary are much lower (i.e. boundary remedial targets are based on the Residential Tier 1 RBTLs; whereas source area remedial targets are based on 3x order of magnitude of the Residential Tier 1 RBTLs, due to the planned incorporation of vapour protection measures in future onsite buildings).

It should be noted that both source area and perimeter SVE systems have the potential to allow for continued use of the site during operations, dependent upon further design considerations (which are beyond the scope of this conceptual evaluation). However, installing large areas of SVE pipework below ground would add additional costs to the remediation.

5.5 Comparative Costs

Ramboll has prepared conceptual costs for the three remediation option technologies, plus the SVE barrier containment. The conceptual costs are provided in Table 5.1 below and are based on the general assumptions stated in the previous sections (i.e. area and depth of treatment area, duration of remediation). Important information about the basis of the costs is provided in Section 5.5.1 below and within the table notes.

The costs presented in Table 5.1 below are based on Ramboll experience on US based projects; costs are therefore presented in US dollars. For comparative purposes and local context, LDD has also provided indicative costs for the installation of below grade equipment and wells based on LDD's experience in Israel (based on local drilling rates and material costs).

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[7] Based on assumption of approximately 9.1m drilling and installation achieved per day, equating to approximately 4.4 days per well location/cluster (this would allow for 2-3 days drilling plus 1-2 days installation time; it assumes a more complex well installation, comprising 3-4 nested vertical screened intervals, each approximately 10-13m in length; it assumes a 8-10 inch diameter borehole). A further 10% has been added to the total drilling time estimation to include an allowance for typical mechanical/weather delays.

Table 5.1 Conceptual Remediation Costs

	Option 1: SVE		Option 2: SVE with Heated Air Injection*	Option 3: ISTR	Option 4: SVE Perimeter Containment Barrier
Design/Construction Costs					
Remedial Design & Permitting	2,450,000 NIS		2,450,000 NIS	2,450,000 NIS	1,750,000 NIS
Above-Grade Treatment Equipment [D]	12,250,000 NIS		26,250,000 NIS	26,250,000 NIS	21,875,000 NIS
Israel estimated below-grade equipment/wells installation (for comparison purposes only)	*12,770,000 NIS*		*44,168,000 NIS*	*44,168,000 NIS*	*19,227,250 NIS*
Total Estimated System Design & Construction Cost	**27,470,000 NIS**		**72,868,000 NIS**	**72,868,000 NIS**	**42,852,250 NIS**
Operations and Maintenance Costs					
Estimated Operations Period (years)**	5 (Short)	10 (Long)	1.5	1.5	30
Total Estimated Operations and Maintenance Costs [G]	**7,000,000 NIS**	**14,000,000 NIS**	**29,750,000 NIS**	**29,750,000 NIS**	**78,750,000 NIS**
Total Estimated System Design, Construction & Operations Costs	**34,470,000 to 41,470,000 NIS**		**102,618,000 NIS**	**102,618,000 NIS**	**121,602,000 NIS**
*Overall Unit Price per m3^*	*233 NIS*	*280 NIS*	*693 NIS*	*693 NIS*	
*Overall Unit Price per m length^*					*130,615 NIS*

Table 5.1 Conceptual Remediation Costs

Notes:

* Pricing for SVE with heated air injection is based on pricing for the ISTR approach, due to the conceptual similarities in these two technologies. Note that ISTR is considered more of a "proven" technology (e.g., documented record of successful full-scale implementation), and SVE with heated air injection is considered more of an "emerging" technology (e.g., pilot testing conducted, but little to no full-scale / large scale implementation record).

** ISTR treatment typically requires 6-8 months to complete, not 1.5 years as shown above. The 1.5-year operations period is based on the significant size of the estimated treatment zone, and the anticipated need to provide heating/treatment in phases. Specifically, the ISTR estimated operations and treatment costs are based on the phased/sequential heating of two vertical zones (each 74,000m^3 in size), each for an estimated period of 7 months in sequence.

A. Pricing above is presented in NIS. Costs are generally estimated based on other completed project work by Ramboll.

B. Unit pricing for Options 1-3 is based on estimated treatment zone volume of 148,000m^3 (3,700m^2 footprint by 40m depth).

C. Unit pricing for Option 4 is based on estimated site perimeter of 931m and estimated average barrier depth of 40m.

D. Above-grade equipment includes systems such as vapour and liquid treatment systems, electrical equipment, instrumentation, etc.

E. Below-grade equipment includes drilling and heating equipment/well installation.

F. <u>All costing is provided for qualitative comparison purposes only and may not to be taken as real-world costs for the remediation of the site.</u>

G. Operations and maintenance costs include allowances for system monitoring, utilities (e.g., electricity) usage, and routine maintenance/minor repairs.

^ *The unit price per m^3 and per m length is provided for indicative purposes only. The costs presented (including the unit rates) are based on a remediation project of the scale (size, depth, duration) presented in the earlier sections of this report. A smaller overall remediation project would generally result in a higher unit price.*

5.5.1 Basis of Costs

Ramboll has prepared the costs in Table 5.1 based on costs incurred during previous remediation projects in the US. Those previous costs have been 'scaled up' to reflect the assumed size of treatment area and anticipated remediation timescales at Beit Hakerem. For this reason, the costs presented above are indicative only, and are intended to give an indication of approximate scale of future remediation costs based on available information. At this conceptual stage, and assuming the treatment zone dimensions are accurate, cost estimates would typically be expected to have an overall potential uncertainty in the range of 50% higher or 30% lower than the values shown in Table 5.1.

<u>It is not appropriate to undertake a detailed remediation costing at this stage.</u> Not least because the final remediation technology is unknown and because the required depth and area (volume of soil) for treatment has been assumed rather than confirmed. In addition to these fundamental unknowns, there are a large number of additional uncertainties which would make detailed remedial costing unfeasible at this stage, some examples of these unknowns are provided below, however this is not an exhaustive list:

- drilling methodology and production rates, potential for difficult drilling conditions due to karstic rock, exact spacing and design of extraction wells;
- the heating and extraction equipment design would be unique to the project and accurate costing could only be provided once that design is complete;

- there are several options as to the method of how air emissions would be treated and the extent of treatment required the selection and sizing of which are dependent on the mass of contaminants to be treated (which is unknown at this time) and will be based on the results of the pilot to determine the appropriate treatment method for the scale and types of contaminants found;
- environmental monitoring requirements during and after remediation have not yet been defined;
- there may be extra fees associate with import of specialist equipment (and installation teams) for some technologies
- there are several options for power supply, depending on availability of an existing power source at the site and this is typically only costed following the pilot;

it is not known to what extent the bedrock remediation would need to be undertaken concurrently with other construction activities at the site. Constraints such as this could have implications on time and costs.

6. DETAILED EVALUATION OF REMEDIAL OPTIONS

This Section describes the procedural methodology and output from a detailed evaluation of the three options for treatment of the source area described in the preceding section and presents our recommendation arising from this review.

6.1 Procedure

The evaluation has been carried out in two stages, firstly identifying the criteria against which the options will be assessed and weighting these according to their importance for the project and secondly undertaking the evaluation of each option against them, on a comparative basis. A simple semi-quantitative scoring procedure is used to facilitate evaluation of the short-listed options in order to enable an objective and defensible approach to be adopted.

6.1.1 Selection and weighting of Criteria

The criteria selected for the evaluation process are presented in Table 6.1. These criteria have typically been used for assessing remedial options in many countries, including for example the recently updated guidance in England[8] and are considered suitable for application in Israel

Table 6.1: Criteria for Options Evaluation with Weighting

Criteria	Issues for consideration	Weighting Factor (1, 3 or 5) (a)
Technical effectiveness	Effectiveness in meeting remedial objectives within a practical timescale and regulatory requirements. Also to what extent effectiveness can be demonstrated through verification.	5
Cost	To include both total cost and cash-flow considerations (up-front costs, installation, operation, post remedial monitoring)	3
Timescale	Rapidity of completion and ability to meet the client's timescale for completion, including the time for enabling works such as treatability/pilot scale testing, permitting, enabling works, as well as the likely requirements for post remedial monitoring and any long-term obligations.	5
Practicability of implementation	To include consideration of how practicable the option is, given the nature of the bedrock formation, depth of contamination, site location, size, access, layout and maintenance needs, ability to fulfil operational need	5
Durability	Ability of the technique to successfully reduce or control risks for a defined period on completion of the remedial works. This criterion has been used to	5

[8] https://www.gov.uk/government/publications/land-contamination-risk-management-lcrm/lcrm-stage-2-options-appraisal

Table 6.1: Criteria for Options Evaluation with Weighting		
	consider the longevity of the remediation, with particular focus on the potential for 'rebound' of contaminant concentrations.	
Track record	Evidence of successful implementation of the approach, at full-scale (rather than just pilot scale), for dealing with similar contaminants and at similar sites (e.g. specific geological and hydrogeological conditions)	5
Availability of technique	This includes availability of resources for implementation including, for example, specialist contractors or specific reagents	3
Health, safety & environment issues	The level of requirements for addressing health and safety issues associated with each option ((i.e. how onerous these are, rather than whether a particular approach is 'safer' than another). This topic considers potential for offsite migration of the contamination as a result of the remediation, as well as on-site health and safety considerations.	3
Stakeholder requirements	Acceptability of the approach to relevant stakeholders including for example client, regulator, future site purchaser/occupier and neighbour	5
(a)	Weighting 1, 3 or 5 with 5 being assigned high importance, 3 moderate importance and 1 low importance.	

A suggested weighting of criteria according to a designation of 1 (lowest importance), 3 (moderate importance) and 5 (highest importance) was provided by Ramboll, which was subsequently reviewed and amended by ESC, with the final agreed weightings presented in table 6.1. It is noted that all of the criteria were assigned either a 'moderate' or 'high' weighting.

6.1.2 Detailed evaluation of options

The second stage involved conducting the evaluation itself, which was undertaken according to the spreadsheet presented in Appendix 2.

Each option was evaluated in turn against each of the criteria set out in Table 6.1 on a comparative basis and the evaluation recorded, highlighting the relative strength or weakness of the option in comparison to the other two. A score was then assigned ranging from 1 (worst) to 5 (best) according to relative performance. This score was multiplied by the corresponding weighting factor shown in Table 6.1 to provide a weighted score for each criterion. Where there were marginal differences between options for a specific criterion, equal scores were assigned. The weighted scores were then summated and normalized (i.e. expressed as a percentage of the maximum weighted score achievable). A similar exercise was undertaken using non-weighted scores for comparative purposes.

To gain the maximum benefit from the evaluation process, which includes the need to consider technical, commercial and regulatory considerations and from the standpoint of the proposed technologies, the specific requirements of ESC and operation within Israel, it was important to have the evaluation performed in a workshop format involving the appropriate combination of expertise. This also reduced some of the subjectivity in assigning the scores.

The evaluation was therefore undertaken by three participants from Ramboll and two from LDD. Each of these was able to provide a particular insight into the assessment process according to the following expertise and professional background:

- Ramboll participants:
  - Ms Hannah Lewis (all round understanding of project requirements, client needs and site issues)
  - Dr Richard Bewley (expertise in Sustainable remediation assessments and comparative technologies)
  - Mr Jeff Levesque (Technical expert in application of physical extractive technologies for CVOCs)
- LDD participants
  - Ms Allison Busgang (Application of remediation in Israel, client requirements, detailed site knowledge)
  - Mr Ori Zvikelsky (Application of remediation in Israel, client requirements, detailed site knowledge)

The process consisted of three stages:

- Review and familiarisation of criteria and option details by all parties prior to the workshop, including previously derived estimates for costs and duration presented in Section 5
- Attendance and participation in the workshop, held by remote meeting on January 20th. An ongoing record of the evaluation and discussion points was made in a spreadsheet format visible to all participants during the workshop. A collective decision was made as to the scores assigned.
- The spreadsheet was reviewed by Ramboll and minor changes made in content primarily for grammatical improvement and clarification purposes. The amended version was then forwarded to LDD for review and approval.

The findings arising from the assessment are presented and discussed below.

6.2 Results of evaluation

Full details of the evaluation undertaken as recorded with the workshop spreadsheet are presented in Appendix 2.

A summary of the output is provided in Table 6.2 which includes the final score for both weighted and unweighted criteria.

Table 6.2: Summary of Remediation Options Appraisal Scores

Criteria	***Weighting Factor (1-5)***	**Score summary for Options (1-5)**		
		1. Soil Vapour Extraction (SVE)	**2. SVE with heated air injection**	**3. In situ thermal remediation (ISTR)**
Technical effectiveness	*5*	2	3	5
Cost	*3*	5	1	1
Timescale	*5*	2	5	5
Practicability of implementation	*5*	5	3	3
Durability	*5*	3	5	5

Table 6.2: Summary of Remediation Options Appraisal Scores				
Track record	*5*	4	1	4
Availability of technique	*3*	5	1	3
Onerousness of health & safety requirements	*3*	5	1	3
Stakeholder requirements	*5*	1	3	5
Total percentage score with weighting criteria as shown		**67%**	**56%**	**80%**
Total percentage score without weighting criteria		***71%***	***51%***	***76%***

The evaluation can be summarised as follows:

- **Technical effectiveness**: SVE is the most basic of the three options and notwithstanding its significant track record of success in different geological formations, the fractured bedrock may prove challenging. Both of the thermal approaches offer advantages over SVE alone through significantly enhancing volatile capture, although there is significantly uncertainty over the efficacy of heat injection compared to ISTR as it has been demonstrated mostly at pilot stage only. As such ITSR is considered to be the most technically robust approach
- **Cost**: The estimated cost of SVE (~$17 -$19M) is almost half that of the two thermal options (~$33M) and there is also a greater potential for it to be reduced (through changes in well spacing) following pilot trials, compared to both other options. As such it is significantly cheaper.
- **Timescale**: The timescale required includes both installation (including drilling) and operation. Whilst the installation time may be longer for the thermal approaches this can be offset by the use of multiple drill rigs, so it is less of a significant factor. The key differences arise from operational time and the potential for rebound arising as a result of back diffusion from the primary porosity following initial reduction in the fractures and fissures. Introduction of heat enhances the rate of partitioning and capture of volatiles and will have a significant effect in mitigating rebound. Whereas both thermal approaches are likely to require approximately 1.5 years of operation, an operational time of 5 to 10 years may typically be expected for the SVE system in order to address potential rebound taking place.
- **Practicability**: Whilst all three options are capable of being implemented at the site, SVE is more practicable inasmuch as there are less potential for challenges in drilling into bedrock than the thermal options. Both of the thermal options require tighter spacing leading to a greater number of installations and therefore a higher overall potential of encountering problems during boring.
- **Durability**: The durability of the SVE approach is significantly reduced by the likelihood of rebound following system turn off, compared to the thermal options, both of which have a much reduced potential arising from the use of heat to improve and enhance the partitioning/capture process.
- **Track record**: SVE has a long and well established track record, though not always being successful in achieving targets. Whilst the track record of ISTR is less, it has a good record of achieving remedial goals and is a 'tried and tested' approach in the USA. In contrast, injection of heated air has a very limited record of application.
- **Availability**: The SVE approach is readily available in Israel through well-established procurement routes (including nationally based suppliers and/or import lines). ISTR is likely to require import of equipment for such purpose, (but which is considered feasible) as well as a power source in the range of 8 – 10 kVA, though this could be provided by a gas fired

source if necessary. The requirements for the heat injection option may be more difficult to fulfil based on its limited track record.

- **Health, safety and environment issues**: The least onerous requirements for addressing installation and operational health and safety risks are associated with the SVE approach due to its relative simplicity, with fewer installations needed than the other options and no requirement for heat. Whilst manageable, the application of heat in Options 2 and 3 raises significant H&S issues especially through the potential for more hazards arising from greater electrical use and burns due to hot equipment. The potential risk of mobilising contamination through the application of heat in Options 2 and 3, and subsequent impact offsite was also considered. There is considered to be a higher risk of this occurring if the treatment zone is located close to the site boundary. There is also perceived to be a higher risk of contaminants being mobilised with Option 2 which involves the injection of heated air when compared to Option 3 (ISTR) which involves heating in-situ. It is noted there is a good record of such risks being managed appropriately in the case of Option 3 (ISTR), whereas there a limited track record exists for heated air injection. In terms of environmental issues, whilst the application of heat to the bedrock is unlikely to result in significant adverse ecological effects to the overlying soil, the energy and carbon footprint represented by Options 2 and 3 will be inherently greater than that of Option 1.
- **Stakeholder requirements**: the various stakeholders with regards to the site include the nearby residents, ministry of environmental protection, Ministry of Finance, and RAMI (Israeli Land Authority), among others all of whom want to see the Beit Hakerem site remediated with minimal risks to future onsite and nearby existing residential neighbourhoods. The most important requirement for all of these stakeholders is effectiveness. As such ISTR, represents the best option for delivering a favourable response to a range of stakeholders, thermal injection is intermediate (relatively short duration but less effective than ISTR) and SVE least due to its prolonged operation and less efficient removal of volatiles.

