dekonta

ENACON

CZECH REPUBLIC
DEVELOPMENT COOPERATION

PROJECT OF DEVELOPMENT COOPERATION OF THE CZECH REPUBLIC AND MACEDONIA

„OLD ENVIRONMENTAL BURDENS IN CHEMICAL PLANT OHIS, SKOPJE“

Updated Feasibility Study

for Remediation of the HCH
Waste Dumps and HCH-Contaminated Soil

Prague, 30th November 2009

ENACON s.r.o.
Na holém vrchu 708/3
143 00 Praha 4, Czech Republic

PROJECT OF DEVELOPMENT COOPERATION OF THE CZECH REPUBLIC AND MACEDONIA

„OLD ENVIRONMENTAL BURDENS IN CHEMICAL PLANT OHIS, SKOPJE“

Updated Feasibility Study

for Remediation of the HCH Waste Dumps and HCH-Contaminated Soil

Elaborated for:
Czech Ministry of Environment
Vršovická 1442/65
100 10 Prague 1

Elaborated by:
ENACON s.r.o
Na holém vrchu 708/3
143 00 Praha 4
Czech Republic

Project Manager:
RNDr. Jan Němeček

Approved by:
Mgr. Zdeněk Matějík

Prague, 30th November 2009

Table of Contents

List of Tables

List of Figures

List of Annexes

List of Abbreviations:

CARDS Community Assistance, Reconstruction, Development and Stabilisation
CHC Chlorinated aliphatic hydrocarbons
1,2-DCA 1,2-dichloroethane
1,2-cis-DCE 1,2-cis-dichloroethene
1,2-trans-DCE 1,2-trans-dichloroethene
DCE Dichloroethene
DOC Dissolved Organic Carbons
HCH Hexachlorocyclohexane
LADD Lifetime Average Daily Dose
MRL Maximal Residue Level
TeCA Tetrachloroethane
PCE Tetrachloroethene
RAIS Risk Assessment Information System
RfD Reference Dose
SF Cancer Slope Factor
TCB Trichlorobenzene
TCE Trichloroethene
VC Vinyl chloride
VOC Volatile Organic Compounds

1. Introduction

The project „Old Environmental Burdens in Chemical Plant OHIS, Skopje" is financed from the Official Development Assistance Programme of the Czech Republic. The project is being implemented by Czech company ENACON s.r.o. that has been contracted by Ministry of Environment of the Czech Republic.

This report presents the outputs of Feasibility Study carried out within the frame of the above project. The feasibility study grew out of a Risk Assessment performed in a previous phase of the project. The feasibility study proposes and assesses alternative remedial actions aiming at reducing and/or eliminating risks related to the existence of hexachlorocyclohexane (HCH) waste dumps and HCH-contaminated superficial soil beneath and in the surroundings of the HCH dumps.

This report has been prepared by ENACON's experts:

- Jan Němeček – Project Manager
- Zdeněk Matějík
- Hana Čudová
- Petr Kozubek
- Petr Pokorný

The following subcontractors participated on this project:

- DEKONTA a.s., Czech Republic – drilling and sampling work, field work supervision and coordination; bench scale laboratory tests on treatability of soil contaminated with HCH by enhanced biodremediation and by chemical exctraction technology;
- PHARMACHEM, Macedonia – technical assistance and local expert support;
- CHEMIA SYSTEM GEO s.r.o. – conceptual proposal of dumps´reclamation and alternatively, installation of controlled hazardous waste landfill, including cost estimates;
- Analytické Laboratoře Plzeň, a.s., Czech Republic – laboratory work;
- AVA Trials & Service, Germany – bench scale laboratory tests on treatability of soil contaminated with HCH by vacuum thermal desorption.

2. Site Settings

2.1 General Information

2.1.1 Geographical Site Definition

The chemical plant OHIS is located at the southeastern edge of the city of Skopje, about 5.5 km apart the city centre. The project deals with old environmental burdens originated from historical production of lindane, monochloracetic acid and chlorine (in the electrolysis plant). Facilities, storage buildings related to the above stated production, and HCH dumps are located in the western part of the OHIS plant further referred as the "site", see Annex 1. HCH waste dumps are situated in the south-eastern portion of the site. The whole OHIS plant covers the area of approximately 0.9 km^2, the "site" covers the area of approximately 0.1 km^2 (10 ha).

2.1.2 Existing and Planned Land Use

The site is located at the southeastern edge of Skopje, in an industrial area that is spread along the road connecting Skopje and the city of Dracevo. The site was developed in the first half of the 60´s, the lindane was produced in the period from 1965 to 1972. The electrolysis plant was in operation in the period from 1965 to 1995. The production of monochloracetic acid took place in the years 1963 - 2004.

At present, the site is mostly abandoned. Some production activities are performed with regards to repackaging of pesticides (produced off-site) from large containers to small retail packaging. Reportedly no pesticides are currently produced at the site. In the area of former electrolysis plant a chlorine distribution facility is still being operated. The chlorine is transported to this facility in pressurized vessels and it is used for production of salt acid.

The present surrounding land use is as follows:

To the north: railway with a railway station and beyond it a private agricultural land and further to the north within a distance of 150 m from the site residential houses of the village of Gorno Lisiče (part of Skopje).

To the southeast: the part of the OHIS plant dealing with production of detergents.

To the southwest: the road connecting Skopje and Dracevo and beyond it a mixed industrial/commercial area with an abandoned glass mill and further to the southwest rural area with dwellings of Kisela Voda.

To the northwest: undeveloped part of OHIS plant and beyond it a small residential area.

2.1.3 Basic Demographic Settings

The nearest residential area is Gorno Lisiče located approximately 200 m to the northeast of the site. Dwellings belonging to Kisela Voda are located about 300 m to

the southwest of the site. Based on the rough estimate, up to 1,000 residents live within a distance of 500 m from the site mainly in Gorno Lisiče. The site itself is almost abandoned. During filed work performed in March 2008 first tens of people are involved in some minor production activities, maintenance and guarding at the site.

2.2 Natural Settings

2.2.1 Geomorphologic Settings

The site is located at the southwestern edge of the flood plain of the Vardar River (see Section 1.2.4), at an average elevation of 239 m above sea level (asl.). The site area is almost flat, just very gently sloping to the northeast. Further to the southwest of the site there are the steep side hills of the Vodno Mountain range.

2.2.2 Climatic Settings

The average annual air temperature is 12.5 °C, and the maximum temperature is 41.2 °C. Usually the climate during the summer period is very dry and warm, in winter the climate is moderate cold. The average annual precipitation is 502.3 mm (Eptisa 2007).

2.2.3 Geological Settings

The bedrock beneath the site area is composed of Pliocene sediments comprising sandstone, marlstone, and conglomerate. The depth to bedrock rapidly increases in north-east direction from first tens of meters to more than 200 m along the Vardar River. The bedrock is overlain by Quaternary proluvial sediments comprising sandy, gravely and silty loams. Quaternary proluvial sediments fill the depression eroded in Pliocene sediments. The thickness of Quaternary proluvial sediments is about 70 m at the site and increases in northern direction to approximately 90 m. The Quaternary proluvial sediments are overlain by alluvial sediments of the Vardar river comprising mainly gravels, sandy, silty and loamy gravels alternating with thin layers (first tens of centimetres thick) of sandy gravelly clay and silt. The uppermost layers of alluvial sediments comprise clayey silt to silty clay. The thickness of these fine grained sediments varies at the site from 1.5 m to 4.5 m (about 2.5 m in the area of HCH waste dumps). The alluvial sediments are locally overlain by fill comprising mostly crashed aggregate, gravelly clay and gravel. The thickness of the fill is less than 0.5 m. Allegedly, it was man-deposed during the various historic construction/revamping stages of the site.

2.2.4 Hydrogeological Settings

Phreatic aquifer is developed in the alluvial sediments of the Vardar River. The permeability of the aquifer is 10^{-3} m/s up to 10^{-2} m/s in formations of pure gravel. Underlying proluvial sediments can be also considered as water bearing strata, however of lower permeability. The depth to groundwater is about 8 to 8.5 m below the ground level (bgl). The saturated thickness of the aquifer is about 60 m at the site and increases in northern direction. Groundwater flows generally toward the east and finally discharges into the Vardar River and into the lowermost section of the Markova reka River.

Groundwater is abstracted in down-gradient and cross-gradient direction in number of domestic wells in the village of Gorno Lisiče. The nearest well is located within the distance of about 150 m to the northeast from the site border. Based on the interviews with the local residents, wells are rather shallow (about 10 to 12 m) and abstracted groundwater is used for irrigation only. Drinking water is supplied by municipal mains there. Two abstraction well fields of OHIS plant are located in the alluvial plain of the Vardar River. Well field "Lisiče 1" consists of 8 wells of the depth of approximately 30 m situated perpendicular to groundwater flow at the distance of 1.2 km to the northeast of the site border (thus cross-gradient with respect to groundwater flow). Well field Lisiče 1 is reportedly more than 6 years out of operation. At the distance of approximately 2.3 km to the northeast of the site (about 200 m to the south of the Vardar River) there is abstraction well Lisiče 2. It is a 23 m deep well 5.5 m in diameter with radial drains 17 to 33 m long. The annual amount of groundwater abstracted from this well was approximately 2 Mil. m^3 in 2007 (average pumping rate of 63 l/s). According to information provided by OHIS representatives abstracted groundwater is used for sanitary purposes and as a source of process water. Groundwater is not used for drinking. Based on the location of well Lisiče 2 with respect to Vardar River and general direction of groundwater flow, the well abstracts mainly surface water of the Vardar River that recharge the alluvial aquifer rather than intercepts groundwater flowing from the site.

2.2.5 Hydrological Settings

The nearest surface water is the Colemni Kamenj creek flowing in direction southwest - northeast at the distance of 400 m to the northwest of the site. The Colemni Kamenj creek discharges into the Vardar River – a regional watercourse flowing in northwest–southeast direction at the distance of 2.3 km to the northeast of the site. Another watercourse in the site vicinity is the Markova reka River flowing in south - north direction within a distance of 1.6 to the east of the site. The Markova reka River discharges into the Vardar River some 1 km downgradient of the estuary of Colemni Kamenj to the Vardar.

The Vardar river covers a catchment area of 4,650 km^2, the mean flow rate (calculated for the profile in Skopje) is 63 m^3/s, the 90% flow rate ($Q_{min90\%}$) is 6,34 m^3/s.

Reportedly, the OHIS property has never been flooded by the Vardar River or by the Markova reka River. In 1962, the OHIS area was flooded by the storm water run-off from the Vodno Mountains. The capacity of the Colemni Kamnej creek was not sufficient to collect stormwater and overflew.

2.3 Previous Investigations

2.3.1 Results of Previous Investigations

No systematic soil and groundwater investigation has been performed at the site in the past.

In 2001, two soil samples of superficial soil were taken within the **CARDS Project** near the present monitoring well HS-1 (next to the former electrolysis plant) and near the present monitoring well HS-2 (next to the HCH dump, respectively). Both soil samples were analysed for the content of lead, mercury and chromium. In the first sample elevated concentration of mercury – 7 mg/kg was found; in the second sample laboratory analyses did not found elevated concentration of any analysed metal.

Screening of soil and groundwater contamination was performed by company BENA, Thessaloniky within the project **CARDS in 2002**. Within this project two monitoring wells HS-1 and HS-2 were installed next to the former electrolysis plant and next to the δ-HCH dump, respectively. Soil samples were taken from the core of both borings and samples of groundwater were taken. In addition, samples of sediment of an old wastewater canal and wastewater sample were taken. Samples were analysed for wide spectrum of inorganic as well as organic parameters. Soil analyses encountered elevated concentrations of total chlorinated hydrocarbons (127 µg/kg calculated as TCE) in the depth interval 4 to 5 m bgl. of boring HS-1 and also in boring HS-2 in the depth interval 3 to 4 m bgl. (42.72 µg/kg). Groundwater sample taken from well HS-1 contained elevated concentrations of trichloroethylene (TCE) – 104.95 µg/l, tetrachloroethylene (PCE) – 132.45 µg/l, α-HCH – 0.239, β-HCH µg/l – 0.282 µg/l, aldrin – 0.3 µg/l and of mercury – 1.1 µg/l. Groundwater sample taken from well HS-2 contained elevated concentrations of α-HCH – 2.4, β-HCH – 3.20 µg/l, γ-HCH – 0.38 µg/l and of bromoform – 18.39 µg/l. No elevated concentrations of polycyclic aromatic hydrocarbons (PAH) or of analysed metals (Pb, Cr) were encountered in any of the groundwater samples.

Laboratory analyses of sediments of the old wastewater canal found elevated concentrations of γ-HCH in order of tens of µg/kg in the depth interval from 0 to 2.5 m below the canal bottom. Maximal concentration was 53.9 µg/kg in the depth interval 0 to 0.5 m below the canal bottom. The sample of OHIS wastewater discharged into the Vardar River contained elevated concentrations of TCE – 23.4 µg/l and of mercury – 0.11 µg/l, the sample was not analysed for content of pesticides.

In **2007**, company **EPTISA** performed limited site investigation within a project managed by the European Agency for Reconstruction. The site investigation consisted of geoelectrical (resistivity) mapping with the goal to evaluate possible

anomaly zones indicating contamination of soil and groundwater by HCH and mercury and to propose strategy for site remediation. Four anomalies were detected by geoelectrical mapping – to the east of the former electrolyses plan (contamination by mercury), to the southeast of the former monochloracetic acid plant, along the north-eastern side of the a-HCH and β-HCH dump and to the east of this dump (contamination by HCH).

In **2007** the **Institute of Public Health in Skopje** collected four superficial soil samples (0.05 to 0.35 m bgl) in the surroundings of the former electrolysis plant and analysed them for the content of mercury. Contents of mercury in these soil samples are given in Table bellow:

Table 1: Content of Mercury in Soil – Institute of Public Health, Skopje 2007

Parameter/sampling point	Unit	Dutch Intervention Value	Point 1	Point 2	Point 3	Point 4
			Next to the former electrolyses plant	Appr. 80 m to the east of the electrolysis plant	Off-site, appr. 250 m to the east of the electrolysis plant	On-site, appr. 250 m to the east to southeast of the electrolysis plant
Hg	mg/kg	10	110	7.64	2	<1

It can be seen, that content of mercury exceeded respective Dutch Intervention Value only in sample taken in point 1.

3. Site Characterization

3.1 Methods and Scope of Field and Laboratory Investigation

The goal of the site characterization was to: (1) investigate contamination of soil, groundwater and construction materials; (2) investigate two dumpsites of waste isomers of hexachlorocyclohexane; (3) screen the impact of contaminants on the home-grown vegeTables in the vicinity of the OHIS site.

The scope of work included:

- Site visit, preparation of sampling plan;
- Execution of 64 soil borings and 8 direct push probes (performed in the period July – September 2007 and March 2009),
- Installation of 16 monitoring wells (performed in March 2008 and March 2009),
- Collection of 195 soil samples (from soil borings in 2007 and 2009, from drilling core during installation of monitoring wells in 2008, 2009, two samples of topsoil in agricultural land in Gorno Lisiče),
- Collection of one sample of street dust taken from paved road next to the former electrolysis plant,
- Collection of one sample of sediment of a sewer at the site,
- Collection of 79 groundwater samples from existing, newly installed monitoring wells as well as domestic and abstraction wells,
- Collection of 10 soil gas samples and 4 ambient air samples,
- Collection of 75 samples of construction materials,
- Collection of 2 samples of lettuce, one sample of celery and one of potatoes grown on the field in Gorno Lišice,
- Laboratory analyses of samples for parameters of potential concern,
- Atmogeochemical Mercurometry Survey (March 2009),
- Surveying of existing and newly installed monitoring wells and of both dumps of HCH waste isomers,
- Field and laboratory data processing and evaluation.

3.2 Site Investigation

3.2.1 Results of Waste HCH Isomers Dumps Investigation

<u>a-HCH and β-HCH dump</u>

Analyses of both samples of waste disposed in the a-HCH and β-HCH dump found almost pure a-HCH, while EPTISA (2007) states that the waste contains 86-88% of a-

HCH, 11-12% of β-HCH and 1 – 2 % of γ-HCH. Based on our drilling campaign (2008) the waste was disposed in this dump onto the natural ground without any protection, which confirms information provided by OHIS representatives. Thickness of waste (of white colour and loose, powdery consistency) varies from 3.2 to 4.6 m. Waste isomers are overlain by a layer of humous loam and sandy clay of the thickness of 0.5 up to 1.6 m (1 m in average). The content of HCH in the soil cover of the dump is 897.13 mg/kg (soil boring S-B-06). Based on the surveing the 3D model was developed, planar and surface areas and volume of waste were calculated. These outputs are summarized in Table 4.

