出國報告（出國類別：其他-國際會議）

出國計畫名稱：赴丹麥哥本哈根參加第 13 屆污染土地國際委員會議 (International Committee of Contaminated Lands，ICCL)

服務機關：行政院環保署
姓名職稱：蔡惠珍 環境技術師
派赴國家：丹麥
出國期間：106 年 9 月 29 日至 106 年 10 月 8 日
報告日期：107 年 1 月 3 日

摘要

本次除至丹麥哥本哈根參加第13屆污染土地國際委員會與ICCL NICOLE聯合研討會，並拜會丹麥政府環境部土壤污染組及土壤與地下水整治顧問公司(NIRAS與COWI)，瞭解丹麥政府對於土壤與地下水污染管制及污染土地再利用管理政策外，並至現地參訪，以與實務執行情況相結合。

藉由本次參加會議及拜會行程，瞭解歐洲各國對於飲用水源高度依賴地下水，故對地下水保護甚為重要。丹麥政府於預算有限情形下，對於土壤與地下水污染之整治，皆以不會造成地下水飲用水源威脅，及有機溶劑蒸氣不會入侵民宅等兩個重點，作為風險評估考量，於達到可接受風險後，即可開放土地再利用或將預算投入至其他污染場址改善。此外，丹麥政府亦積極推廣示範驗證場址，藉以找尋更適合的整治技術。

目次

一、目的

13th meeting of the International Committee on Contaminated Land 於丹麥哥本哈根舉辦，由污染土地國際委員會（International Committee on Contaminated Land）主辦，丹麥區政府（Danish Regions）協辦。本屆研討會共分為兩階段行程，包括 10 月 3 日至 4 日的污染土地國際委員會會議（ICCL Meeting）與共同論壇（Common Forum），以及 10 月 5 日至 6 日 ICCL 與 NICOLE（Network for Industrially Co-ordinated Sustainable Land Management in Europe）合辦之聯合研討會（Joint ICCL-NICOLE Conference）及實地考察 (Field Trip)。

除前述兩場會議外，本次出國參訪行程亦安排拜會丹麥首都區政府（Capital Region），以及 NIRAS 與 COWI 兩家工程顧問公司，藉以瞭解丹麥如何促使受污染私人場址同時進行整治及兼顧開發行為，藉此行程學習丹麥污染土地再利用在技術層面或法規層面之作法，供臺灣未來相關法規研擬或技術引進之參考，並希望達成下述目標。

1. 瞭解國際污染土地政策和管理制度，取其值得學習或應用之處，回饋至我國污染土地再利用政策制訂及推動。
2. 透過研討會與各國污染土地決策者、技術顧問等交流機會，接軌國際污染土地發展願景。

二、行程概述

106.9.29（五）-9.30（六）	啟程，出發至丹麥哥本哈根
106.10.1（日）	資料整理
106.10.2（一）	拜會丹麥政府中央區土壤污染組、土壤與地下水整治顧問公司 NIRAS，並至現地參訪（Skuldelev DNAPL 整治示範模場）
106.10.3（二）	拜會丹麥地下水整治顧問公司 COWI，並至現地參訪（哥本哈根港區污染土地開發）
106.10.4（三）	參加 ICCL 會議 (ICCL Meeting)
106.10.5（四）	參加 ICCL NICOLE 聯合研討會 (Joint ICCL NICOLE Conference)
106.10.6（五）	參加 ICCL NICOLE 聯合研討會 (Joint ICCL NICOLE Conference)，至現地參訪（Stengaarden Landfill 整治示範模場）
106.10.7（六）-10.8（日）	返程，回到臺北

三、過程

(一)拜會丹麥首都區政府

10 月 2 日上午拜會首都區政府（Capital Region）區域發展與土壤污染處的主管（*Head of Department, Department for Regional Development, Soil Contamination*）Gitte Larsen 女士，瞭解丹麥污染土地管制相關規定與現況；當日參訪照片如圖 3-1，Gitte Larsen 女士提供簡報如附錄 1。

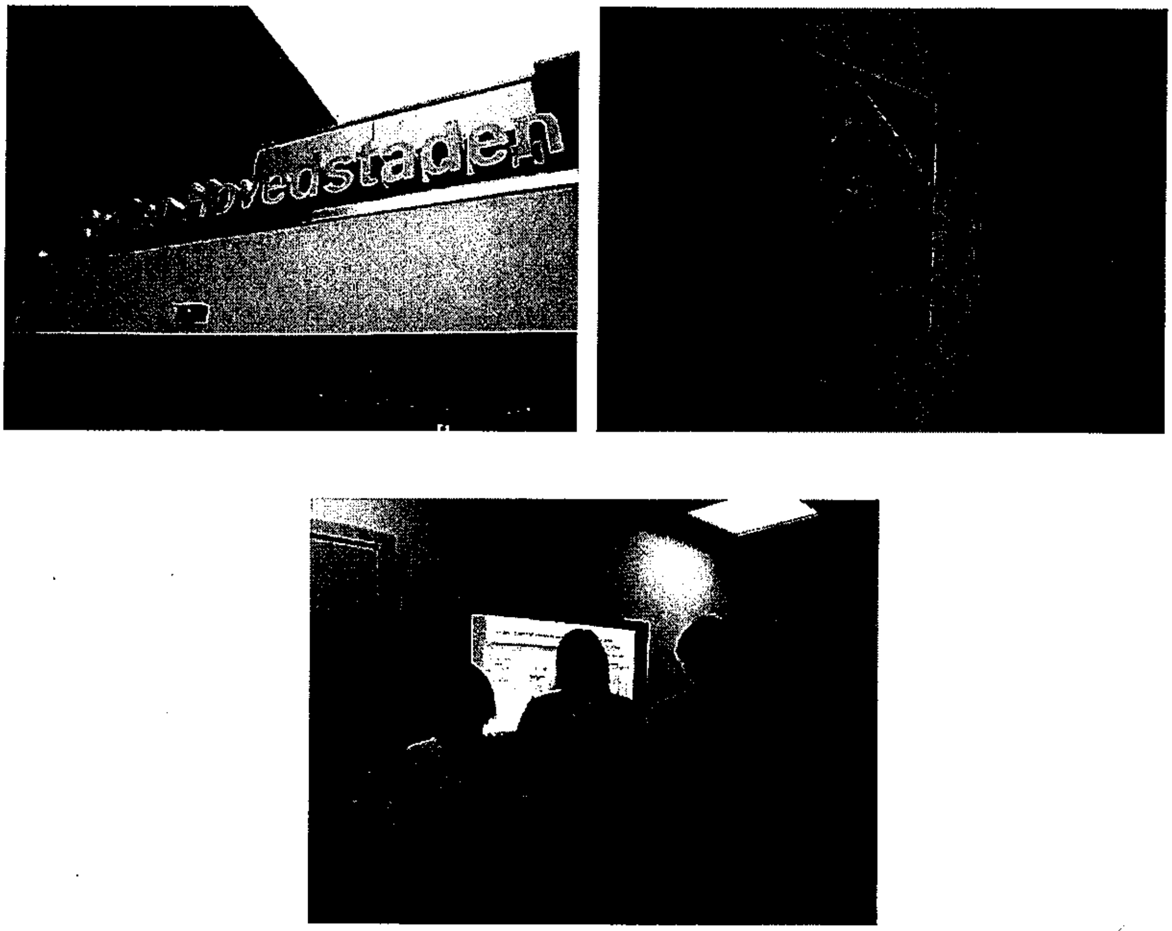


圖 3-1　首都區政府辦公室、與 Gitte Larsen 女士合影

丹麥在環保事務方面，中央為環境與食安部(Ministry of Environment and Food Safety)，下設 Danish EPA，負責政策、法規與各類行政指導，丹麥地方政府包括五個區（Region，相當於省，由過去之縣合併），以及 98 個市（Municipality）。其中五個區分別為首都區 (29 市)、西蘭區 (17 市)、南丹麥區(22 市)、中日德蘭區 (19 市) 以及北日德蘭區 (11 市)。

丹麥地勢平坦，沒有水庫，地下水是丹麥唯一飲用水水源，因此丹麥各級政府積極投入土壤與地下水污染整治，並充分考量人體健康風險、地下水水體保護，以及地表水體保護三大目標。

丹麥於 1980 年代中期後，因地下水污染飲用水水源問題日趨嚴重，因此展開污染場址調查，整治作業亦獲重視，並於 2001 年公告污染土壤法（Contaminated Soils Act）；當污染物濃度超過丹麥土壤與地下水污染物監測標準者，則登錄為「污染場址」（Registered sites）；截至 2017 年調查作業仍持續進行中。

於 2001 年污染土壤法公告前所發現之污染場址，或污染行為人已不在之污染場址，一般稱為「舊場址」（Old sites）。丹麥政府認為，因相關污染之造成，發生時間經常為 1960、1970 年代，甚或更早之前，係當時缺乏知識、技術侷限或法律規範不足所致，因此會由政府編列公務預算來清除舊場址的污染；一個典型的案例為當時農場大量使用除草劑等農藥，然而當時普遍缺乏妥善處理容器與殘留藥劑之觀念，致使許多廢棄容器隨一般廢棄物掩埋，甚或直接在農場內掩埋，導致掩埋場滲出水污染地下水以及農地污染等狀況。

在目前作業機制上，一般由環境與食安部責成各區政府（Danish Regions）執行前述場址調查，並經模型進行風險評估，擇定對人民具有高度健康風險之舊場址（Risk sites，數量估計為舊場址總數的 1~4%）者，由區政府每年投入一定預算，依風險高低進行排序，擇高風險者進行整治，至污染物濃度降到可接受之健康風險以下（一般為 10^{-6}）或對附近居民、地下水源、地表水體無明顯威脅（採定性方式描述風險）。其分類包括 L0（素地）、L1（列管而疑似污染）、L2（列管而確定有污染，但無風險）、L3（具健康風險場址，需要整治）。

考慮地下水對於丹麥水源供應之高度重要性，此處之「健康風險」經常以污染團對飲用水水源之地下水質所造成威脅程度作為評估，或是產生之有機溶劑蒸氣入侵民宅者；經評估風險較低者，則僅登錄而不予整治；另，2001 年後發現污染行為人明確之場址，依污染者付費之原則（“Polluters-pay” rule），由污染行為人整治。

據 Gitte Larsen 女士表示，達風險整治目標後，該場址仍持續登錄於環保單位之名單上，並作管控，為污染場址，只有經評估所有用途的風險都符合時，方予解除登錄。除出資整治之外，Danish Regions 也持續進行圖資比對，找尋可能之污染行為人，當確立污染事實發生在法規公告之後且污染行為人明確時，仍會循污染者付費原則，要求其整治。

全丹麥已登錄之污染場址（確定污染或可能污染）超過 34,000 個，預估實際總數可能超過 45,000 處；其中首都區（Capital Region）就有 6651 個登錄場址，該區過去數年投入土水整治相關計畫經費平均約 1 億 7 千萬丹麥克朗（約新臺幣 8 億 5 千萬元），其中研究經費約占 10%（1,000 至 1,200 萬丹麥克朗)，其中 DNAPL 類的污染，尤其在黏土層所造成之累積，為近年重要議題。另在污染土壤法公告後，石油公司已進行環境保險，當污染發生時，保險公司支付整治費；針對汽油、柴油類污染，丹麥政府另外已設置基金因應之。

Gitte Larsen 女士表示，丹麥為高稅收國家（稅率超過 40%），因此政府預算相對充裕，亦認為自身對於國民健康負有重大責任，因此會主動投入前述場址之整治。然許多舊場址污染情形相當複雜，擴及甚大面積，整治費用高昂，加上預算每年變動，可以投入整治場址數會受到侷限，居民亦會透過民意代表爭取對其土地優先進行整治；因此 Danish Regions 投入土壤及地下水整治時，亦僅處理至達某一可接受風險值，避免影響水源或不再危害住戶（如地下水或土壤受有機溶劑污染時，對住戶造成蒸氣入侵，Danish Regions 之整治措施尚包含幫住戶安裝通風設備等硬體），目標達成後，即會盡快執行下一處污染場址之整治工程。

在風險管理方面，包括整治目標之制定、溝通，以及後續監督等，則依個別整治計畫之內容，負責者可能由 Danish Regions，或各市政府（Municipality）分別執行，各案例均不盡相同；若涉及褐地開發，Gitte Larsen 女士表示目前有市政府委託啟動，或是由不動產開發商自行推動等兩種樣態，前者由市政府與不動產開發商負責揭露資訊（網站）並與民眾溝通，後者則由開發商自行負責。

(二)拜會 NIRAS 土污整治工程顧問公司

10 月 2 日下午，由 NIRAS 的環工部門計畫經理(*Projektleder, miljøingeniør*) Maria Heisterberg Hansen 帶領前往 Skuldelev 污染場址示範模場，參觀該公司負責之重質非水相液體(DNAPL)污染場址；Maria Heisterberg Hansen 女士解說情形如圖 3-2。

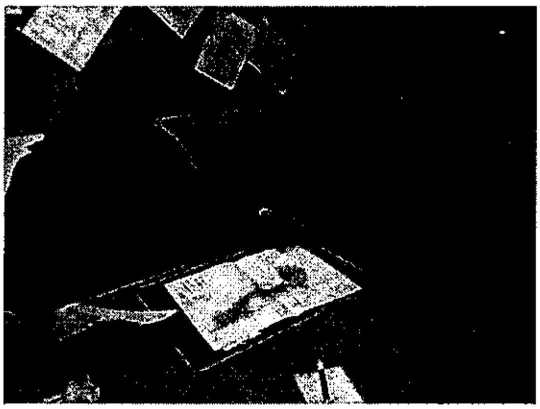


圖 3-2　Maria Heisterberg Hansen 女士解說情形

NIRAS 為一間跨領域的國際工程顧問公司，員工數約 1,400 位，由 Jørgen Kristian Nielsen 和 Konard Rauschenberger 於 1956 年在丹麥成立，經過多年發展，NIRAS 涉及領域有建築及工業、能源、交通、營造及周邊建設、環境及氣候變遷、發展規劃顧問與公共建設等，在世界各地有超過 8 千多個計畫進行中。

在土壤與地下水方面，NIRAS 一項主要的業務為接受 Danish Regions 之委託，協助進行前述舊場址整治前之場址調查、整治復育，以及後續開發案之風險監督等，目前已執行過超上千處污染場址之整治，NIRAS 亦搭配開發商針對褐地開發案所進行的整治工作。Maria Heisterberg Hansen 表示，舊場址之污染類型非常多元，包括汽柴油類、有機溶劑類等工業類型，與丹麥常見的因殺蟲劑造成污染之垃圾掩埋場址，以及全氟與多氟烷基碳化物等新興污染物樣態。