6.3 Conclusions

The following conclusions can be drawn regarding the three options:

- Option 2, SVE with Injection of heated air is likely to result in a significant improvement in technical effectiveness, durability, and timescale over SVE alone. It is a technique however with a limited track record of application, mostly restricted to pilot scale and as such may have less overall availability in Israel. It also has significant (though not insurmountable) Health and Safety issues and is almost twice as expensive as SVE alone. As such it is considered to be the least favoured of the three options.
- Option 1, SVE has the main advantage of being almost half the cost of the two thermally-based options. It is the easiest and most practicable of the three options to implement, with a good track record, design flexibility, readily available in Israel and with far fewer Health & safety related issues to address than the other two. It also performs well environmentally over thermal approaches. Against this however it is technically inferior to the thermally based approaches, especially in addressing rebound and as such would be expected to require an extended operational period of typically three to six times longer (reducing its advantage of environmental sustainability). Both these aspects make it the least favourable approach for stakeholders.
- Option 3, ISTR is significantly more expensive than SVE and performs less well in terms of practicability, availability, environmental, health and safety considerations. Such disadvantages are easily outweighed however by its greater effectiveness, durability and substantially reduced timescale, all of which make it favourable to the key stakeholders.

In summary, the Remediation Options Appraisal (ROA) identified in-situ thermal remediation (ISTR) as the most appropriate technology for the Beit Hakerem site. ISTR achieved an overall percentage score of 80% (76% without weighting) as well as being the highest scoring option in a number of categories including technical effectiveness, timescales, durability, track record, and stakeholder requirements. However, despite its many advantages, ISTR is expected to be a much more expensive treatment option when compared to Soil Vapour Extraction (SVE). The conceptual remediation costs indicate that that ISTR could be approximately twice the cost of SVE, which in turn achieved the second highest overall score of the ROA (67%, or 71% without weighting).

Boundary Treatment

As noted, only SVE was considered as being suitable for active treatment at the boundary as heat based technologies such as injection of heated air or ISTR would be commercially prohibitive. Furthermore, addition of heat along the boundary could potentially represent a concern in terms of mobilisation of contamination off-site. This review has underlined SVE's suitability for boundary treatment, in the event that such treatment be deemed necessary, particularly as the focus of treatment along the boundary would be preventing the migration of soil vapour contamination, rather than targeting the source. Additionally, rebound is likely to be less of an issue in the peripheral zone compared to the source. As such, its technical limitations are of lesser significance in this instance.

7. EXAMINATION OF CONSTRUCTION OPTIONS (CHAPTER 3)

7.1 Vapour Protection for Onsite Buildings

As discussed in previous sections of the report, it has been assumed that vapour mitigation systems would be included in the construction of future on-site buildings; this would enable the adoption of more advantageous target levels as source area remediation criteria, and would also provide for protection of future on-site receptors (e.g. building occupants) from exposure to residual concentrations of VOCs in soil gas.

Based on design/installation experience at many sites, vapour mitigation systems can be highly effective in mitigating soil gas vapours entry into buildings, and are relatively low-cost to install and maintain (especially if the systems are integrated into new building construction).

7.1.1 Membranes

As background, the Israeli Ministry of Environmental Protection (MoEP) requires the use of a membrane to protect against vapour intrusions when soil gas concentrations at a site (prior to construction) are measured to be *up to* three orders of magnitude higher than the soil gas threshold limits for residential or industrial land use, as appropriate. If concentrations exceed this limit, a membrane is no longer considered sufficiently protective against potential vapour intrusion and further remedial action is required. For the purpose of this ROA, we have assumed remedial targets based on three orders of magnitude of the residential soil gas Tier 1 RBTLs; therefore, vapour protection membranes must be provided in buildings as a minimum.

Vapour membranes are a passive, physical barrier to intrusion from volatile organic compounds. Membranes must be appropriately selected, designed and installed (in accordance with Israeli guidance and MoEP approval).

The installation of the membrane must be the last step before pouring the slab. The performance of a membrane is only as good as the quality of its installation, in particular seals that can be achieved and maintained at joints in the membrane and at utility penetrations. Membranes should therefore be installed when the building is first constructed, as these can be difficult to fit retrospectively.

7.1.2 Sub Slab Depressurization (SSD) systems

There are many types of SSD systems available. This report focuses on active and passive SSD systems as primary means of vapour intrusion mitigation in new and existing buildings.

Active Systems

The US EPA defines SSD technology as "a system designed to achieve lower sub-slab air pressure relative to indoor air pressure by use of a fan-powered vent drawing air from beneath the slab" (https://archive.epa.gov/epa/sites/production/files/2014-11/documents/model_standards.pdf).

Active systems have been used successfully to mitigate the intrusion of VOC vapour into buildings and have been successfully installed and operated in residential, commercial, and school buildings during construction (and post construction in existing buildings, as discussed in Section 7.2). Active SSD is the more commonly-used approach for existing structures and/or where installation of a membrane system below the foundation is not feasible and is a reliable mitigation method.

Adequate negative pressures under the slab are a good indicator of SSD system effectiveness. The most common approach to achieving depressurization beneath the slab is to install suction points through the floor slab into the crushed rock, drainage mat or pit underneath the slab. Ideally the slab will have been built on a gravel or sand layer or over a drainage mat. A negative pressure is applied at the suction points sufficient to achieve depressurization of approximately 4-10 Pa beneath the building foundation slab.

Off-gas management (i.e. of air that is actively pumped from under the building) is typically arranged as individual vents/stacks per house. *Generally speaking, in Ramboll's experience, off-gas treatment for smaller residential systems within the US has often not been required (based in part on their smaller size). However the need for off-gas treatment is assessed as part of the design of each system, and is driven by local air emissions/permitting requirements (which have not been evaluated as part of our conceptual evaluation at this time).*

Passive Systems

Passive SSD systems are intended for situations where the potential vapour intrusion is minor. The US EPA has defined a passive sub-slab depressurization system as "a system designed to achieve lower sub-slab air pressure relative to indoor air pressure by use of a vent pipe routed through the conditioned space of a building and venting to the outdoor air, thereby relying solely on the convective flow of air upward in the vent to draw air from beneath the slab" (https://archive.epa.gov/epa/sites/production/files/2014-11/documents/model_standards.pdf). The passive stack (vent pipe) produces a reduced pressure zone below the building, intended to prevent VOC-bearing soil gas from entering the building. This process is driven entirely by the surrounding environmental conditions. Since mechanical devices do not control the system, understanding the effects of wind and stack height on overall performance is crucial. While passive systems derive some benefits from stack height and wind velocity, the primary driving forces originate from the buoyancy of the air that is warmed by passing through the heated indoor space. Since these driving forces are relatively small, all piping should be large diameter and risers should rise vertically from the collection point with as few bends in the pipe as possible.

Summary

SSD systems (either passive or active) are proven and cost-effective remedial approaches that are recommended as part of the site redevelopment. Regardless of the source area remedial technology selected, residual concentrations of site-related VOCs are likely to remain in soil gas following completion of the initial remediation work, and the use of SSD systems in the planned future construction for the site will provide cost-effective protection of future building occupants. Installation costs for SSD systems are typically in the range of $54-$107 USD per square meter of building footprint.

The use of SSD systems in future construction could potentially provide enhanced vapour intrusion mitigation when compared to a membrane alone.

If off-gases from the SSD systems exceed MoEP threshold discharge requirements, these will likely need to be controlled. *The general cost range presented above takes into account the potential need for emissions treatment.*

7.2 Development Design

7.2.1 Building Depth

The design and construction of the vapour protection system (membrane or SSD) should be coordinated with the design of the buildings planned as part of the site redevelopment.

For example, buildings without basements (i.e., slab on grade construction) may simplify the design and construction of the required vapour protection systems, and buildings with basements/subsurface levels may require closer attention to vapour protection system design/construction details. The presence and use(s) of basements can be further considered following further site investigations and as part of detailed design.

7.2.2 Clean Cover and Capping

This Remediation Options Appraisal only considers the bedrock remediation. It is understood that remediation of hotspots of contamination in the shallow overburden soils (which extent to approximately 6-10m depth) is being undertaken before any construction at the site.

Nevertheless, it will be important to ensure that potential pollutant linkages associated with future site user's contact with shallow soil are appropriately mitigated. If the relevant contaminant risk-based target levels (RBTLs) in shallow soils are not achieved, then additional mitigation such as capping or installation of clean cover soils in landscaping areas will likely be required. This type of mitigation is outside the scope of LDD-Ramboll's review and is not discussed further here.

7.3 Management of Contamination Risks during the Construction Phase

All construction activities must be undertaken in accordance with best practice in terms of contamination control. The developer and its contractor's risk assessments and method statements must take into consideration the contaminated nature of the site and must ensure that the construction activities do not cause mobilisation of contamination or impact to sensitive receptors.

Neighbouring Residents

During construction and enabling activities, potential risks to neighbouring site users must be considered and control measures implemented. For example, this could include tenting of excavations and localised air excavation to prevent odour nuisances, dust and VOC impacts to neighbouring residents. Other mitigation methods that could be considered include careful sequencing of the works to avoid large areas of contaminated materials being exposed, sheeting of stockpiled soils and covering of waste lorries before leaving site. Drilling and foundation excavation techniques must be selected that will not cause increased risk of soil vapour migration offsite. It will be the developer and its contractor's responsibility to ensure mitigation measures employed during the construction phase are appropriate and are consistently implemented.

Environmental monitoring will likely be required during construction and enabling works. Monitoring stations should be set up at the site borders (particularly where residential neighbourhoods are in close proximity), and potentially also at the point of excavation, to monitor air quality for VOC's.

Stakeholder engagement with local residents should form an important part of a successful development scheme.

Risks to Construction Workers

The developer and its contractors must ensure it has mitigated risks to construction workers through selection of appropriate methodologies to minimise potential staff exposures and use of PPE.

Foundation Risk Assessment

Given the depth to groundwater at the site (approximately 100m), it is unlikely that construction piles will extend to this depth. However, it will be important for the developer and its designers to ensure that the foundation design of future buildings does not introduce additional risks in terms of contamination, for example by introducing the contamination to different geological horizons or creating preferential pathways for contamination migration. Operatively, this might mean restricting the depth and/or method of piling that is allowed to avoid creating preferential pathways for contaminant migration.

Risks to Waters

It will be important to ensure that the construction works and future development do not cause contamination in unsaturated soils to migrate towards sensitive water bodies (such as surface watercourses or deeper groundwater). For example, water flush techniques should be avoided during drilling and piling in determined hot spots, because this can mobilise contaminants within the unsaturated soils.

When designing future drainage schemes, soakaways should not be installed in parts of the site that are affected by contamination.

Care should also be taken not to introduce large areas of landscaping or unsurfaced ground in areas that were previously largely occupied by buildings or hardstanding. This is because the increased infiltration can wash contaminants deeper into the soil, potentially towards sensitive groundwater receptors. This consideration is important both within the final design and also during the construction phase during site clearance.

The requirements associated with drainage in the building code (in Hebrew בנייה משמרת מים), especially as they relate to infiltration systems for rainwater runoff, should be reviewed in light of the potential risks of creating preferential pathways along with the risk of mobilising the existing contamination within the bedrock towards the groundwater thereby potentially exacerbating the contamination issues at the site. It is recommended to consult with a hydrologist on this topic.

Selection of Appropriate Building Materials

As with all brownfield developments, it will be important to ensure that the building materials selected are appropriate and sufficiently resistant to the contaminants present. For example, this includes ensuring that concrete foundations and below ground structures will not be impacted by degradation from contaminants. The selection of future drinking water supply pipes must ensure that the materials used are sufficiently impermeable to site contaminants.

Buried wastewater pipes, communications, and electric networks, together with associated infrastructure should also be constructed with sufficiently impermeable and contaminant-resistant materials, especially so for manholes used for routine maintenance, where there is a greater exposure risk of workers to potential soil gas contamination.

All buildings on site should be constructed with vapour intrusion prevention membranes. Engineering and installation of these membranes should address any pipework leading into buildings including wastewater, communications, and electricity, such that the membrane should prevent any vapour intrusion originating from preferential pathways caused by these pipe networks.

Programme Considerations

The remediation, site preparation and wider enabling works would typically commence before building construction. It may be possible to begin the construction phase at the site while soil gas remediation is on-going. For this, areas dedicated to the soil gas remediation would need to remain as public/communal areas (such as parks, walkways, etc.) to allow access for maintenance and monitoring.

7.4 Vapour Protection for Offsite Existing Buildings

While offsite receptors are outside the scope of this work, they are recognized as a potential receptor for soil gas contamination based on previous soil gas studies conducted at nearby offsite locations. While the onsite remediation of soil gas may potentially have a minor effect in reducing the soil gas concentrations found offsite, this requires further study. As such, it is recommended to perform monitoring of soil gas within the residential neighbourhoods as well as specific indoor air monitoring within buildings for which there is a concern of soil gas intrusion.

Only once an actual risk to offsite users has been identified should construction options be considered and implemented to prevent the intrusion of soil gas to buildings. Construction options for offsite existing buildings include passive and active SSD systems which while more expensive to adapt to existing buildings due to the need to drill below existing infrastructure, can provide protection to existing buildings in which a specific risk has been determined. *The cost for the retrofit SSD systems to existing offsite buildings would vary hugely based on the design of the existing buildings and is not possible to determine at this stage.*

In existing structures, installing an SSD system entails drilling one or more holes in the slab, removing a small quantity of soil from beneath the slab to create a "suction pit," and then placing vertical suction pipes into the holes. These pipes are connected to a manifold containing an exhaust fan, and vapours are in turn vented outdoors.

8. RECOMMENDATION OF THE PREFERRED REMEDIATION STRATEGY (CHAPTER 4)

8.1 On Site Remediation Recommendation

The Remediation Options Appraisal (ROA) identified in-situ thermal remediation (ISTR) as the most appropriate technology for the Beit Hakerem site. ISTR achieved an overall percentage score of 77% (72% without weighting) as well as being the highest scoring option in a number of categories including technical effectiveness, timescales, durability, track record, and stakeholder requirements, as detailed in section 6 of this report.

However, despite its many advantages, ISTR is expected to be a much more expensive treatment option when compared to Soil Vapour Extraction (SVE). The conceptual remediation costs indicate that that ISTR could be approximately twice the cost of SVE, which in turn achieved the second highest overall score of the ROA (66%, or 70% without weighting).

Taking into consideration the outcome of the ROA exercise, and also LDD's in-country remediation experience in Israel, it is considered that SVE is likely to be a more practical remediation approach for much of the Beit Hakerem site, particularly if active remediation of such large areas is required. SVE does not typically cause significant disruption to site operations once it has been installed and, whilst this is also true of ISTR, the operation and maintenance associated with SVE systems are generally more straightforward and are expected to be better understood by Israel based contractors that already have experience with the implementation and maintenance of SVE as opposed to ISTR, which to date, is not commonly implemented in Israel.

Whilst ISTR was identified as being a more robust technical method of remediation, the relative disadvantages of SVE (such as longer timescales and a greater potential for contaminant rebound) could be mitigated by implementing complimentary mitigation methods. For example, enhanced vapour protection (e.g. sub-slab depressurisation (SSD)) could be installed in new onsite buildings, rather than membranes alone; enhanced monitoring and, if required, mitigation should be implemented in relation to offsite risks. Both of these complimentary mitigation approaches are discussed further below.

For this reason, SVE is recommended as the primary approach for bedrock remediation at the Beit Hakerem site. The SVE bedrock remediation should be combined with the incorporation of SSD into onsite buildings and be undertaken alongside offsite monitoring and, if required, mitigation. The advantages of SVE are particularly apparent if further investigation and delineation of contamination at the site confirms that active treatment is required over a large area (as has currently been assumed).

Nevertheless, the technological advantages of ISTR, including its speed and proven effectiveness, should not be ignored. It may therefore be appropriate to apply a combination of remedial technologies to the site. For example, ISTR could be implemented in areas with the highest contaminant concentrations (i.e. hotspot remediation), with SVE utilised across the wider treatment area to complement the ISTR and capture soil gas from a larger area. This combined approach could potentially be then used to reduce the overall site development timescales, particularly if there is a restriction on commencing the construction due to high concentrations of soil gas in a particular location.

LDD-Ramboll recommend a combined approach for remediation of the soil gas at the site utilizing both SVE and ISTR technologies. Due to the costs of ISTR, it is recommended to implement the technology in specific hot spots, that will be determined in the pilot phase of work, to quickly reduce the bulk of the contamination, while SVE could be implemented as a longer-term solution in other slightly less contaminated parts of the site.

8.2 Next Steps

Prior to adopting any remediation technology, there must be a phase of data collection to complete data gap analysis as identified in the first phase of this work. To recap, these include the following information gaps (which are discussed extensively in the LDD-Ramboll's Chapter 1 report):

- the required remediation depth;
- the affected area (including treatment of hot spots versus full site);
- determining if a free phase exists within the bedrock; and
- the nature and extent of fractures.

Concurrent to the further investigations, a pilot scale project should be undertaken before implementing full scale remediation works (see Chapter 5). As noted above, we consider that SVE should be considered for remediation. In particular, SVE pilot trials are important to confirm the necessary spacing between extraction wells, which could have significant effects on the costs and timescales of the remediation.

If SVE pilot trials show limited treatment success, or significant contaminant rebound; or if the further investigations show a clear presence of significant hotspots and possible free phase contaminants, there could be merit in incorporating ISTR into the remediation approach.

Pilot trial designs for SVE & ISTR are expanded on further in the following Chapter 5 of this report.

8.3 Construction Design

There are opportunities to optimise the wider site remediation through careful construction design. We understand that all future buildings on the Beit Hakerem site would be required to be installed with a vapour membrane barrier at a minimum (less conservative remedial targets have been assumed on this basis). Installation of SSDS in new buildings is a relatively cost-effective way of mitigating vapour intrusion and has immediate effect; the use of SSDS could therefore help the site to achieve its development value.