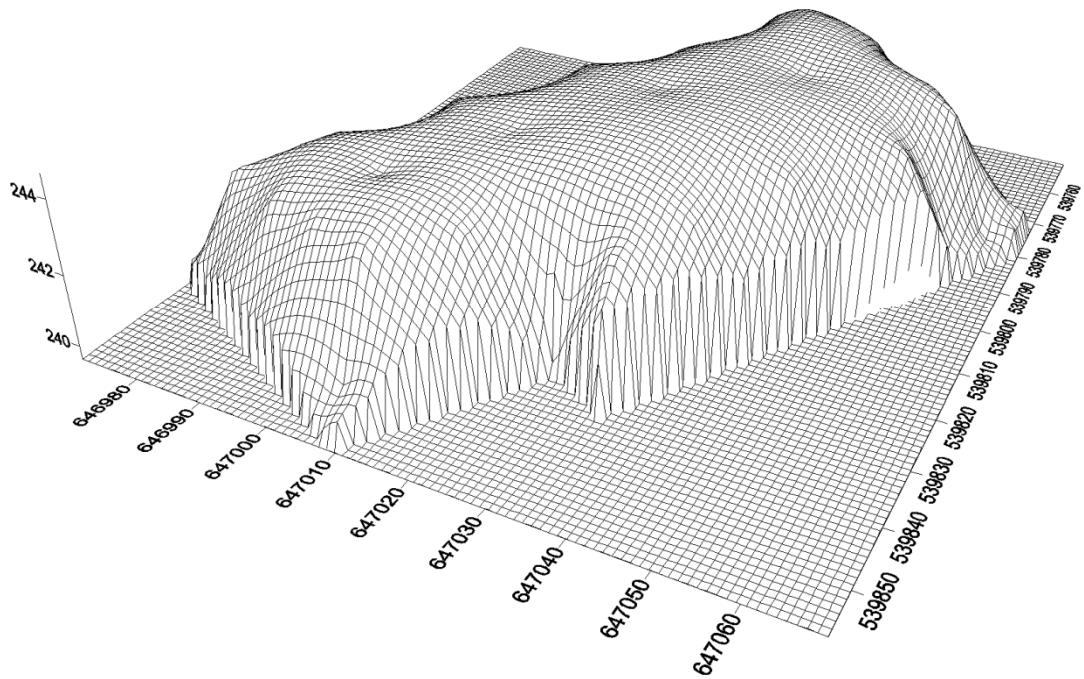


Figure 1: 3D model of the a-HCH and β-HCH dump

Table 2: Basic Parameters of the a-HCH and β-HCH dump

Parameter	Value	Note
Planar area	5,140 m^2	
Surface area	5,270 m^2	
Total dump volume	20,200 m^3	In comparison, EPTISA (2007) states 25,000 m^3
Volume of HCH waste	15,000 m^3	
Mass of HCH waste	28,100 t	Density of 1.87 g/cm^3 used for calculation. In comparison, EPTISA (2007) states 13,900 t
Character of the waste	88% of a-HCH, 11-12% of β-HCH and 1 – 2 % of γ-HCH	Source: EPTISA 2007
Volume of the overlying contaminated soil	5,200 m^3	
Mass of the overlying contaminated soil	9,400 t	Density of 1.8 g/cm^3 used for calculation. In comparison, EPTISA (2007) states 14,000 t

δ-HCH dump

The δ -HCH dump consists of 5 concrete basins of the total area of approximately 940 m^2. Bottom of the basins is situated approximately 1.7 m bgl. The waste was dumped also beyond the perimeter of the basins (total planar area of the dump is 1,240 m2). Content of δ-HCH dump is rather heterogeneous. The δ-HCH waste recognized by yellow-brown color and by soft, pasty consistency was encountered only on the bottom of south-eastern concrete basins. The average thickness of the δ-HCH waste is 1.65 m. Based on analysis of the δ-HCH waste collected from boring S-B-02, it contains 16% of a-HCH, 1% of β-HCH, 44% of γ-HCH and 39% of δ-HCH. In comparison, EPTISA (2007) states the relative content of individual HCH isomers in the δ-HCH waste as follows: 22-26% of a-HCH, 5-7% of β-HCH, 16 – 19% of γ-HCH and 38-50% of δ-HCH. The δ-HCH waste is overlain by sandy and clayey layers with arious content of individual HCH isomers. The uppermost layer comprises humous loam 0.4 to 0.6 m thick. On the bottom of the northwestern concrete basins δ-HCH was not found and the waste is loamy containing mostly a-HCH isomer (81% to 93%). Total content of HCH is in order of tens of thousands of mg/kg.

Based on the surveying the 3D model was developed, planar and surface areas and volume of waste were calculated. These outputs are summarized in Table 3.

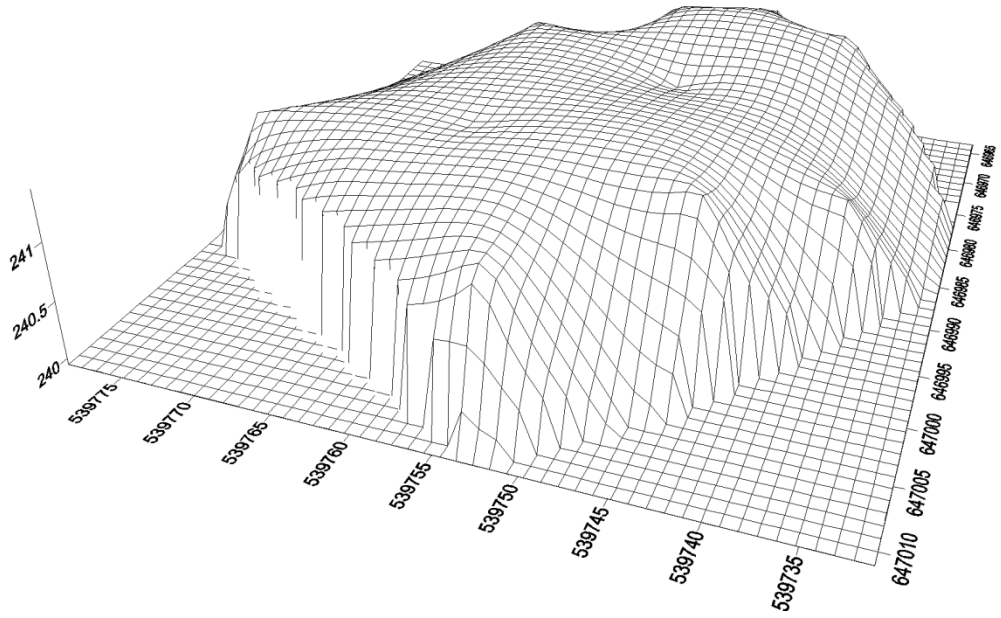


Figure 2: 3D model of the dump of δ-HCH

Table 3: Basic Parameters of δ-HCH dump

Parameter	Value	Note
Planar area	1,240 m^2	
Surface area	1,250 m^2	
Total dump volume	2,630 m^3	
Volume of δ-HCH waste	620 m^3	
Mass of δ-HCH waste	930 t	Density of 1.5 g/cm^3 used for calculation
Character of δ-HCH waste	16% of α-HCH, 1% of β-HCH, 44% of γ-HCH and 39% of δ-HCH	In comparison, EPTISA (2007) states 22-26% of α-HCH, 5-7% of β-HCH, 16 – 19% of γ-HCH and 38-50% of δ-HCH
Volume of dumped contaminated soil and other waste	2,010 m^3	
Mass of dumped contaminated soil and other waste	3,620 t	Density of 1.8 g/cm^3 used for calculation

3.2.2 Results of Soil Investigation

Soil of the superficial layer (to the depth of 1 m bgl.) is impacted by HCH isomers in most of the assessed area of the OHIS property. The highest concentrations of HCH were found under and next to both HCH waste dumps where sum HCH concentrations exceed Dutch Intervention Limit more than 100 times, see Annex 6. Soil contamination by HCH isomers sharply ceases with depth. Nevertheless, under the both HCH dumps, in the vicinity of the δ-HCH dump and sporadically also in other locations HCH concentrations are still high - exceeding the Dutch Intervention Limit by more than one order even in the deepest sampled interval (4.6 – 4.8 m bgl.)
The topsoil of the agricultural land some 100 m to the north of the site found sum HCH concentration slightly exceeding the Dutch Intervention Value. In one of three samples analysed for dioxins content the concentration exceeded Dutch Indicative Level for Serious Contamination. Extent of soil contamination by DDE, DDD and DDT and its intensity is significantly lower compared to HCH and is limited to the superficial layer in sector A (former lindane production area, see Annex 2) only. Contamination of soil by chlorobenzenes in the superficial layer as well as in the depth interval 1.4 – 1.9 m bgl. was found only locally.

Elevated concentrations of Hg in soil gas were detected in most of borings within the former electrolysis plant and its close surroundings with observed general decrease of concentration with depth. Higher Hg concentration in soil gas were measured along the north-western side of the building of the former electrolysis plant. Maximal concentration of Hg in soil gas 44.3 µg/m^3 in a superficial layer (0.6 m bgl) next to the settling sump.

Analyses of soil gas samples found elevated contents of trichloroethene (TCE) and tetrachlorethene (PCE). In sector C (production of monochloracetic acid). Maximal TCE concentration was 2940 mg/m^3 in boring S-C-4 located in the area of former above-ground tanks for this semiproduct.

3.2.3 Results of Groundwater Investigation

Two main pollutant groups were found in **groundwater** – HCH and chlorinated aliphatic hydrocarbons (CHC). Maximal HCH concentrations in groundwater exceeding Dutch Intervention Limit 141 times and 86 times, respectively were found in September 2009 next to probable source of contamination - lindane production and storage blds. and the dump of a-HCH and β-HCH. Contamination plume migrates in direction of groundwater flow to the east towards domestic well DW-6, where the sum HCH concentration also exceeded the Dutch Intervention Value (3.5 times). Hotspot of groundwater contamination by CHC was discovered at the eastern edge of the former monochloracetic acid production facility. Comparing concentrations of individual CHC with respective Dutch Intervention Values, in the very hotspot, the Dutch Intervention Value was exceeded 2.3 times for TCE and 7 times for PCE. Of all sampled downgradient domestic wells, the Dutch Intervention Value for PCE was exceeded 6 times in well DW-6. No Intervention value is defined for 1,1,2,2 TeCA that dominates there. Local groundwater contamination by mercury in the vicinity of the former electrolysis plant, by trichlorobenzene near the former lindane production plant was found, exceeding respective Dutch Intervention Values 20 times and 70 times, respectively. In groundwater taken from well MW-3 for laboratory testing of candidate remedial method, high content of 1,1,4,4 – tetrachloro 1,3 – butadiene was identified by a gas chromatograph in order of magnitude of hundreds of µg/l. Origin of this constituent was not discovered.

3.2.4 Results of Analyses of Vegetables

Results of laboratory analyses of lettuce, potatoes and celery were compared with maximum residue level (MRL) of pesticides defined by Regulation (EC) No 396/2005 of the European Parliament and of the Council on maximum residue levels of pesticides in or on food and feed of plant and animal origin. As regulation does not define MRL specifically for HCH isomers and for DDD, DDE and DDT, Default MRL in foodstuffs of 10 µg/kg was used. Default MRL was not exceeded in any sample of lettuce and potatoes, however was exceeded by β-HCH in the celery (25 µg/kg). Some residues of PCB in the range of tenths of µg/kg were found in samples of lettuce (under detection limits in potatoes and celery). Lettuce was analysed also for the content of mercury and was under the detection limit.

3.3 Risk Assessment

3.3.1 Migration of Contamination

Results of the assessment of contaminants migration can be summarized as follows:

- low-permeable layer of clayey silt to silty clay overlying the aquifer serves as protective layer, nevertheless is not sufficient with regards to amounts of contaminants leaching from above ground contamination sources. Based on the mathematical modelling of contaminant transport approximately 30 kg/year of **HCH isomers**, 30 kg/year of **PCE** and 90 kg/year of **TeCA** seep through the unsaturated zone to aquifer. Of other contaminants **mercury**, **trichlorobenzene** and **DDD, DDE and DDT** were found locally in groundwater in elevated concentrations and thus their mobility and leaked amounts have overcome the retention capacity of the unsaturated zone, nevertheless not to a large extent.
- velocities of migration of main pollutants in groundwater (HCH isomers, PCE and TeCA) were estimated considering advection and sorption. HCH isomers migrate in groundwater by velocity of approximately 0.08 to 0.9 m/day (30 to 330 m/year). Velocity of PCE and TeCA is approximately 0.2 to 2.4 m/day (70 to 900 m/year). Higher migration velocities refer to the surroundings of abstraction wells Lisiče 1 and Lisiče 2 (see Annex 4), where low concentrations of chlorinated aliphatic hydrocarbons were detected only. Based on calibrated mathematical model HCH - contaminated groundwater spread some 1.4 km downgradient (to the south-eastern part of Gorno Lisiče) from the source within approximately 40 years. CHC are substantially more mobile pollutants. Model results for the year 2008 (i.e. after approximately 40 – year duration of the contamination source) show that the edge of the PCE and PCA plumes is about 2.0 km to the east to northeast from the contamination source area and were attracted by the Lisiče 1 and Lisiče 2 abstraction wells. Thus, based on the model results, trace concentrations of CHC found in groundwater of the Lisiče 2 well and especially in groundwater of the Lisiče 1 well have very likely origin in the OHIS plant.
- Based on the mathematical model, as long as the Lisiče 2 abstraction well is active, it will act as an interceptor of the CHC contaminant plume migrating from the OHIS plant. Even in the case of termination of groundwater abstraction from the Lisiče 2 well, the impact on surface water quality by draining of contaminated groundwater into the Vardar River will be negligible due to the high dilution factor. According to the model results the Markova River does not drain groundwater (groundwater level is below the surface water level thus cannot be affected either).
- Natural attenuation processes are not very likely of such significance that would prevent further migration of groundwater contamination by CHC and HCH off-site. Sorption is the main process that prevents significant spread of HCH contamination in groundwater (in comparison to CHC). However sorption retards the migration rather than decrease the total content of the contaminant.

3.3.2 Human Risk Assessment

The relevant exposure scenarios were identified based on the actual information on contamination character and its extent considering the real transport mechanisms and current land use.

Under the current land use the potential risk acceptors are associated with the following:

- contaminated top soil horizon (to the depth of 1 m below surface). It includes the contact (inhalation of dust / fine particles generated from unpaved areas) with contaminated soil during a routine walkover by on-site workers in site Sectors A (former lindane production area)and B (HCH waste dumps), see Annex 2;
- contaminated soil to a depth of approximately 2 m below surface. It includes the contact with contaminated soil during the temporary excavation activities at the site carried out by external workers;
- contaminated construction material - it includes the inhalation of dust and fine particles released from construction material by on-site workers during routine activities in sectors A and D (former electrolysis plant);
- contaminated soil gas – it includes the excavation activities and vapors intrusion into on-site buildings and their subsequent inhalation by on-site workers;
- contaminated groundwater off-site – it includes the contact with groundwater during irrigation of gardens and small fields located north-easterly the site;
- contaminated soil in gardens and small fields off-site – it includes the contact with soil impacted by dust originated from the site during gardening;
- contaminated vegetables – it includes the ingestion of home-grown vegetables on gardens and small fields located northerly the site.

Unacceptable human health risk was identified with regards to:

- outdoor and indoor inhalation of α-HCH contaminated dust particles by on-site worker;
- indoor inhalation of VOC (TCE) vapours by on-site worker;
- outdoor inhalation of VOC (TCE) vapours by excavation worker;
- accidental ingestion of γ-HCH contaminated soil by excavation worker;
- dermal contact excavation worker with γ-HCH contaminated soil;

- ingestion of root vegetables grown on a-HCH and β-HCH contaminated topsoil off-site and irrigated by groundwater contaminated by β-HCH and PCE.

The risk for human health on an acceptable level was found by the quantification of exposure scenarios for remaining selected priority contaminants.

Unacceptable evironmental risks were not identified.

3.3.3 Proposal of Corrective Measures and Target Concentrations

The main risks related to the existence of HCH-contaminated soil and both HCH waste dumps (a-HCH and β-HCH dump, and δ-HCH dump) comprise airborne contamination of the topsoil of the neighbouring agricultural land (and final bioaccumulation in root vegetables), inhalation of dust and fine particles contaminated by a-HCH by on-site workers and leaching of HCH isomers into the subsurface (contamination of underlying soil and groundwater). Furthermore, emissions of HCH isomers cause odour nuisances. The HCH dumps and HCH-contaminated soil should be either capped or removed and disposed off-site or treated. All approaches (capping, removal and off-site disposal of, treatment) are further assessed within the scope of this feasibility study. Surface areas, total volumes of each the dump as well as volumes of deposited waste are given in Tables 2 and 3.

The target concentrations for HCH-contaminated soil were proposed by backward calculations of contaminant concentrations that yield in acceptable level of carcinogenic and/or non-carcinogenic risk for respective exposure scenario.

Table 4: Proposed Target Concentrations

Medium	Contaminant	Unit	Target concentration	Note
On-site soil to the depth of 1 m bgl.	a-HCH	mg/kg	160	Derived from acceptable risk for a gardener via dermal contact with soil impacted by airborne transport of contamination from the site - adequate reduction of the level of contamination in source areas in order to achieve the accepTable level of a-HCH and β-HCH in topsoil in gardens in the Gorno Lisiče area
	β-HCH	mg/kg	270	
On-site soil to the depth of 2 m bgl.	γ-HCH	mg/kg	4000	Derived from accepTable risk for a excavation worker (accidental ingestion)

Lateral extent of soil contaminated by HCH isomers above proposed target concentrations is displayed in Annex 13.

4. Remedial Goals

The remedial objectives for the OHIS HCH waste dumps and HCH-contaminated soil were identified in response to the site's characteristics. The remedial objectives will be used to guide the development of specific remedial alternatives that address the objectives.

The remedial objectives for the HCH waste dumps and HCH-contaminated soil are as follows:

- Protect human health from threats caused by exposure to hazardous substances released from the HCH dumps and superficial HCH-contaminated soil (related to inhalation of contaminant vapours and contaminated dust/fine particles, dermal contact with contaminated material, ingestion of root vegetables, grown on contaminated topsoil off-site).
- Protect from leaching of HCH isomers into the subsurface and contamination of underlying soil and groundwater.