Skuldelev DNAPL 場址為丹麥最大也最嚴重的重質非水相液體(DNAPL)污染場址之一，早年為金屬罐製造工廠，在使用含氯溶劑（PCE 等）去除油脂的過程，造成污染，廢液與排放廢水從管線漏出，導致附近湖泊也受污染，造成重質非水相液體(DNAPL)污染深度超過 5 公尺，遺留污染範圍甚廣且深，

土壤中驗出之有機氯濃度大於 100 毫克/公斤，地下水則超過 200,000 微克/升；因為其發生時間點早於法令發布之前，屬於前文所述之舊場址，故由首都區政府（Capital Region）整治之。Capital Region 在此處設置整治示範模場，由 NIRAS 接受委託管理，調查後已界定七處較嚴重區塊進行整治，工程部分則與 ARKIL 公司合作。針對前述區塊，再開放由整治技術商或工程公司進駐，評估各種整治技術之應用效果；依據 NIRAS 之評估結果，Danish Regions 也會視示範場址測試結果，採購一定比例之新整治技術為後續所用。模場現地照片如圖 3-3。

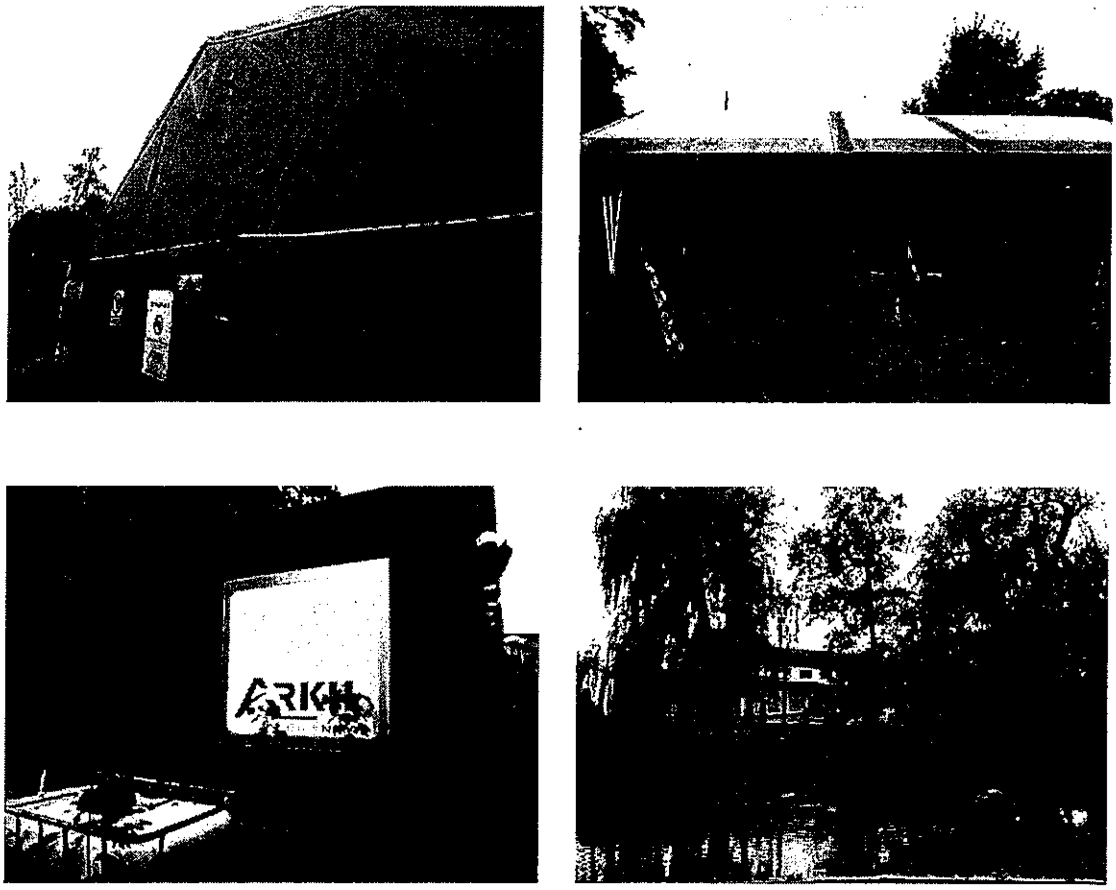


圖 3-3　Skuldelev 場址示範模場及污染場址

考慮當地鄰近處有抽取地下水之淨水場，在 Capital Region 接管後，已先排空場址附近之埤塘，鋪不透水層後，與地下水分開，因此埤塘水源大致已無污染，而當地所有私有地下水井亦已禁抽。目前對於當地居民較大之威脅在於蒸氣入侵（Vapor intrusion），有機氯物質之濃度最高可達 50,000 微克/立方公尺，因此於整治的同時，Capital Region 也考量當地室內室外空氣品質，幫住家加裝通風設備；於持續監測過程中，也發現有些住戶居住

於污染團的上方，但並無蒸氣入侵問題，然有些遠離污染團者卻有蒸汽入侵，推估與受污染地下水滲入下水道管線有關，因此也需再進一步搭配下水道管線滲漏修復。

現場可看到 NIRAS 為配合試驗所設置之大型帳篷，在帳篷內設置各類設備與機具，隨污染移動，帳篷也會跟著移動（帳篷內禁止攝影）。Maria Heisterberg Hansen 女士介紹目前在當地試驗以去除四氯乙烯(PCE)等重質非水相液體(DNAPL)的數種工法，包括：熱脫附法、現地氧化法、電流強化生物處理法（EK-Bio）等：

- 熱脫附法（Thermal Desorption）為在現場裝設鍋爐，從大約 2-3 公尺深逼出有機溶劑蒸氣，再用 vapor cap 捕捉（參與公司包括美國 Teratherm、德國 Krueger 等），經評估效果相當理想，未來可能進一步試驗搭配 jet injection。

- 現地氧化法（In situ chemical oxidation），則採用利用零價鐵搭配微生物 (KB1)，將污染物氧化（四氯乙烯→三氯乙烯→二氯乙烯→氯乙烯），另外控制 pH 與溶氧，藉以微生物強化氯乙烯降解脫氯的過程（參與公司包括 Sivern 等）。

- EK-Bio 則是將電極結合 Bentonite，從正極將水抽至負極的過程，強化細菌與土壤之接觸，以乳酸鹽（Lactate）作為營養鹽，強化電子傳輸，以提升降解脫氯之效率。

(三)拜會 COWI 土污整治工程顧問公司

10 月 3 日上午，由 COWI 的 Troels Wenzel（*Market Director, Project Development and Environment*）與 Torben Højbjerg Jørgensen（*Chief Specialist, Waste and Contaminated Sites*）協助講解丹麥的褐地開發政策，並於下午前往參觀 COWI 所參與一系列位於哥本哈根港的褐地開發計畫；當日拜會 COWI 照片如圖 3-4，Troels Wenzel 先生所提供簡報如附錄 2。

圖 3-4　拜會 COWI 公司總部

COWI 成立於 1930 年，是全球最大工程顧問公司之一，也是丹麥最大的工程顧問公司，總部在 Kongens Lyngby（在哥本哈根市中心外圍）。1974 年丹麥頒布環境保護法案後，COWI 就開始提供各類環境諮詢服務，於土壤與地下水污染領域，COWI 亦從 1980 年代即開始提供服務，服務範圍包括丹麥、挪威、瑞典、中歐、東歐以及中國等，目前土水部門總共有超過 150 位名成員，服務主要對象包含中央政府單位、區政府、市政府等公部門提供政策研擬、場址調查、技術評估，及對高度健康風險、影響地下水水源、建築物室內空品的舊場址進行整治等服務，針對工業及計畫開發商等私部門提供污染細密調查、整治作業，以及褐地再利用與開發等；COWI 在國外亦有執行許多世界銀行補助計畫。COWI 與 NIRAS 一樣未設置自己的實驗室，然擁有機具，以提供一部分之工程試驗與服務，針對場址特性選擇最適合的整治技術提出建議，如：土壤翻堆方式、何種氧化劑之添加... 等。

丹麥各地方政府（Municipality）因有許多建築與開發上之限制，以維護歷史建築與城市整體景觀，在重新進行都市計畫規劃時（一般為每十年），常擇定已沒落的工業地帶（多為圍繞港區之舊工廠所遺留之污染場址），重

新劃定為住宅區或住商用地，故透過整體規劃，促使民間開發商資本投入新開發案時，優先選擇污染場址加以整治後再作利用；前述限制包括舊建物必須加以保存、市中心高度限建（不超過五層樓），以及保留一定比例綠地不開發等。

以哥本哈根為例，因其為丹麥王國數百年來之首都，古老建物甚多，亦成為重要文化財與觀光財，為保護歷史舊建物而有嚴格限拆規定，故在都市內之可用面積有限，加上前述保留綠地以及容積限制等規定，使得工業遷移出首都圈後所釋出之土地（尤其是哥本哈根港區），為新社區及商圈開發之重點，而這些土地則同時兼有荒廢與污染兩種特徵，其中一部分污染行為人亦已不復存在；此些因素都使得「褐地開發」成為哥本哈根等丹麥大城市之都市規劃重點，褐地也變得搶手，在哥本哈根類似此大面積開發之點位，推估目前至少有 10 處在進行中。

COWI 等顧問公司的角色為與大型開發商合作，進行民眾與公部門溝通、收購適當土地（Off-Market sites，開發前地價較低者，褐地即為一種樣態）、土地狀況調查、建構現金流模型（Cash flow models）並確認可行後、協助取得環保、建築...等單位之許可、規劃公設與界定地役權（identification of easement）等；一般前置作業（包括與民眾溝通）經常需要 5 到 6 年，較短也要兩年，整體開發時程大約會在 10 年，COWI 公司目前在哥本哈根港經手的案例（總面積約 10 公頃），預定開發 15,000 個住宅空間，總開發預算高達 10 幾億歐元。另一案例為哥本哈根南方的 Koge，地方政府在進行 10 年為期的整體規劃，指定特定褐地為待開發區塊，包括將既設工廠移至填海工業區，再將原工廠用地（污染或未污染）重新開發與改建為住商用地。在哥本哈根港區污染土地開發再利用的案例中，一般需經過 2-5 年，與當地居民及地方政府各部門溝通協調，因此「調查-整治-開發-銷售」週期約需 10-15 年。

與我國土污法規定差異較大者在於丹麥現行法令對於污染場址（包括前述舊場址或高健康風險場址[risk site]）的買賣、處分、私部門辦理分區變更、抵押貸款等並未加以限制（在北歐諸國中為較寬鬆者），然可貸的額度遠低於無污染土地，分區變更程序也會較複雜而不易達成；因此商業誘因將促使有土地交易壓力之私部門必須盡速完成整治。反之，對於污染行為人不

明之場址（Orphan site）或因其他因素而長期荒廢的土地，當位置適當時，透過地方政府前述的都市計畫整體變更，可吸引開發商進駐投資，購置土地並加以整治開發，賦予新價值，再由後續出售房屋物件以獲得回報，解決原本可能是區政府或市政府環保單位需要面對之污染問題，亦促成都市繁榮。搭配地方政府之限建與都市計畫引導，丹麥各大城市之污染土地開發市場甚為熱絡，間接地解決了污染問題。

在上述建管法規、環保法規與土地供給之背景下，Troels Wenzel 先生表示丹麥目前已發生的污染土地開發再利用個案，多具下列特徵：

- 位於污染程度較輕微之舊場址（經評估整治成本較低）。
- 多數由開發商主動收購土地（包含場址和附近未污染土地），少數與地主合資開發。
- 大面積褐地通常採分區整治，逐塊達到整治目標後再作開發，透過銷售建物以彌補前端整治與進行負擔下一區塊整治支出。

惟 Troels Wenzel 先生也表示，點位較為孤立的單一小面積場址，基本上沒有開發題材，若是屬於私部門所造成之污染，投入整治的意願與資源同樣也會少而延宕，甚或是最後仍需公部門出面處理。

依前述顯示，驅動丹麥褐地開發之起點包括整體都市土地供給之高度限制，以及地方政府的整體都市規劃（鼓勵利用褐地而非使開發資本投入農地或未污染土地），環保單位之角色在於：

- 審查開發過程中的整治目標是否合理
- 使用整治工法之合宜性，發予許可
- 監督開發過程是否造成污染擴散
- 後續驗收以及持續之風險控管

丹麥之污染土地開發時之整治目標係以健康風險導向，係整治至符合用途之可接受健康風險；COWI 等顧問公司協助開發商透過縝密調查，確認污染整治需求，依健康風險評估計算（部分案例會以其他定性考量）設定整

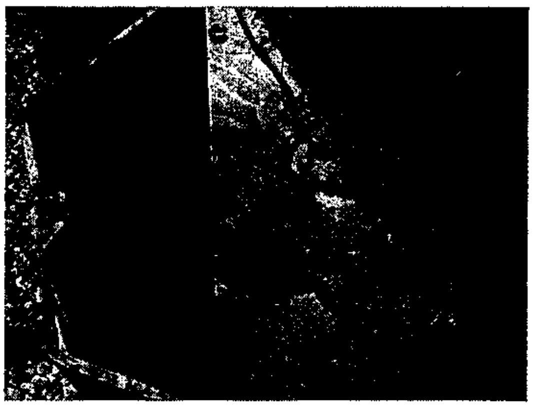
治目標，由環保單位審查通過後，推動整治工程與整區規劃。其中整治目標之設定，必須考慮多重風險控管，包括蒸氣入侵可能影響室內或室外空氣品質、對近海/湖泊/河川之水質保護、地下水飲用水源之保護等；後續追蹤依許可，一般由地方政府與區政府共同執行；因為仍是登錄之場址(registered)，開發商必須依許可定期提交報告；另在部分案例中，土壤整治完成後仍有地下水持續整治中，因此在取得開發許可時，尚會搭配許多定性要求規定，包括施工安全規範，地下水禁止使用等。

Troels Wenzel 先生針對我國推動污染土地再利用時，希望釐清之問題，以丹麥現況為例，作出說明：

- 針對一處褐地開發案，一般會有啟始會議（start meeting），邀集地方政府之所有單位，連同整治目標、土地分區變更、建管要求等事宜，一起確認後，再執行；環保單位非為整個開發案之啟始單位或最終審核單位。
- 若開發後又發現污染新事證，通常要由開發商概括承受，並承擔與購屋者之各類民事訴訟，故前期調查，實屬重要。
- 開發商確實可能因為前期財務/現金流模型沒作好，而無法執行（如破產等），但基於前述丹麥土地供給政策之限制，很快即有其他開發商能夠接手，不至於荒廢。
- 與美國褐地開發集中於沒落的工業城，溝通對象往往為當地社區民眾；丹麥之案例經常為舊工業土地經重劃後之全面性開發，購屋者多為外來之民眾或企業，對既有土地之感情連結較弱，故溝通上為強調機能性。至污染土地可能帶來的污名化問題，針對「仍登錄為污染場址」問題，確實可能令購屋者（私人物業）介意，包括土地價損問題，惟 COWI 也注意到一般人對於公共空間有此問題顯然較不在意。因此 COWI 於協助前期規劃時，也會作適當之空間配置，然據該公司觀察顯示，價格好、設施完整、位置適當即會吸引客戶，淡化了污名化問題；而 COWI 在開發期間，每兩個月就由團隊中有記者此類較擅於溝通之角色，以較非公開方式與相關單位持續互動，避免有預期外之爭議突然出現。