8.4 Off-site Soil Vapour Risks

As part of the ROA, methods were considered to prevent the movement of contamination from within the site boundary to off-site receptors. An SVE barrier around the boundary of the site was considered to be the most viable option; some basic assumptions were made including that the barrier would be required around the entire site boundary (931m) and to an assumed remediation depth of 40m. However, the conceptual costs that were developed for this scenario were extremely high and not likely to represent a feasible approach. This was partly due to the assumed length and depth of the barrier and also due to the more stringent requirement to meet Residential Tier 1 RBTLs along the border of the site (as opposed to the higher assumed remedial target values within the site, where membranes would be installed in new buildings).

We consider a more pragmatic approach to managing and mitigating offsite risks would be to initially undertake monitoring along the site boundary and close to sensitive receptors such as nearby residents. If monitoring identifies areas of concern along the border, localised mitigation should be considered in those areas, using the methods outlined above.

Additionally, to protect off-site residents, indoor soil gas monitoring should be performed in buildings for which a concern has been raised (e.g. buildings in areas where soil gas contamination has been detected off-site, in exceedance of threshold values), as well as further soil gas monitoring in off-site public spaces. If potential vapour intrusion concerns are identified in offsite buildings, the resistance of such buildings to soil gas intrusion (e.g. through the presence an appropriate vapour membrane) should be evaluated. If a risk is identified as a result of soil gas/indoor air monitoring, for which mitigation is not already in place, the installation of SSD systems may then be necessary. SSD can often be installed with relative ease in existing buildings, as discussed in section 7 of this report.

APPENDIX 1
REMEDIATION OPTIONS APPLICABILITY SCREENING

Table A1

Broad screening of remedial options (long list) to identify potentially viable alternatives for chlorinated hydrocarbon treatment at Beit Hakerem applicable for unsaturated zone (**Bedrock only)**

Type of remedial approach	Remediation technique (a)	Summary description/explanation	Assessment	Verdict: rejection or potential consideration (b)
Civil engineering	Horizontal containment - cover systems	Placement of horizontal barrier (hardstanding, membrane etc.) to prevent migration of contaminant upwards to receptors on surface or downwards to impact groundwater	Does not address objective of mass reduction, though vapour barrier essential for mitigation of residual VOCs present in soil gas, assuming a remedial criterion based on 3x the IRBCA Tier 1 RBTL within site boundary	Inclusion of vapour barrier as part of remedial strategy necessary for fulfilment of remedial criteria. Otherwise horizontal containment as standalone approach does not address remedial objectives
Civil engineering	Sub-slab depressurization	Installation of a system designed to achieve lower sub-slab air pressure relative to indoor air pressure by use of a fan-powered vent drawing air from beneath the slab via a series of PVC pipes and discharging to atmosphere. Telemetry may be used to communicate monitoring data directly to authorities.	Does not address overall objective of mass reduction, though may provide appropriate degree of mitigation to enable residential development to proceed	Potential mitigation measure as alternative to vapour membrane that may be implemented in conjunction with active measures for remediation of contamination within bedrock: outside scope for remediation of bedrock
Civil engineering	Hydraulic containment combined with Pump & Treat	Manipulation of groundwater flow through pumping /abstraction to protect hydraulically downgradient receptors (primarily off-site residents), as well as providing for remediation of groundwater itself through ex situ treatment (Pump & Treat). Re-injection of treated groundwater (potentially with supplements/reagents to promote in situ treatment) or disposal to foul sewer	Hydraulic barrier / Pump & Treat relates to contamination within saturated zone not unsaturated zone, therefore not appropriate as an option as does not address remedial objectives	Rejected
Civil engineering	Containment - in ground barriers	Vertical cut-off wall (e.g. piles, slurry walls, grout curtains) to prevent lateral migration of contaminant	Does not address objectives for contamination within site boundary as it retains contamination with no mass loss. Whilst it may address migration of contamination off-site it would be very complicated to install due to the nature of the fractured bedrock and would likely be cost-prohibitive	Rejected
Civil engineering	Excavation and disposal	Excavation of contamination and off-site disposal/treatment at licensed facility with replacement by 'clean' backfill	Impracticable given depth of contamination, and volume of material involved	Rejected (for bedrock, though option for disposal of overburden in development footprints, especially where mixed contamination exists)
Biological	Natural attenuation	Reliance on natural processes (primarily microbial degradation) to achieve requisite mass loss of contamination	Would not achieve objectives in required timescale for site and for CHCs, more suited to saturated zone systems. Also, conditions in vadose zone may not be conducive for significant degradation.	Rejected
Biological	Enhanced in situ bioremediation (anaerobic)	Enhancing activities of microbial community to achieve contaminant destruction through reductive dechlorination (ERD), whereby chlorinated compounds ultimately degraded to ethene, ethane and inorganic chloride, primarily through application of a carbonaceous substrate (lactate, molasses, vegetable oil) that is metabolised by bacteria to create the hydrogen required for this process. May also involve application of specific bacteria (*Dehalococcoides* spp) to accelerate the process (bioaugmentation)	Process is more suited to the saturated zone: unsaturated zone does not have the continuum of water for transport of reagents. Would be impracticable to achieve the necessary degree of coverage/permeation of the matrix by the requisite substrates/inoculum in any unsaturated medium to achieve conditions conducive for ERD but especially in a bedrock	Rejected
Biological	Bioventing (cometabolic bioremediation, CL-OUT® process)	Alternative microbial mechanism to ERD involves cometabolism, where, when provided with a specific substrate certain bacteria create particular enzymes to metabolise it as a source of energy and food. These enzymes fortuitously degrade chlorinated hydrocarbons. The process is aerobic therefore oxygen needs to be supplied by air injection or extraction. The first of these mechanisms (the CL-OUT® process) requires injection of specific bacteria together with dextrose as the substrate	The process is best suited to the saturated zone as it is reliant on successfully distributing the dissolved substrate (dextrose) and the inoculated bacteria throughout the soil matrix, requiring a continuum of water. Effective distribution cannot practicably be achieved in the unsaturated zone, especially not in the karstic bedrock	Rejected
Biological	Bioventing (cometabolic bioremediation by monooxygenases)	Alternative microbial mechanism to ERD involves cometabolism, where, when provided with a specific substrate certain bacteria create particular enzymes to metabolise it as a source of energy and food. These enzymes fortuitously degrade chlorinated hydrocarbons. The process is aerobic therefore oxygen needs to be supplied by air injection or extraction. The second of these mechanisms requires injection of a mixture of methane or propane and air to stimulate certain indigenous bacteria into producing monooxygenase enzymes that effect degradation of the chlorinated organics. Would need to be part of an SVE system (particularly for controlling gas distribution)	Whilst most examples of this process have taken place in the saturated zone, the use of a gaseous substrate potentially allows delivery through the unsaturated zone, though this would still be reliant on the presence of the requisite bacteria that produce methane or propane monooxygenase. Most examples of this process have not required bioaugmentation (inoculating with specific bacteria), but these have been in the saturated zone. In unsaturated bedrock there may be a paucity of the specific bacteria that can undertake this transformation, so this would require evaluation and there is no certainty that these are present in sufficiently high number throughout the entire thickness of unsaturated zone undergoing treatment. Most significantly, potential difficulties are likely to be encountered in achieving permeation of the gaseous alkane/air mixture throughout the bedrock	Rejected
Biological	Biosparging	Injection of air / substrate into groundwater to provide oxygen and stimulate cometabolism (see above)	Technique is only for saturated zone therefore not applicable option for site	Rejected
Biological	Slurry phase biotreatment	Excavation of soil and subsequent biological treatment in a suspension of water in an engineered bioreactor	Unsuitable due to excavation limitations: formation being bedrock rather than soil and depth of contamination	Rejected
Biological	Phytoremediation	Various applications of plants for remedial purposes such as phytoextraction (collection in plant tissue or loss through transpiration), hydraulic control, rhizoremediation (promotion of biodegradation in root zone)	Only suited for soil at shallow to moderate depth and/or groundwater, not for deep/bedrock	Rejected
Chemical	Chemical oxidation using liquid based oxidant	Application of a solution of a chemical oxidant (peroxide, permanganate, persulphate or percarbonate- based compound) to degrade the chlorinated compounds to water and chloride through oxidation process.	For water soluble oxidants, the process is best suited to the saturated zone, firstly as it is totally reliant on achieving contact between the oxidant and the contaminant which will be difficult to achieve within the vadose zone and secondly successfully distributing such oxidants throughout the entire matrix, requires a continuum of water. Within a fractured bedrock matrix , the difficulties of achieving this, particularly over the depths to be treated at the site are considered to make this approach impracticable	Rejected

Table A1

Broad screening of remedial options (long list) to identify potentially viable alternatives for chlorinated hydrocarbon treatment at Beit Hakerem applicable for unsaturated zone (**Bedrock only)**

Type of remedial approach	Remediation technique (a)	Summary description/explanation	Assessment	Verdict: rejection or potential consideration (b)
Chemical	Chemical oxidation using ozone	Application of ozone to degrade the chlorinated compounds to water and chloride through oxidation process. Ozone would be made on site by electrical generators that produce a high voltage discharge in air and the ozone-enriched air stream injected into the formation. This could be combined with a vapour extraction system to facilitate distribution (using a push-pull approach)	As a gaseous substance, ozone is technically a potentially viable oxidant that could be applied in the vadose zone. However as ozone is very unstable, highly reactive and has a short half life, very closely spaced delivery points are usually required. Even if such close spacing was possible (which may be challenging for a bedrock) it is likely to be difficult to achieve the appropriate degree of contact with the contamination due to its short half life and instability, taking account of the travel time from the injection point to all areas of the bedrock (and having sufficient residence time to allow for diffusion into the rock matrix itself). Some reports also indicate that ozone may be less effective for chlorinated ethanes (TCA and DCA)	Rejected
Chemical	Chemical reduction	Application of zerovalent iron (ZVI, in particulate, colloidal or nanoparticulate form) for chemical reduction of chlorinated organics to chloride and water, avoiding accumulation of intermediates such as DCE and VC that occur through biological ERD	Process is more amenable for saturated zone conditions requiring the continuum of water for effective distribution. Any form of ZVI would be difficult to distribute effectively throughout the bedrock in the vadose zone to achieve the appropriate density and contact with contamination present.	Rejected
Chemical	Chemical dehalogenation	Application of alkaline polyethylene glycol (APEG) to remove the chloride from each organochloride compound and replace with polyethylene glycol	Ex situ process taking place in a reactor under controlled conditions. Volume and nature of material (bed-rock at depth) makes ex situ treatment - and thereby this approach - unsuitable for application	Rejected
Chemical	Soil flushing / solvent extraction	Application of water with an additive to enhance contaminant solubility or a solvent solution, with recovery and treatment of the recovered mixture.	Impracticable to apply in bedrock and over the treatment depths required: would not be possible to control, distribute or recover injected fluids	Rejected
Physical	Soil vapour extraction (SVE)	Application of a vacuum to the soil through boreholes or trenches to induce a flow of air through the unsaturated zone, facilitated by installation of passive air inlet wells and/or thermal enhancement through heated air injection. Extracted air is then treated thermally or by GAC on the surface prior to atmospheric discharge. At the site this could be undertaken for the entire unsaturated zone as a single process (this option), or in a phased manner.	Applicable approach, though would require pilot scale testing prior to application	For consideration - potentially with or without thermal enhancement
Physical	Dual phase / multi-phase extraction	Extension of SVE to saturated soils through a dual pump system or treatment of saturated zone by separate wells with a stinger positioned at the water table to 'slurp' water/air/product. Also useful in vadose zone with lower permeability and potential for upconing.	Not applicable - system is focused on saturated zone or at least the lower part of the vadose zone where there is potential for upconing	Rejected
Physical	Air sparging	Injection of air into saturated zone to promote partitioning of volatiles to vapour phase, usually complemented by an SVE system to subsequently recover vapourised contamination from vadose zone	Saturated zone treatment only so not applicable	Rejected
Physical	Permeable reactive barriers	Barrier constructed of reactive material / reagent to promote contaminant destruction a groundwater flows through it	Groundwater treatment only so not applicable	Rejected
Physical	Soil washing	Excavation of soil and washing in a treatment plant, based on assumption that majority of contamination adhering to fine grained particles. Clean soil can then be re-used, washing requires treatment and filter cake (concentrate) requires treatment and disposal	Applicable for relatively soil rather than bedrock: as an ex situ process excavation would be impracticable for the depths required for treatment	Rejected
Physical	Vitrification/stabilisation & solidification	Various processes that can be undertaken ex situ (typically vitrification) or potentially in situ (stabilisation/solidification) whereby stabilising agent (e.g. reactive clay) injected and mixed into soil by continuous flight augers creating series of overlapping cylindrical columns	In situ stabilisation would pose significant geotechnical problems for treatment of bedrock and could not be practicably implemented for the required depth not the unsaturated zone needing treatment. Additionally very limited stabilising agents demonstrated to have long term effectiveness for chlorinated organics	Rejected
Physical	Incineration	Ex-situ process requiring excavation of soil and high temperature destruction of contamination	As an ex situ process excavation would be impracticable for the depths required for treatment and based on the volumes involved energy/costs would be exorbitant, even if material could be accessed from the shallower depths only	Rejected
Physical	Thermal	There are two main types of thermal remediation available. For in situ thermal remediation (ISTR), thermal desorption involves application of heat to the bedrock to enable desorption of contamination from solid surface and subsequent extraction by SVE system and capture/destruction on the surface. Heat can be applied by one of three methods: Electrical Resistive Heating (ERH) uses an electrical current generated by electrodes driven into the sub-surface, Steam Enhanced Extraction (SEE) involves pumping steam via injection wells, thermal conduction heating (TCH) involves placement of heaters in steel pipes that also serve as vacuum wells. A second type of thermal approach involves SVE combined with heated air injection to enhance CHC removal in certain areas where higher CHC impacts are expected, or in zones where expedited CHC removal may be desired to promote site redevelopment.	Of the commercially available processes for in situ thermal remediation (ISTR), thermal conduction heating (TCH) or possibly Electric resistive heating (ERH) are likely to represent the most practicable approaches for the site, based on potential applicability to bedrock, although costs are likely to be prohibitive for treatment of the entire depth profile. As such it is considered to be a potentially viable approach for treatment of shallower contamination - particularly with the objective of expediting development, with the deeper contamination being subject to long term remediation through an SVE system, which continues to operate post development. Similarly, heated air injection as a variant of SVE is also considered to represent a viable option.	Both methods (ISTR and heated air injection) recommended for consideration as potential options, e.g. for treatment of shallower contamination in combination with SVE for long term remediation of deeper soil depths

(a) List taken from the (English) Environment Agency Remediation Option Applicability Matrix https://www.gov.uk/government/publications/land-contamination-remediation-option-applicability-matrix with additional techniques included

(b) Shading as follows:

(green)	To be taken forward for evaluation as a standalone technique and /or in combination with other technique
(yellow)	To be taken forward for evaluation but only in combination with other option (in green)
(red)	Rejected as unsuitable for application at Beit Hakerem - no further consideration

APPENDIX 2
REMEDIATION DETAILED OPTIONS APPRAISAL

APPENDIX

EVALUATION OF SHORT LISTED REMEDIAL OPTIONS

Project Reference Number	1620007286
Project Name	BEIT HAKEREM - REMEDIATION OPTIONS APPRAISAL
Client	LDD / Environmental Services Company
Site	BEIT HAKEREM
Location	Israel
Project Objective	Provision of unsaturated bedrock remediation advice
Name & Organisation of persons performing ROA	
Name	**Organisation**
Richard Bewley	Ramboll
Hannah Lewis	Ramboll
Jeff Levesque	Ramboll
Allison Busgang	LDD
Ori Zvikelsky	LDD
Options being assessed (short-listed)	
Number	**Name**
1	Soil Vapour Extraction (SVE)
2	SVE with heated air injection
3	In situ thermal remediation (ISTR)

Prposed criteria	Issues for consideration as part of assessment (generic)	Proposed weighting (a)
Technical effectiveness	Effectiveness in meeting remedial objectives within a practical timescale and regulatory requirements. Also to what extent effectiveness can be demonstrated through verification .	5
Cost	To include both total cost and cash-flow considerations (up-front costs, installation, operation, post remedial monitoring)	3
Timescale	Rapidity of completion and ability to meet the client's timescale for completion, including the time for enabling works such as treatability/pilot scale testing, permitting, enabling works, as well as the likely requirements for post remedial monitoring and any long-term obligations.	5
Practicability of implementation	To include consideration of how practicable the option is, given the nature of the bedrock formation, depth of contamination, site location, size, access, layout and maintenance needs, ability to fulfil operational need	5
Environmental	The relative ability of each option to achieve the remedial objectives in a safe and timely manner whilst minimising the environmental impact of the work.	3
Durability	Ability of the technique to successfully reduce or control risks for a defined period on completion of the remedial works	5
Track record	Evidence of successful implementation of the approach, at full-scale (rather than just pilot scale), for dealing with similar contaminants and at similar sites (e.g. specific geological and hydrogeological conditions)	5
Availability of technique	This includes availability of resources for implementation including, for example, specialist contractors or specific reagents	3
Onerousness of health & safety requirements	The level of requirements for addressing health and safety issues associated with each option ((i.e. how onerous these are, rather than whether a particular approach is 'safer' than another)	3
Stakeholder requirements	Acceptability of the approach to relevant stakeholders including for example client, regulator, future site purchaser/occupier and neighbour	5