Each remedial alternative developed in this FS addresses one or more of these objectives to varying degrees. Thus, the alternatives span a range of technical complexity, design features and estimated cost.

5. Identification and Screening of Available Remedial Technologies

5.1 Technology Identification

Due to the complexity of the old environmental burdens within the OHIS site, this FS refers to remediation of the HCH waste dumps and HCH-contaminated soil only. Remediation of other contaminated media (HCH-contaminated buildings, VOC-contaminated groundwater, Hg-contaminated soil and buildings) will be assessed in separate studies.

As given in Chapter 3.3.3, the HCH waste dumps and HCH-contaminated soil should be either capped or removed and waste disposed off-site or treated. These general remedial response actions will be further developed according to remedial technologies used and screened in this Chapter.

The relationship between the general categories of remedial technologies and the remedial objectives is summarized in Table 5.

Table 5: Summary of Remedial Objectives and General Remedial Technologies

Environmental Media	Remedial Objectives	General Remedial Response Actions	Types of Remedial Technologies
HCH waste dumps, HCH-contaminated soil	PROTECTION OF HUMAN HEALTH Protect human health from threats caused by exposure to hazardous substances released from the dumps PROTECTION OF THE ENVIRONMENT Protect from leaching of CHC isomers into the subsurface and contamination of underlying soil and groundwater.	Containment Removal Disposal Treatment	Containment Capping Excavation Disposal Landfilling Disposal in an underground depository Treatment Waste treatment by GPCR (Gas Phase Chemical Reduction) Waste treatment by BCD (Base Catalyzed Desorption) Waste treatment by Supercritical Water Oxidation Waste treatment by pyrolysisWaste treatment by SET (Solvated Electron Technology) Waste treatment by MCD (Mechanochemical Dehalogenation) Soil treatment by biodegradation (DARAMEND) Soil treatment by vacuum thermal desorption Soil treatment by chemical extraction

5.2 Treatability Tests

Two soil treatment methods were tested in a bench scale within the feasibility study:

Vacuum Thermal Desorption (performed by company AVA Trials & Service GmbH, Herrsching. Germany), and

Chemical Extraction (performed by University of Jan Evangelista Purkyne in Usti nad Labem, Czech Republic).

5.2.1 Description of Bench Scale Tests Carried out

5.2.1.1 **Vacuum Thermal Desorption**

The principle of the Vacuum Thermal Desorption is to apply heat (HCH boiling point ~ 350°C) and vacuum simultaneously to the contaminated soil. Displacement efficiency reaches 100% due to evaporation, boiling, oxidation and pyrolysis. More than 95% of contaminants mass is destroyed. The rest is treated in a flameless thermal oxidizer or in a condensation chamber. Products from decomposition are captured in a scrubber or in AC adsorbers.

The bench scale testing was performed by company AVA Trials & Service GmbH in two different trials:

<u>Trial 1</u>

Process temperature: 400°C (related to atmosphere pressure),

Process pressure: 850 mbar (a),

Process period: 360 min

Output soil samples: V1 and V2

<u>Trail 2</u>

Process temperature: 300°C (related to atmosphere pressure),

Process pressure: <50 mbar (a),

Process period: 240 min

Output soil sample: V3

5.2.1.2 Chemical Extraction

The principle of the tested remedial method is to dissolve HCH contained in the soil by appropriate organic solvent (methanol, acetone, isopropanol). After gravimetric separation, solvent is further separated from HCH by evaporation/condensation and can be further reused.

The bench scale test was performed with the HCH-contaminated soil taken for the OHIS site. 2-propanol was used as the extraction agent. The test comprised washing the soil by 3 and 5 pore volumes of 2-propanol and alternatively 3 and 5 volumes of 2 propanol with 20% content of water.

Prior to the test, soil has been homogenized (not sieved). Two samples have been taken after homogenization and anaylzed for γ-HCH. In the second step, porosity of the soil has been determined (37%). 100 g of soil has been then emplaced with one pore volume of the extraction agent in the glass jar having the outlet in its bottom. After a contact time of 30 minutes liquid was drained and replaced with another pore volume of the extraction agent. Finally, after washing the soil with 3 (alternatively 5) pore volumes, the soil was washed with one pore volume of distilled water. After homogenization and drying on ambient air, the soil sample was analyzed for γ-HCH content.

Figure 3: Laboratory setup

5.2.2 Results of Bench Scale Tests

5.2.2.1 Vacuum Thermal Desorption

Results of the bench scale test of Vacuum Thermal Desorption are given in Table 6. Except for β – HCH in sample V1, content of all HCH isomers in treated samples were under laboratory detection limit (<0.05 mg/kg). However, the initial HCH

concentration was rather low – in the range of magnitude of units of mg/kg. Thus removal efficiency in case of β – HCH in sample V1 was "only" 92%.

Table 6: Results of Bench Scale Test of Vacuum Thermal Desorption

Sample ID	Treatment	Concentration					
		d.m.	*α – HCH*	*β – HCH*	*γ – HCH*	*δ – HCH*	*Σ HCH*
		wt. %	mg/kg d.m.	mg/kg d.m.	mg/kg d.m.	mg/kg d.m.	mg/kg d.m.
OHIS – 3	untreated	84.5	9.05	1.43	8.28	2.86	21.62
	treated V1	99.9	< 0.05	< 0.05	< 0.05	< 0.05	0
	treated V2	99.9	< 0.05	0.12	< 0.05	< 0.05	0.12
	treated V3	99.9	< 0.05	< 0.05	< 0.05	< 0.05	0
DIV		NA	not defined. sum HCH max 2 mg/kg				2

DIV – Dutch Intervention Value

5.2.2.2 Chemical Extraction

Results of the bench scale tests are given in Table 7.

Table 7: Results of Bench Scale Test of Chemical Extraction

Extraction agent	Residual concentration of γ-HCH (g/kg) / removal efficiency (%)	
	3 pore volumes	5 pore volumes
2-propanol	28.8 / 67	11.5 / 87
2-propanol (80%)	47.7 / 46	32 / 64

Heavily HCH-contminated soil was used for testing of the Chemical Extraction – the initial γ-HCH content in soil was 85.3 g/kg and 92.4 g/kg, respectively. Maximal efficiency was 87% applying 5 pore volumes of pure 2-propanol. Lower number of pore volumes or presence of water decreases significantly the removal efficiency. It can be expected that residual content of γ-HCH could be further decreased applying another pore volumes of 2-propanol. In general, removal efficiency is limited by the fraction of contaminant tightly bounded on soil particles. Such fraction can vary in the range of magnitude of units up to tens of mg/kg. Thus, residual γ-HCH concentration achieved 11.5 g/kg could be further reduced. Consumption of the extraction agent per unit mass of extracted contaminant increases with number of pore volumes flushed and thus also treatment cost. The average cost for treatment of 1 ton of heavily HCH-contaminated soil of the OHIS site using the Chemical Extraction method is 400 to 500 Euro.

5.3 Screening Method

5.3.1 Organization of Remedial Technologies

The screening of remedial techologies is organized by grouping the remedial technologies into a three-tier hierarchical system for describing the remedial processes. This system uses the following categories, in order of increasing specificity: general response action, remedial technology and process option. For example, removal is general response action; one of the remedial technologies is physical-chemical treatment and one of the several options is pyrolysis.

On the basis of this organizational approach, the descriptions of the remedial technoloiges considered to the OHIS HCH waste dumps and HCH-contaminated soil are summarized in Table 8. These are remedial technologies that were carried forward and screened to assess which technologies merit further consideration for the remedial alternatives.

5.3.2 Screening Criteria

The remedial technologies are screened using three broad criteria to judge the suitability of each to the remediation of HCH dumps and HCH-contaminated soil. The criteria are:

Effectiveness

Consideration of effectiveness focuses on the degree of reliability of the process that can be expected to have for the types of hazardous substances and the physical condition at the site. Other considerations are the likelihood of meeting the remedial goals and the possible risks generated during implementation.

Implementability

Implementability encompassess the technical and administrative aspects for implementing a remedial technology. Factors in cosidering implementability include the availability of the special facilities, equipment and labor required for some remedial technologies.

Estimated Cost

Estimated cost is considered in a relative way. The estimated costs are judged as relatively low, medium, or high on the basis of general assumptions. At this screening stage, estimated cost does not have a substantial effect on the screening process except in cases where technologies are relatively equal and one has a substantially greater cost.

Table 8: Remedial Technologies for HCH Dumps and HCH-contaminated soil

General Response Action	Remedial Technology	Process Option	Description of Remedial Technology
No action	None	None	No remedial action at the site, the site remains as it is.
Containment	Capping	Geocomposite bentonite mat, protective liner (HDPE 2 mm) with drainage and vegetative layers on the top	Compacted landfill surface, geocomposite bentonite mat, covered with HDPE 2 mm thick foil, geotextile a granular drainage layer and a vegetative support layer
Removal	Excavation	Removal of overlying contaminated soil	Excavation would be done by backhoe or other conventional technique under stringent health and safety measures.
		Waste removal	Excavation would be done by backhoe with toothless bucket or other conventional technique. Dumped waste is of paste to stiff consistency. Excavation will be performed under stringent health and safety measures.
Disposal	Landfilling	Off-site landfilling	Landfilling would require designing and construction of an on-site landfill for disposal of hazardous waste, made in accordance to professional standards and Macedonian regulations.
		Off-site landfilling	Excavation of the waste would require a variety of techniques, depending on the consistency of materials encountered. Landfilling would require designing and construction of an off-site landfill or free capacity in existing landfills for disposal of hazardous waste.
Treatment	Chemical treatment	Waste treatment by GPCR (Gas Phase Chemical Reduction)	Waste is thermally desorbed under reductive conditions at temperature about 600°C. Volatilized organic compounds are swept into GPCR reactor, where reduction with hydrogen occurs. Acid process gases are treated in the caustic srubber, where HCl is neutralized. Offgas can be further used for hydrogen production or as a supplementary fuel.

General Response Action	Remedial Technology	Process Option	Description of Remedial Technology
		Waste treatment by BCD (Base Catalyzed Decomposition)	First, organochlorine compounds are thermally desorbed from waste (maximum particle size is 50mm) with use of sodium bicarbonate. Waste concentrate can be added directly into stirred reactor where it reacts with suspension of carrier oil, as a hydrogen donor, appropriate catalyst and sodium hydroxide as a base at temperature around 326°C. Chlorine is converted to sodium chloride by this exothermic reaction. It is a discontinuous batch process. (APEG modification using sodium glycolate at lower temperature 180°C can be used)
		Waste treatment by SCWO (Supercritical Water Oxidation)	Oxygen, or oxygen peroxide, is unlimitedly soluble in water above the critical point (374°C and 22,1Mpa). Solubility of organic compounds is also enhanced by lower polarity of water, so total oxidation up to carbon dioxide can occur. Organic chlorine is converted to chloride ions. Neutralization by means of e.g. NaOH is necessary.
		Waste treatment by SET (Solvated Electron Technology)	Alkaline metals (Na, K, Li) are dissolved in ammonia or amine to create solution of metal cations solvated with free electrons. Chlorine atoms are striped from organic compound by free electrons and then captured by metal cations to form salts. Process occurs at room temperature.
		Treatment of HCH–contaminated soil by Ex-situ Chemical Extraction	HCH is extracted from soil by appropriate organic solvent (methanol, acetone, isopropanol). After gravimetric separation, solvent is further separated from dissolved HCH by evaporation/condensation and can be reused. Extracted HCH requires further treatment or disposal.

General Response Action	Remedial Technology	Process Option	Description of Remedial Technology
	Physical-chemical treatment	Waste treatment by pyrolysis	Plasma torch is used to achieve high temperatures (3000-5000°C). All of organochlorine compounds are dissociated under these conditions to elemental atoms but then recombined, when cooled. Gaseous products are cleaned up in the scrubber and filter and can be used as a syn-gas.
		Treatment of HCH–contaminated soil vacuum thermal desorption	Heat (HCH boiling point ~ 350°C) and vacuum simultaneously to the contaminated soil. Displacement efficiency reaches 100% due to evaporation, boiling, oxidation and pyrolysis. More than 95% of contaminants mass is destroyed. The rest is treated in the flameless thermal oxidizer or in condensation chamber. Products from decomposition are captured in scrubber or in AC adsorbers.
	Mechano-chemical treatment	Waste treatment by MCD (Mechanochemical Dehalogenation)	Waste is placed in the ball mill together with hydrogen donor and alkali metal (Mg, Na). Reductive reaction is initiated by mechanical forces and chlorinated waste is converted into chloride salt and hydrocarbon. Reaction occurs at room temperature and under ambient pressure.
	Biological treatment	Treatment of HCH–contaminated soil by biodegradation	HCHs degrade under anaerobic condition yielding benzene and chlorobenzene. Anaerobic conditions are achieved by irrigation of superficial layer of soil with water solution containing organic substrate (hydrogen donor), nutrients (N,P) and zero valent iron (technology DARAMEND). The intermediates are further converted under aerobic conditions to carbon dioxide and water.

5.3.3 Technology Screening

The screening of remedial technologies according the three criteria is summarized in Table 9.

5.3.4 Screening Summary

On the basis of screening assessments of the remedial technologies, some of the technologies were chosen to be incorporated in the overall remedial alternatives. The selected technologies are favored because of advantages in effectiveness, implementability, cost, or a combination of features. The reasons for using the remedial technologies in the overall alternatives are presented in Table 10.

The results of technology screening are not intended to eliminate or preclude consideration of other remedial technologies during future stages of remedial study or design. The screening is intended to show the rationale for technology selection at this point in the FS. As new information becomes available, other remedial technologies may become favorable, warranting changes to the remedial alternatives.

Table 9: Remedial Technology Screening for HCH Dumps and HCH-contaminated Soil

General Response Action	Remedial Technology	Process Option	Comments		
			Effectiveness	Implementability	Relative Estimated Cost
No action	None	None	No action would allow continued release of hazardous substances into ambient air. Risk of exposure by direct contact would continue.	Not applicable	Not applicable
Containment	Capping	Geocomposite bentonite mat, protective liner (HDPE 2 mm) with drainage and vegetative layers on the top	Very effective in reducing infiltration. Effective in reducing release of hazardous substances into ambient air.	Implementable.	Moderate to high capital costs
Removal	Excavation	Removal of overlying contaminated soil	Very effective in minimizing of infiltration and elimination of release of hazardous substances into ambient air if the waste is also removed. However, must be accomplished with a subsequent step of soil disposal or treatment.	Implementable, necessary precautions to be taken in order to eliminate dust release	Low capital cost However, cost for soil disposal or treatment must be added.
		Waste removal	Very effective in minimizing	Waste removal	Moderate cost

General Response Action	Remedial Technology	Process Option	Comments		
			Effectiveness	Implementability	Relative Estimated Cost
			of infiltration and elimination of release of hazardous substances into ambient air. However, must be accomplished with a subsequent step of waste disposal or treatment.		However, cost for soil disposal or treatment must be added.
Disposal	Landfilling	Off-site landfilling	Very effective in elimination of infiltration and reducing release of hazardous substances into ambient air.	Rather difficult to implement. Would require design and construction of a landfill for hazardous waste. Not in compliance with current EU legislation. Only soil contaminated with HCH below 5000 mg/kg could be landfilled.	High cost
		Disposal in underground depository	Very effective in elimination of infiltration and reducing release of hazardous substances into ambient air.	Implementable only for soil with the content of HCH below 40wt%. Not in compliance for waste with higher content of HCH.	High cost
Treatment	Chemical treatment	HCH waste treatment by GPCR (Gas Phase Chemical Reduction)	Very effective in elimination of infiltration and release of hazardous substances into ambient air.	Implementable. However, many unknowns about availability of facilities accessible to waste from OHIS dumps (currently not available in Europe)	High cost
		HCH waste treatment by BCD (Base Catalyzed	Very effective in elimination of infiltration	Implementable. However, some unknowns about	High cost

General Response Action	Remedial Technology	Process Option	Comments		
			Effectiveness	Implementability	Relative Estimated Cost
		Decomposition)	and release of hazardous substances into ambient air.	current availability of facilities accessible to waste from OHIS dumps	
		HCH waste treatment by SCWO (Supercritical Water Oxidation)	Very effective in elimination of infiltration and release of hazardous substances into ambient air.	Implementable. However, technical limitations with regards to treatment of particles > 200 µg/ and no commercial experience with HCH treatment.	High cost
		HCH waste treatment by SET (Solvated Electron Technology)	Very effective in preventing infiltration and release of hazardous substances into ambient air.	Implementable. However, no commercial experience with presticides	Very high cost
		Treatment of HCH–contaminated soil by Ex-situ Chemical Extraction	Effective in elimination of infiltration and release of hazardous substances into ambient air.	Implementable. However, no commercial experience with HCH.	High cost for heavily HCH contaminated soil
	Physical-chemical treatment	HCH waste treatment by pyrolysis	Very effective in elimination of infiltration and release of hazardous substances into ambient air.	Implementable. However, little information on treatment of HCH and on side products of pyrolysis.	Very high cost
		Treatment of HCH–contaminated soil by Vacuum Thermal Desorption	Very effective in preventing infiltration and release of hazardous substances into ambient air.	Implementable. However, no commercial experience with HCH and on side products of pyrolysis	High cost

General Response Action	Remedial Technology	Process Option	Comments		
			Effectiveness	Implementability	Relative Estimated Cost
	Mechano-chemical treatment	HCH waste treatment by MCD (Mechanochemical Dehalogenation)	Very effective in elimination of infiltration and release of hazardous substances into ambient air.	Implementable. However, no commercial experience with treatment of HCH. Limited capacity.	Very high cost
	Biological treatment	Treatment of HCH–contaminated soil by biodegradation	Very effective in elimination of infiltration and release of hazardous substances into ambient air.	Implementable, however need to be tested in the site specific conditions (Pilot Test)	Low cost

Table 10: Remedial Technology Screening Summary for HCH Dumps and HCH-contaminated Soil

General Response Action	Remedial Technology	Process Option	Comments
Containment	Capping	Geocomposite bentonite mat, protective liner (HDPE 2 mm) with drainage and vegetative layers on the top	Retained and incorporated in containment alternatives.
Removal	Excavation	Removal of overlying contaminated soil	Retained as it is required for the waste-removal alternatives.
		Waste removal	Retained as it is required for the waste-removal alternatives.
Disposal	Landfilling	Off-site landfilling	Not retained due to high capital cost and noncompliance with the current EU legislation.
		Disposal in underground depository	Retained as it is effective for contaminatefd soil in terms of prevention of infiltration and release of hazardous substances into ambient air.
Treatment	Chemical treatment	Waste treatment by GPCR (Gas Phase Chemical Reduction)	Retained as GPCR will destroy organic hazardous substances.
		Waste treatment by BCD (Base Catalyzed Decomposition)	Retained as BCD will destroy organic hazardous substances.
		Waste treatment by SCWO (Supercritical Water Oxidation)	Not retained due to technical limitations with regards to treatment of particles > 200 µg/ and no commercial experience with HCH treatment.
		Waste treatment by SET (Solvated Electron Technology)	Not retained due to lack of commercial experience with HCH treatment.
		Treatment of HCH–contaminated soil by Ex-situ Chemical Extraction	Not retained due to high cost of treatment of heavily contaminated soil.
	Physical-chemical treatment	Waste treatment by pyrolysis	Not retained due to little information on treatment of HCH and on side products of pyrolysis.