討論後隨即前往參觀 COWI 於哥本哈根港之三處開發中的場址，分別位於哥本哈根港之北區(Nordhavnen，油類與 PAHs 污染)、南區(South harbor，汞污染)，以及 Aalborg University 附近（油類與 PAHs 污染)。以北區場址為例，該處面積約 32,000 平方公尺，污染嚴重，污染深度達 5 公尺，整治費前後估計達約 1 億歐元。首先將殘油抽出，打 10 公尺之鋼板樁，防止受污染之地下水擴散，現場亦設有地下水淨化設備，海面上可見攔油索，避免油污於海面上擴散；於將遭受油污染之土壤挖除離場後，以燒結方式製成磚、混凝土等進行再利用(bricks、dikes)。現場照片如圖 3-5。

三處案例都將開發成綜合性社區，目前仍在進行中，已進行 4 至 5 年，全期預期需 15 年，採分區解列，已完成之物件目前已有部分出售，開發商已獲利，並持續進行整治中。



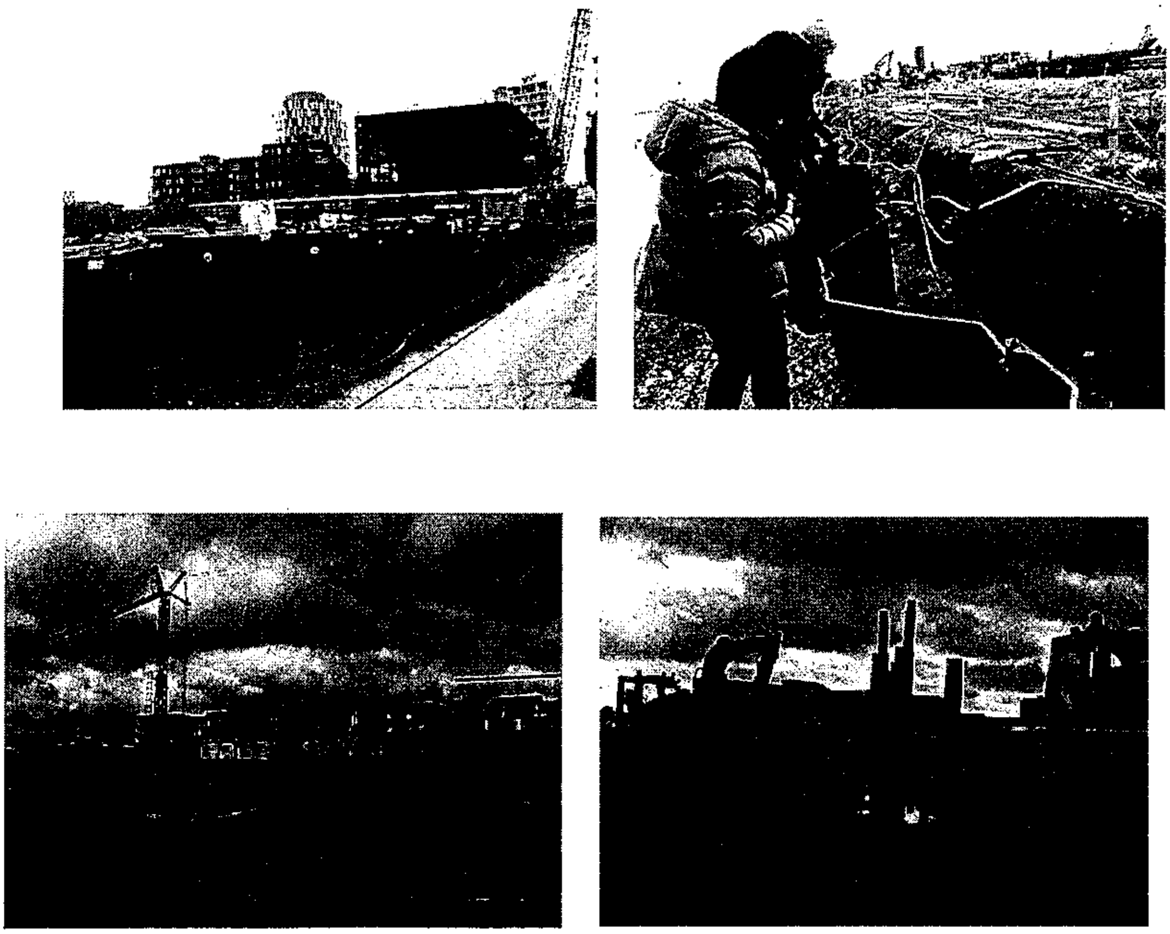


圖 3-5　哥本哈根港污染土地整治暨開發參訪

(四)参加 ICCL Meeting

10 月 4 日參加 ICCL Meeting。ICCL Meeting 由污染土地國際委員會 (International Committee on Contaminated Land) 於 1993 年發起，是污染土地決策者、監管機構處理受污染土地管理的技術顧問之交流平台，提供污染土地政策、研究、技術和管理概念及其他利益相關者提之專業知識交流機會，主要成員為歐盟國家。

本次已是第 13 屆會議，邀集各國環保署、研究機構與環境工程相關從業人員共同參加分享經驗。此次研討會共 3 場專題講座，分別為(1)污染場地修復/法律、技術、財務和社會問題、(2)水資源污染管理、(3)新興污染物，並聚焦於各國地下水管制法規；現場照片如圖 3-6。

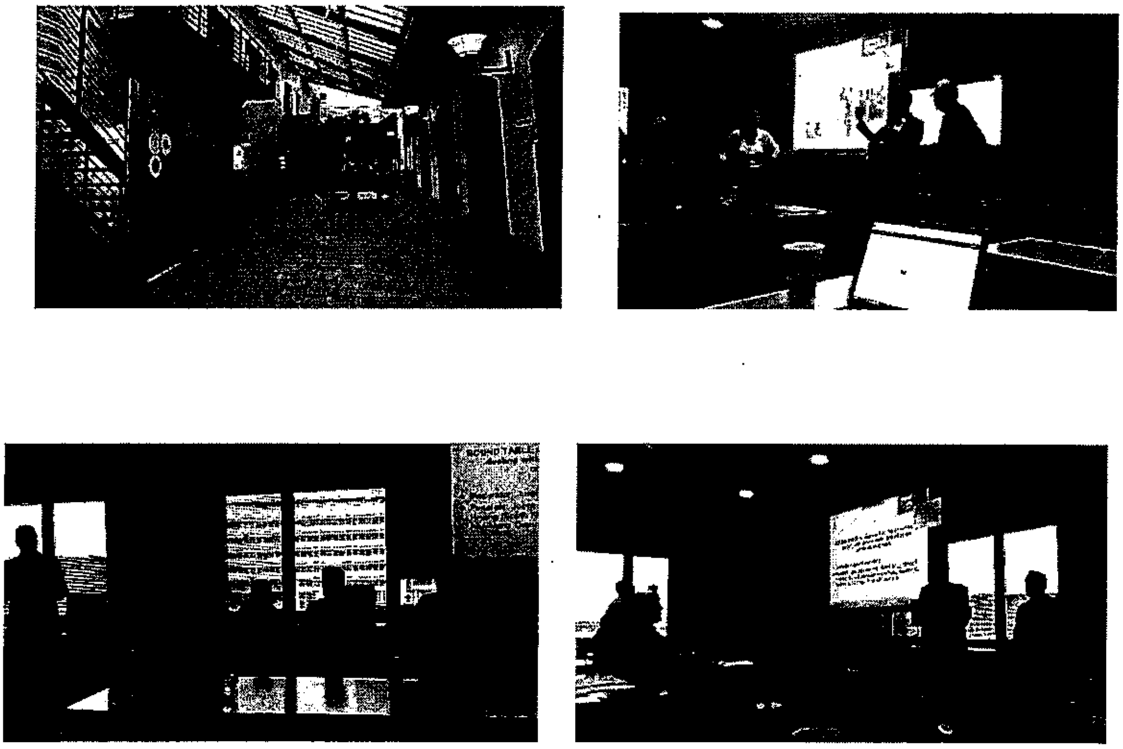


圖 3-6　參加 ICCL Meeting 現場照片

包括丹麥在內，歐洲等各大陸國飲用水源高度倚賴地下水，普遍認為維持各地方之地下水權為天賦人權與財產權，因此政府主動投入整治亦有保障國民健康之目的。本次與會之歐盟各國（如丹麥、德國、法國等）、澳洲、南韓、哥倫比亞揭櫫以健康風險設定整治目標為普遍原則，而非須回到原本之效益目標（Beneficial use），法規管理上強調要保留彈性給各地方政府，

避免過於僵硬之管理；然各國代表亦認同整治之困難，並呼籲記取教訓，積極投入地下水質監測預警網之建置，防範於未然。

各國因處於不同發展階段，所關注之場址污染物亦有不同，我國、南韓、德國、法國等，因工業發達，重質非水相液體(DNAPL)等含氯溶劑之污染最為普遍；而丹麥除重質非水相液體外，其農業發達，過去年代農民因知識不足未妥善處理即隨意掩埋之殘留殺蟲劑、除草劑等，演變成至今一大問題；而哥倫比亞等國家因礦產業發達，故重金屬、氰化物、汞等污染，十分常見。

於簡報後，有熱烈的意見交換，以下節錄針對地下水法規管制方向之討論重點：

1. 各國代表均反覆討論，發現地下水污染問題時，是希望整治到符合原本之效益用途（beneficial use）？或是直接禁用（影響權益、水權）？基於地下水水權經常與地方政府或公民團體之利益、財產有關，各國代表傾向要積極投入整治，惟在成本限制下，不可能完全恢復到既有效益用途之標準，多數以可接受健康風險為標的，進行整治。

2. 各國代表普遍意識到，在過去 20 年之投入經驗中，導入健康風險評估等工具，以及各類新工法，整治成本仍不斷上升，且歷史遺留的舊場址之問題迄今亦未完全解決，此顯示預警系統（precautionary policy）極為重要，公部門與私部門須針對污染容易發生之地區，全力投入資源，並整合相關數據。

3. Danish Regions 的 Christian Andersen 先生援引丹麥狀況，談到舊場址因為是政府出錢整治以保障民眾健康，僅針對污染最嚴重，風險最高者進行處理，只要對地下水之威脅或影響室內空氣品質等問題降至最低，即會將預算移至其他場址，就技術面而言，部分污染物仍在；行政上的配套則是持續登錄為污染場址，並投入公務預算進行監測；若作為開發，則要求更多公設作為配套（包括全面性的通風設備、飲用水淨化、行人棧板等），阻絕污染造成之風險。

4. 澳洲維多利亞省環境部 Anne Northway 女士說明澳洲各省/領土因

為地下水狀況差異甚大，政策與風險評估模型均有所差異，各省/領土在聯邦的法 (Act) 之下，各有其單行法規（Environmental orders）、政策規劃（planning system），以及長程之環境監督（auditors）。

5. 本次韓國由 KECO（韓國環境公司）、KEI（韓國環境保護研究院）派員參與；韓國 KEI 的黃相一博士，說明韓國地下水因應不同用途，設定了地下水多種標準，然該標準係作為整治目標訂定之參考，而非唯一之剛性標準限制；黃博士表示，目前整治責任問題 (liability problem) 之追究，包括透過鑑識技術之發展，是 KEI 投入重點。

6. 德國環境部 Joerg Frauenstein 先生，說明管制的重點在於除根，除污染源外，有些污染物還停在非飽和層，若不移除，現階段的整治並無意義，長程仍會出現其他問題（ "Future use" orientation），因此需要投入資金，持續對於地質狀況進行更深入的研究，藉以開發更適合的整治方法。而德國政府所投入之地下水整治技術，是否有被專利保護？或向公眾開放？目前也成為德國環保領域產官學研討論中之問題。

7. 哥倫比亞環境部的 Ana-Maria Ocampo Gomez 女士提到該國亦有超級基金之機制，藉以處理過去所遺留之大量殺蟲劑污染、金礦開採所造成的地下水污染問題。

8. 現場與各國交流時，我方亦指出台灣飲用水的主要來源以地表水為主，地下水為次要；若有污染，則限制使用或飲用，主要擔心抽地下水作為工業、抑制揚塵或澆灌用（主要的風險暴露途徑反而是為接觸）。

9. ICCL 秘書處在進行綜合結論時，彙整未來願景，希望地下水與土壤污染場址，應該從場址管理，走向永續經營，並因應循環經濟之趨勢進行思考；技術面上則應該針對汞、採礦所造成地下水污染、底泥污染累積造成的生態影響，以及全氟化合物新興污染物投入更多的關注。

(五)參加 ICCL NICOLE 聯合研討會

10 月 5 日與 6 日參與 ICCL NICOLE 聯合研討會並發表海報(研討會資料如附錄 3)。本研討會在 ICCL Meeting 後舉行，由 NICOLE 與 ICCL 兩大組織合辦，本項系列活動與會者超過 200 人，包括產官學研各界，發表論文較之於 ICCL Meeting 之政策性討論，更具技術性；現場照片如圖 3-7。

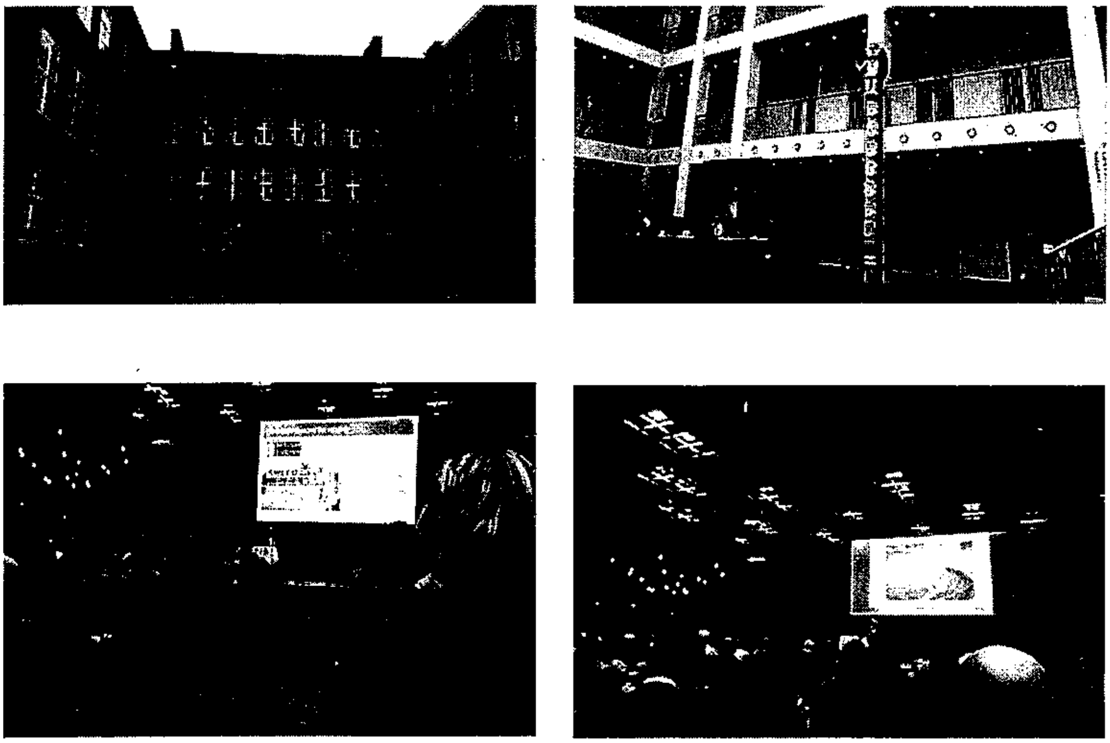


圖 3-7　ICCL NICOLE 聯合研討會場照片

本研討會發表內容即涵蓋地下水污染管制、場址管理、新技術設備應用等三層面；部分開發中國家（如阿根廷等）近年亦積極投入大量無責任人或歷史遺留污染土地之整治，政策引導上由政府機關主導整治與後續開發，藉以彌補整治支出及活絡沒落之工業城。