Relative Importance:
5: Relatively Higher Importance
3: Relatively Medium Importance
1: Relatively Lower Importance

Criterion	Weighting	1. Soil Vapour Extraction (SVE)			2. SVE with heated air injection			3. In situ thermal remediation (ISTR)		
		Installation of approx. 80 vapour extraction (SVE) well clusters to treatment depth of 40m, connected via pipework to above ground extraction unit. Blower used to create suction drawing in volatilised contaminants from sub-surface and treating using GAC (and/or thermal oxidation) prior to discharge of off-gas to atmosphere			**As for Option 1 but also including the installation of 225 air injection wells interspersed between same number of SVE wells, through which heated air is injected into the formation to accelerate transfer of contaminants into the gaseous phase whereupon they are captured vis the SVE wells**			**Installation of approx. 225 heating elements & SVE wells to treatment depth of 40m. Application of heat directly to subsurface (probably through thermal conduction) to facilitate transfer of contaminants to vapour phase and capture via SVE. Extraction and treatment of VOCs as per Options 1 and 2**		
		Evaluation according to criteria	**Score**	**Weighted score**	**Evaluation according to criteria**	**Score**	**Weighted score**	**Evaluation according to criteria**	**Score**	**Weighted score**
Technical effectiveness	5	The most basic of the three approaches. SVE has a very long track record and is a proven technology. However it is noted that the geology could be particularly challenging for this technology. Whilst it is typically effective in porous media, it may struggle more in fractured geology	2	10	This technology is enhanced compared to just SVE, so would be expected to be more effective. The introduction of heat is expected to make it substantially more effectve than SVE alone. However it is not a commonly used approach, and one which has generally only been used in pilot studies (rather than full scale implementation). We have scored this technology lower than ISTR for this reason.	3	15	This technology is enhanced compared to just SVE, so would be expected to be more effective. The introduction of heat is expected to make it substantially more effectve than SVE alone. It has a good track record of effectiveness and is a proven technology.	5	25
Cost	3	Estimated to be in the order of $17M to $19M in total (installation & operation) There is notable potential for cost reduction following pilot trials. This is because a fairly conservative well spacing has been assumed based on the complex geology at the site. If SVE is shown to be effective using a larger well spacing, this could introduce substantial cost savings.	5	15	Estimated to be in the order of $33M in total (installation & operation). Compared to the SVE method (Option 1) and to some extent the ISTR method (Option 3) as well, there is less potential for the pilot trial to identify opportunity for well spacing reduction and therefore cost reduction.	1	3	Estimated to be in the order of $33M in total (installation & operation) Compared to the SVE method (Option 1), there is less potential for the pilot trial to identify opportunity for well spacing reduction and therefore cost reduction.	1	3
Timescale	5	Estimated to be in the range of 5 - 10 years. The required remediation target of 3x orders of magnitude higher than the Tier 1 values may be achieved before this date (e.g. 3-5yr?). However rebound would be expected following turn-off of SVE; longer timescales have been presented to reflect this. It is noted that due to a smaller number of wells compared to Options 2 and 3, there may be a notably shorter drilling timescale (i.e. set-up) compared to those other two options..	2	10	Estimated to be in the range of 1.5 years. Rebound considered less likely than SVE alone, due to the introduction of heat. Note, due to more wells being required, initial set-up/drilling times may be longer than for SVE; although multiple drill rigs could be deployed to speed up installation.	5	25	Estimated to be in the range of 1.5 years Rebound is typically not seen. However this is subject to good site characterisation and appropriate targeting of the remediation. Complexities of the site mean that we cannot rule out rebound (e.g. may be untreated mass due to size/complexity of site that has not been identified and that the ISTR has not targeted). Note, due to more wells being required, initial set-up/drilling times may be longer than for SVE; although multiple drill rigs could be arranged to speed up installation.	5	25
Practicability of implementation	5	SVE is a technology that is well understood in Israel, particularly in how it is implemented. Of the three Options, it is the most practicable to implement as there are fewer challenges in terms the number of boreholes and so less drilling into bedrock, compared to the alternative options that additionally involve application of thermal approaches	5	25	LDD perceived added complexity with implenting thermal systems at depths below 20m, especially given that this remediation method is not commonly used in Israel. It is noted that tighter spacing and more wells will require more bedrock drilling (i.e. more potential for problems to be encountered during drilling).	3	15	LDD perceived added complexity with implenting thermal systems at depths below 20m. However it was noted that US case studies exist of ISTR treatment at depths up to 300ft (100m). It is noted that tighter spacing and more wells will require more bedrock drilling (i.e. more potential for problems to be encountered during drilling).	3	15
Environmental	3	Longer duration of remediation and therefore a longer period over which energy will be required for extraction Environmental impacts from remediation (e.g. VOC emissions) will be lower 'per year' but will continue for a longer duration.	3	9	Shorter duration of remediation, but substantially more energy used for heating. Also more energy/ resource use for drilling (as a higher number of boreholes). Environmental impacts from remediation (e.g. VOC emissions) will be higher 'per year' but occur for a shorter duration.	2	6	Shorter duration of remediation, but substantially more energy used for heating. Also more energy/ resource use for drilling (as a higher number of boreholes). Environmental impacts from remediation (e.g. VOC emissions) will be higher 'per year' but occur for a shorter duration.	2	6
Durability	5	High potential for rebound of contaminant concentrations following 'turn-off' of the remediation system.	3	15	Lower potential for rebound due to the addition of heat to the SVE process. (assuming that source has been adequately targeted).	5	25	Lower potential for rebound due to the addition of heat to the SVE process. (assuming that source has been adequately targeted)	5	25
Track record	5	Long track record. SVE is a 'tried and tested' method, including in Israel, and has been used in bedrock. However SVE is not always succesful at acheiving targets (i.e. it may struggle to sufficiently reduce soil gas concentrations).	4	20	SVE with heated air injection has a limited track record beyond pilot trial stage.	1	5	Good track record. Whilst ISTR has not been used for as long as SVE, and is less commonly used in Israel, it is a 'tried and tested' method in the US. ISTR tends to be more successful than SVE at achieving remediation targets and avoiding rebound.	4	20
Availability of technique	3	There is good availability of this technology in Israel. This includes established import supply lines, as well as several suppliers within Israel who can provide bespoke equipment.	5	15	Due to limited track record of this technology beyond pilot trial, it is expected that it will be much more difficult to identify apropriate large scale equipment providers.	1	3	LDD is not aware of Israel based manufacturers for ISTR systems. Thie equipment would likely require full import (including metal well installations, injectors, heating transfer units etc.) Energy requirements for the site (to supply heat) were also discussed. It was noted that a power source in the range of 8-10 kVA would likely be needed. However it was also noted that there are 'gas fired' options for in situ technoology.	3	9
Onerousness of health & safety requirements	3	The hazards associated with SVE installation and operation are well understood; the hazards are considered lower than the other two options.	5	15	Proper fencing around above grade equipment should mitigate risks relating to people accessing the site. However there would be more electrical use (so associated increased hazard) and the potential for burns due to hot equipment. The potential risk of mobilising contamination through the application of heat and subsequent impact offsite was also discussed. There is considered to be a higher risk of this occurring if the treatment zone is located close to the site boundary. There is also perceived to be a higher risk of contaminants being mobilised, when compared to ISTR, due to the injection of heated air (rather than heating in-situ).	1	3	Proper fencing around above grade equipment should mitigate risks relating to people accessing the site. However there would be more electrical use (so associated increased hazard) and the potential for burns due to hot equipment, though it is noted that there is a good track record of these risks being appropriately managed in ISTR remediation. The potential risk of mobilising contamination through the application of heat and subsequent impact offsite was also discussed. There is considered to be a higher risk of this occurring if the treatment zone is located close to the site boundary. However ISTR has good track record of maintaining well pressures, thereby reducing potential for migration away from the treatment area.	3	9
Stakeholder requirements	5	It was perceived that the nearby resident stakeholders would be most interested in the works being completed quickly, whereas regulator's focus would likely be on effectiveness. As noted above, the remediation duration is likely to last longer, and the technology is not expected to be as effective as the options that involve heat enhancement.	1	5	It was perceived that the nearby resident stakeholders would be most interested in the works being completed quickly, whereas regulator's focus would likely be on effectiveness. As noted above, the remediation duration is likely to be shorter, and the technology is expected to be more effective than SVE alone. Whilst SVE with heated air injection has the potential to be as effective as Option 3, it has been given a lower score due to less track record.	3	15	It was perceived that the nearby resident stakeholders would be most interested in the works being completed quickly, whereas regulator's focus would likely be on effectiveness. As noted above, the remediation duration is likely to be shorter, and the technology is expected to be more effective than SVE alone. ISTR also has a good track record.	5	25
Total Score				139			115			162
Percentage score				66%			55%			77%

Table
Beit Hakerem: Remedial Options Evaluation Summary

Criteria with weighting	**Score summary for Options**		
	1. Soil Vapour Extraction (SVE)	**2. SVE with heated air injection**	**3. In situ thermal remediation (ISTR)**
Technical effectiveness	10	15	25
Cost	15	3	3
Timescale	10	25	25
Practicability of implementation	25	15	15
Environmental	9	6	6
Durability	15	25	25
Track record	20	5	20
Availability of technique	15	3	9
Onerousness of health & safety requirements	15	3	9
Stakeholder requirements	5	15	25
Percentage score with weighting	**66%**	**55%**	**77%**

Criteria without weighting	**Score summary for Options**		
	1. Soil Vapour Extraction (SVE)	**2. SVE with heated air injection**	**3. In situ thermal remediation (ISTR)**
Technical effectiveness	2	3	5
Cost	5	1	1
Timescale	2	5	5
Practicability of implementation	5	3	3
Environmental	3	2	2
Durability	3	5	5
Track record	4	1	4
Availability of technique	5	1	3
Onerousness of health & safety requirements	5	1	3
Stakeholder requirements	1	3	5
Percentage score without weighting	**70%**	**50%**	**72%**

Intended for

Environmental Services Company Ltd.

Date

September 2021

BEIT HAKEREM
REMEDIATION OPTIONS APPRAISAL: CHAPTER 5

Issue No.	**01**
Date:	**03 October 2021**
Made by:	**Matan Cymbalista, Allison Busgang, Ori Zvikelsky (LDD)**
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Revision	Date	Made by	Reviewed by	Approved by	Description
01	03/02/2022				First Issue

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APPENDICES

1. INTRODUCTION

Ramboll UK Ltd (Ramboll) is acting as a subconsultant (International Consultant) to LDD (Local Consultant) in its delivery of remediation advice relating to the Environmental Services Company (ESC, the ultimate Client) regarding the IMI Beit Hakerem project.

Ramboll is acting as the International Consultant, and LDD as the Local Consultant. Ramboll (formerly Environ) and LDD have worked closely together on numerous ground contamination projects in Israel and have a proven track record of joint successful delivery of complex technical solutions. A Memorandum of Understanding exists between the two companies, dated 19th July 2018.

In this report, where joint LDD and Ramboll assessments and recommendations are being described, this will be presented as 'LDD-Ramboll'.

The IMI Beit Hakerem site is a 40 dunam (4 hectare) area adjacent to the Beit Hakerem neighbourhood in Jerusalem. The site was formerly occupied by Israel Military Industries (IMI) between 1951 and 1997 and was used as a factory for the manufacture of metal products. The former manufacturing activities at the site utilised organic solvents, which has led to ground contamination. It is understood that the site was closed and decommissioned in the late 1990s and is now intended for unrestricted redevelopment. Numerous environmental surveys have been undertaken at the site, including of soil, soil gas, and groundwater. The soil profile has been described as being mostly karst bedrock (overlain by overburden soils up to 6m deep); the groundwater is greater than 100m deep. The main contaminants at the site include chlorinated organic compounds, TCE and PCE.

Objectives and Scope

The objectives of this project are to provide remediation advice to ESC regarding the IMI Beit Hakerem site. Specifically, the scope of works is defined as follows:

- **Chapter 1 - Review of the Conceptual Site Model (CSM) for Beit Hakerem and provision of case studies for three similar projects** from around the world, presenting the type and concentration of contaminant, treatment, remediation targets attained, timelines, and project budget.
- **Chapter 2 - Consideration of remediation options** to treat the bedrock contamination, to include the advantages and disadvantages of each option in terms of execution costs, timeframes, effectivity, reliability, feasibility, etc. The assessment also includes environmental, regulatory, and statutory considerations.
- **Chapter 3 - The examination of construction options** at the site with an emphasis on basements and combining treatment systems with the buildings at the site.
- **Chapter 4 - Recommendation of the preferred remediation strategy** and outline for moving forward.
- **Chapter 5 - Preparation of a Work Plan** to execute the recommended remediation strategy including detailed plan for a pilot, examination of whether additional surveys are required within the site or outside of the site, timeframes, and approximate cost ranges.

This document forms **'Chapter 5'** of the project and sets out the work plan for the recommended remedial approach, based on our understanding of the Conceptual Site Model and the objectives of the proposed remediation.

2. REMEDIATION OBJECTIVES

The remedial objectives and associated criteria as set out below are based on the premise that all of the assumptions set out in Sections 5 and 6 of Chapter 1 of the report are applicable.

It should be noted that this report does not discuss the remediation of the overburden (which must be considered by the Client as part of the complete strategy for remediation). It does not discuss clean cover systems, which are likely to be required in landscaped areas to mitigate 'direct contact' pathways.

There are two key objectives for the remediation of the Beit-Hakerem site:

Objective 1: Reduction in Chlorinated Hydrocarbons within the Karstic Bedrock

Objective 1 is to reduce chlorinated hydrocarbons at the site, as measured in soil gas within the karstic bedrock and above the water table, to concentrations that are acceptable for the proposed redevelopment, assuming 'unrestricted' use (i.e., commercial, industrial, residential or landscaped), through fulfilment of the following criteria:

- The achievement of soil gas concentrations within the on-site treatment zone no greater than three orders of magnitude higher than the respective IRBCA 'Tier 1' RBTLs[1] (risk based target levels) for the contaminants of concern based on values prescribed for a residential and recreational use (see table 1 below) on the assumption that these are protective of future site residents subject to the installation of appropriate vapour mitigation system(s) (e.g. vapour barriers, and potentially sub-slab depressurization systems) in new buildings to be constructed on the site.
- The treatment of land within the site boundary based on an assumed area of 3,700m^2 (representing the footprint area of the LDD-defined 'hotspots', multiplied by 2.5) and considering that the treatment depth (i.e Target Depth) within the unsaturated bedrock extends to approximately 40 m below ground level[2].

Objective 2: Mitigate Risks to Off-Site Residents from Onsite Contamination

Objective 2 is to mitigate unacceptable risks to off-site residents (or other human receptors) arising from current / future chlorinated hydrocarbons within the site boundary, within the vadose zone, through fulfilment of the following criterion:

- The achievement of soil gas concentrations at applicable parts of the site boundary, no greater than the respective IRBCA 'Tier 1' RBTLs (risk-based target levels) for the contaminants of concern based on values prescribed for a residential use (see table 1 below).
- The applicable parts of the site boundary where treatment is required (for the purpose of this ROA, we have assumed that mitigation would be required around the entire site boundary (i.e. an assumed length of 931m). Future surveys and sampling may demonstrate that treatment is not necessary along the entire length of the site boundary, however this is not currently known.

[1] The IRBCA Tier 1 Residential RBTLs are Israel's most stringent threshold values for soil gas that are suitable for the most sensitive suitable land uses such as residential and recreational use.
[2] The 40m assumed treatment depth was chosen to build the cost estimates for this remediation options appraisal. The pilot trial and further investigation that will be planned as part of 'Chapter 5' will delineate and better define the locations and depths where treatment is required.

Remediation Target Levels

The relevant IRBCA Tier 1 RBTLs (and the amended three orders of magnitude target that is applicable to this site for the on-site areas) are presented in Table 1 below. These are consistent with the values presented in the Chapter 1 report; they are provided again in Table 1 of this report for ease of reference.

Table 2 – Soil Gas Tier 1 RBTLs

Contaminant of Concern	Max. Concentration detected by LDD zonal sampling (μg/m3)	IRBCA Tier 1 RBTL for Residential Use (μg/m3)	3 orders of magnitude IRBCA Tier 1 RBTL for Residential Use* (μg/m3)
1,1,2-trichloroethane	708.76 (38m)	23.1	**10,000**
1,1-dichloroethane	4,472.41 (6m)	234	**100,000**
1,1-dichloroethene	58,326.07 (6m)	27,809	**10,000,000**
1,2-dichloroethane	7,199.16 (6m)	38	**10,000**
Benzene	250.47 (76m)	130	**100,000**
Chloroform	5,579.76 (6m)	16.3	**10,000**
Tetrachloroethylene (PCE)	1,247,763.50 (15m)	2,100	**1,000,000**
Trichloroethylene (TCE)	254,680.59 (15m)	200	**100,000**
Vinyl Chloride (VC)	54,743.24 (29m)	85.1	**10,000**

*Calculation based on the clarification from MoEP to LDD regarding exceptions in soil gas tests above 3 orders of magnitude dated 29/01/2020

The Requirement for Groundwater Treatment

As stated in Chapter 1, LDD-Ramboll considers it unlikely that contamination within the groundwater would be significantly contributing towards the soil vapour concentrations detected at more shallow depths on site. Risk assessment / contaminant modelling could be undertaken to assess whether contaminant concentrations in the Upper Aquifer are likely to be a significant source of the elevated soil gas concentrations, particularly at shallow depth. Such work is outside the scope of LDD-Ramboll's current remediation support, but could provide further confidence in the CSM, and support the basis of the technical assumptions underpinning the ROA and associated recommendations. This ROA therefore focuses on technologies to remediate contamination with the unsaturated part of the karstic bedrock (rather than remediation of the groundwater). It is therefore considered that focusing treatment efforts on the unsaturated bedrock rather than the groundwater is likely to be more efficient at reducing the contaminant concentrations in soil gas.