General Response Action	Remedial Technology	Process Option	Comments
		Treatment of HCH–contaminated soil Vacuum Thermal Desorption	However, no commercial experience with HCH and on side products of Vacuum Thermal Desorption.
	Mechano-chemical treatment	Waste treatment by MCD (Mechanochemical Dehalogenation)	Not retained due to lack of commercial experience with treatment of HCH. Limited capacity.
	Biological treatment	Treatment of HCH–contaminated soil by biodegradation	Retained because it is an effective and not expensive technology for less contaminated soil treatment.

6. Assembly and Description of Remedial Alternatives

In this chapter, the remedial technologies that were carried forward through the screening evaluation in Chapter 5 are combined to create several remedial alternatives for the remediation of HCH dumps and HCH-contaminated soil at the OHIS site. The development of the remedial alternatives was guided by the need for alternatives that will achieve the objectives of the remedial action and provide a range of remedial actions. Four remedial alternatives were developed using this approach. These alternatives intentionally differ in several respects, including:

- Remedial objectives they achieve and the degree to which they achieve them.
- Their reliance on containment versus removal, treatment and off-site disposal
- Estimated cost

These alternatives are consistent with the scope of work for this FS.

The major components of each of the four remedial alternatives are summarized in Table 9. The four alternatives are:

Alternative 1: Capping of both HCH dumps, including adjacent HCH contaminated soil

Alternative 2.1: Excavation of dumped HCH waste and HCH-contaminated soil with on-site waste treatment using Gas Phase Chemical Reduction and treatment of soil by biodegradation

Alternative 2.2: Excavation of dumped HCH waste and HCH-contaminated soil with on-site waste treatment using Gas Phase Chemical Reduction and disposal of contaminated soil in underground depository

Alternative 3.1: Excavation of dumped HCH waste and HCH-contaminated soil with on-site waste treatment using Base Catalyzed Decomposition and treatment of soil by biodegradation

Alternative 3.2: Excavation of dumped HCH waste and HCH-contaminated soil with on-site waste treatment using Base Catalyzed Decomposition and and disposal of contaminated soil in underground depository

These remedial alternatives are described in the following sections.

Table 11: Summary of Remedial Alternatives Being Considered for Remediation of HCH Dumps and HCH-contaminated Soil

Remedial Action	Remedial Technology	Process Option	Alternative 1	Alternative 2.1	Alternative 2.2	Alternative 3.1	Alternative 3.2
Containment	Capping	Geocomposite bentonite mat, protective liner with drainage and vegetative layers on the top	x				
Removal	Excavation	Removal of contaminated soil		x	x	x	x
		Waste removal		x	x	x	x
Disposal	Landfilling	Disposal in underground depository			x		x
Treatment	Chemical treatment	Waste treatment by GPCR (Gas Phase Chemical Reduction)		x	x		
		Waste treatment by BCD (Base Catalyzed Decomposition)				x	x
	Biological treatment	Treatment of HCH–contaminated soil by biodegradation		x		x	

Alternative 1: Capping of both HCH dumps

Alternative 1 relies on containment to address the remedial objectives. In alternative 1 both HCH dumps will be capped, with a deliberately minimal amount of movement of waste material. Alternative 1a comprises capping of both dumps and adjacent areas with contaminated soil only. Such alternative allows disposal of another 5,000 to 8,000 m^3 of waste (for example originated from demolition of former OHIS production and/or storage buildings). Alternative 1b comprises extension of present footprint of existing dumps by another 11,500 m^2 of impermeable bottom. Such extension allows dumping another 30,000 to 35,000 m^3 of waste.

The major components of Alternative 1 are:

- Site preparation (removal of bush, dissassembly of iron construction on the top of dump of α- and β- HCH);
- Installation of the impermeable base in the area between and surrounding (approximately 4,500 m^2 for Alternative 1a and 11,500 m^2 for Alternative 1b);
- Construction of a grading fill on both dumps;
- Capping of the regraded dumps, revegetation;
- Monitoring.

Figure 4 displays a cross section of the cap and the impermeable base of dumps to be installed. Figure 5 shows a layout of dump capping considered in Alternatives 1a and 1b. Figure 5 gives schematic cross sections of reclaimed dumps.

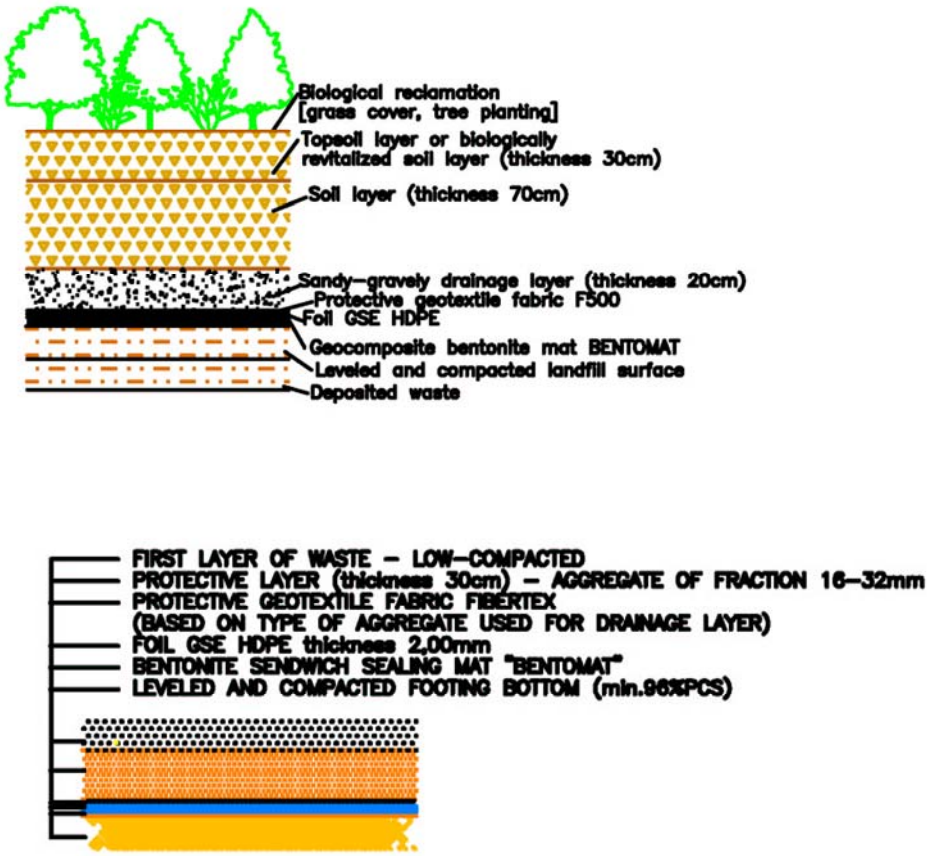


Figure 4: Cross section of impermeable cap (top) and base (bottom) of reclaimed dumps

Figure 5: Layout of dump capping (Alternative 1a – left, Alternative 1b – right)

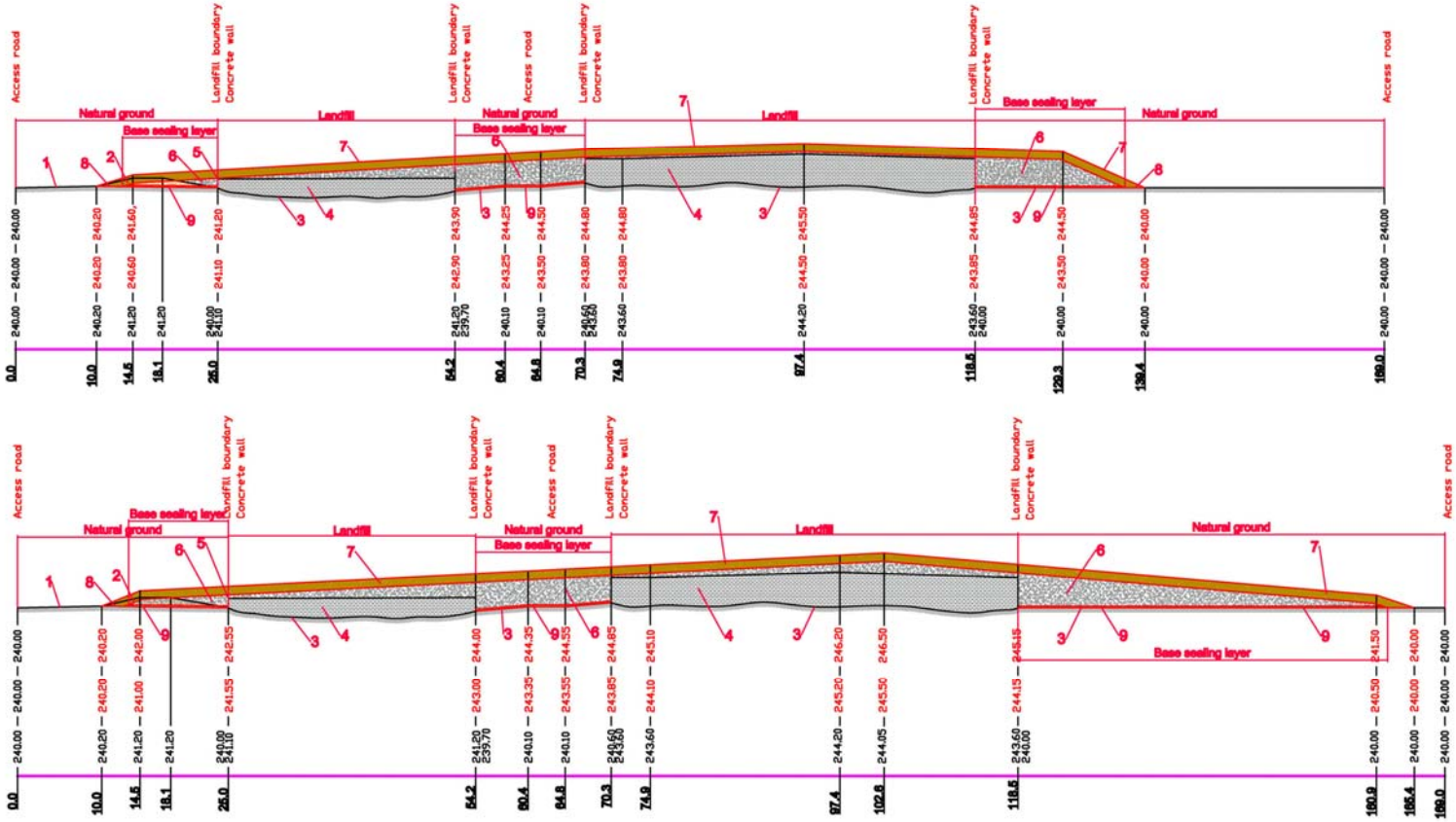


Figure 6: Cross section of capped dumps (Alternative 1a – top, Alternative 1b – bottom)

Alternative 2.1: Selective excavation of dumped HCH waste and HCH contaminated soil with on-site treatment of HCH waste using Gas Phase Chemical Reduction and on-site treatment of contaminated soil using biodegradation

Alternative 2.1 relies on removal and on-site treatment to address the remedial objectives. The major components of Alternative 3 are:

- Site preparation (removal of bush, dissassembly of iron construction on the top of dump of α- and β- HCH),
- Selective excavation of dumped waste, contaminated soil overlying and underlying both dumps as well as contaminated soil surrounding the δ- HCH dump and concrete constructions in both dumps.
- Treatment of excavated HCH waste on-site using Gas Phase Chemical Reduction technique.
- Treatment of excavated HCH-contaminated soil and debris (after crashing) using on-site biodegradation (DARAMEND).
- Backfilling of excatated pit by treated soil and landfilling of treated debris as non-hazardous waste.
- Monitoring.

Selective Excavation of Waste and Contaminated Soil

Alternative 2.1 consider selective excavation of HCH waste and HCH-contaminated soil and debris. Volume of material to be excavated is given in Table 9. Excavation would be by backhoe or other conventional technique under stringent health and safety measures. Excavated contaminated soil and debris will have to be temmporarly piled at the site. Measures must be undertaken (excavation *per partes*, capping of a temporar pile) in order to minimize emissions of contaminated dust from the pile.

Treatment of excavated material on-site using Gas Phase Chemical Reduction technique

The alternative 2.1 consider treatment of 29,000 tons of HCH waste by GPCR in a semi-mobile TORBED reactor of the capacity 500 to 2,000 tons/month. The full-scale 2xTORBED reactor would be installed on-site (required area 4,000m^2) with a capacity of 200 tons/month. Duration of treatment will be 13 years.

Treatment of excavated HCH-contaminated soil and debris (after crashing) using on-site biodegradation (DARAMEND®).

Approximately 22,300 tons of HCH-contaminated soil and crushed concrete will be biodegraded on-site using DARAMEND technology. Roofed and paved area of about 3,000 m^2 will be used (existing unused storage buildings can be used also). Assuming treatment of one batch (3,000 t) in 100 to 150 days, total duration of treatment will be 3 to 5 years. Underlying soil will have to be treated after excavation and treatment of HCH waste.

Alternative 2.2: Selective excavation of dumped HCH waste and HCH contaminated soil with on-site treatment of HCH waste using Gas Phase Chemical Reduction and disposal of contaminated soil in underground depository

Alternative 2.2 differs from Alternative 2.1 in handling with contaminated soil (and debris):

Disposal of excavated HCH-contaminated soil and debris (after crashing) in an underground depository.

Approximately 22,300 tons of HCH-contaminated soil and crushed concrete would be disposed in controlled underground depository of K+S Entsorgung GmbH in Herfa-Neurode, Germany. Obtaining permits for transportation of hazardous waste via transit countries and into Germany would take approximately 6 months. Transportation and disposal of contaminated material in the underground depository would take another 6 months (capacity of the underground depository is 200 000 tons/year). Underlying soil will have to be excavated/disposed after excavation and treatment of HCH waste.

Alternative 3.1: Selective excavation of dumped HCH waste and overlying soil with on-site treatment of HCH waste using Base Catalyzed Destruction and on-site treatment of contaminated soil using biodegradation

Alternative 3.1 relies on removal and treatment to address the remedial objectives. Alternative 3.1 differs from Alternative 2.1 only in technology used for HCH waste treatment. The major components of Alternative 3.1 are:

- Site preparation (removal of bush, dissassembly of iron construction on the top of dump of α- and β- HCH),
- Selective excavation of dumped waste, contaminated soil overlying and underlying both dumps as well as contaminated soil surrounding the δ- HCH dump and concrete constructions in both dumps.
- Treatment of excavated HCH waste on-site using Base Catalyzed Destruction (BCD) technique (such technology is currently operated by BCD CZ a.s. in Neratovice, Czech Republic).

- Treatment of excavated HCH-contaminated soil and debris (after crashing) using on-site biodegradation (DARAMEND).
- Backfilling of excatated pit by treated soil and landfilling of treated debris as non-hazardous waste
- Monitoring.

Volumes of excavated HCH waste and contaminated soil/debris is the same as in Alternatives 2 and 3. Treatment of contaminated soil and debris will be performed in the same way as in Alternative 2.1.

Treatment of excavated material on-site using BCD technique

The alternative 3.1 consider treatment of HCH waste (29,000 tons) on-site by BCD technique. The installed BCD technology can treat 750 tons per year per reactor, based on information given by the BCD licence holder (BCD CZ a.s., Czech Republic). More modules can be installed. Duration of treatment: 8 to 10 years.

Alternative 3.2: Selective excavation of dumped HCH waste and overlying soil with on-site treatment of HCH waste using Base Catalyzed Destruction and and disposal of contaminated soil in underground depository

Alternative 3.2 differs from Alternative 3.1 in handling with contaminated soil (and debris). Contaminated soil (and debris) will be disposed in the controlled underground depository in the same way as in Alternative 2.2.