在技術面上，本次有許多設備商於現場以口頭或海報方式展示其新設備/技術，包括新型注藥系統（i-SAV）、地下水流向監測系統（iFLUX）、樹芯污染調查、無毒奈米觸媒（NanoREM）等；在整治技術上，重質非水相液體(DNAPL)之熱脫附法有數家顧問公司均於實際工程中予以驗證評估，並獲致良好效果。

本次會議重點發表節錄如下：

1. Danish Regions 的 Jens Mandrup 先生，討論丹麥目前土壤及地下水整治政策，指出丹麥政府每年約花 6 千萬歐元在整治無主污染場址（Orphan site），尚不含調查之預算；因為預算有限，只會將錢花在有風險的場址(risk site)，尤其威脅地下水安全者。因過去工業區與港區高度交集，造成很多污染場址都圍繞在港邊。目前除投入整治，Danish Regions 將盡量地揭露相關污染資訊，並且投入 7 個場址示範模場（test sites），驗證技術，避免浪費公帑，以使各級政府充分交換技術資訊。

2. 丹麥水公司 DANVA 的 Carl-Emil Larsen 先生指出，調查顯示有相當比例之地下水污染來自於農業行為所造成的非點源污染，如：硝酸鹽氮、殺蟲劑；點源則包括乾洗店、加油站、工廠、掩埋場，污染已相當程度地影響了水公司的運作；目前 DANVA 已積極建構預警系統，並且監控新興污染物。

3. ICCL 的 Dominique 女士指出，針對歷史遺留污染、運作中之場址管理、再利用、場址調查，持續努力；歐盟的觀念整體而言也分階段，從過去的標準管理，走向以風險來作設計。不過歐洲幅員廣大，地下水污染可以是場址規模(site level)、城市規模(community level)、甚或是流域規模（catchment/river level），如何解決，並不宜單一場址管理之理念一概而論。Dominique 女士亦指出新興污染物不一定是針對污染物，已知污染物但難解決不易去除者，更難以處理；例如近期發現從混凝土溶出而滲到地下水之污染物，就引起極大的關注。

4. ADVISEN、ARCADIS/NICOLE、BQGM 等顧問公司於本次會議中，均提出多種決策模型，評估地下水受污染後之財務損失模型，以及如何選擇適當整治工法（或是不予整治），以及整治目標；考量因子包括法規 (如 Water Framework Directive/WFD 之相關規定)、當地地下水之運用效益、污染區塊大小、地方政府（或私部門）的財務狀況、以及各種整治工法的全生命週期（綠色整治）等；透過此些模型，再建立概念模型（conceptual model），藉以協助進行健康風險

評估、設定整治目標、確認最適技術（BAT）等。

5. 顧問公司 Ramboll（South Africa）本次探討使用地下水擴散模型，討論四氯乙烯污染團之擴散，並納入四氯乙烯之降解途徑，藉以建構類似風險圖像之分析地圖。

6. Veolia 與 EDM 等顧問公司本次都報告以不同溫度之熱脫附法處理重質非水相液體(DNAPL)，瞭解溫度對於脫除效果之影響，以及其他污染物 (如汽油) 同時存在時，可能造成之干擾；在會後交流時，與 10 月 2 日 NIRAS 參訪類同，兩家顧問公司均對熱脫附法應用於重質非水相液體(DNAPL)之效能給予高度評價。

7. 顧問公司 TAUW 探討地下水中的汞污染 (elemement Hg)，其採用現地沉澱法，使硫酸鐵去吸附，或使汞(Hg)在厭氧環境下和硫離子(S_2^-)反應沉澱，並評估去除效果。

8. 芬蘭環境部報告，說明其正積極構建國家級試驗模場（national pilot projects），選擇幾處嚴重污染場址，由中央跟地方共同合作，透過招標找到理想廠商，在一定期間內進行測試，並瞭解測試效果；此與丹麥目前七處示範測試場址有高度類似之處。

9. 阿根廷環境部本次報告，提出該國境內大量無主場址（orphan site）造成許多問題，目前除積極調查並建立通報機制，該國正評估一項可能性，即由環境部投入資金整治並進行後續開發，初步顯示確實可能從開發過程獲得足夠利益，以補前階段之整治費用。

10. 有鑑於全氟化合物等新興污染物於地下水污染逐漸浮現，澳洲與紐西蘭兩國環境部刻啟動一項計畫，監測跨境化學物質之移動，以及相關監測數據、整治技術相關資訊的共享。

本次研討會中亦以海報方式發表本會委辦風險圖像計畫成果「The Application of Pollution Transfer Model and Health Risk Map on the Brownfield Revitalization in Taiwan」(現場照片如圖 3-8)，本研究結合地下水傳輸模式、風險圖像、風險管理，以及工業區再開發願景等（附錄 4）。

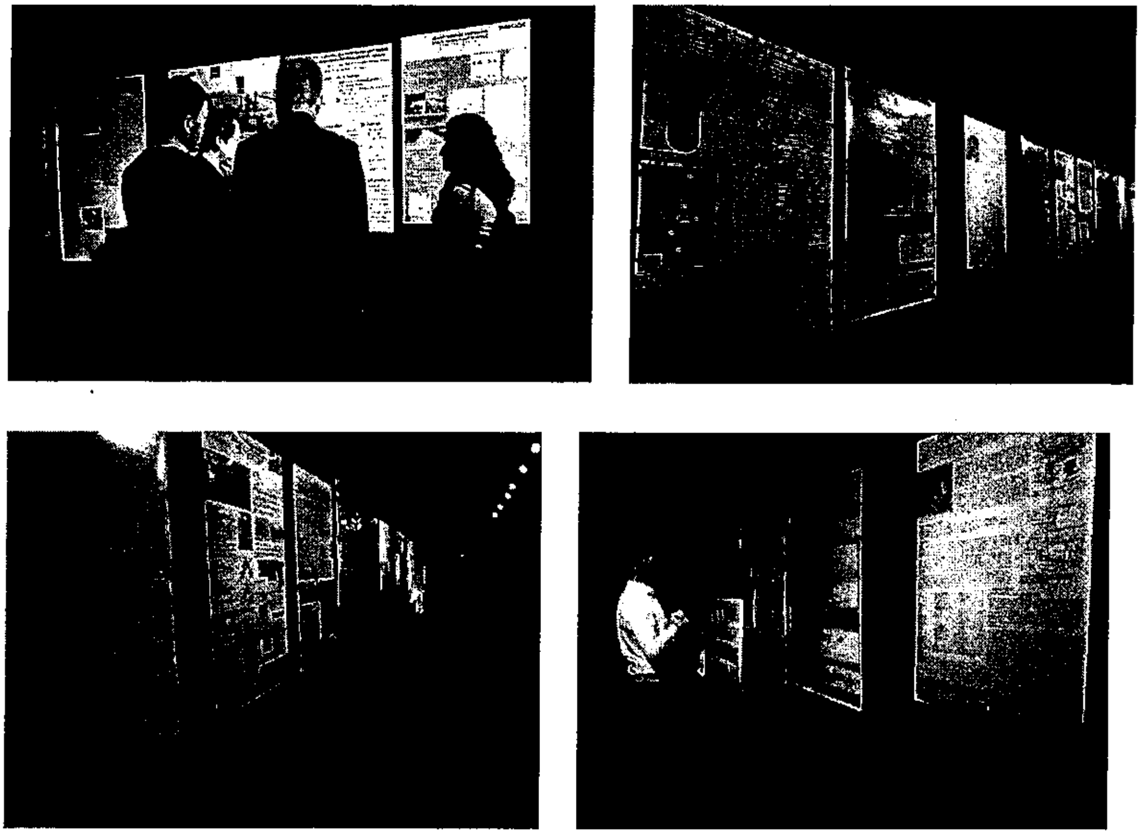


圖 3-8　ICCL NICOLE 聯合研討會海報發表

(六)會後參訪

丹麥目前的示範驗證場址，除前述 10 月 2 日參訪之 Skuldelev 外，本次在 ICCL NICOLE 聯合研討會所安排的會後參訪，10 月 6 日下午參觀另一處示範場址 Stengaarden Landfill，屬西蘭區（Zealand Region）之管轄範圍，委託 Danish Soil Partnership 經營（圖 3-9）。

Danish Regions 環保部門非常重視示範驗證場址之成果，該部門發現透過公私合作機制，讓更多技術可以測試並驗證成果，累積知識，若結果顯示效果理想，再由 Danish Soil Partnership 或 NIRAS 等受委託單位協助推廣；該處場地與設備可以免費使用。

Stengaarden Landfill 為早年設置之掩埋場，有一般家戶垃圾，亦有大量農業廢棄物（包括殺蟲劑等）不當埋入，造成地下水嚴重污染，該場址有 23 處地下水監測井，幾乎均測得高濃度殺蟲劑，現場尚有甲烷氣收集單元，於淨化後，送入附近天然氣站進行發電。

目前該場址有兩項技術導入驗證以評估對於地下水之淨化效果，第一項為接觸膜生物法（Biobassin）用以降解殺蟲劑，菌體形成顆粒型式，係由當地土壤細菌所培養出來的，現場共有三池，包括無氧、好氧與砂濾。

第二項為高級氧化與薄膜之搭配；將井水抽出，導入處理單元，前端為砂濾及過氧化氫(H_2O_2)，再進去薄膜系統，將之濃縮殺蟲劑，強化高級氧化效果，最後分別以臭氧處理。

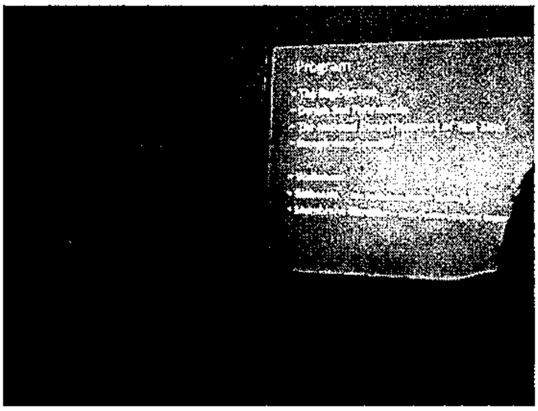


圖 3-9　參訪 Stengaarden Landfill 示範驗證場址

四、心得及建議

從本次會議各國發表成果顯示，在實質管理上，以健康風險設定地下水與土壤之整治目標（包括污染土地再利用），為世界各國普遍趨勢，剛性管制標準主要用於判定污染場址與整治先後順序，可作為土壤及地下水污染整治法未來修法之參考。

參考丹麥污染土地開發再利用案例之經驗，污染土地再利用建議可針對污染行為人不明場址，採示範推動方式，先篩選出適當場址，鼓勵各縣市政府擇適合者，結合適當經費，主動投入整治，藉以推廣健康風險及污染土地再利用等制度；至非屬前述污染行為人不明之場址，可鼓勵開發商與污染責任人結盟，提出整治計畫，使整治與開發併行，然亦須明確規範開發商責任，避免責任不易釐清；另，並須使各縣市環保局熟悉審查程序與後續行政配套。

本署致力於污染整治模場試驗推動與土壤及地下水健康風險評估工具建置已有多年，仍可借鏡幾個國家發展現況，如強化污染行為人不明場址之整治模場試驗，針對已完成污染範圍調查且面積較大之污染場址，可分為幾區個別進行試驗，以取得該場址最佳整治技術，除減少閒置之污染場址，並能增加整治技術發展；另，可加強各縣市環保局及各界對健康風險評估制度與相關工具之瞭解，以廣泛應用於污染場址，降低人體危害風險，並須強化民眾溝通概念，建構正確觀念，以獲共識，使相關工作得以順利進行。

五、附錄

附錄 1　Capital Region 簡報

附錄 2　COWI 簡報

附錄 3　ICCL NICOLE　聯合研討會資料

附錄 4　海報

附錄 5　丹麥污染土壤法律及整治現況簡介

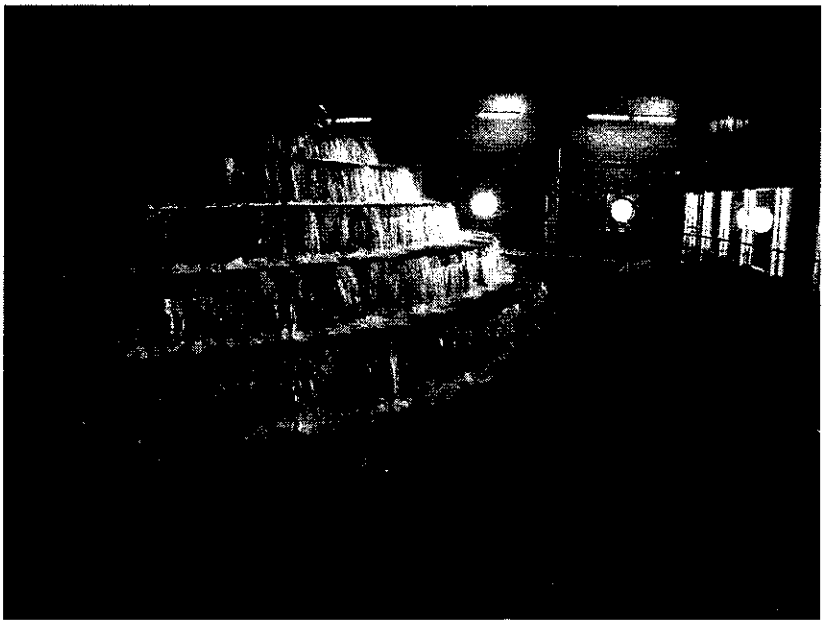
附錄 1

Soil Contamination in the Capital Region of Denmark

Gitte Larsen
Head of Department
Soil Contamination

A PART OF GREATER COPENHAGEN

Ground water is the only source of drinking water in Denmark



What is protected?