Consideration of Off-Site Sources of Contamination

There is a third remediation objective which is outside the scope of this assessment. The third objective is to 'mitigate any unacceptable risks to off-site residents (or other human receptors) arising from chlorinated hydrocarbons outside the current boundary site'.

The current scope of this work does not extend to contamination that is present outside the current site boundary (either from contamination sources that originate from outside the current site boundary, or contamination which may have originated from the subject site but has previously migrated offsite.). Specifically, the current work scope does not include assessment of existing residential areas which have previously been developed on other parts of the former IMI Beit Hakerem site (i.e., outside of the current site boundary).

3. REFERENCES

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21. **TASK Centre of Competence for Soil, Groundwater and Site Revitalisation:** Guidelines In situ thermal treatment (ISTT) for source zone remediation of soil and groundwater. 5.2013.

4. PROPOSED REMEDIATION TECHNIQUES

LDD Advanced Technologies (LDD) and Ramboll (subconsultant to LDD) have been contracted by the Environmental Services Company (ESC) to plan the pilot study for the potential remediation by soil vapor extraction (SVE) and in-situ thermal remediation (ISTR). These two remediation techniques were recommended for the soil remediation of the potential source areas tentatively identified at the IMI Beit Hakerem compound following the remediation options appraisal (chapters 2, 3, & 4) conducted by Ramboll and LDD.

As part of the remediation options appraisal, three methods of remediation focused on the potential source areas were proposed for site restoration. Each method was evaluated and compared based on criteria previously agreed upon with the client and a combination of ISTR and SVE were deemed to be the most viable remediation techniques for the site. This document provides a pilot scale implementation plan for ISTR & SVE at the site.

It should be emphasized that in light of the existing data gaps regarding the vertical and spatial distribution of underground pollution - the demarcation of the contaminated area (including the demarcation of pollution sources), the depth of remediation required, and the underground structure of the bedrock in the contamination source areas including the need to locate and characterize the fractures (karst) in the field, there are still many question marks regarding the pilot and how the future remediation will be carried out.

A plan for performing feasibility tests in the field (pilot) proposed below, is based on (a) the need to provide additional site characterization data (b) the need to provide data for the full-scale remediation system design.

The pilot plan includes the construction of underground infrastructure for the pilot testing in a limited number of sites, selected in accordance with the findings of the previous environmental investigations carried out at the site. As part of the work to establish the underground infrastructure, operations will be carried out with the purpose of collecting information to address existing information gaps. This data will be used to update the pilot program.

The proposed plan includes conducting a field test (pilot) to examine a proposed remediation method - SVE (Soil Vapor Extraction) which will be tested in three different areas (in each area a single pilot will be performed). In addition, a pilot is offered for a thermal method - ISTR (In-Situ Thermal Remediation) that will be performed at a single source area.

The remediation methods, the pilot areas, the scope of the pilot, the required infrastructure and the structure of the wells for the pilot phase are detailed in this plan.

The program addresses target pollutants from the chlorinated volatile organic compounds family, TCE and PCE in particular and their derivatives.

As part of the plan, it is proposed that during the drilling in the pilot phase, core drilling will be carried out in the potential contamination source areas (pilot areas) and in other suspected source areas where remediation is planned (in which the pilot is not carried out), in order to allow accurate planning of the treatment depth, the distance and spacing between SVE & monitoring wells for the full-scale remediation.

Base data for remediation and the pilot plan

- The assumed remediation depth is 40 m below ground level
- The target contaminants are CVOCs – TCE & PCE and their derivatives.

5. PROPOSED PILOT LOCATIONS

Three (3) areas are proposed for the pilot, based on the findings of the recent remediation excavations at the site, and the recommendations given in the summary survey findings report - passive soil gas, active soil gas, and metals (Reference 15).

The proposed locations for the pilot are marked on passive soil gas survey findings report, 2014 (Figure 1) and on a map of contaminated areas requiring excavation (Figure 2). The proposed pilot areas are marked as A, B, C.

Figure 1 – proposed SVE pilot locations on the map of passive soil gas survey findings

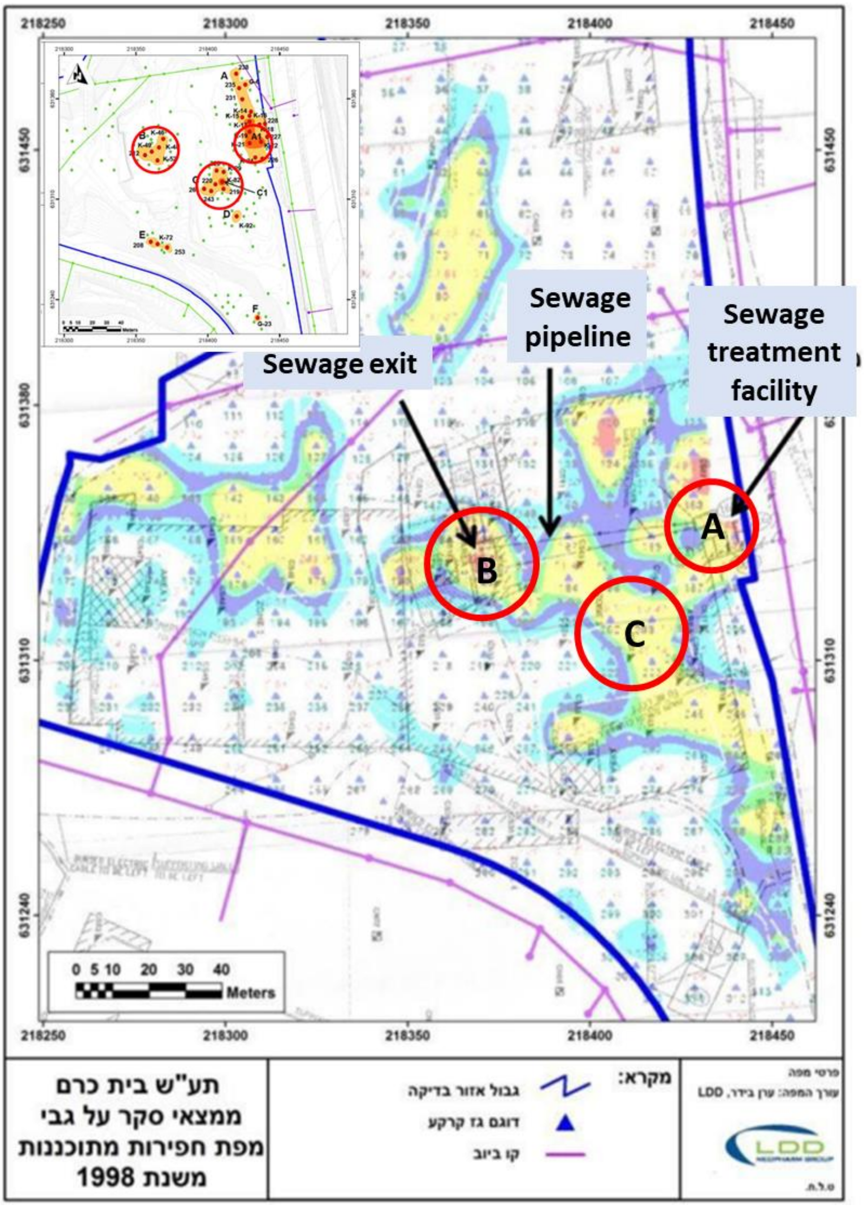
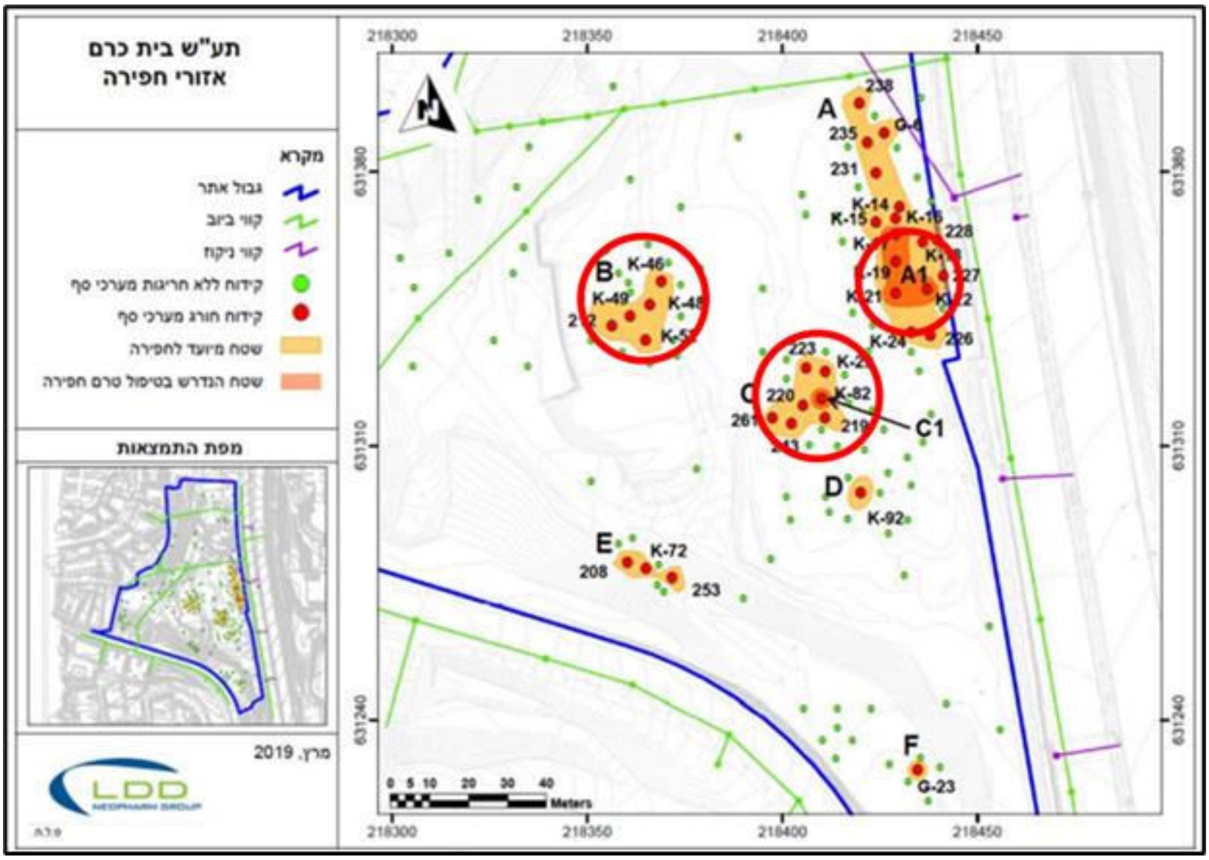


Figure 2 – proposed SVE pilot locations on the map of areas marked for excavation



6. PROPOSED FEASIBILITY TESTS (PILOTS)

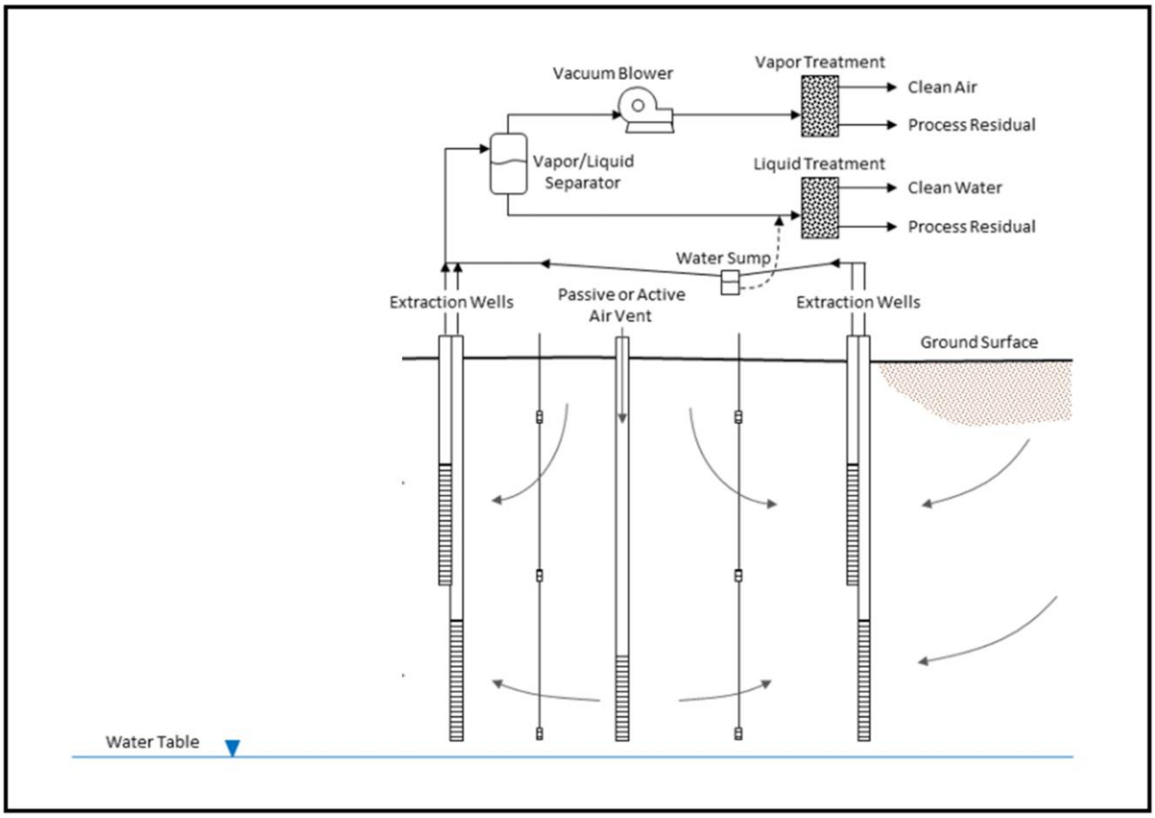
6.1 Remediation via soil vapour extraction (SVE)

6.1.1. background

SVE is a common soil remediation technique for treating volatile organic compounds. The technique is recommended for soils with relatively higher permeabilities and contaminants with a partial pressure greater than 0.5 mm Hg, which constitutes the majority of the contaminants encountered at the site.

The principle of operation of the system is the activation of vacuum (sub-pressure) in vapor extraction wells installed in the unsaturated medium and the transfer of the extracted air to an above-grade treatment system. A schematic description of a typical SVE system is shown in Figure 3. The proposed configuration for an SVE-based remediation system will have the effect of removing volatile contaminants from the unsaturated zone in the soil cross-section and creating an underground capture zone that will reduce soil gas migration out of the contamination source areas.

Figure 3 – schematic description of a typical SVE system



source: USEPA (reference 20)

6.1.2. Pilot goals

The purpose of the field test is to determine the feasibility and suitability of the proposed remediation method for the site, as well as to gather planning information for the full-scale remediation system, including:

- Completion of geological information at the pilot execution points
- Examination of the feasibility of the proposed remediation method
- Examination of the suitability of the proposed method for application on the site
- Collection of planning information for the complete remediation system

Data that will be collected during the test

- The structure and composition of the lithological unit
- Characterization of the karst (fracture) system
- Concentrations of VOCs (field measurements using PID) at various locations and depths
- Contaminant load – laboratory analysis to determine the specific compounds and concentrations of pollutants in the extracted air using SUMMA canisters. The method of treatment of the extracted air for a full-scale remediation system will be evaluated based on these data.
- Changes in air pressure monitoring wells as a function of distance from the extraction well and rate of extraction
- Conductivity of the soil to the air

An additional goal of the pilot is to demonstrate the ability of the treatment unit to handle pumped gases in accordance with regulatory requirements

Calculated parameters from the results of the test:

- Radius of influence:
  - The distances of the extraction effect on the monitoring wells (horizontal and vertical dimension)
  - The horizontal distance between the extraction well in which a pressure differential of less than 2% of the extraction well is measured (defined as the end of the radius of influence)
- Contaminant load
- Energy load
- Contaminant treatment requirements

Data for the planning of the full-scale system (based on the pilot findings):

- The distances between the extraction wells in the complete remediation system, to be determinates based on the calculated ROI, conductivity of the soil to the air
- Extraction and monitoring wells depths and screened intervals

6.1.3. Pilot plan

<u>Example of proposed pilot array</u>

Detailed planning will be carried out according to the bidder's specifications and the systems in his possession that will be used, as long as the pilot objectives are met.

It is proposed that the SVE pilot tests be conducted in three areas (focal points). The wells will be installed in clusters of 4 wells each. The wells will be installed to different depths according to core sampling results to determine the most effective remediation depth..