7. Detailed Analysis of Selected Alternatives

The criteria for evaluating the remedial alternatives are technical, institutional, and economic considerations that decision-makers will take into account in selecting the remedial actions.

The following criteria were used to evaluate each remedial alternative:

- Protection of Human Health and the Environment
- Short-term Effectiveness
- Long-term Effectiveness
- Implementability
- Compliance with Current Env. Laws and Regulations

- Cost

Each of these evaluation criteria is described below.

PROTECTION OF HUMAN HEALTH AND THE ENVIRONMENT

This evaluation criterion provides a final check to assess whether each alternative provide adequate protection of human health and the environment.

SHORT–TERM EFFECTIVENESS

This evaluation criterion addresses the effects of the alternative during the construction and implementation phase until remedial response objectives are met. Under this criterion, alternatives are evaluated with respekt to their effects on human health and the environent during implementation of the remedial action addresing following factors:

- Protection of community during remedial actions
- Protection of workers during remedial actions
- Environmental impacts that may result from the construction and implementation of a remedial alternative
- Time until remedial action objectives are achieved.

LONG-TERM EFFECTIVENESS AND PERMANENCE

The evaluation of alternatives under this criterion addreses the reset of a remedial action in terms of this risk remaining at the site after response objectives have been met.

Long-term effectiveness will be evaluated according to (1) magnitude of residual risk remaining at the site after implementation of the remedial alternative and (2) the adequacy and reliability of remedial controls. The long-term reliability of the remedial actions is judged according to the need for replacing components of the remedy and consequences of the failure of those components.

IMPLEMENTABILITY

The implementability criterion encompasses the technical and administrative feasibility of implementation and the availability of required services and materials taking into account following factors:

- Ability to construct and operate the technology
- Reliability of the technology

- Ease of performing additional remedial work if necessary
- Ability to monitor effectiveness of remedy
- Ability to obtain approvals from authorities
- Coordination with authorities
- Availability of offsite treatment, storage, and disposal services and capacity
- Availability of necessary equipment and specialists
- Availablity of prospective technologies

An important aspect of implementability is the availablity of equipment and services (i.e. equimpent and services available in Macedonia).

For the FS assumption is that all workers would be trained in the specific health and safety procedures required by the Macedoinian regulatory authorities.

SOCIOECONOMIC EFFECTS

The socioeconomic effects will be evaluated according to the economic effect of the landuse after completion of each alternative.

COMPLIANCE WITH CURRENT ENVIRONMNETAL LAWS AND REGULATIONS

The assessment against this criterion describes how the alternative complies with the current Macedonian environmental legislation or if a waiver is required and how it is justified.

COST

The costs for the corrective measures are made up of capital cost, operating and maintenance cost.

The capital cost consist of direct (construction) and indirect (nonconstruction and overhead) costs. Direct costs include expenditures for the equipment, labor and materials necessary to install remedial actions. Indirect costs include expenditures for engineering, financial and other services that are not part of actual installation activities but are required to complete the installation of remedial alternatives.

Operating and maintenance costs are post-construction costs necessary to ensure the continued effectiveness of a remedial action.

Capital cost and operating and maintenance cost estimates for each of the remedial alternatives were prepared using information from Macedonian construction experience, estimates of remedial contractors and ENACON experience with similar projects. Unit cost estimates for capping of both dumps were

prepared by CHEMIA SYSTEM GEO, a Czech engineering company working under a subcontract of ENACON. Unit cost for treatment of HCH waste using BCD method was provided by company BCD CZ a.s., Czech Republic (license holder). Unit cost for disposal of HCH-contaminated soil was provided by company K+S Entsorgung GmbH (operator of the controlled underground waste depository in Herfa-Neurode, Germany).

The cost estimates were prepared as the part of the overall evaluation of remedial alternatives. The estimates were based on information available at the time of the FS and on contraction assumptions that are reasonable for the state of the practice in Macedonia. The availability and cost of remedial services is expected to change, so these cost estimates should be refined in further stages of design or as new information becomes available.

Final project costs will depend on actual labor and material costs, the capabilities of local contractors, the amount of imported equipment and labor, actual site conditions, productivity, actual health and safety requirements, competitive market conditions, final project scope, final project schedule, the firm selected for final engineering design and other factors.

The cost estimates in this FS are considered order of magnitude with an expected accuracy of plus 50% to minus 30%. The cost-estimate is an unavoidable consequence of the conceptual stage of this remedial project. The range does not account for changes in the scope of the alternatives.

Table 12: Detailed Evaluation of Remedial Alternatives

Criteria	Alternative 1 Capping of both HCH dumps	Alternative 2.1 Selective excavation of dumped HCH waste and HCH contaminated soil with on-site treatment of HCH waste using GPCR and on-site treatment of contaminated soil using biodegradation	Alternative 2.2 Selective excavation of dumped HCH waste and HCH contaminated soil with on-site treatment of HCH waste using GPCR and disposal of contaminated soil in underground depository	Alternative 3.1 Selective excavation of dumped HCH waste and overlying soil with on-site treatment of HCH waste using BCD and on-site treatment of contaminated soil using biodegradation	Alternative 3.2 Selective excavation of dumped HCH waste and overlying soil with on-site treatment of HCH waste using BCD and disposal of contaminated soil in underground depository
Protection of Human Health and the Environment					
- inhalation of HCH contaminated dust particles	Cap will minimize the emission of HCH vapours and contaminated dust thus will reduce inhalation risk at the site	Removal of waste and its landfiling off-site would eliminate emission of HCH vapours and thus reduces inhalation risk	The same as for Alternative 2.1	The same as for Alternative 2.1	The same as for Alternative 2.1
- ingestion of contaminated vegetables grown on HCH contaminated off-site topsoil (airborne migration)	Cap will minimize the emission of HCH contaminated dust thus reduces ingestion risk.	Removal of waste and its landfilling off-site would eliminate emission of HCH contaminated dust thus reduces inhalation risk	The same as for Alternative 2.1	The same as for Alternative 2.1	The same as for Alternative 2.1
- groundwater contamination	Cap will minimize leaching of HCH into underying aquifer by reducing/eliminating infiltration	Removal of waste and contaminated superficial soil will significantly reduce leaching of HCH into underlying aquifer, however will not totally eliminate it unless complete treatment of unsaturated zone is performed.	The same as for Alternative 2.1	The same as for Alternative 2.1	The same as for Alternative 2.1
Short-term effectiveness					
- community protection	Temporary increase (however not significant) in dust production through cap installation	Waste/contaminated soil would remain uncovered during excavation. Temporary increase of off-site emissions of vapours and contaminated dust would create some risks to community. The risks could be reducted by using	Similar potential risks to those in Alternative 2.1, however limited to a nearby community (disposal of contaminated soil off-site, rather than on-site treatment). Similar protective measures must be undertaken.	The same as for Alternative 2.1	Similar potential risks to those in Alternative 2.1, however limited to a nearby community (disposal of contaminated soil off-site, rather than on-site treatment). Similar protective measures must be undertaken.

		special equipment and procedures.			
- worker protection	Cap-system construction would probably require chemical-resistant suit with an air-purifying respirator.	Excavation activities probably require chemical-resistant suit with an air-purifying respirator or even with a self-contained breathing apparatus (SCBA). Continuous monitoring would be required to maintain the adequacy of the protective measures. GPCR technology for waste treatment is very stable and robust, but handling with hydrogen requires special care.	Excavation – see Alternative 2.1 Contaminated soil will be hauled to the underground depository in air-tight big bags	Excavation – see Alternative 2.1 BCD technology usues heath&safety procedures approved for much more toxic waste (dioxines)	Excavation – see Alternative 2.1 Contaminated soil will be hauled to the underground depository in air-tight big bags
- environmental impacts	Environmnetal effects during construction are expected to be minor if good construction practises are used. Some increased contaminated dust emissions would be expected as the cap is contructed.	Environmetal effects during remedial action would be limited to fugitive vapour and contaminated dust emissions from excavation operations. Techniques of excavation and pace of work must be maintained in oder to minimize vapour and contaminant dust releases. GPCR technology produced neutralization water from a scrubber. Produced hydrocarbons and methane can be reused in the process or burned. Biological remediation of HCH-contaminated soil by DARAMEND® will reduce its ecotoxicity.	Excavation activities and GPCR treatment – the same as for Alternative 2.1 Disposal of contaminated soil in the underground depository is environmentally safe. Questionable is transportation of 22300 tons of soil to Germany (1700 km) from the CO_2 production point of view.	Excavation activities - similar to Alternative 2.1 Final waste generated by BCD technology is salt that can be used for winter treatment of roads. Other by-products (oil and sodium hydroxide) can be reprocessed. Biological remediation of HCH-contaminated soil by DARAMEND® will reduce its ecotoxicity.	Excavation activities – and BCD treatment – the same as for Alternative 3.1 Disposal of contaminated soil in the underground depository is environmentally safe. Questionable is transportation of 22300 tons of soil to Germany (1700 km) from the CO_2 production point of view.

- time until action is complete	Construction of the cap would require about 4 months, following design approval. Another 6 months of designing and approval phase. In total about 1 years.	Considering capacity of GPCR 200 tons/months – 13 to 15 years. Another 2 years of designing and approval phase. In total 16 to 18 years.	Considering capacity of GPCR 200 tons/months – 13 to 15 years. Another 2 years of designing and approval phase. Transportation and disposal of contaminated soil in the underground depository in Germany would last 1 year, incl. permitting. In total 16 to 18 years.	Considering capacity of the BCD technology 750 tons/ year /reactor and operating 4 reactors - 8 to 10 years. Another 2 years of designing and approval phase. In total 11 to 13 years.	Considering capacity of the BCD technology 750 tons/year/reactor and operating 4 reactors - 8 to 10 years. Another 2 years of designing and approval phase. Transportation and disposal of contaminated soil in the underground depository in Germany would last 1 year, incl. permitting. In total 11 to 13 years.
Long-term effectiveness					
- inhalation of HCH contaminated dust particles	Risk eliminated/minimized as long as cap is maintained. Because source is only contained, inherent hazard of waste remains	Risk eliminated forever (assuming the underlying superficial contaminated soil is treated as well).	The same as for Alternative 2.1	The same as for Alternative 2.1	The same as for Alternative 2.1
- ingestion of contaminated vegetables grown on HCH contaminated topsoil (airborne migration)	Risk eliminated/minimized as long as cap is maintained. Because source is only contained, inherent hazard of waste remains	Risk eliminated forever (assuming the underlying superficial contaminated soil is treated as well).	The same as for Alternative 2.1	The same as for Alternative 2.1	The same as for Alternative 2.1
- groundwater contamination	Risk eliminated/minimized as long as the cap is maintained, , inherent hazard of waste remains	Risk minimized forever however not totally eliminated it unless complete treatment of unsaturated zone is performed.	The same as for Alternative 2.1	The same as for Alternative 2.1	The same as for Alternative 2.1
Adequacy and Reliability of Controls	Capping is considered adequate method for containing waste materials in place and controlling releases of hazardous materials. Reliabity of cap can be high if designed and installed properly.	Removal (excavation) of waste is adequate and reliable if done with proper health and safety procedures and contingency measures in place for leaching control and vapour and dust suppression.	Excavation activities and on-site treatment of HCH waste – the same as for Alternative 2.1 Disposal of hazardous substances in a controlled underground depository is considered a reliable	Similar to Alternative 2.1	Similar to Alternative 2.2

		On-site treatment of excavated waste and contaminated soil is considered a reliable means of control.	means of control.		
Socioeconomic Effects					
Socioeconomic Effects	Cap will limit the future land use of the site to industrial one and will reduce the on-site area that can be in future leased or sold to an investor.	Removal of waste and contaminated superficial soil will allow broader future use of the land (except for sensitive ones – residential area, schools, hospitals,..)	The same as for Alternative 2.1	The same as for Alternative 2.1	The same as for Alternative 2.1
Implementability					
- ability to construct and operate	Simple to construct.	Excavation of the waste material is rather difficult but technically feasible with current technology. Controlling vapour, dust and odor releases during excavation and transportation would be a major constrain and could cause work to stop or slow down if emission become excessive. GPCR method for HCH waste treatment is theoretically implementable, however **has not been proved in a full scale.** There are many unknowns about current availability of GPCR treatment facility.	The same as for Alternative 2.1.	Excavation of waste and contaminated soil, see Alternative 2.1. BCD method for HCH waste treatment is implementable. BCD treatment facility is currently operated in a full scale by company BCD CZ s.r.o. in the Czech Republic	The same as for Alternative 3.1
- ease of doing more action if needed	Rather simple to extend and/or modify a cap.	Will not be needed. Alternative considers removal of all waste in both dumps and superficial contaminated soil.	The same as for Alternative 2.1.	The same as for Alternative 2.1.	The same as for Alternative 2.1.
- ability to monitor effectiveness	Proposed monitoring can give notice of failure, however, interference of monitoring results by other contaminant sources (contaminated buildings)	Removal of waste (above-ground dumps) is rather transparent activity. Remedial monitoring will be focused on monitoring of vapour and dust release	The same as for Alternative 2.1	Similar to Alternative 2.1	Similar to Alternative 2.1

	may occur.	during excavation and on sampling of contaminated soil to be excavated. Monitoring of potential off-gases from GPCR and of treated soil is easy to perform.			
- ability to obtain approvals and coordinate from/with authorities	Need a construction permit. Should be easy to obtain.	Installation of such facility will have to pass EIA procedure.	Installation of such facility will have to pass EIA procedure. Transporation of contaminated soil to underground depository in Germany will require permits of transit countries and of relevant German Authorities.	Installation of such facility will have to pass EIA procedure.	Installation of such facility will have to pass EIA procedure. Transporation of contaminated soil to underground depository in Germany will require permits of transit countries and of relevant German Authorities.
- availability of equipment, materials	Material (HDPE liner) is readily available.	GPCR technology is not available in Macedonia, must be purchased or leased from the vendor. Present availability of such facility is not known at present.	The same as for Alternative 2.1.	BCD technology is not available in Macedonia at present. However, BCD CZ would be able to bring its technology 2 reactors.	The same as for Alternative 3.1.
- availability (status) of technologies	Cap technology readily available	The GPCR technology is not commercialized, yet. Experience with PCB, DDT or HCH, not yet with HCH. GPCR facility is not available in Macedonia, must be purchased or leased from the vendor. Present availability of such facility is not known. Biological remediation of HCH-contaminated soil by DARAMEND® is proved method.	For GPCR technology, see Alternative 2.1. Underground waste depository in Herfa-Neurode, Germany is authorized to store HCH-contaminated soil and has sufficient free capacity.	The BCD technology is commercialized since the beginning of 1990ś. In 2000 – 2002 the technology was used in Spain to destruct 3,500 t of HCH waste. Recently BCD technology was successfully applied for remediation of construction waste and soil contaminated with dioxins and some chlorinated pesticides in Neratovice, Czech Republic. Biological remediation of HCH-contaminated soil by DARAMEND® is proved method.	For BCD technology, see Aternative 3.1
Compliance with Current Env. Laws and Regulations					

Compliance with Current Env. Laws and Regulations	This alternative probably would meet current Macedonian regulations.	This alternative probably would meet current Macedonian regulations.	This alternative probably would meet current Macedonian regulations.	This alternative probably would meet current Macedonian regulations.	This alternative probably would meet current Macedonian regulations.
Estimated Cost					
Estimated Cost (Million Euro)	0.5 (Alternative 1a) – 1.2 (Alernative 1b)	17	31	24	38

8. Comparative Analyses of Selected Alternatives

The comparative analysis of the remedial alternatives is intended to identify differences among alternatives and highlight the discriminating features listed in Table 11. The comparative analysis discusses tradeoffs among remedial alternatives.

PROTECTION OF HUMAN HEALTH AND THE ENVIRONMENT

All of the remedial alternatives are considered protective of human health and the environment. The differences are in the techniques used and the degree of protectivness. Alternative 1 would minimize emission of HCH vapours and contaminated dust and would minimize leaching of HCH into aquifer by capping of both HCH dumps. Alternatives 2 and 3 would provide the additional degree of protection by removing the HCH waste and contaminated soil and disposing it off-site or treating it on-site. Leaching of HCH into underlying aquifer would not be totally eliminated unless complete treatment of unsaturated zone is performed however would be sufficiently reduced.

SHORT–TERM EFFECTIVENESS

The effects on the community during the implementation of remedial actions are related to the risks caused by dismantling and excavation of HCH dumps (Alternatives 2 and 3), to the amount of truck traffic required to haul HCH-contaminated soil for disposal in Germany (Alternatives 2.2 and 3.2) and to HCH waste and HCH-contaminated soil handling during on-site treatment (Alternatives 2.1 and 3.1). These effects can be reduced by preventive measures. Nevertheless, Alternatives 2 and 3 would generate significantly higher degree of potential exposure and nuissances (noise, odour) than Alternative 1.

With regards to worker protection, all alternatives consider protection of workers performing remedial activities. In Alternative 1, cap construction activities would require use of chemical-resistant suit with an air-purifying respirator. Excavation of HCH waste within Alternatives 2 and 3 would require use of the same protection however in some workplaces use of chemical-resistant suit with self-contained breathing apparatus (SCBA) would be necessary. In case of Alternatives 2 to 3 continuous monitoring would be required to maintain the adequacy of the protective measures.