<u>According to the Contaminated soil act the regions shall protect :</u>

- Human health:
  - Air in (and around) homes
  - Sensitive land use (soil in residential areas, kindergardens, playgrounds)
- Groundwater (primarily in “drinking water areas”)
- Surface water

Authorities on soil contamination

Ministry of Environment and Food of Denmark

- Legislation
- Guidelines
- National quality criteria

- 5 Regions

- Responsible for “old sites”
- Registration
- Investigation and risk assessment
- Prioritization
- Remediation
- Permits for changing land-use on contaminated sites

- 98 municipalities

- Enforce “polluter pays principle”
- Inspection and control of industries etc.
- Permits for changing land-use on contaminated sites
- Soil logistics
- Ground water protection action plans

The public soil and groundwater effort in Denmark:

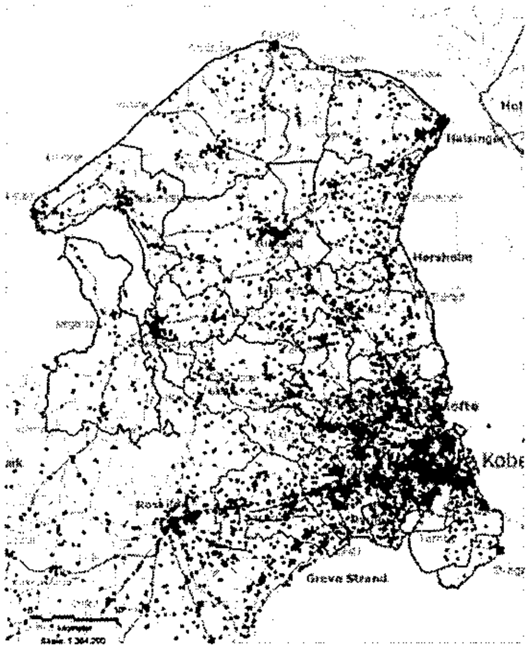
- The Danish system for contaminated site management has been developed over the past 35 years
- Focus on the protection of human health, groundwater and surface waters
- All contaminated sites are registered, but only risk sites are remediated
- The goal of remediation is to reduce the risks to acceptable levels

The Capital Region of Denmark

The public soil and groundwater effort in Denmark:

- Government (regions) fund investigation and remediation of "old sites" where the "polluter pays principle" does not apply
- Important players: Regions, municipalities, private developers, specialized consultants and contractors, laboratories, universities and research institutions

Registered sites in the Capital Region



Sites mapped as potentially con-taminated in the Capital Region

6.651 sites mapped as contaminated or potentially contaminated

Denmark
34.000 sites mapped as contaminated or potentially contaminated

THE PROCES OF PRIORITIZATION:

- 100 sites "of interest"
- 50 – 60 sites potentially contaminated
- 40 sites basic investigation
- 20 - 30 sites contaminated
- 5-10 sites detailed investigation
- 1-4 sites remediation

The public spending on mapping and remediation of soil contamination 2015

The Capital Region:

- 137,7 mio. CNY in operating funds
- 78 full-time employees, equivalent of a total cost of 48,4 mio CNY

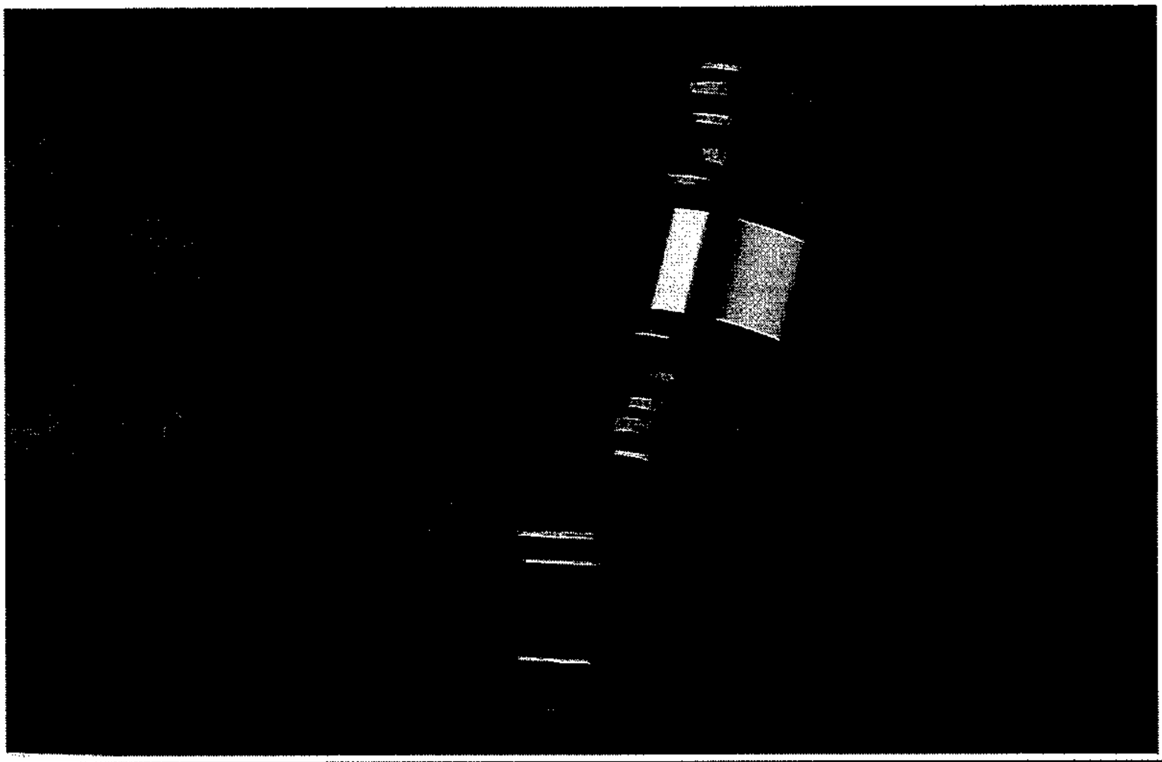
In total: 186,1 mio CNY

The Capital Region of Denmark

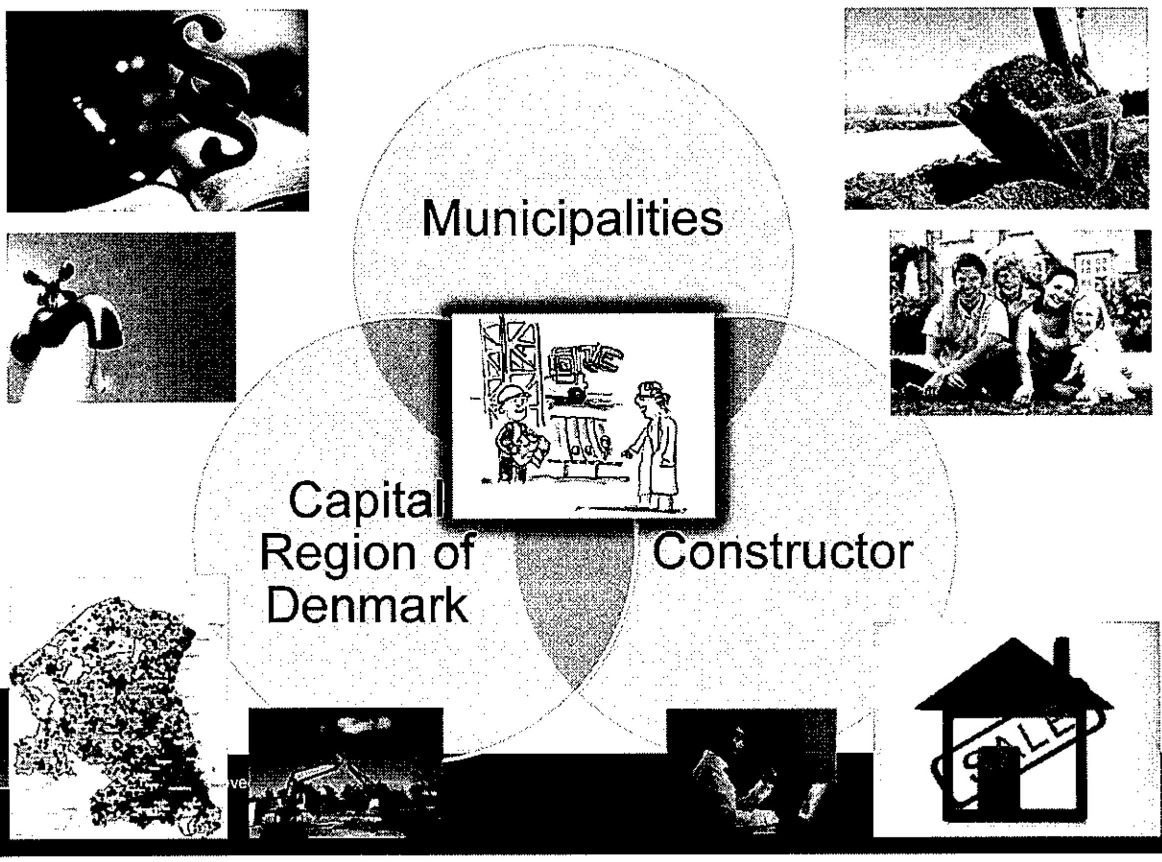
Typical types of soil contamination in Denmark

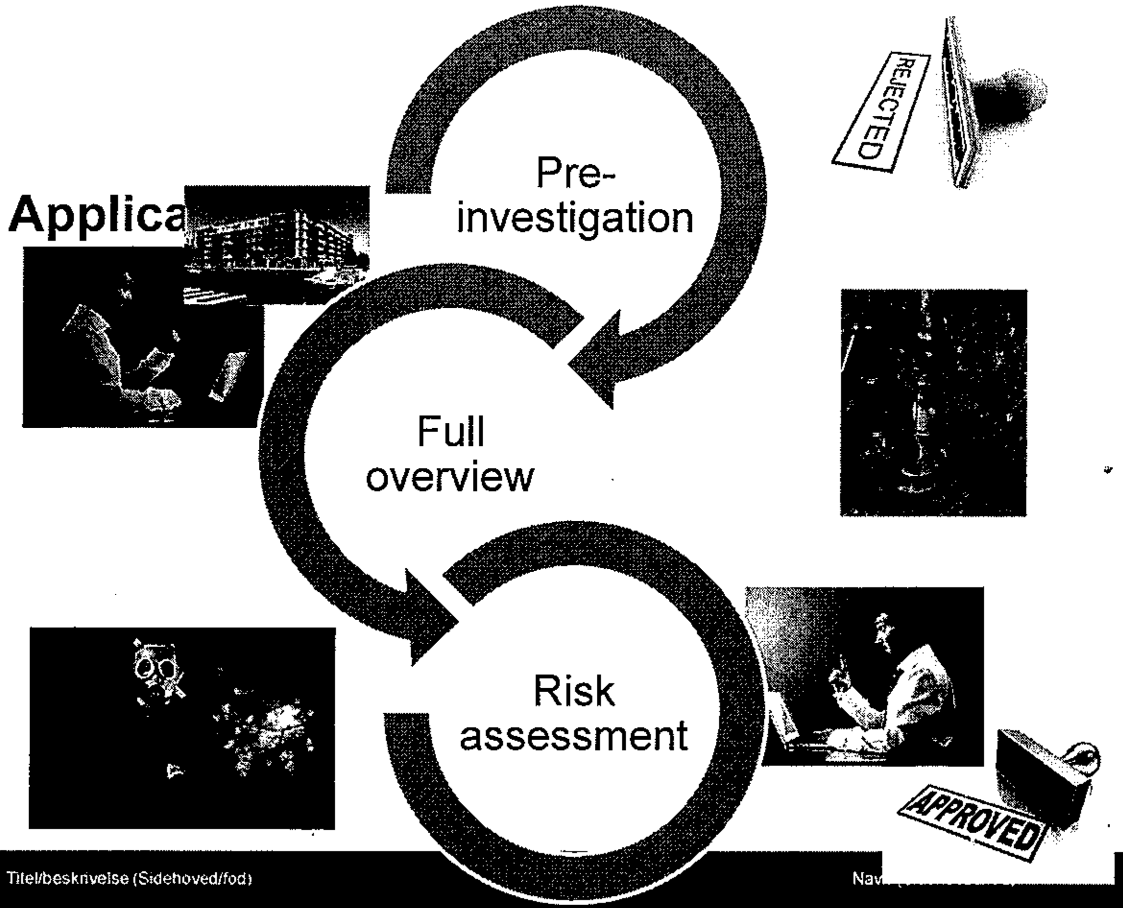
- Chlorinated solvents
- Oil and gasoline
- Heavy metals
- Pesticides
- Coal tar and phenols

Permission

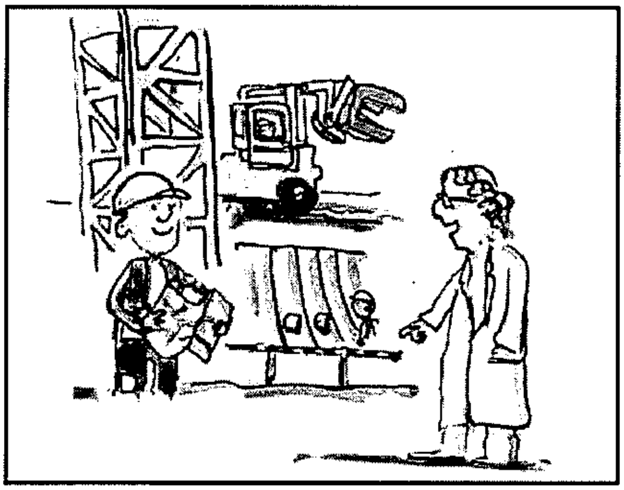


Collaboration in spite of interests





A permission with terms



- Futher investigations
- Remediation
- Ensure climate in-door and outdoor
- Monitoring
- Documentation