- Number of extraction wells in each area (PVC) – 4
- Number of vacuum monitoring wells in each area (PVC) – 12
- The pipeline deployment plan will be determined in accordance with the findings of previous investigations.
- The depth of the screened interval in each well will be determined in accordance with the findings of the core drilling that will be carried out during the installation of the wells.
- Pilot phase treatment system: activated carbon. The amount of activated carbon for the pilot phase will be determined according to the expected pollutant load at the pilot locations selected and the duration of the planned pilot.
- Duration of the pilot after completion of the installation of the infrastructure for the pilot: 3-5 working days per area
- Soil gas monitoring will be performed using a field device (PID) after the wells are installed and after the pilot is completed

6.1.3.1. Core drilling

At each pilot location, at least one 4" core will be drilled (Wireline Core-barrel) to the target depth (40 meters) to obtain a continuous and unbroken section of the bedrock from the surface and up to the target depth. According to the findings, the depths of the screens will be determined in the vapor extraction and monitoring wells (SVE).

6.1.3.2. Vapor extraction and monitoring wells

For the pilot test, three sets of extraction wells to different depths will be installed. All wells will be 2" in diameter, and have a screened section ~3 m long at the bottom. The wells will be installed in a drill with a diameter of at least 4". The hole will be filled with quartz or "sesame" gravel to a depth of about one meter above the top of the screen. Above the screen, granular bentonite will be applied and above that, sealing will be performed using grout to the surface. The final depth of each extraction well and of the screened section will be determined according to the drill findings prior to installation. In each cluster, 4 wells will be installed in the maximum possible proximity or in a single drill ("cluster"). Schematic structure of the deployment of SVE extraction and monitoring wells in one area is shown in Figure 4.

The well piping is made of PVC with a screen with grooves 0.5 or 1 mm thick. Figure 5 shows a collection of pumping wells and monitoring wells on a lithological section.

All wells can be used for pumping contaminants and monitoring pressure. The wells will be protected by standard prefabricated concrete trenches with a lid that will be used to protect against damage to the wells, and so that they can be used in the future as part of the infrastructure of the full-scale remediation system. At the top of each well, a tap will be installed that allows control of the amount of air drawn from each well.

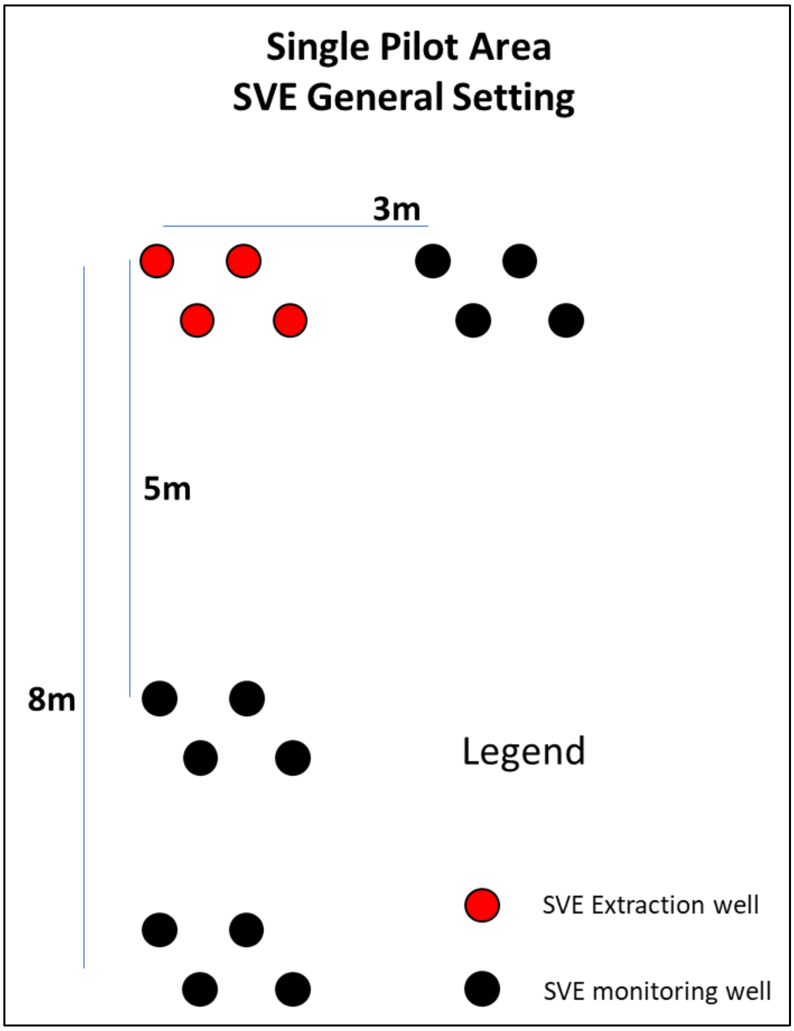
A total of 4 vapor extraction wells and 12 vacuum monitoring wells will be installed in each of the pilot areas examined.

6.1.4. Vapor extraction system during the test

The vapor extraction system will consist of a faucet fan that controls the extraction regime from the various wells and a blower suitable for a flow rate of about 500 m^3/h against a counter pressure of 200 millibars and suitable for work in areas where flammable gases are present.

The various flow rates will be determined using a frequency converter or using a dilution tap from the atmosphere.

Figure 4 – schematic deployment of the SVE pilot wells



Note: Each cluster includes 4 wells to be installed in the maximum possible proximity or in a single drill (cluster)

6.1.5. Extracted air treatment unit

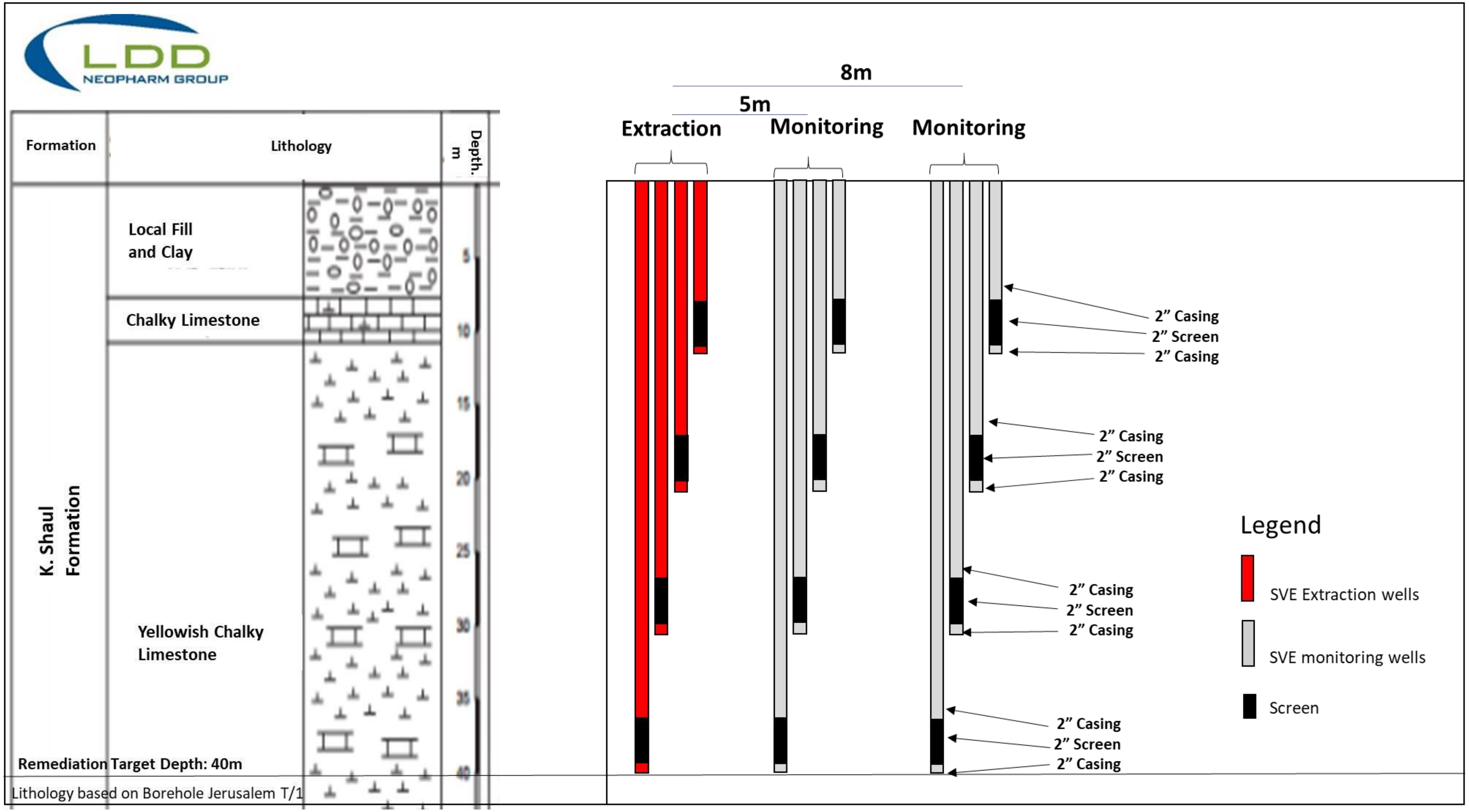
Performing soil gas extraction typically requires treatment of the extracted air. It is proposed that in order to avoid a health and safety hazard during the pilot test, the extracted air will be treated using activated carbon filters.

The amount of activated carbon will be determined according to the expected pollutant load, blower flow and extraction test duration.

An explosive meter and a portable PID device will be used to verify that the carbon filter(s) has not been breached. In addition, carbon vessel influent/effluent sampling for specific compounds via SUMMA Canister sampling or other methods, to evaluate the specific compounds and concentrations in the extracted air at each pilot location.

Break-through of the carbon will be considered according to regulatory requirements. It should be emphasized that prior to the pilot, emission values and sampling guidelines for the relevant air quality thresholds must be obtained.

Figure 5 – Principal cross-section design of the SVE and vapor monitoring wells



6.1.6. Duration of the pilot

An extraction test will be performed on site in stages for the evaluation of the planning parameters. This test involves performing air extraction at several intensities and examining the effect of the varying extraction on the negative pressure in the soil and the extracted air concentrations. At each stage, it will be necessary to wait until the negative pressure in the soil stabilizes. The negative pressure in the soil usually stabilizes within a few minutes (in dry sandy soil) and within up to about an hour (in moist clay).

Extraction will be performed from each extraction well separately, with extraction capacities of 100%, 75%, 50%, and 25% of the maximum flow (as far as the blower and soil conditions allow). The extraction capacity will be determined by means of a frequency converter and/or by a tap that injects air from the atmosphere into the blower or by means of a tap that diverts some of the air from the outlet to the inlet to the blower.

6.1.7. Test measurements

At each stage of extraction, measurements will be made for:

- Contaminant concentrations – to estimate the change in contaminant concentration under various flow rates. Measurement will be made with a portable PID
- Negative pressure – will be measured in the active extraction well, in the adjacent extraction well(s), and in the vacuum monitoring wells installed to the same depth as the active extraction well. Negative pressure will be measured by electronic pressure gauge capable of storing data or with an appropriate vacuum pressure gauge installed at the top of each head.
- Blower flow rate – the blower flow rate will be measured using a pilot tube flow meter
- Efficiency of the treatment system – during the test, the concentrations of the emitted gases from the carbon filters using PID and explosive meter and SUMMA Canister sampling or other methods, to evaluate the specific compounds and concentrations in the extracted air at each pilot location to verify that the treatment system has not been breached
- Energy load and contaminant treatment

6.1.8. Soil gas sampling

Air sampling will be performed from each of the extraction wells in each area at the end of the extraction testing (a total of 4 samples/area). The samples will be taken using a canister that will be transferred to a laboratory certified to the ISO17025 standard for analysis of VOCs by the Laboratory Accreditation Authority or an equivalent abroad. The vapor treatment unit will be monitored according to the MoEP guidelines and regulations.

6.1.9. reporting

The results report will include:

- pilot execution details
- results of the pilot
- discussion of the results
- estimation of flow rates and working pressures for the full-scale remediation phase
- recommendation regarding the deployment of the full-scale treatment system and depths of treatment

- estimation of full scale energy consumption and contaminant treatment materials

6.2. ISTR (In-Situ Thermal Remediation)

6.2.1. Background

The principle of operation of this method is based on heating a porous medium (Heating Elements / Electrodes - Heater Wells) to approximately the boiling temperature of water using heating elements that will be installed inside sealed boreholes. This heating results in significant thermodynamic changes that will increase the volatilization of the pollutants. Extraction of the pollutants will be done through an array of extraction wells and transmission lines that will allow the air to flow to above-grade treatment equipment.

The guiding principle is that the vapor pressure of volatile organic compounds (VOCs, including chlorinated hydrocarbons such as TCE and PCE) increases with temperature and in particular the vapor pressure of VOC non-aqueous phase liquid (NAPL) increases considerably with temperature.

Because the subsurface soils in the treatment zone are heated from ambient temperature to temperatures in the range of 100 °C, the vapor pressure of NAPL components will usually increase significantly (Tables 2-3). In addition to increasing the evaporation of pollutants from the unsaturated zone, thermal decomposition of organic compounds may also occur in place (in-situ).

Another advantage of this method is its suitability for a wide range of rock types and mediums - in sedimentary and metamorphic rocks, in large and small grain fractions, in a medium containing large and small grain intermediate layers and in fractured rock.

Table 3 – boiling points of common organic compounds (Task, 2013)

Table 1: Boiling temperatures and co-boiling temperatures of selected contaminants at normal pressure [derived from REID ET AL. 1987], **NAPL-pressure-coefficients** [HIESTER 2009]

Contaminant	Boiling temperature of the contaminant	Co-boiling temperature with water (azeotrop)	NAPL-pressure-coefficient
	[°C]	[°C]	[-]
1,2-cis-dichloroethene	60	55	6,0–10,0
trichloroethene	87	73	2,8–3,9
benzene	80	69	3,4
toluene	111	84	1,8
tetrachloroethene	121	88	1,6–1,8
(m-) xylene	139	93	1,3
mesitylene, trimethylbenzene	165	97	1,1
dichlorobenzene	180	98	1,08
naphthalene	218	99	1,0

Table 4 – physical characteristics of common volatile organic compounds (Task, 2013)

Substance	Boiling point	Vapour pressure 20°C | 50°C | 80°C	Water solubility (at 20°C)	Density at 0°C, 1013 mbar
	[°C]	[mbar]	[mg/l]	[kg/m³]
vinyl chloride	−13.4	*>1,013* | *>1,013* | *>1,013*	1,100	2.86
dichloromethane	40	470 | *>1,013* | *>1,013*	20,000	1,330
1,2-cis-dichloroethene	60	216 | 704 | *>.1013*	600–800	1,280
trichloroethene	87	78 | 284 | 812	1,000	1,460
tetrachloroethene	121	19 | 82 | 748	160	1,620

The most significant effects of heating are:

- increasing the vapour pressure of the non-aqueous phase
- increasing the temperature from ~20°C to ~100°C increases the Henry's constant by ~one order of magnitude in PCE/TCE contaminated soils
- adsorption is generally an exothermic process, during which the adsorption rate decreases during the heating which leads to an increased rate of evaporation of organic compounds from the soil
- for most VOCs, there is an inverse relationship between temperature and viscosity. Thus, increase in temperature brings a decrease in viscosity
- the diffusion coefficients in both liquids and air are proportional to and increase with temperature

6.2.2. Pilot goals

The purpose of the pilot is to achieve and maintain a target temperature in a given area. a secondary goal is to examine the environmental impacts of the method and to show that there is no excess movement of gases offsite as a result of the treatment method and that the treatment of the collected gases is according to regulatory standards.

The secondary goals are:

- Collection of planning information for the full-scale remediation system
- Examination of the feasibility of the proposed remediation method
- Examination of the suitability of the proposed method for application on the site
- Completion of geological information at the pilot execution points
- Calculation of energy requirement and contaminant treatment requirements

The parameters to be collected during the test:

- Rate of temperature changes in the temperature sensors throughout the pilot that will be installed to monitor the subsurface temperature depending on the time and distance from the heating point.
- Energy consumption

- The structure and composition of the lithological cross-section
- Volatile organic matter concentration profile (field measurement using PID)
- Pollutant load - laboratory analysis to determine the content and amount of pollutants in the air in the extraction well at the beginning, throughout, and end of the pilot

The parameters calculated from the results of the test

- Temperature changes throughout the cross-section and at a given distance from the heating point
- Radius of influence
- The effect of temperature changes on the variety and concentration of pollutants in the monitoring wells (horizontal and vertical dimension)
- Energy load
- Contaminant treatment materials consumption

Data for design of the full-scale remediation (based on the pilot findings):

- Deployment of the heating points on a full scale basis – will be determined in accordance with the calculated radius of influence and the plan for evaluating the potential remediation
- Deployment of the full scale network of monitoring wells
- Depths of the heating points and depth of the vapor extraction wells/screens

6.2.3. Pilot design

Example of a proposed pilot plan

- In the selected pilot area, an array of 6 heating wells (in a hexagonal structure) will be installed around the array of vapor extraction wells.
- In the center, 5 vapor extraction wells will be placed to different depths, from which soil gases will be extracted and discharged into a treatment system using activated carbon. The extraction wells will be installed in the maximum possible proximity or in a single drill (cluster). The amount of activated carbon for the pilot test will be determined according to the expected pollutant load at the location selected and the duration of the planned pilot.
- In addition, 2 temperature monitoring points will be installed to monitor the temperature of the unsaturated medium using fixed temperature gauges.
- All heating wells will be installed to a depth of 40 m.
- The vapor extraction wells will be installed with a screened section at different depths depending on the fracture distribution of the subterranean cross-section.