The differences in the environmental effects are similar to the issues raised regarding community protection. That is, environmental effects would be related to releases generated during dismantling and excavation of HCH dumps (Alternatives 2 and 3). Additional risk of releasing hazardous substances to the environment relates to the on-site handling HCH-contaminated soil during on-site treatment (Alternatives 2.1 and 3.1) and to transportation of large amounts of hazardous waste to the underground depository in Germany (Alternatives 2.2 and 3.2). Technologies for HCH waste treatment are environment friendly. Products and by-products of treatment can be reused or reprocessed.

The major differences among alternatives in the time required for completing remedial actions are between Alternative 1 (capping) and the other alternatives. Alternative 1 would be the most readily implemented action, requiring approximately 1 year including designing and administration approval. Excavation alternatives would require between 11-13 years (Alternatives 3) and 16-18 years (Alternatives 2). It should be stressed that total time requirements of Alternatives 2 and 3 would strongly depends on capacity of GPCR and BCD technologies utilized.

LONG-TERM EFFECTIVENESS

For all remedial alternatives residual risks at the site were judged according to whether hazardous substances would remain or would be removed from the site, with or without treatment. For Alternative 1, all hazardous substances would remain on the site but would be isolated from direct contact and the effects of infiltration and leachate generation. Alternatives 2 and 3 would result in the removal of the HCH waste and HCH-contaminated superficial soil, leaving the least residual risk at the site.

SOCIOECONOMIC EFFECTS

Alternative 1 will limit the future land use of the site to industrial one and will make impossible to use the dump area in future. Nevertheless the site itself is located within the industrial zone and change of the landuse in at least medium-term is very unlikely.

Alternatives 2 and 3 would allow broader future use of the property except for sensitive ones such as residential, schools, hospitals, etc.

IMPLEMENTABILITY

Alternatives 1 is technically easy to implement and would require mainly conventional construction procedures modified to meet health and safety rules. Alternatives 2 and 3 that involve removal of HCH waste would be technically feasible but rather difficult to implement due to following factors:

- risks involved in excavation;
- control of air emissions during excavation (dust and organic vapours);
- operation of on-site treatment equipment;
- logistics of transporting large volumes of contaminated material off-site (Alternatives 2.2 and 3.2).

There are many unknowns about availability of GPCR (Alternatives 2) treatment facility. Furhermore GPCR method has <u>not</u> been commercialized, yet.

Both facilities GPCR (Alternatives 2) and BCD (Alternatives 3) must be imported to Macedonia from abroad. BCD technology has been already successfully applied in a full scale.

Administrative feasibility is difficult to judge. Final approval of Alternatives 2 and 3 will be very likely conditioned by EIA procedure. It can significantly prolong start of the remedial action. Administrative feasibility of Alternative 1 is much easier.

COMPLIANCE WITH CURRENT ENVIRONMENTAL LAWS AND REGULATIONS

The conceptual remedial alternatives considered in this FS were developed to comply with the expected requirements of the pending Macedonian environmental regulations and requirements defined in EU regulations. As Macedonian environmental legislation is being developed, the final design of the remedial actions must be tailored to comply with the exact requirements of the regulations that will be in effect when remedial activities are implemented.

ESTIMATED COST

Alternative 1 considering capping is relatively cheap (0.5 up to 1.2 million Euro). Costs for alternatives considering removal of HCH waste and HCH-contaminated soil range from about 17 million Euro (Alternative 2.1) to about 38 million Euro (Alternative 3.2).

9. Summary

The comparison of the remedial alternatives revealed four areas of relatively clear distinctions:

- Short-term effectiveness
- Technical feasibility
- Socioeconomic effects, and
- Estimated cost

There are no significant differences between individual alternatives with regards to protection of human health and the environment and to long-term effectiveness.

With regards to short-term effectiveness, Alternatives 2.1, 2.2, 3.1 and 3.2 (considering excavation of HCH waste and HCH-contaminated soil) would generate significantly higher degree of potential exposure to hazardous substances and nuissances (noise, odour) than Alternative 1 (capping of both HCH dumps and adjacent contaminated soil).

The estimated time for implementing the remedial alternatives was affected most significantly by the option of containing the HCH waste dumps or removing all the waste, including HCH-contaminated superficial soil and secondly, by option of handling the excavated material. Alternative 1 considering capping is estimated to take 1 year (including designing and approval phase). Excavation alternatives would require between 11-13 years (Alternatives 3) and 16-18 years (Alternatives 2). It should be stressed that total time requirements of Alternatives 2 and 3 would strongly depends on capacity of GPCR and BCD technologies utilized.

All alternatives were judged technically feasible. Alternatives 2 to 3, however would involve excavation of HCH waste and thus would be more difficult to implement mainly due to health and safety reasons. There are many unknowns about availability of GPCR treatment facility (Alternatives 3), furthermore GPCR method has not been commercialized, yet. Both GPCR and BCD facilities must be imported to Macedonia from abroad. BCD technology has been already successfully applied in a full scale (e.g. in the Czech Republic).

The socioeconomic effects discussed in this report depend on the removal of HCH dumps. Alternative 1 (considering capping) will limit the future land use of the site to industrial one and will make impossible to use the dump area in future. Nevertheless, the site itself is located within the industrial zone and change of the landuse in at least medium-term is very unlikely.

Alternatives 2 and 3 would allow broader future use of the property except for sensitive ones such as residential, schools, hospitals, etc.

Alternative 1 considering capping is relatively cheap (0.5 million to 1.2 million Euro). Costs for alternatives considering removal of HCH waste and HCH-contaminated soil range from about 17 million Euro (Alternative 2.1) to about 38 million Euro (Alternative 3.2). There is significant difference in cost between Alternatives 2.1 and 2.2 and

between Alternatives 3.1 and 3.2 due to significantly cheaper on-site treatment of contaminated soil (debris) using Daramend™ technology in comparison to disposal in the controlled underground depository in Germany (which is on the other hand more robust solution).

In sum, Alternative 1 is recommended for further considerations mainly due to relatively short time needed for achieving acceptable reduction of existing risks, relatively low exposure to hazardous substances during remedial action and low cost in comparison to other alternatives. Further, extension of present footprint of existing dumps with impermeable bottom and cap would allows dumping of waste originated from demolition of abandoned contaminated buildings in OHIS. Implementation of Alternative 1 will not disqualify any final displacement and treatment of waste in future, when advanced technologies will be further developed (and may be cheaper). Fundraising in the range of tens of millions € can be rather difficult under current economic situation. Alternative 3.1 comprising on-site treatment of excavated HCH waste using BCD technology and on-site biodegradation treatment of contaminated soil/debris using Daramend™ technology (for 24 million Euro) can be considered as the second best option, however pilot test of both method with "real" material is strongly recommended prior to final decision.

Prague, November 30, 2009

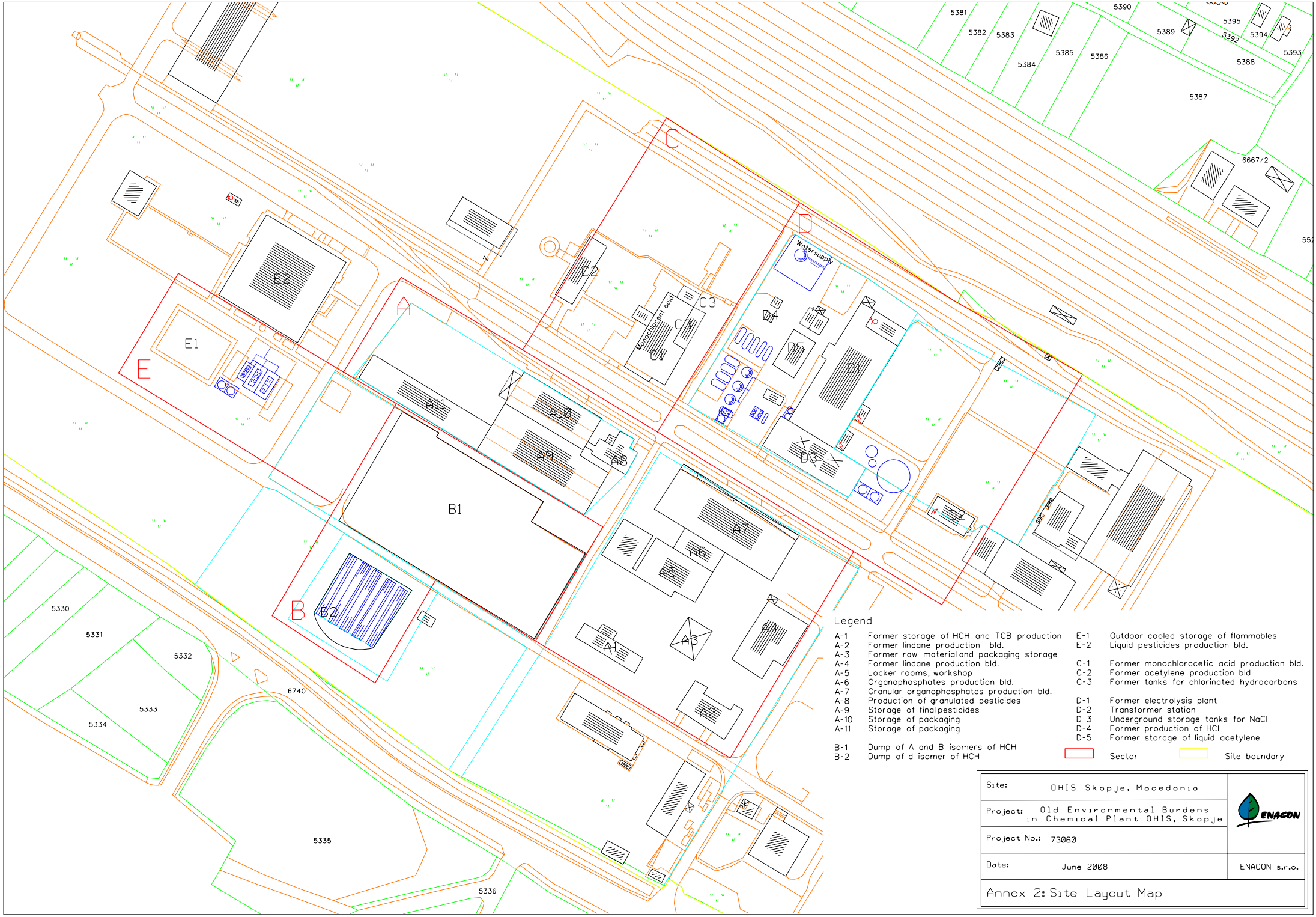
Annex 1

Site location map

Site: OHIS Skopje, Macedonia	ENACON
Project: Old Environmental Burdens in Chemical Plant OHIS, Skopje	
Project No.: 73060	
Date: July 2008	ENACON s.r.o.
Annex 1 : Site Location Map	

Annex 2

Site layout map



Legend

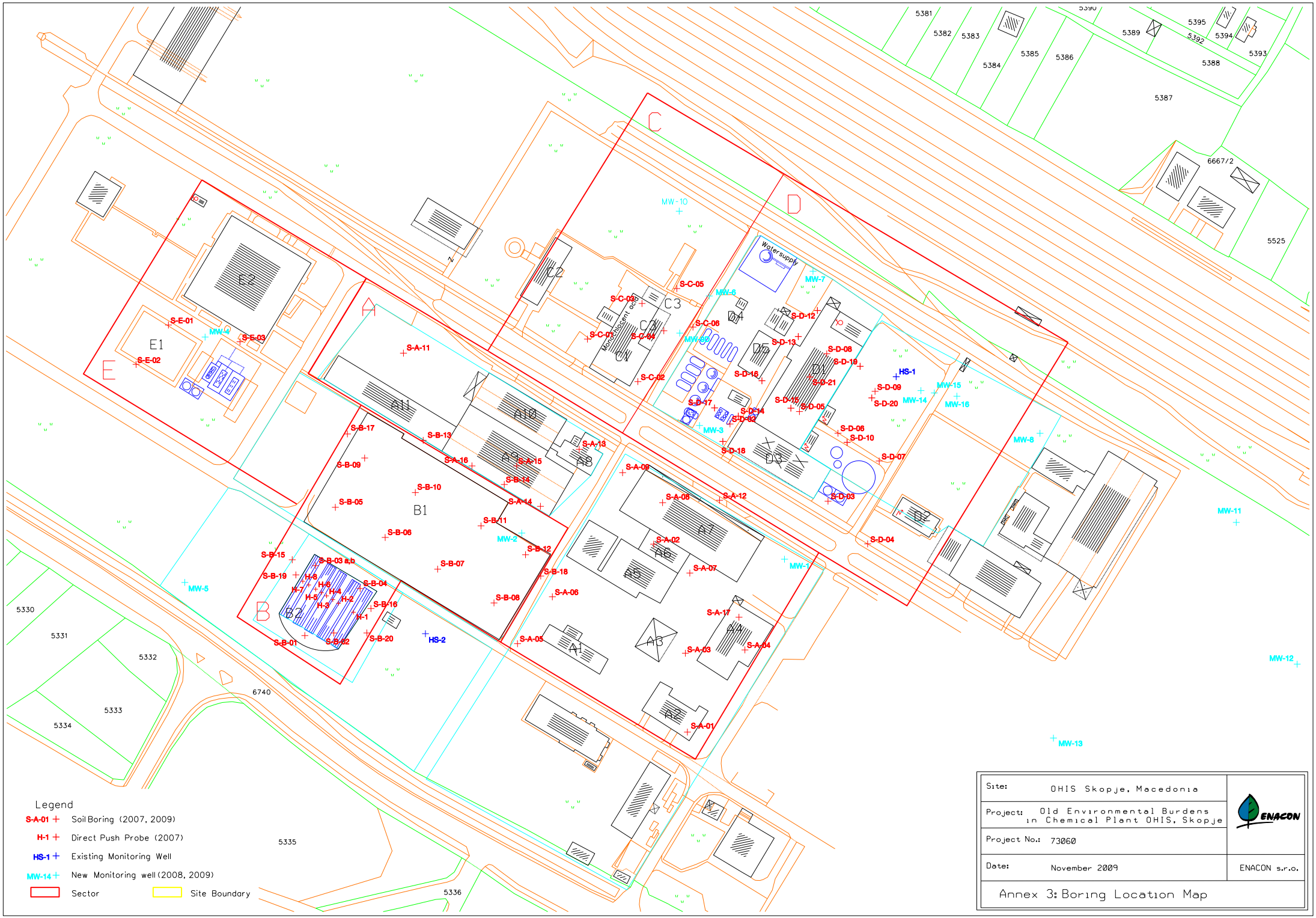
A-1	Former storage of HCH and TCB production	E-1	Outdoor cooled storage of flammables
A-2	Former lindane production bld.	E-2	Liquid pesticides production bld.
A-3	Former raw material and packaging storage		
A-4	Former lindane production bld.	C-1	Former monochloracetic acid production bld.
A-5	Locker rooms, workshop	C-2	Former acetylene production bld.
A-6	Organophosphates production bld.	C-3	Former tanks for chlorinated hydrocarbons
A-7	Granular organophosphates production bld.		
A-8	Production of granulated pesticides	D-1	Former electrolysis plant
A-9	Storage of final pesticides	D-2	Transformer station
A-10	Storage of packaging	D-3	Underground storage tanks for NaCl
A-11	Storage of packaging	D-4	Former production of HCl
		D-5	Former storage of liquid acetylene
B-1	Dump of A and B isomers of HCH		
B-2	Dump of d isomer of HCH		Sector / Site boundary

Site:	OHIS Skopje, Macedonia	ENACON
Project:	Old Environmental Burdens in Chemical Plant OHIS, Skopje	
Project No.:	73060	
Date:	June 2008	ENACON s.r.o.