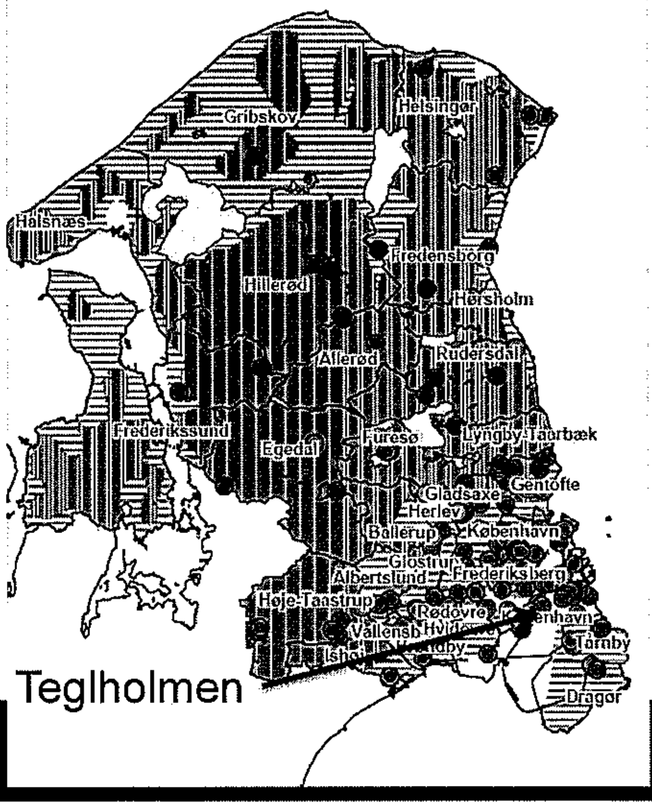
Examples of terms in a permission

"Establish ventilation below the floor to remove toxic vapour from the contaminated soil"

"Supply with 0,5 meters uncontaminated soil or establish tiles upon the soil"

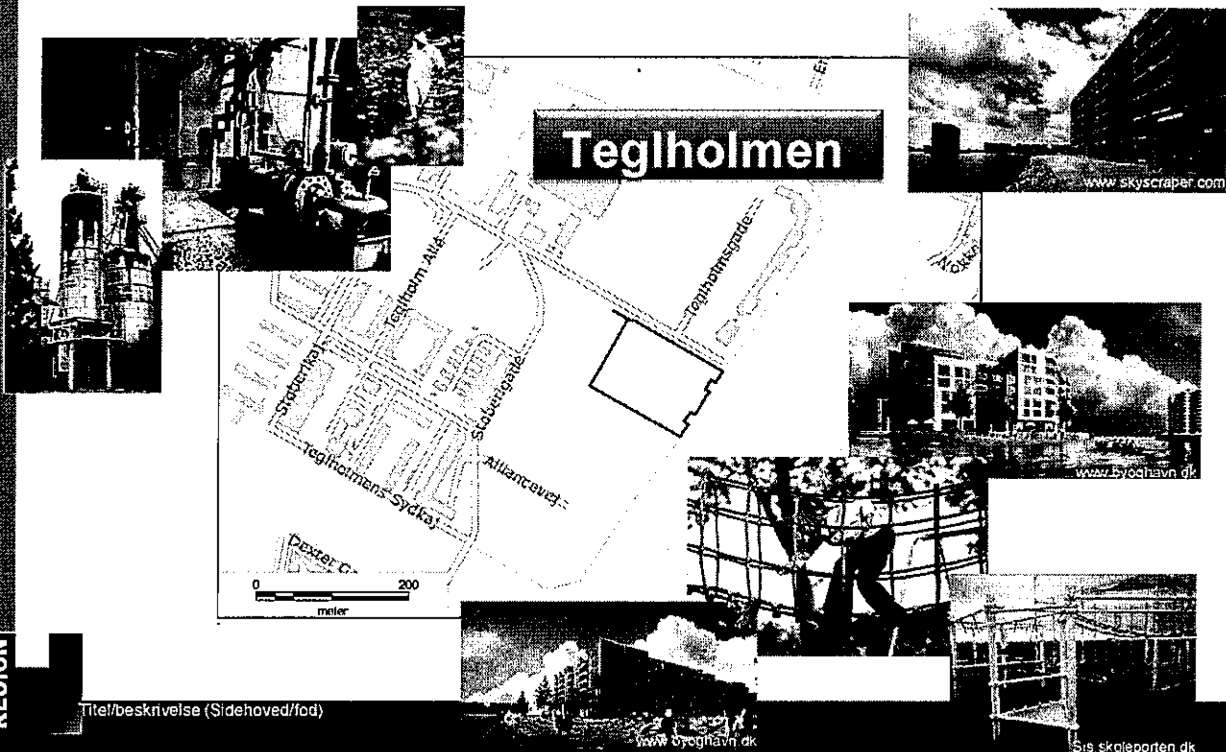
REGION

Active projects on a contaminated sites



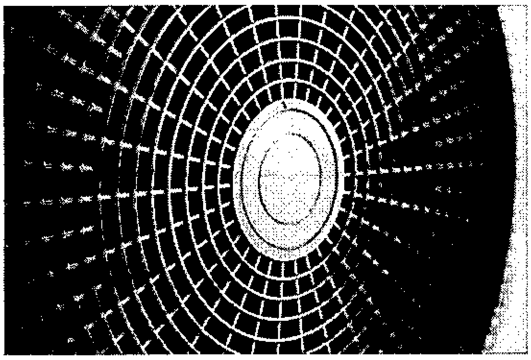
REGION

Urban development on a contaminated site



An example on Teglholmen

When it is not possible to clean up



- Further investigations
- Risk assesment
- Sketch of ventilation under the floor
- Monitoring

⬇

- Change ventilation type

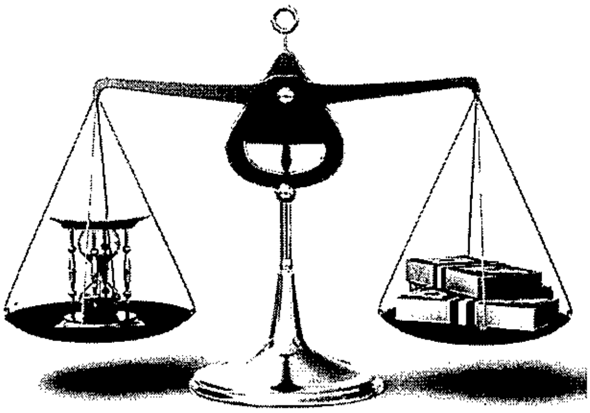
⬇

- Site remains registrated

REGION

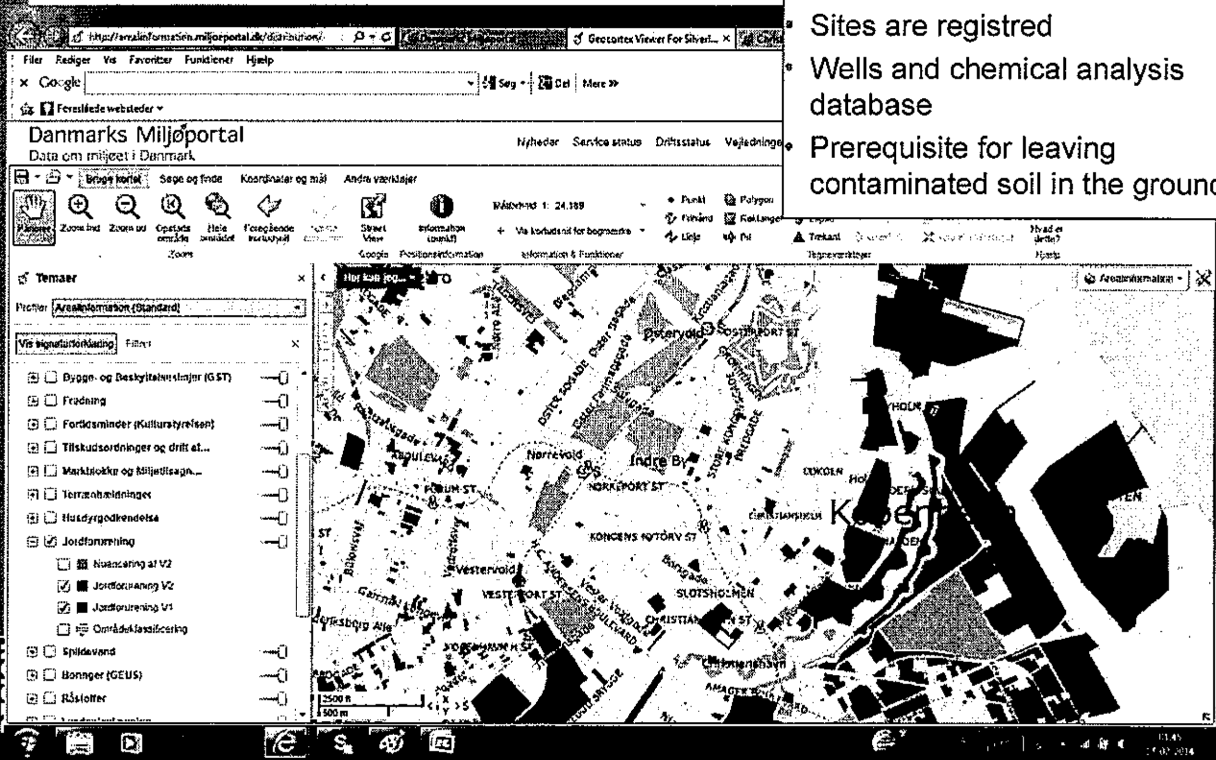
Challenges

- Limitation of the legislation
- Lack of time
- Insuficient surveys
- The municipality is also sometimes the constructor



REGION

Public internet based inventory of contaminated sites



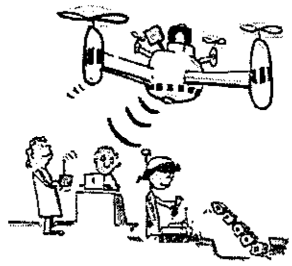
- Webbased GIS database
- Sites are registred
- Wells and chemical analysis database
- Prerequisite for leaving contaminated soil in the ground

Innovation and cooperation

Goal Increased green growth in the region

How

- Test sites
- Increased corporation with private and public actors as well as research institutions
- Cheaper, faster and more sustainable methods
- Ground water protection
- City planning and development
- Development of partnerships
- Export of Danish solutions



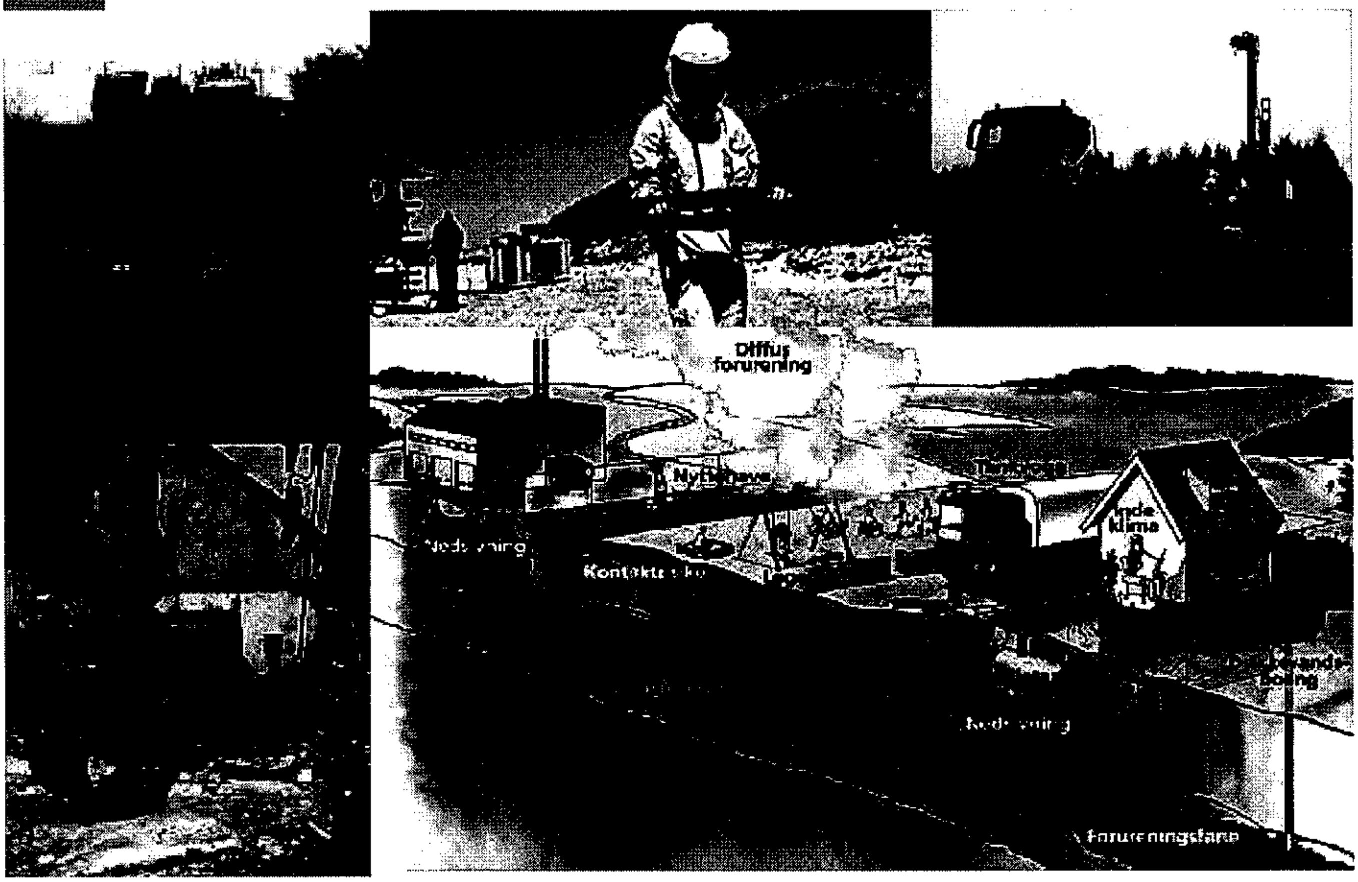
Test and demonstration

- Universities
- Companies

➡

New methods of remediation

Thank you for your attention!