- Duration of the pilot after completion of the installation of the infrastructure for the pilot: until the desired target temperature is reached.
- Soil gas monitoring will be performed using a field device (PID) and active soil gas monitoring (TO-15) after the wells are installed, throughout the pilot stage, and after the pilot is finished.

Core drilling

At each site, at least one 4" (Wireline Core-barrel) core will be drilled to the target depth (40 meters) to obtain a continuous and unbroken section of the bedrock from the surface and up to the target depth. According to the findings, the depths of the screens will be determined in the vapor extraction and monitoring wells (SVE).

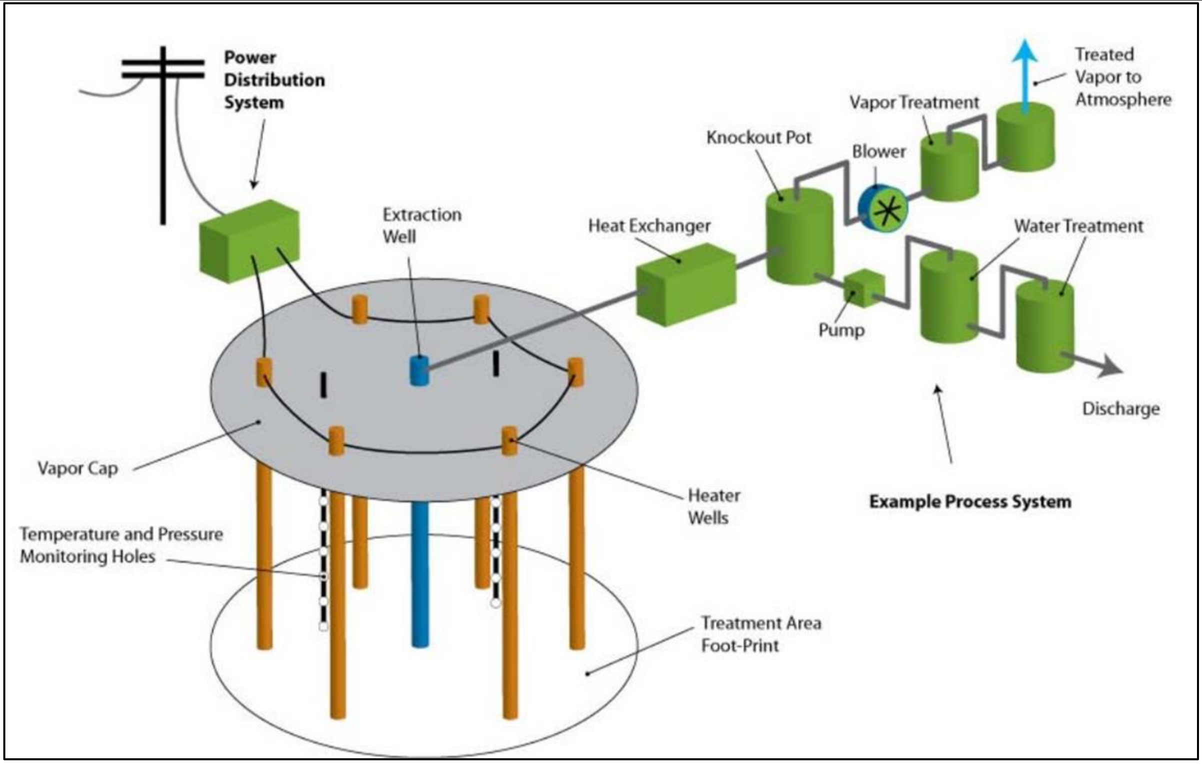
Heating/extraction/monitoring wells

It is proposed that in the pilot testing, an array will be installed that will include heating wells (to be carried out using gas/electricity), points for temperature monitoring and vapor extraction wells (SVE). The proposed configuration for the well array is shown in Figures 6-8. As stated, it is proposed to install an array of heating wells in a hexagonal structure around the array of extraction wells and two wells for monitoring temperature. The heating wells will be installed in assumed radius of 2-3 m from the extraction wells.

The schematic structure of the ISTR array is shown in Figure 6. The array includes a single extraction well located in the center of the area, surrounded by heating wells in a hexagonal structure and two wells for temperature monitoring. A schematic diagram (plan view) of the proposed arrangement of the ISTR pilot wells is shown in Figure 7. A schematic diagram of the ISTR pilot wells along a lithological section is shown in Figure 8.

The location, spread and distances between the wells during the full remediation phase will be determined in accordance with the findings of the pilot. In the pilot phase, the rock temperature will be measured in the wells that will be drilled for this purpose. During the full-scale remediation, the air underground will be extracted from vapor extraction wells using an above-grade blower. The blower will convey the extracted air to vapor treatment equipment (e.g., activated carbon, thermal oxidizer).

Figure 6 – schematic layout of a typical ISTR system (USEPA) for full-scale remediation



Note: The conceptual figure shows typical components for a full-scale ISTR remediation. The proposed ISTR pilot will include only some of the components shown above. Further consultation with ISTR firms regarding the specific objectives of the pilot is necessary.

6.2.4. The pilot heating system test

The heating system will consist of a heating element that will be positioned in a way that will allow heating along the entire length of the element until the desired target temperature is reached in the subsurface, as measured at the temperature monitoring points. Possible heating methods are using natural gas or electric heaters.

6.2.5. Duration of the pilot test

The test will involve the following stages:

a. Continuous and simultaneous heating of the full depth interval along the unsaturated zone to the target depth.
b. Temperature and PID monitoring in the temperature monitoring points and the vapor extraction wells.
c. Continue heating until the target temperature is reached in the temperature monitoring wells. As long as a target temperature is not reached, heating will be performed until the maximum temperature that is obtained stabilizes.
d. Continue heating until reaching a stable temperature in the temperature monitoring gauge
e. Measurement of energy consumption over time until equilibrium is reached (stabilization of temperature at the temperature monitoring sensors)

6.2.6. Test measurements

Measurements will be performed for the following:

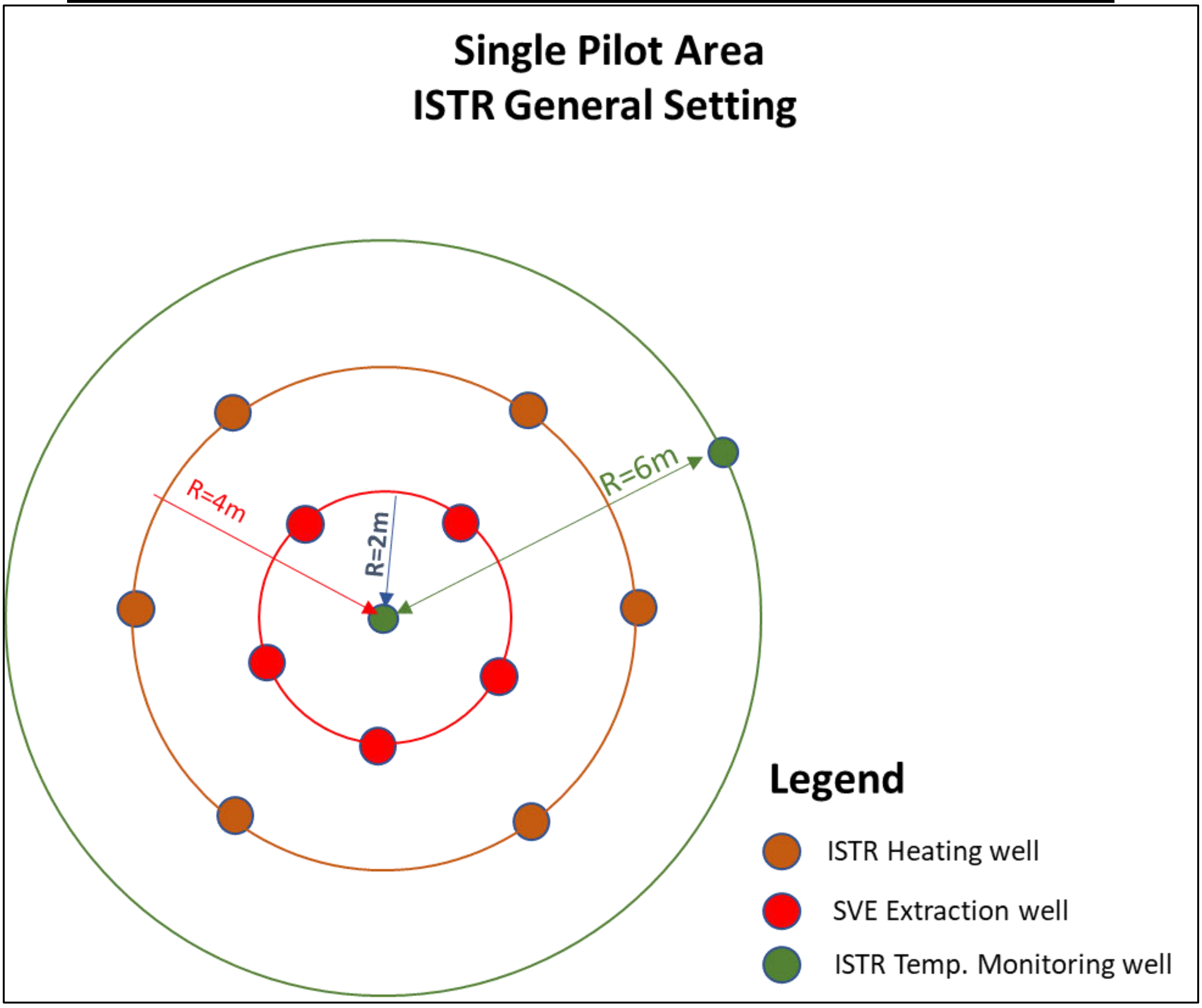
- Contaminant concentrations – to estimate the change in contaminant concentration during the test. It will be performed using a portable PID at the vapor extraction wells.
- Sampling with a canister for VOCs (TO-15). Will be conducted from the vapor extraction wells throughout the duration of the pilot.
- Temperature – will be measured with temperature sensors that will be installed at various depths in the temperature monitoring points.
- Energy load and contaminant treatment

6.2.7. Reporting

The results report will include:

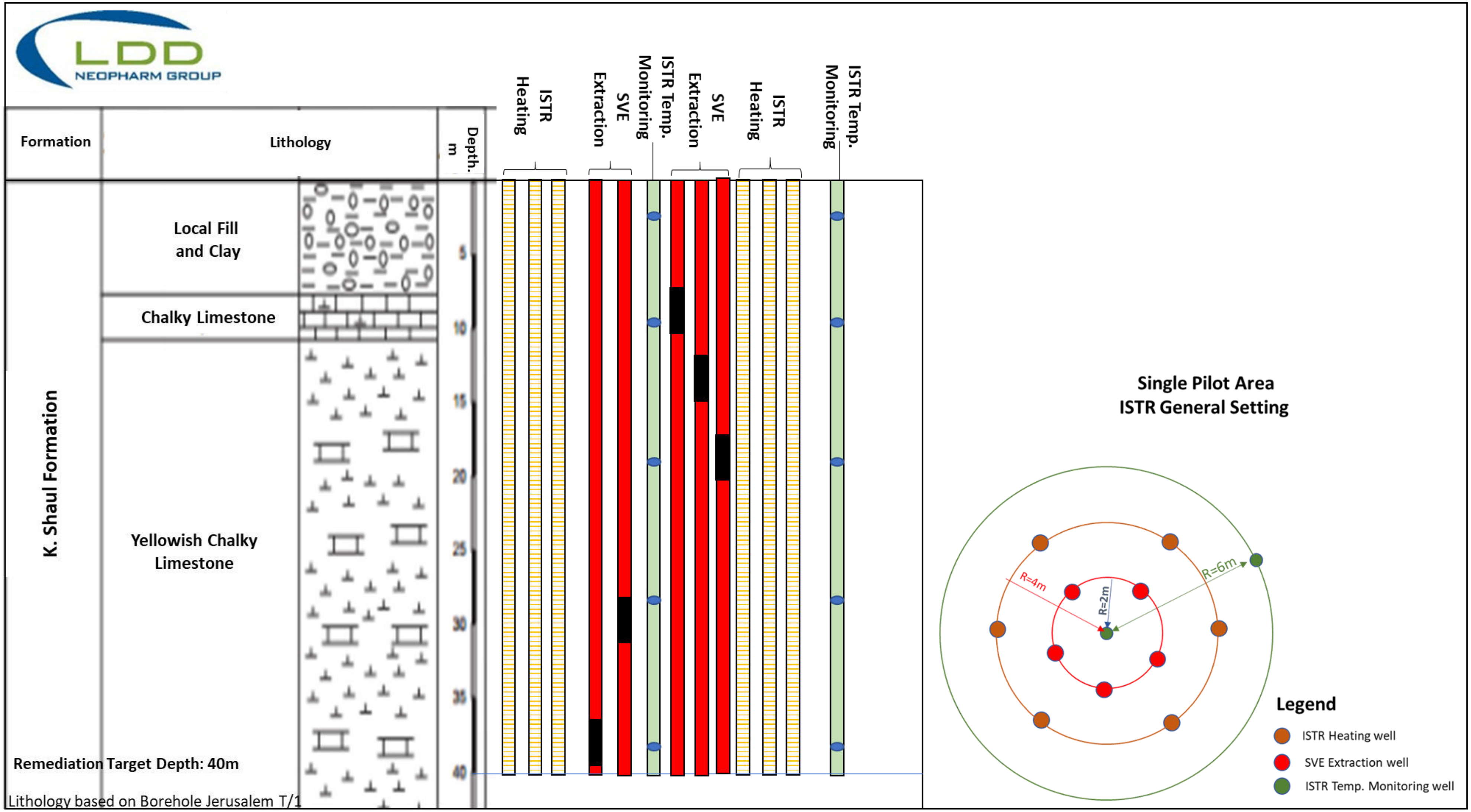
- Pilot execution details
- Results of the pilot
- Discussion of the results
- Recommendations regarding the type of full-scale treatment equipment
- Recommendations regarding the deployment of the full treatment system and treatment depth(s)
- Calculation of energy requirement and contaminant treatment requirements

Figure 7 – schematic diagram (plan view) of the array of wells for the ISTR pilot



Note: The pumping wells (in a red circle) will be installed in the maximum possible proximity or in a single drill (cluster).

Figure 8 – Schematic diagram (cross section view) for the heating, vapor extraction, and monitoring wells – ISTR pilot



7. FURTHER INVESTIGATION

In order to complete the information required for the full remediation design, it is proposed to plan additional investigation with the purpose of filling data gaps, such as:

- Geophysical investigation to identify and characterize the fracture and karst system in the bedrock.
- Cross-section lithology and composition – will be examined using core drilling during which the exact type of bedrock will be accurately examined as well as the presence of fine grained fractures that can serve as preferential pathways for contamination migration in the subsurface.
- Fractures – will be determined through core drilling to identify and characterize preferential pathways. The results will be used to update the vapor extraction and monitoring well design.
- Soil gas sampling and rock section characterization, including sampling if possible to characterize the soil gas concentrations and to assess whether source area(s) may be present at depth(s) greater than the maximum planned depth (40 m) of the pilot testing
- Deep soil gas sampling at the boundaries of the site, mainly in the residential neighborhoods.

Table 5– summary of the field tests (for one area)

Pilot type	Number of wells per area			measurements	Measured/calculated data for planning
	Vapor extraction	Monitoring	Heating		
SVE	4	12	0	Flow, pressure, VOCs (pid + TO-15)	Radius of influence, pressures, contaminant content and concentrations, SVE well structure for full scale remediation (number of wells, distances, well depths, screen interval depths)
ISTR	5	2	6	Temperature, Energy Consumption, VOCs (pid + TO-15)	Thermal radius of influence, pressures, temperature, temperature gradient (horizontal and vertical), energy consumption, contaminant content and concentration, SVE well structure for full scale remediation (number of wells, distances, well depths, screen interval depths)
Data completion – core drilling	At least 1			Observational sorting: quantity, size, crack density	Estimation of screen placement

Note: If a combination of the pilots is performed, all wells will be installed in metal (SS / CS) in locations where there will be an overlap of the SVE and thermal pilot.

- document end-

Appendix 1 – Ramboll/LDD meeting minutes

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MINUTES OF MEETING

Project name	**Beit Hakerem Remediation Support**
Project no.	**16200007286**
Subject	**Chapter 5: Work Plan for Pilot Trials - First Team Call with LDD**
Meeting date	**07/07/2021**
Called by	**Hannah Lewis (Ramboll)**
Taken by	**Hannah Lewis (Ramboll)**
Participants	**Jeff Levesque (Ramboll), Richard Bewley (Ramboll), Allison Busgang (LDD), Ori Zvikelsky (LDD)**
Absent	**Oren Rinat (LDD)**
Next meeting	**Follow up call scheduled for 27/07/2021**

1 Purpose of Meeting

- The meeting was held to discuss the Work Plan for remediation pilot trials of the chlorinated solvent impacted bedrock at the Beit Hakerem site for which Ramboll and LDD have been working together to provide remediation support to ESC. To recap, Ramboll led the preparation of Chapters 1-4 of the remediation support, which LDD reviewed and made input into.
- LDD is leading the final part of this project (Chapter 5: Work Plan for Remediation Pilot Trial) and is undertaking the preparation of the Work Plan report. Ramboll's input into the Work Plan process is therefore through discussions via conference call, with recommendations regarding the Pilot Trials being documented by issue of formal meeting minutes and review and input to the draft prepared by LDD.