Annex 2: Site Layout Map

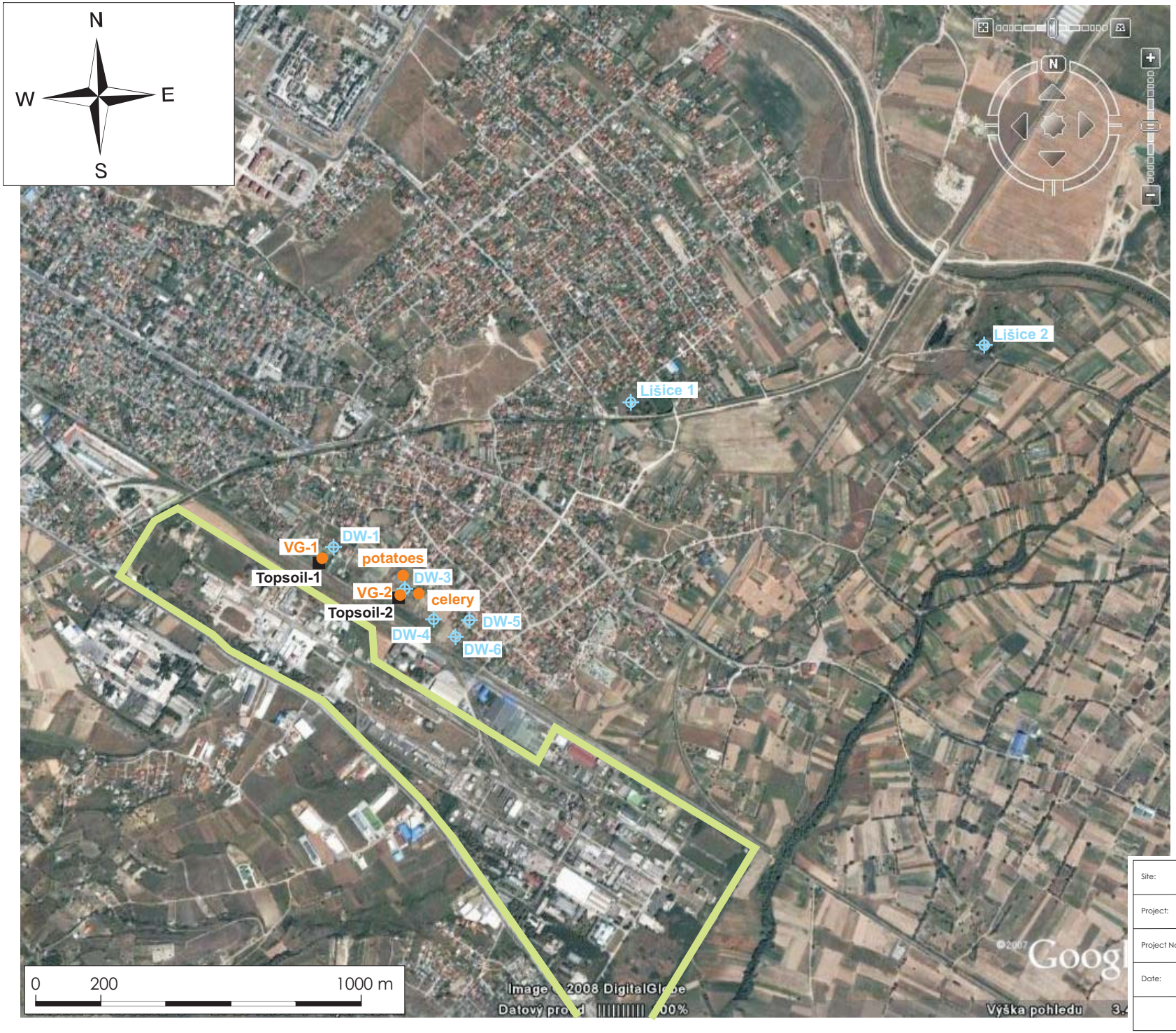
Annex 3

Boring and monitoring well location map


Legend
S-A-01 Soil Boring (2007, 2009)
H-1 Direct Push Probe (2007)
HS-1 Existing Monitoring Well
MW-14 New Monitoring well (2008, 2009)
Sector
Site Boundary
Site: OHIS Skopje, Macedonia
Project: Old Environmental Burdens in Chemical Plant OHIS, Skopje
Project No.: 73060
Date: November 2009
ENACON s.r.o.
Annex 3: Boring Location Map
ENACON
Water supply
Monodiacetat acid

Annex 4

Off-site sampling map



Legend:

- Groundwater sample
- Topsoil sample
- Vegetables sample
- OHIS boundary

Site:	OHIS Skopje, Macedonia
Project:	Old Environmental Burdens in Chemical Plant OHIS, Skopje
Project No.:	73060
Date:	November 2009

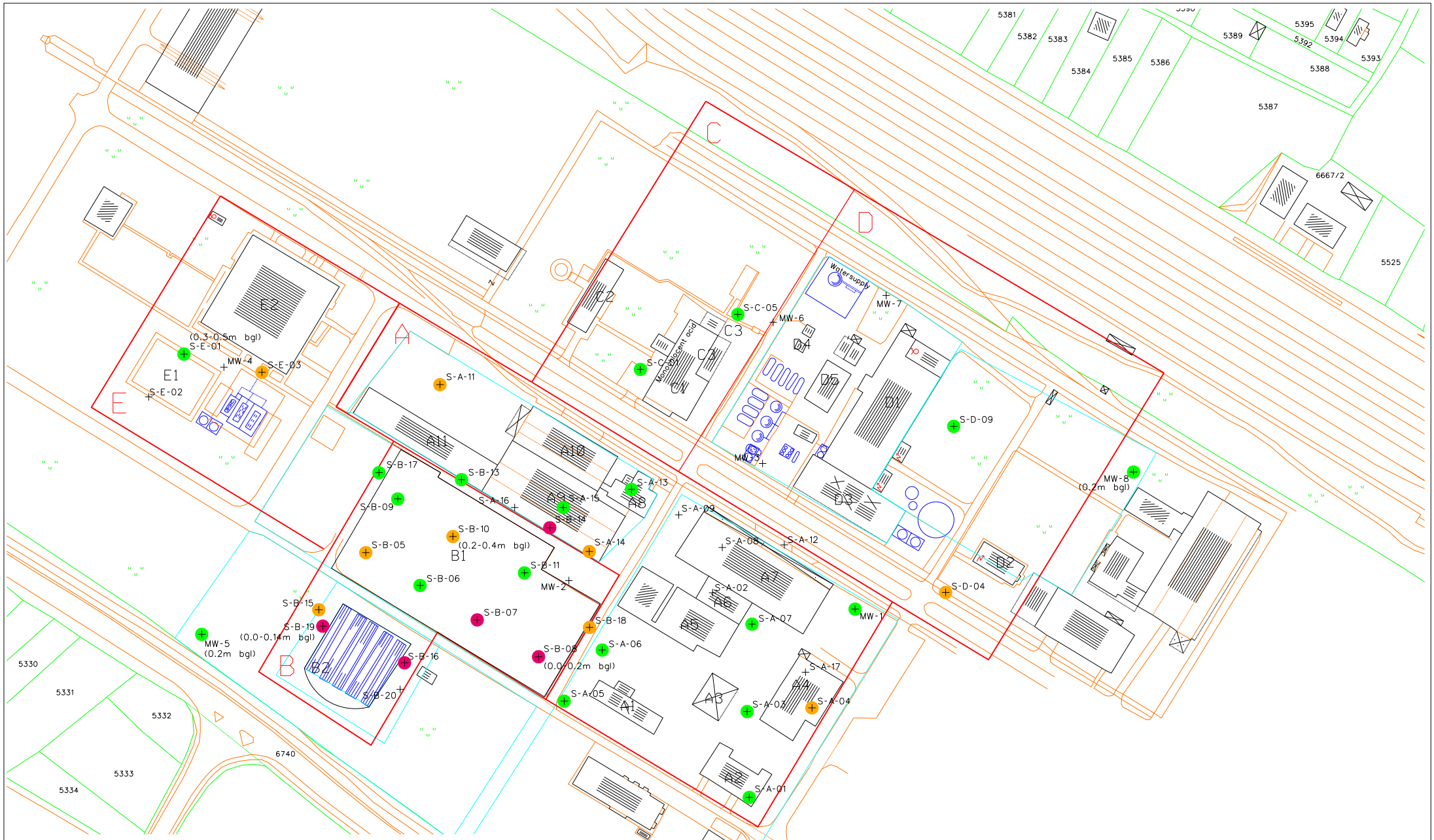
ENACON

ENACON s.r.o.

Annex 3.2: Off-site Sampling Map

Annex 5

Map of soil contamination by HCH (0.5 – 1.0 m bgl)



Legend

Concentration of HCH sum in Soil (mg/kg dry matter)
Depth interval: 0.5 - 1.0 m bgl

- c >= 200
- 200 > c >= 20
- 20 > c >= 2 (=Dutch Intervention Value)

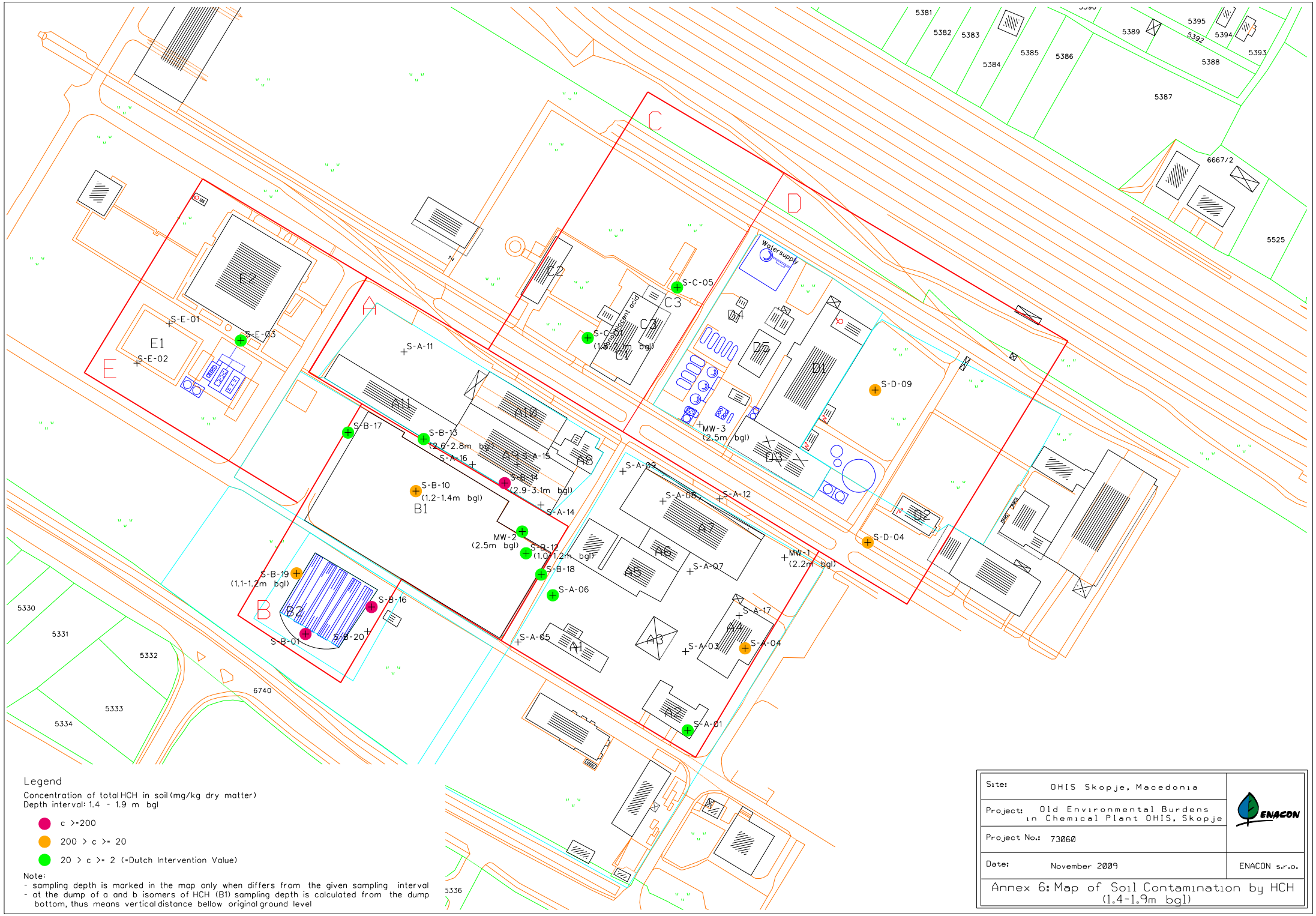
Note:
- sampling depth is marked in the map only when differs from the given sampling interval
- at the dump of a and b isomers of HCH (B1) sampling depth is calculated from the dump bottom, thus means vertical distance bellow original ground level

Site: OHIS Skopje, Macedonia	ENACON
Project: Old Environmental Burdens in Chemical Plant OHIS, Skopje	
Project No.: 73060	
Date: November 2009	ENACON s.r.o.

Annex 5: Map of Soil Contamination by HCH (0.5-1.0m bgl)

Annex 6

Map of soil contamination by HCH (1.4 – 1.9 m bgl)



Legend

Concentration of total HCH in soil (mg/kg dry matter)
Depth interval: 1.4 - 1.9 m bgl

- c >= 200
- 200 > c >= 20
- 20 > c >= 2 (=Dutch Intervention Value)

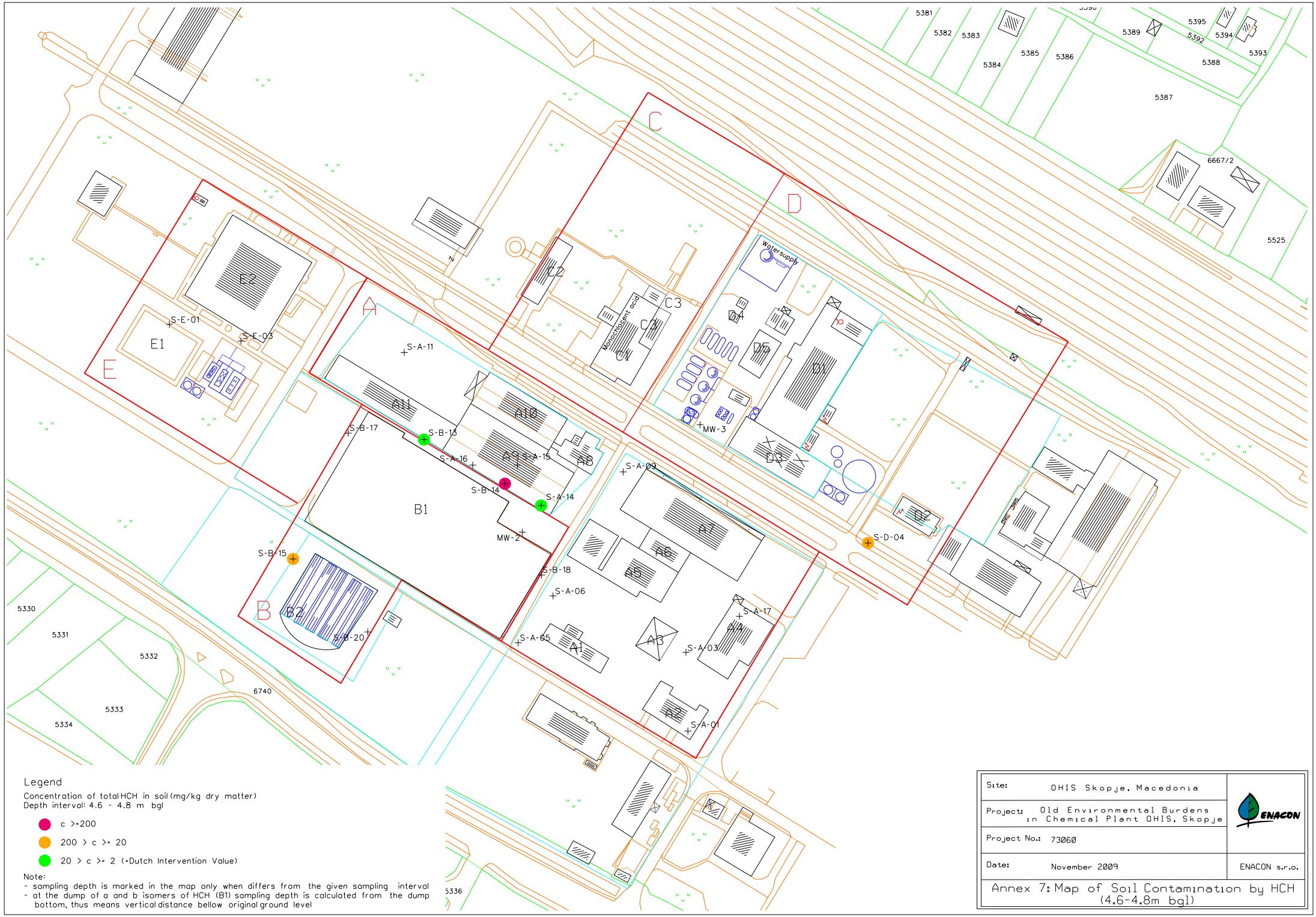
Note:
- sampling depth is marked in the map only when differs from the given sampling interval
- at the dump of a and b isomers of HCH (B1) sampling depth is calculated from the dump bottom, thus means vertical distance bellow original ground level

Site: OHIS Skopje, Macedonia	ENACON
Project: Old Environmental Burdens in Chemical Plant OHIS, Skopje	
Project No.: 73060	
Date: November 2009	ENACON s.r.o.