附錄 2


Development of Larg Brownfield Sites in Denmark
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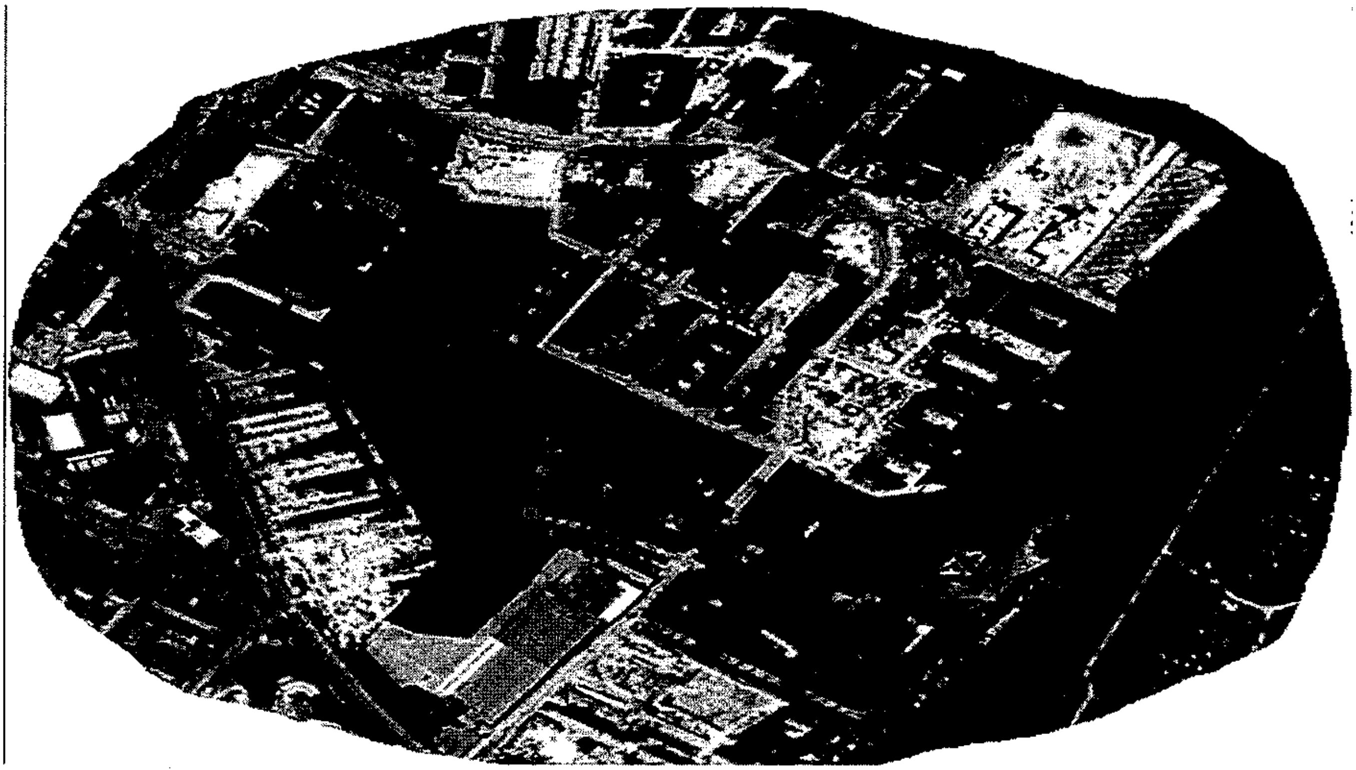
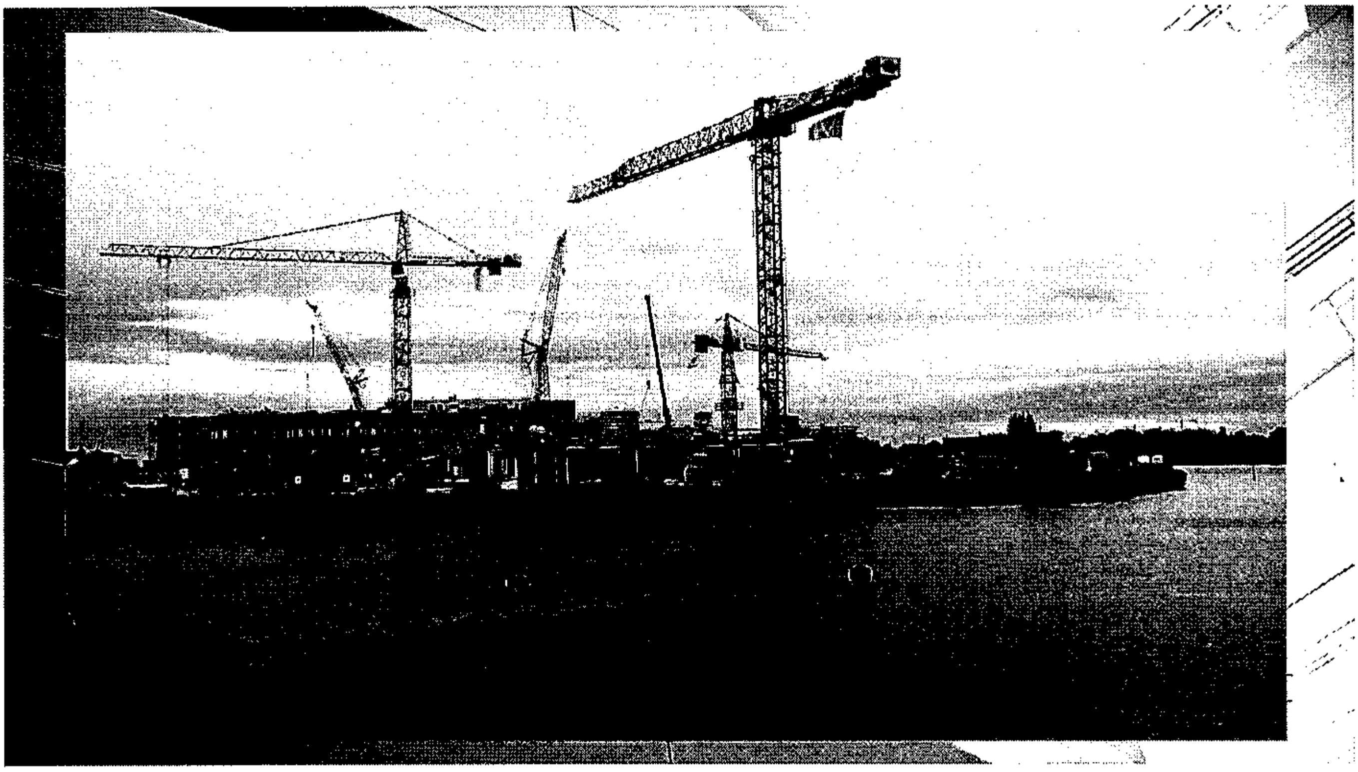
03-10-2017 TROELS WENZEL
COWI





Important aspects in private project development

- Solid knowledge of market intelligence, economic and political aspects
- Respect opinions, both public and politicians – especially the public opinion
- Off-market sites are often high-yield sites in larger cities
- Business case and cash-flow models are important from project time zero
- Master plans and detailed plans have to be generated in the early development phase
- Solid knowledge of on site utilities and planned future facilities
- Identification of easements are important in the early phase

Important aspects in private project development

- Start dialogue with the authorities very early in the development phase and frequently follow up regularly (development of relationships)
- Discuss investigation design and assessments with authorities regularly – this builds up trust and thereby smooth and rapid handling by the authorities
- Respect the requests and procedures from the authorities - site specific.

Environmental Issues

- Pollutants: soil, groundwater, pore space, building contamination and disposed waste
- Flora/Fauna: Bats, reptiles and rare plants
- "Cross-border pollutants": smoke stacks, noise
- Expenses related to environmental issues have to be calculated early in the development phase
- Investigation and assessment of environmental issues at the right level in the actual development phase related to investor risk profile
- Always follow up frequently on all environmental issues and expenses in the business case

Remediation targets, assessment of health risks and monitoring

- Remediation targets are set by the 5 Danish Regions. The targets are set in relation to:
  - Indoor/outdoor climate, sea/lakes and streams and groundwater quality
- Health is assessed by specific assessment models made by the Danish EPA and Regions
- Monitoring health and environmental risks is designed to the specific project and the specific possible threats which has been identified in the investigations
- The monitoring take from weeks to years
- All results are processed, validated and reported to the local authority and the Region where the site is located

附錄 3

NICOLE
Network for Industrially Co-ordinated Sustainable Land Management in Europe

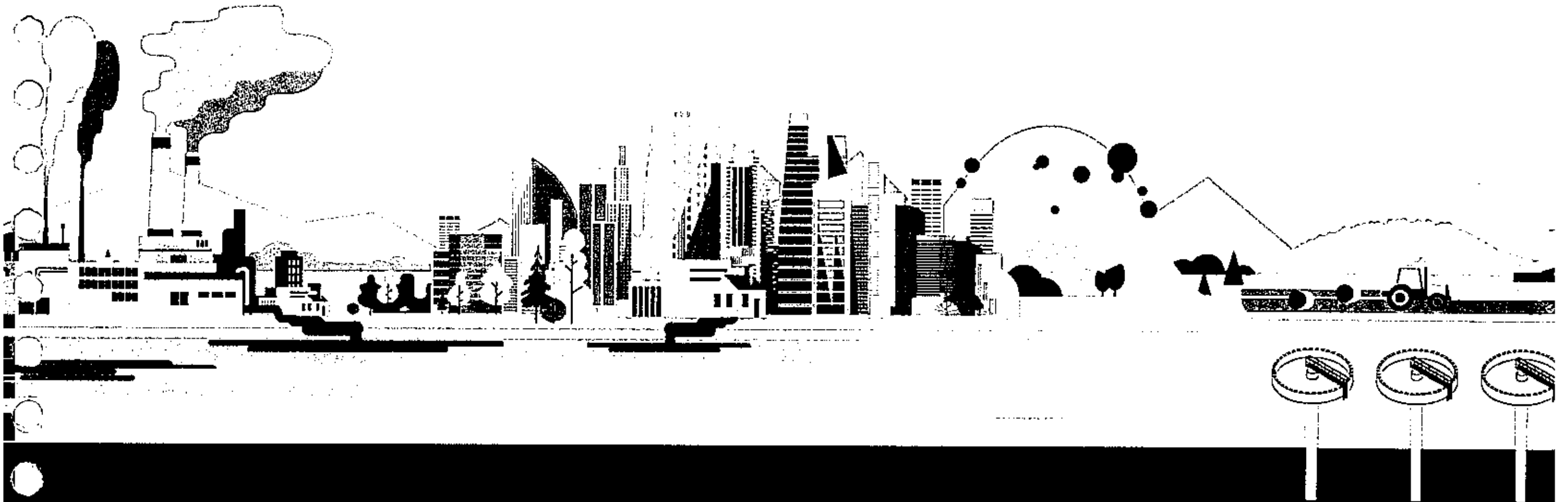
ICCL
international committee on contaminated land

Danish Soil Partnership

DANISH REGIONS

Common Forum

INNOVATION NETWORK FOR ENVIRONMENTAL TECHNOLOGY



Joint ICCL – NICOLE conference
Groundwater Management on Contaminated Sites

Conference program

5th to 6th October 2017, National Museum, Copenhagen, Denmark.

The conference is following the back-to-back meetings of the
ICCL and NICOLE on 3rd to 4th of October in Copenhagen.

NICOLE Organizing Committee

Lucia Buvé (Chairman) - Umicore/ NICOLE
Dominique Darmendrail - BRGM/ ICCL
Neal D. Durant - Geosyntec Consultants/ NICOLE
Arthur de Groof - Sweco/ NICOLE
Carlos Pachon - USEPA/ ICCL
Dietmar Müller - Grabherr - EA Austria/ ICCL
Rick Parkman - AECOM/ NICOLE
Christian Andersen - Danish Regions/ ICCL

Venues

Conference & workshops
National Museum of Denmark
Ny Vestergade 10, Copenhagen

Conference dinner (boat service available)
Toldboden
18-24 Nordre Toldbod, Copenhagen

Registration

Please complete the conference registration form, available online through NICOLE.org and/or the NICOLE secretariat. Deadline for registration: 26 September 2017.

Fees

Participation in the joint ICCL & NICOLE conference 2017 is free of charge for NICOLE and ICCL members, and conference speakers. Information on admission fees for other participants can be obtained through the NICOLE secretariat.

NICOLE Secretariat

For further information on NICOLE membership, workshop programs, registration & fees, or any other practical issue regarding the conference, please contact:

Nan Su (Dutch Sino Business Promotions)
P.O. Box 28249 – 3003 KE Rotterdam, The Netherlands
Phone: +31 (10) 310 0829
E-mail: nan.su@nicole.org

NICOLE

Network for Industrially Co-ordinated Sustainable Land Management in Europe

ICCL international committee on contaminated land

Thursday 5 October 2017
CONFERENCE DAY 1 - Main venue

08:00 - 08:30 **Registration**

08:30 - 10:25 **Intro session** - Chair: *Phil Crowcroft* - ERM

Key-note speakers

Lucia Buvé - Umicore/ NICOLE / **Dietmar Müller - Grabherr** - EA Austria/ ICCL
Jens Mandrup - Political committee for traffic and environment in the Capital Region of Denmark (Chairman)
Carl-Emil Larsen - Danish Water and Wastewater Association (Executive director)
Pascal Mallien - Baker McKenzie / NICOLE
CF or ICCL member - Institute

Panel discussion

10:25 - 11:00 **Break** (Network event @ secondary venue)

11:00 - 13:10 **Technical session 1** - Chair: *Arthur de Groof* - Sweco
Managing natural resources and financial aspects in remediation

Innovation Award

Paul van Riet - Dow Benelux
Hans-Peter Koschitzky - VEGAS, Versuchseinrichtung zur Grundwasser- und Altlastensanierung, Universität Stuttgart

Poster pitches

Jim Wragg - Geosyntec
Niels Ploug - KRÜGER A/S
Thomas G. Reichenauer - AIT Austrian Institute of Technology GmbH

Presentations

Leonardo Pflüger - Argentinean Ministry of Environment
(Funded by the German Ministry for the Environment, Nature Conservation, Building and Nuclear Safety)
The Argentinean context on Contaminated sites and Groundwater pollution: cases and challenges.

Tim Bartlett - Advisian
Improving cost-benefit and sustainability assessments by estimating groundwater resource loss

Hans Slenders - Arcadis
From cost-benefit to impact-benefit analyses in sustainability appraisals

Jarno Laitinen - Centre for Economic Development, Transport and the Environment Finland
Finding ways to implement sustainability in remediation through procurement

13:10 - 14:15 **Lunch** (Network event @ secondary venue)

Continues on next page >>

Thursday 5 October 2017
CONFERENCE DAY 1 - Main venue

14:15 - 16:00	Technical session 2 - Chair: *Jim Wragg* – Geosyntec Consultants Innovation in investigation, remediation and source removal technologies

Poster pitches

Irene Jubany - CTM
Mohamad Sakizadeh - University Teheran, Iran
Jeremy Birnstingl - REGENESIS
Hans-Peter Koschitzky - VEGAS, Versuchseinrichtung zur Grundwasser- und Altlastensanierung, Universität Stuttgart

Presentations

Anne Northway - Environment Protection Agency Australia / Victoria
Australia's Regulatory Journey: Cross jurisdictional collaboration towards nationally consistent approaches to environmental regulation of PFAS.