2 Overview of LDD Proposals for Pilot Trial

- LDD are developing a Work Plan for a Remediation Pilot Trial based on Soil Vapour Extraction (SVE) technology, which is anticipated to be the primary remediation method. LDD wanted to discuss the potential benefits of undertaking a pilot trial for In-situ Thermal Remediation (ISTR), which may be used to target smaller hotspot areas.
- In addition to the remediation pilot trials, the Work Plan will also cover further investigation. Further investigation is required to understand: the extent of the area where remediation is required (extent and depth of source area) and to inform the detailed design of the remediation pilot trial.
- It was also noted by Ramboll that further investigation would be useful to better understand off-site soil vapour risks and the extent of mitigation required in this regard, although investigation relating to offsite migration was not discussed further during this call. LDD agreed that it would be useful to sample at the site boundary and offsite conditions but that this is

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outside the scope of work and only a recommendation for the client to undertake.

3 Further Investigation

- LDD-Ramboll's earlier reports for this project (Chapters 1-4) had discussed additional soil vapour sampling to delineate the extent of this contamination. However on further consideration, LDD does not believe this to be the best approach. This is because soil vapor can move (including preferentially, through fractures); high soil vapour concentrations of contaminants may therefore not be representative of where areas of greater contaminant mass are present in the soil matrix.
- LDD noted that ESC had arranged further soil vapour investigation at the site (by others), which focused on overburden soils following their emplacement as part of a large overburden remediation exercise. Elevated contaminant concentrations were detected in soil vapour within the overburden soils at higher concentrations than previously detected, despite the soil having recently been imported and not previously contaminated. Whilst LDD noted that there was some uncertainty about the accuracy of the data, Ramboll noted the high concentrations now detected in the overburden soils could potentially be reflective of more permeable material having been used compared to the original soils that had been removed.
- Ramboll was in general agreement with LDD that monitoring of soil vapour may not be the best way to delineate the extent of contamination and determine where to target remediation. This is because soil vapour data is indicative (as it can travel). Instead, collection of soil samples / rock cores was discussed (discussed further below).
- LDD noted that it was considering recommending the use of sonic drilling at the site which can provide high quality rock cores to provide an improved understanding of the bedrock geology.
- Ramboll made the general comment that it considered detailed site characterisation information (i.e. further site investigation data) to be important to this project. Although it is acknowledged that further investigation and site characterisation is costly, without this information, there is a real risk that expensive remediation could be targeted in the wrong place and not achieve what it is intended to. This, combined with pilot trials should then be used to determine the depth / extent of full scale remediation.
- Ramboll therefore recommended that the site characterisation include investigation (such as rock core/marl samples) in the wider site (i.e. outside of the pilot trial area) to determine the extent of the area requiring treatment. Additionally, Ramboll recommended that the investigation / characterisation include consideration of depths beyond the proposed 40m depth of the pilot trial.

3.1 Collection of Marl Samples / Rock Cores

- The general geology of the bedrock was discussed. LDD stated that the bedrock was predominantly limestone with the presence of fractures noted. It was noted that previous investigations of the bedrock had identified the presence of Marl within the Limestone, however the distribution of the Marl was unknown.
- Ramboll noted that solvents tend to sorb onto fine grained material, such as marl. Areas of Marl within the limestone could therefore represent zones of greater contaminant mass within the bedrock (including NAPL) where remediation could be targeted. Ramboll therefore recommended collection of samples of Marl for laboratory analysis if encountered in investigative boreholes; there may also be benefit in undertaking sampling of rock cores for comparative purposes.
- Ramboll noted that, if areas of Marl were encountered during investigations that contained high concentrations of chlorinated solvents, that information could be used to help determine where to target the use of localised heat based remediation (such as ISTR). Generally speaking, the technologies such as ISTR would be expected to be more effective at removing contaminant mass from fine grained material such as Marl, in comparison to SVE.

3.2 Geophysical Investigation

- The potential benefits of geophysical investigation was discussed, in terms of how it could be used to map-out fractures.
- Ramboll noted that, on a site such as this where there is expected to be a large amount of heterogeneity, geophysical investigation has the potential to be very useful, albeit there will always be some limitations.
- Ramboll noted that at sites that it had worked on in the US, the geophysics team had been able to map dips / planes / bedding angles and, in turn, had been able to predict where pockets of NAPL had been located.
- Whilst it was strongly noted that there will not always be this level of success, geophysical investigation was considered likely to be a worthwhile exercise.
- Ramboll noted that there was not a geophysics specialist on the call, but that there are in-house specialists within Ramboll if there are specific questions. The following general information was provided:
  - ◊ There are different tools and techniques that can be used in geophysics testing, which can give a different type of resolution.
  - ◊ It was noted that acoustic televiewer was a method that had been used successfully in the US to identify the location of fractures and provide information about the depth, dip and angle of those fractures.
- For geophysical surveys in the US, Ramboll noted that it would typically instruct a specialist subcontractor to provide these services. It was discussed whether such specialist contractors would be available in Israel. LDD stated that its intent would be to consider contacting the Israel Geophysical Institute for support with this recommended element of the work.

4 Remediation Pilot Trials

- LDD stated that the planned depth of pilot trial is 40m (i.e. consistent with the assumed treatment depth considered in the remediation options appraisal (ROA). *As minuted above, Ramboll noted during the call that it will be important to undertake site characterisation to ensure that this assumed (and arbitrary) treatment depth is appropriate.*
- LDD is currently considering three parts of the site to undertake a pilot trial. *LDD would aim to share a plan of these areas during or in advance of the next Work Plan call.*

4.1 SVE Pilot Trial

- As a minimum, LDD plan there to be a SVE pilot trial.
- LDD propose to install nested wells (looking at 4-5 different screened depths within the well, each with approximately a 3-5m screen). Ramboll agrees that the use of nested wells is more appropriate given the depth of treatment and the potential for fractures to be present.
- LDD’s approach would be to target the main fissures / cracks, rather than focusing on targeting specific depth. A preliminary survey would be undertaken (as discussed previously) with the aim of identifying the cracks.
- Ramboll recommended that LDD be generous with vacuum monitoring points – i.e. that these be spaced outwards radially in more than one direction. This was considered important due to the heterogenic nature of the bedrock. LDD confirmed this was its preferred approach.

4.2 ISTR Pilot Trial

- The potential benefits of conducting an ISTR pilot trial were discussed.
- Ramboll explained that, in the US, thermal vendors do not typically undertake pilot studies, largely due to the high cost of the pilot. Albeit, it was noted that that there are exceptions to this (e.g. Ramboll is currently scoping pilot studies for a planned steam-enhanced extraction (SEE) remedial action for a site in the US, which is being undertaken due to the complex geology at that site).
- Ramboll noted that if, for cost reasons, a full ISTR or thermal pilot trial was not required there may be some partial data that could be collected, for example via a steam communication test (rather than a full pilot trial): the focus of this is to evaluate how well you can inject steam into the formation. This would be a less expensive pilot option (in a case where steam injection may be considered).
- LDD stated the main purpose of an ISTR pilot trial would be about understanding the zone of influence, and ensuring the required temperatures are achieved.
- Ramboll noted that, within the US, suppliers of thermal systems tend to have a good feel of how far the heat will spread (i.e. a pilot may not be needed in order to determine treatment well spacing).
- Ramboll noted that a more comprehensive pilot would be needed if the main objective is to determine the level of clean-up that can be achieved (i.e. how low a concentration can be achieved).
- Ramboll's overall view was that a successful mapping of solvent source areas would be of greater overall value to designing a thermal based approach than a full ISTR pilot trial

4.3 Depth of Pilot Trial

- LDD stated that the intended maximum depth of the SVE pilot trials would be 40m (i.e. in line with the assumed depth used in the LDD-Ramboll Remediation Options Appraisal (ROA)). It was acknowledged by both LDD and Ramboll that the 40m assumed depth was an arbitrary number that was selected to enable comparison of remediation methods. i.e. 40m may not represent the ideal treatment depth.
- As noted previously, additional investigation / site characterisation is recommended by Ramboll-LDD to determine the zone (depth and area requiring remediation).
- Additionally, Ramboll made the following suggestions about how the SVE pilot trial (with nested wells at various depths) could be used to collect information to inform the vertical extent of future remediation, as summarised below:
    - ◊ Collection of passive vapour samples from each of the nested wells prior to start-up of the SVE system;
    - ◊ Plan for there to be down-time in-between / following the soil vapour extraction, to enable further passive vapour sampling.
    - ◊ Comparison of the before/after passive sampling data in each nested well could be used to assess whether soil vapour concentrations quickly recover. This type of data could help inform where (i.e. at which depths) there are more predominant lenses of source material / pockets of contaminant mass.
    - ◊ Similarly, photo-ionization detector (PID) measurements could be taken during extraction, to measure the reduction in concentrations in each of the nested extraction wells.

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MINUTES OF MEETING

Project name	**Beit Hakerem Remediation Support**
Project no.	**16200007286**
Subject	**Chapter 5: Work Plan for Pilot Trials - Second Team Call with LDD**
Meeting date	**29/07/2021**
Called by	**Hannah Lewis (Ramboll)**
Taken by	**Hannah Lewis (Ramboll)**
Participants	**Jeff Levesque (Ramboll), Allison Busgang (LDD), Matan Cymbalista (LDD), Ori Zvikelsky (LDD),**
Absent	**Richard Bewley (Ramboll), Oren Rinat (LDD),**
Next meeting	**N/A**

1 Purpose of Meeting

- The meeting was held to discuss the Work Plan for remediation pilot trials of the chlorinated solvent impacted bedrock at the Beit Hakerem site for which Ramboll and LDD have been working together to provide remediation support to ESC. To recap, Ramboll led the preparation of Chapters 1-4 of the remediation support, which LDD reviewed and made input into.
- LDD is leading the final part of this project (Chapter 5: Work Plan for Remediation Pilot Trial) and is undertaking the preparation of the Work Plan report. Ramboll's input into the Work Plan process is therefore through discussions via conference call, with recommendations regarding the Pilot Trials being documented by issue of formal meeting minutes and review and input to the draft prepared by LDD.
- These minutes are for the second meeting (conference call) held to discuss the Pilot Trial Work Plan (Chapter 5). The first meeting (also a conference call) was held on July 7, 2021 and comprised a discussion of LDD's initial proposals for the pilot trials. The purpose of this second call (summarised below) was to further the previous discussions and review preliminary Work Plan details developed by LDD.

2 Overview of LDD Proposal for Pilot Trial

- LDD is developing a Work Plan for a Remediation Pilot Trials based on Soil Vapour Extraction (SVE) technology, SVE with heated air injection, and in-situ thermal remediation (ISTR), which are being considered as potential remediation methods for use at the site. Based on Chapters 1-4 of the site remedial evaluation, SVE is considered as the most likely primary remedial approach for use at the site, but LDD noted that the other heat based technologies are being considered to enhance or speed up the remediation. All three technologies are therefore included in the Work Plan to allow comparison to SVE, and also based on the request of ESC. Based on prior

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Ramboll and LDD discussions, the heat based remedial technologies (such as ISTR) may be used to target smaller hotspot areas at the site.

- In addition to the remediation pilot trials, the Work Plan will also cover further investigation on the site. Further investigation is required to understand the extent of the area where remediation is required (extent and depth of source area), and to inform the detailed design of the remediation pilot trial.
- As previously noted by both Ramboll and LDD, further investigation would also be useful to better understand off-site soil vapour risks and the extent of mitigation required in this regard. LDD confirmed that further investigations and assessment offsite are outside the scope of work for the pilot trials, but would be a recommendation for the client to undertake.

3 Remediation Pilot Trials Overview

- LDD is planning to test two remedial technologies (SVE and ISTR) at three locations at the site. Three locations are proposed based on the heterogeneity of the subsurface conditions at the site (generally fractured bedrock with lenses of fine-grained soils). The planned depth of pilot trials is 40m (i.e. consistent with the assumed treatment depth considered in the remediation options appraisal (ROA)). *Ramboll and LDD discussed during the call that it will be important to undertake site characterisation to ensure that this assumed (and arbitrary) treatment depth is appropriate.*
- A plan view showing the approximate layout of LDD's proposed SVE extraction wells, ISTR heater well (ISTR hole), and SVE heated air injection wells at each of the three pilot locations was discussed, together with proposed SVE monitoring wells and ISTR temperature monitoring points (holes).
- LDD clarified during the call that each group of five wells shown on the drawing represents a cluster of wells, with screens/monitoring intervals to be installed at a variety of depths.
- LDD clarified during the discussion that only one ISTR heater well (ISTR hole) is proposed at each pilot location (a correction to the two locations shown on the layout). The general approach depicted is to install monitoring points at various distances (3m, 5m, 8m as shown) from the SVE extraction wells, ISTR heater wells, etc.
- A cross section view showing the various screened/monitoring intervals for the pilot testing (to the planned depth of 40m) was discussed.
- The type(s) of monitoring data planned for collection during the pilot trials for each technology include VOCs measurements/sampling, temperature monitoring, and pressure (vacuum) monitoring.

4 Pilot Discussion

- Ramboll noted that it considered that the general layout of the pilot trial area looked reasonable, with monitoring points located at various distances outward from SVE extraction/ISTR heater wells.
- The SVE monitoring points were also positioned in different directions from the treatment wells. Ramboll agreed position the monitoring points in this way could provide useful information given the expected heterogeneity of the bedrock.
- Ramboll also suggested LDD consider also positioning the heat gauge monitoring points (wells) in multiple directions (as part of evaluating the heterogeneity).
- Ramboll noted that it considered that the cross section view looked reasonable, with various discrete screened intervals for monitoring at various depths down to 40m. Ramboll suggested (and LDD concurred) that operation of SVE extraction at individual discrete depths may provide insight as to the locations of higher VOC impacts within the subsurface, which may help with targeting of the full-scale remediation (i.e. which vertical intervals to focus treatment efforts).

- Ramboll noted that the implementation of pilot testing for the three technologies (SVE, SVE with heated air injection, ISTR) would entail higher costs than for SVE pilot work alone. LDD agreed, and indicated that the proposed approach of piloting the three technologies was requested by ESC.
- Ramboll noted that it may be beneficial to focus the pilot testing on SVE and ISTR technologies, based on the following:
  - As discussed in the ROA (Chapters 2 and 4), SVE with heated air injection and ISTR are conceptually similar, in that both technologies combine the application of heating with air injection/extraction in the subsurface. Therefore, testing of only one of these technologies may provide sufficient information regarding the remedial benefits of the addition of heat to the subsurface.
  - As also noted in the ROA, ISTR is a remedial technology with a more proven track record of successful full-scale implementation in the US, and several commercial US firms are well-versed in the application of the technology and can provide technical and implementation support for field pilot work. By contrast, SVE with heated air injection is a less-proven technology (available information indicates it has been used on a limited pilot basis, with no proven full-scale implementation track record) and it may be difficult to identify commercial firms for this type of pilot work.
- Regarding monitoring during the pilot trials, Ramboll recommended that, in addition to monitoring VOCs at the offset monitoring well locations, there could also be benefit in monitoring VOC concentrations (e.g. via PID readings or samples) from the extraction wells themselves. This data may help to quantify the mass of contaminant being removed from difference depths.
- Sequencing of the pilot trials was discussed. LDD confirmed it is intending to extract from the individual screened depths separately and in sequence, in order to gather data which could help inform how best to target the full scale remediation.
- To recap, and as discussed in the initial meeting, ESC had arranged further soil vapour investigation at the site (by others), which focused on overburden soils following their emplacement as part of a large overburden remediation exercise. Elevated contaminant concentrations were detected in soil vapour within the overburden soils at higher concentrations than previously detected, despite the soil having recently been imported and not previously contaminated. Ramboll previously noted that the high concentrations now detected in the overburden soils could potentially be reflective of more permeable material having been used compared to the original soils that had been removed. LDD concurred, clarifying that the newly-placed soils are understood to be generally sandy in nature. Ramboll noted that near-surface pilot testing may need to consider the potential for short-circuiting of air flow if these soils are highly permeable.

5 Further Investigation

- LDD noted that the drilling work for the pilot would include detailed logging of borings to identify the subsurface geology (bedrock, locations of fine-grained soils such as marl, etc.), and LDD is also considering the inclusion of borehole geophysics to identify bedrock fracture locations, dip, and strike information. Ramboll concurred that additional subsurface information would be highly beneficial to supporting both the pilot work and the full-scale remedial design.
- Ramboll and LDD discussed again the importance of additional site characterisation include investigation (such as rock core/marl samples) in the wider site (i.e. outside of the pilot trial area) to determine the extent of the area requiring treatment. Additionally, Ramboll recommended that the investigation / characterisation include consideration of depths beyond the proposed 40m depth of the pilot trial.
- LDD also intends to conduct additional characterisation near the site boundary to understand what kind of contaminants and concentrations can be measured at the border. LDD noted that they are

considering the installation of one or more soil gas monitoring wells/points along the boundary for this purpose.

6 Follow-Up

- LDD indicated that they intend to provide a draft of the pilot testing Work Plan for Ramboll's review.