Annex 6: Map of Soil Contamination by HCH (1.4-1.9m bgl)

Annex 7

Map of soil contamination by HCH (4.6 – 4.8 m bgl)



Legend

Concentration of total HCH in soil (mg/kg dry matter)
Depth interval: 4.6 - 4.8 m bgl

- c >= 200
- 200 > c >= 20
- 20 > c >= 2 (=Dutch Intervention Value)

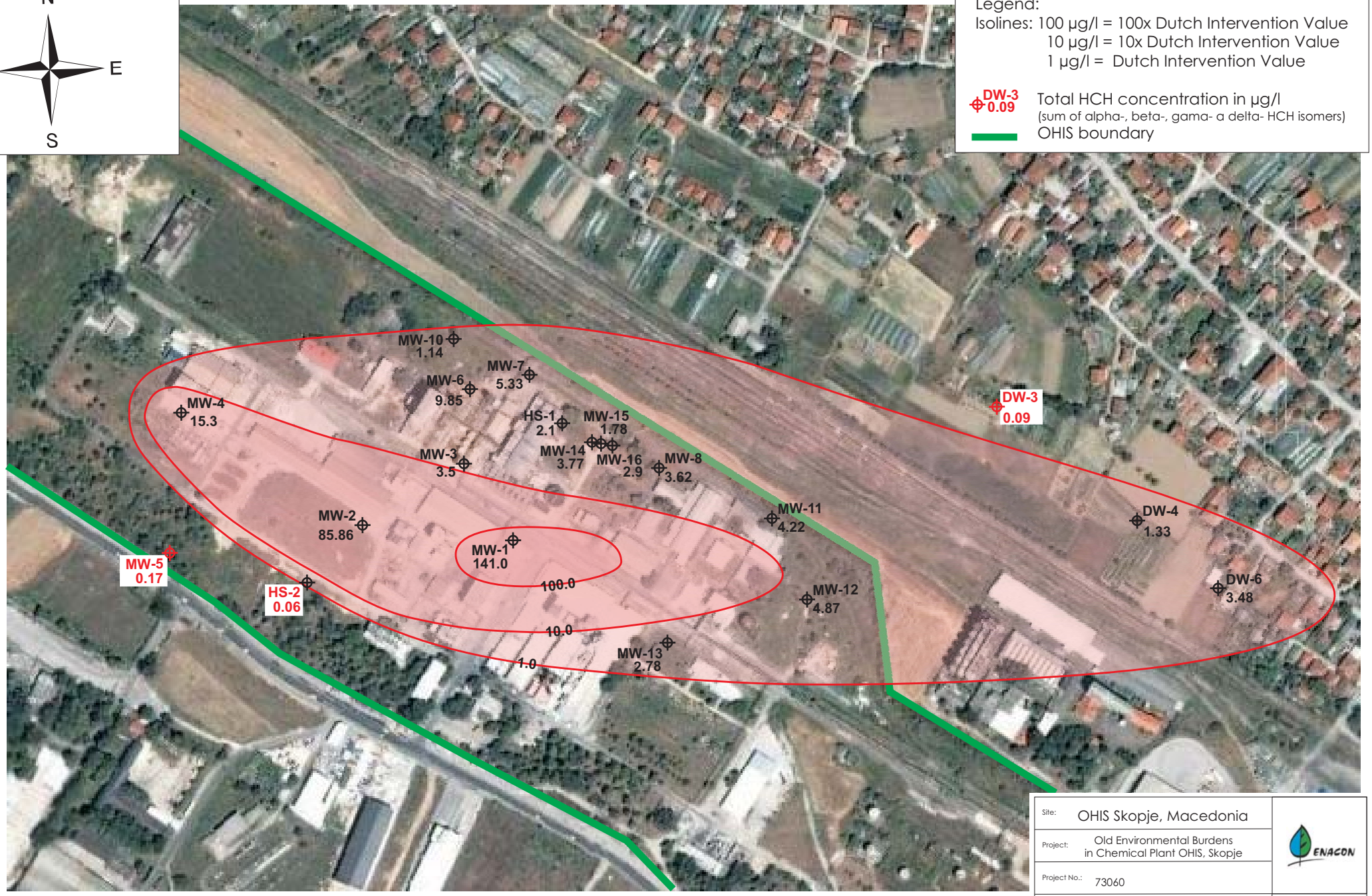
Note:
- sampling depth is marked in the map only when differs from the given sampling interval
- at the dump of a and b isomers of HCH (B1) sampling depth is calculated from the dump bottom, thus means vertical distance bellow original ground level

Site: OHIS Skopje, Macedonia	ENACON
Project: Old Environmental Burdens in Chemical Plant OHIS, Skopje	
Project No.: 73060	
Date: November 2009	ENACON s.r.o.

Annex 7: Map of Soil Contamination by HCH (4.6-4.8m bgl)

Annex 8

Map of groundwater contamination by HCH isomers



Source of satellite image: Google Earth

0 40 200 m

Site:	OHIS Skopje, Macedonia
Project:	Old Environmental Burdens in Chemical Plant OHIS, Skopje
Project No.:	73060
Date:	November 2009

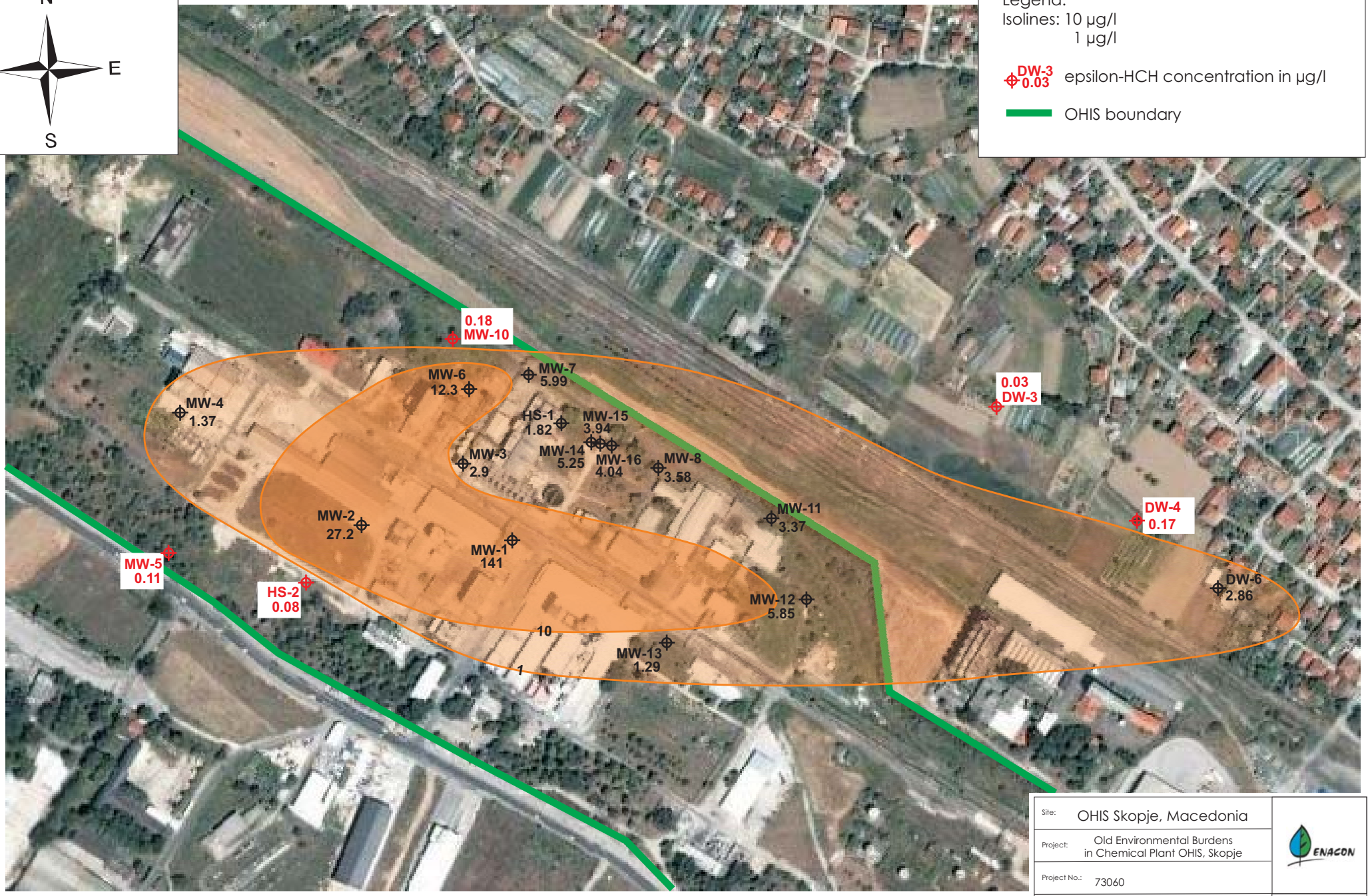
ENACON

ENACON s.r.o.

Annex 8: Map of Groundwater Contamination by HCH isomers (September 2009)

Annex 9

Map of groundwater contamination by ξ-HCH



Site: OHIS Skopje, Macedonia	ENACON
Project: Old Environmental Burdens in Chemical Plant OHIS, Skopje	
Project No.: 73060	
Date: November 2009	ENACON s.r.o.

Annex 9: Map of Groundwater Contamination by epsilon-HCH (September 2009)

Annex 10

Map of groundwater contamination by TCE

Site:	OHIS Skopje, Macedonia
Project:	Old Environmental Burdens in Chemical Plant OHIS, Skopje
Project No.:	73060
Date:	November 2009

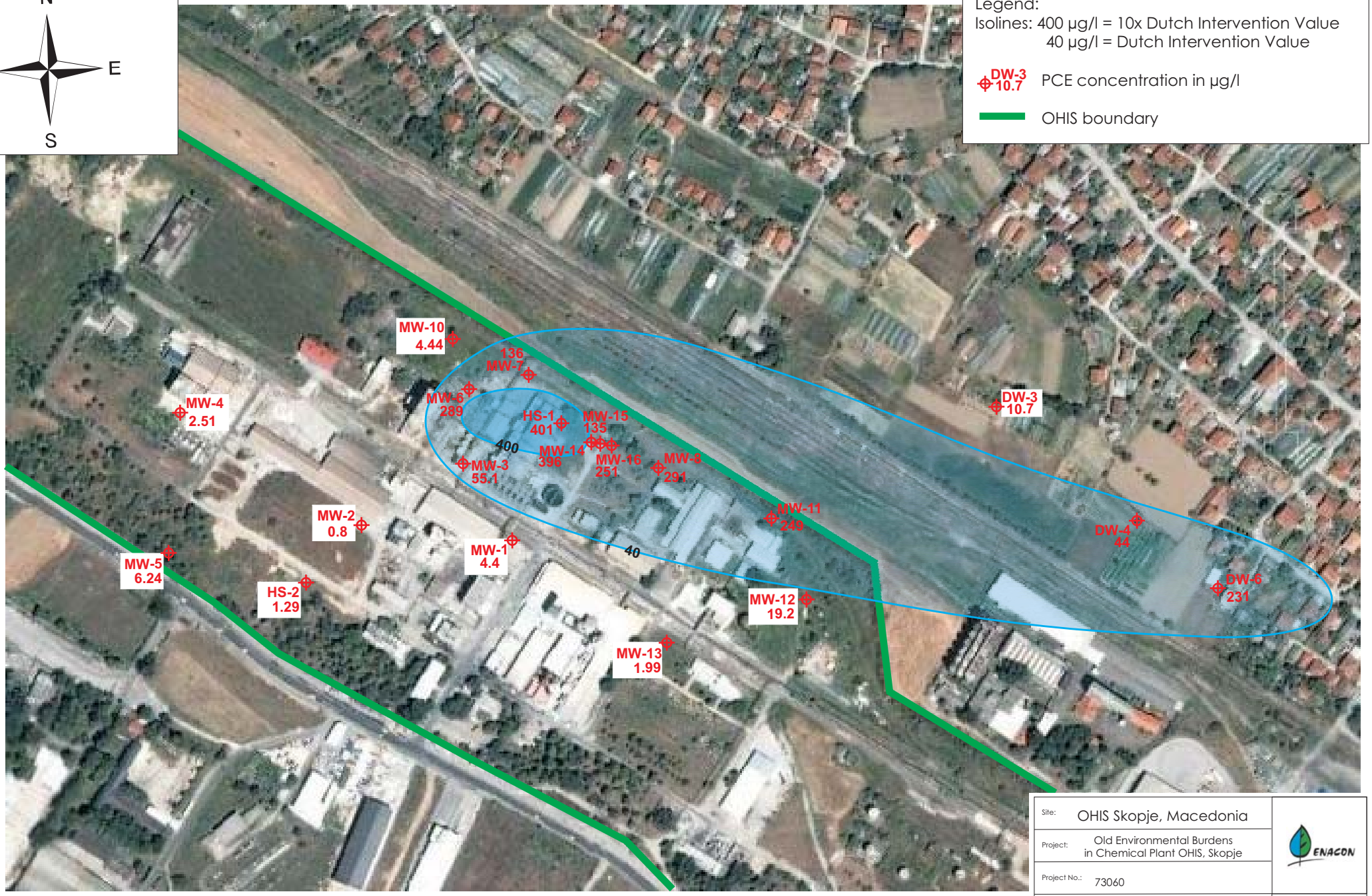
ENACON

ENACON s.r.o.

Annex 10:Map of Groundwater Contamination by TCE (September 2009)

Annex 11

Map of groundwater contamination by PCE



Site:	OHIS Skopje, Macedonia
Project:	Old Environmental Burdens in Chemical Plant OHIS, Skopje
Project No.:	73060
Date:	November 2009

ENACON

ENACON s.r.o.

Annex 11: Map of Groundwater Contamination by PCE (September 2009)

Annex 12

Map of groundwater contamination by TeCA

Site:	OHIS Skopje, Macedonia
Project:	Old Environmental Burdens in Chemical Plant OHIS, Skopje
Project No.:	73060
Date:	November 2009

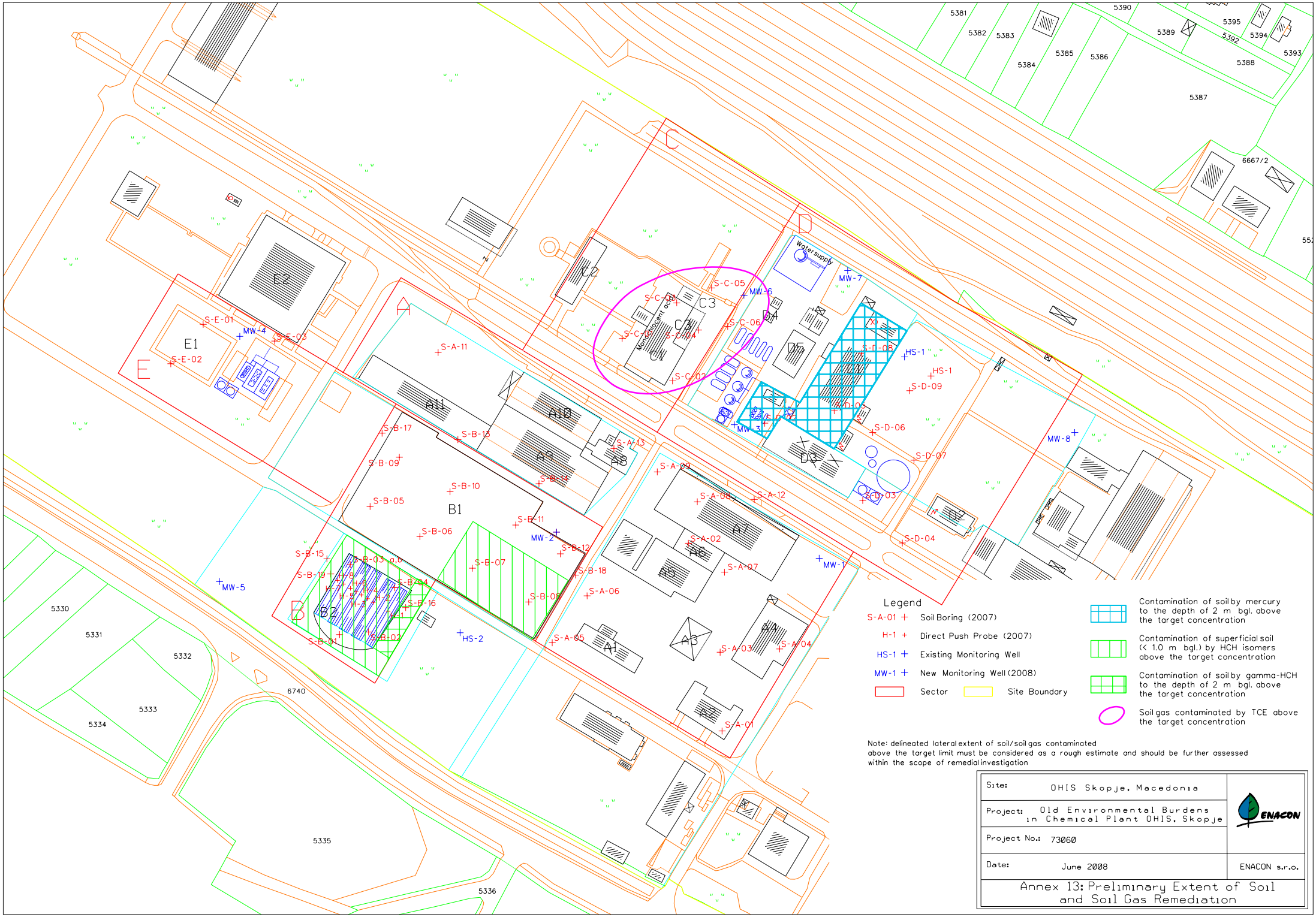
ENACON

ENACON s.r.o.

Annex 12: Map of Groundwater Contamination by 1,1,2,2 TeCA (September 2009)

Annex 13

Preliminary extent of soil and soil gas remediation


Legend
S-A-01 Soil Boring (2007)
H-1 Direct Push Probe (2007)
HS-1 Existing Monitoring Well
MW-1 New Monitoring Well (2008)
Sector
Site Boundary
Contamination of soil by mercury to the depth of 2 m bgl. above the target concentration
Contamination of superficial soil (< 1.0 m bgl.) by HCH isomers above the target concentration
Contamination of soil by gamma-HCH to the depth of 2 m bgl. above the target concentration
Soil gas contaminated by TCE above the target concentration
Note: delineated lateral extent of soil/soil gas contaminated above the target limit must be considered as a rough estimate and should be further assessed within the scope of remedial investigation
Site: OHIS Skopje, Macedonia
Project: Old Environmental Burdens in Chemical Plant OHIS, Skopje
Project No.: 73060
Date: June 2008
ENACON s.r.o.
Annex 13: Preliminary Extent of Soil and Soil Gas Remediation
Water supply
Monochloracetic acid
E1
E2
B1
B2
A1
A2
A3
A4
A5
A6
A7
A8
A9
A10
A11
C2
C3
D2
D3
D4
D5
MW-1
MW-2
MW-3
MW-4
MW-5
MW-6
MW-7
MW-8
HS-1
HS-2
5330
5331
5332
5333
5334
5335
5336
6740
5381
5382
5383
5384
5385
5386
5387
5388
5389
5390
5392
5393
5394
5395
6667/2