Niels Ploug - KRÜGER A/S
First European Thermal Remediation of Crystalline Rock on a busy urban development site

James Baldock - ERM
Sustainable Low Temperature Thermal Remediation of Pesticides

Dirk Paulus - Tauw België N.V.
In-Situ Metal Precipitation of a mercury impacted aquifer

16:00 - 16:30 **Break** (Network event @ secondary venue)

16:30 - 17:35	Technical session 3 - Chair: *Dietmar Müller-Grabherr* – EA Austria Innovation in investigation, remediation and source removal technologies

Poster pitches

Giovanni Buscone - Tauw Italia S.r.l.
Phil Studds - Ramboll Environ
Erwin van der Pol - Witteveen + bos

Presentations

Hans-Peter Koschitzky - VEGAS, Versuchseinrichtung zur Grundwasser- und Altlastensanierung, Universität Stuttgart
Nanoremediation for Soil and Groundwater Clean-up
What can we learn from NanoRem: Possibilities and Future Trends

Olivier Sibourg - Enoveo
Real-time and in situ monitoring of aquatic environments using indigenous microbial community - based biosensors

Continues on next page >>

Thursday 5 October 2017
CONFERENCE DAY 1 - Evening program

17:35 - 19:00 **Drinks in the main lobby and access to the poster exhibition**

19:00 - 19:30 **Boat to restaurant**

19:30 - 23:00 **Dinner & Innovation Award**
Dinner costs are 400 DK (approx. €50) p.p and should be paid in cash to the NICOLE Secretariat

Innovation Award Top 3 candidates

University of Antwerp
Integrated passive groundwater mass flux sampling technology

WSP
Ultra-resolution analysis of coal tars

RisCom
Innovative In-Situe Injection Technology i-SAV

Thursday 5 October 2017
Matchmaking & Networking event - Assembly Hall (Festsalen)

During the joint NICOLE/ICCL conference a large number of professionals from Denmark, the rest of Europe and the world are expected to visit. In order to promote knowledge exchange, the Danish Organisation Innovation Network for Environmental Technologies (Innovation-MT) offers all participants a matchmaking and networking event on Thursday 5 October.

This event will be located at the Assembly Hall (Festsalen) in the National Museum.

To take part in this unique event, you can register yourself as a participant on https://www.b2match.eu/iccl-nicole-networking2017

The matchmaking website is open for profile registration now. Booking of matchmaking meetings will open on the 15th of September. On the 2nd of October the registration will close and meeting programs will be sent out to participants on the 3rd of October.

For more information or questions, please contact Ulla Kistine Brandt ukb@cleancluster.dk

Friday 6 October 2017
CONFERENCE DAY 2 - Main venue

09:00 **Morning welcome**

09:00 - 10:45 Technical session 4 - Chair: *Christian Andersen* – Danish Regions
GW management on Large Scale and Multisource sites: regulatory framework and adaptive approaches

Presentations

Dietmar Müller-Grabherr - Environment Agency Austria
Understanding WFD objectives in groundwater management

Corinne Merly - BRGM
Towards a less stringent groundwater body objective?
Feedback from a French heavily industrial and urban study area

Johanne Urup - Ramboll
Water supply in an urban area with many well-known pollution sites – one case study in the Copenhagen area

Chiara Senzolo - Advisian
Integrated Water Resources Management in South America

10:45 - 11:00 **Closing remarks**

11:00 - 14:30 **Site visit** (By bus, including lunch pack. Registration required)

14:30 **National Museum drop-off**

15:00 **Airport drop-off**

Participants

Pol Tock	Administration de l'Environnement
Tim Bartlett	Advisian
Guillermo Bonder	Advisian
Steven Whittall	Advisian
Chiara Senzolo	Advisian
Rick Parkman	AECOM
Regina Vilao	Agencia Portuguesa do Ambiente
Thomas Reichenauer	AIT Austrian Institute of Technology
Wilfred van Noord	AkzoNobel
Hervé Constantin	Arcadis
Maxime Petrignet	Arcadis
Hans Slenders	Arcadis
Kathy Verhelst	Bekaert
Maurice Henssen	Bioclear earth
Sytze Keuning	Bioclear earth
Birgitta Beuthe	BP
Valérie Guérin	BRGM
Corinne Merly	BRGM
Alain Roger	BURGEAP
Pascal Mallien	BVBA
Paul Nathanail	CABERNET & INSPIRATION (University of Nottingham)
Gitte Ellehave Schultz	Capital Region
Jytte Gad lauridsen	Central Denmark Region
Anette Specht	Central Denmark Region
Karsten Rosenkilde	Central Denmark Region
Jarno Laitinen	Centre for Economic Development-, Transport and the Environment Finland
Claudio Albano	CH2M
Rob Sweeney	CL:AIRE
Mathieu Morlay	COLAS Environnement
Jérôme Rheinbold	COLAS Environnement
Dominique Darmendrail	Common Forum
Matthew Ingram	Cornelsen Ltd
Jit Joytishna	CRC CARE / UniSA
Andreas Zissimos	Cyprus Geological Survey
Niels Bukholt	Danish EPA
Christian Andersen	Danish Regions
Kurt Moller	Danish Regions
Kit Jespersen	Danish Regions
Nanna Thomsen	Danish Regions
Carl-Emil Larsen	Danish Water and Wastewater Association
Ana María Ocampo Gómez	Dirección de Asuntos Ambientales Sectorial y Urbana, Ministerio de Ambiente y Desarrollo Sostenible de Colombia
Sheila Verónica Zacarías Ríos	Dirección General de Calidad Ambiental del Ministerio del Ambiente de Perú
Pedro Alberto Sifuentes Amez	Dirección General de Calidad Ambiental del Ministerio del Ambiente de Perú

Participants

Paul van Riet	Dow Benelux
Philippe Menoud	DuPont
Dan Alexander	EarthSoft
Jannik Stephanus	EarthSoft
Ana Paya Perez	EC - Joint Research Center
Matteo Donati	Ecologia
Paul Sheehan	Ecologia
Caroline Dionisi	EDF
Olivier Sibourg	Enoveo
Dietmar Müller - Grabherr	Environment Agency Austria
Rebecca Hughes	Environment Protection Authority (South Australia)
Anne Northway	Environment Protection Authority Victoria
Hui-Chen Tsai	Environmental Protection Administration Taiwan
Dragana Vidojevic	Environmental Protection Agency
James Baldock	ERM
Phil Crowcroft	ERM
Bavo Peeters	European Commission
Andreas Bieber	Federal Ministry for the Environment, Germany
Christiane Wermeille	Federal Office for the Environment
Irene Jubany	FUNDACIO CTM CENTRE TECNOLOGIC
Jim Wragg	GEOSYNTEC CONSULTANTS
Neal D. Durant	Geosyntec Consultants
Jean-Jacques Peraudin	GEOVARIANCES
Thomas Strassburger	German Ministry for the Environment
Åke Eriksson	Golder Associates
Thierry Imbert	Golder Associates
Lena Torin	Golder Associates
Joanna Ankersmit	Government of Canada - INAC
Henriette Korpershoek	Havenbedrijf Rotterdam
Klaas de Jong	HMVT
Nicholas Tymko	HONEYWELL
Tim Op 't Eyndt	iFlux
Goedele Verreydt	iFlux
Ana Isabel Alzola Echazarra	IHOBE
John Vijnen	IHPA
Horst Herzog	Infraserv GmbH & Co. Höchst KG
Jung Auk Park	Korea Environment Corporation
Young Kyuem Choi	Korea Environment Corporation
Sang-Il Hwang	Korea Environment Institute
Maiken Faurbye	Krüger A/S
Niels Ploug	Krüger A/S
Rasa Radiene	Lithuanian Geological Survey
Rob Rutjes	LyondellBasell
Habib Diallo	MEADD

Participants

Jordi Boronat	MEDITERRA (ENVIRONMENTAL CONSULTANTS)
Pernille (Nila) Nielsen	MEDITERRA (ENVIRONMENTAL CONSULTANTS)
Antoine Billard	Ministére de l'environnement - France
Leonardo Pflüger	Ministerio de Ambiente y Desarrollo Sustentable de Argentina
Co Molenaar	Ministry of Infrastructure and Environment
Margot de Cleen	Ministry of Infrastructure and Environment
Bernarda Podlipnik	Ministry of the Environment and spatial planning
Kevin Ooteman	MWH, now part of Stantec
Mpho Tshitangoni	National Department of Environmental Affairs
Olivier Maurer	Nicole Brasil (CH2M)
Lida Schelwald-van der Kley	NICOLE ISG/ Envision-S
Nan Su	NICOLE Secretariat
Monique Keizer	NICOLE Secretariat
Elze-Lia Visser	NICOLE SPG Secretariat
Kine Martinsen	Norwegian Environment Agency
Emre Burcu Ozkaraova	Ondokuz Mayis University
Mette Algreen	Orbicon
Katerina Tsitonaki	Orbicon
Eddy Van Dyck	OVAM (Public Waste Agency of Flanders)
Johan Ceenaeme	OVAM (Public Waste Agency of Flanders)
Michael Mueller	PeroxyChem Environmental Solutions
Achim Constantin	Peruvian Ministry of Environment / ReLASC
Johan de Fraye	Philips
Chris Schuren	Philips Lighting
Jarno Laitinen	Pirkanmaa ELY-Centre
Guido de Jong	Port of Rotterdam
Esther Goidts	Public Administration of Wallonia (SPW)
Paul Bardos	r3 Environmental Technology Ltd.
Hans Bengtsson	Ramboll
Geert De Buysscher	Ramboll
Marianne Wilton-Blom	Ramboll
Aldo Trezzi	Ramboll
Johanne Urup	Ramboll
Mette Christophersen	Rambøll
Susanne Sandanger	Rambøll
Phil Studds	Ramboll Environ
Katariina Koikkalainen	Ramboll Finland
Liisa Koivulehto	Ramboll Finland
Åsa Fritioff	Ramböll Sverige AB
Jeremy Birnstingl	REGENESIS
Jack Shore	REGENESIS
José Tomás Albergaria	REQUIMTE/ISEP
Jack Schreurs	Royal Philips
Martin van der Hop	Royal Philips

Participants

Salahadein Alzien	RWTH Aachen University
Paolo Ambrosini	Saipem spa
Ezgi Bahar Cilesiz	Seza Engineering, Architecture and Consulting Ltd.Co.
Gozde Guvensoy	SEZA MÜHENDISLIK MIMARLIK MÜSAVIRLIK
Elise Noel	Shell
Marcus van Zutphen	Shell Global Solutions
Karina Cady	Shell International
Ching-Ping Chu	Sinotech Engineering Consultants, Inc.
Willem Havermans	Stantec
Arthur de Groof	Sweco
Femke Haest	Sweco
Wesley van Breda	Sweco
Kristian Kirkebjerg	Sweco Danmark as
Nik Dixon	Sweco UK Limited
Bjorn Johansson	Swedish EPA
Jussi Reinikainen	SYKE
Luigi Volpe	SYNDIAL SPA
Dirk Paulus	Tauw België N.V.
Laurent Bakker	Tauw BV
Giovanni Buscone	Tauw Italia
Jens Mandrup	The Capital Region of Denmark
Ida Olesen	The Region of Southern Denmark
Sandrine Demeure	TOTAL Refining Chemicals
Arne Hüttmann	Umicore
Lucia Buve	Umicore
Joerg Frauenstein	Umweltbundesamt
Aleksandra Siljic Tomic	UN Environment
Paul Bardos	University of Brighton / r3 Environmental Technology Ltd
Mohamad Sakizadeh	University Teheran
Jean-Louis Seveque	UPDS
Carlos Pachon	USEPA
Hans-Peter Koschitzky	VEGAS, University of Stuttgart
Tom Bosma	Wageningen University
Eduard Marquez i Bargallo	Waste Agency of Catalonia
Nuria Boguet	Waste Agency of Catalonia
Erwin van de Pol	Witteveen+Bos
Per Johansson	WSP
Russell Thomas	WSP
Jan Huus Vestergaard	Zealand Region
Hasse Milter	Zealand Region
Lisbeth Fomsgaard Bergman	Zealand Region

- **Session 1:** **Managing natural resources and financial aspects in remediation**
- **Chair:** **Arthur de Groof - Sweco**

Innovation Award Top 3 candidates

a. University of Antwerp

Integrated passive groundwater mass ux sampling technology

b. WSP

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c. RisCom

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Poster pitches: Jim Wragg - Geosyntec
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Presentations:

- **Leonardo P üger - Argentinean Ministry of Environment(Funded by the German Ministry for the Environment, Nature Conservation, Building and Nuclear Safety)**

The Argentinean context on Contaminated sites and Groundwater pollution: cases and challenges.

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- **Jarno Laitinen - Centre for Economic Development, Transport and the Environment Finland**

Finding ways to implement sustainability in remediation through procurement

Nicole
INNOVATION
AWARD 2017

iFLUX

Integrated passive groundwater mass flux sampling technology

envision groundwater in motion

Author: Dr. Ing. Goedele Verreydt
Postdoc researcher University of Antwerp, Belgium
Founder of iFLUX
contact: goedele@ifluxsampling.com

co-authors: *Ir. Tim Op 't Eyndt*
Msc. Filip Meesters
dr. Jan Bronders
dr. Ilse Van Keer

research funded and supported by University of Antwerp & Vito, Belgium

Universiteit Antwerpen

vito
vision on technology

Executive Summary

iFLUX entails a proven innovative measurement solution to explore the motion of groundwater pollution. The patented technology in combination with the specific data interpretation methodology guarantees a more accurate and complete view of water and pollution movement beneath the surface. These detailed insights enable problem owners to reduce the cost of total contaminated site remediation significantly.

The monitoring and management of soil and groundwater is a challenge. Current methods for the determination of movement of pollution in groundwater use no direct measurements but only simulations. This entails large uncertainties which cause remediation failures and higher costs for contaminated site owners. On top of that, the lack of useful data makes it difficult to get approval for a *risk-based management* approach which completely avoids costly remedial actions.

iFLUX introduces the first *modular flux sampler* operational in the market, that provides accurate in situ measures of groundwater and pollution movement. Currently, two designs have been developed: 1. the iFLUX sampler for installation in existing monitoring wells, and 2. the iFLUX Prospector for direct installation in the subsoil. The modular design enables to sample several types of pollution at the same time and for a longer period (1 week to 6 months). When installed in an existing monitoring well or directly in the saturated subsoil, it intercepts the groundwater flow and captures the compounds of interest. Lab analysis will result in time-averaged groundwater and target compound fluxes. The iFLUX technology currently comprises one Waterflux cartridge to monitor speed and direction of flow and three cartridges to monitor different sources of pollution – VOC's, heavy metals and nutrients.

The integrated Flux Solution includes lab analysis and data interpretation in order to deliver trustworthy groundwater flux information. The end-result is an analytical report containing detailed and reliable flux data, with comprehensible graphs and maps of the designated field. This leads to a novel approach of dynamic remediation management in a more cost-effective and faster manner.

The method is validated and demonstrated at several projects in Flanders, Wallonia, France, Switzerland and the Czeck Republic. Local regulators, research institutes, consultants and problem owners were involved. The technology is on track to be accepted and recommended by environmental regulators as the number one technology for in situ mass flux determination.

Inventor and key developer of the iFLUX technology is Dr. Goedele Verreydt, who spent 8 years to optimize a flux sampler that fits market needs. Together with Tim Op 't Eyndt and Filip Meesters, they finished the iFLUX prototype and specified the business concept ready to launch commercially as a spin-off of VITO and the University of Antwerp.

1. *Introduction*

Even though safety and environmental compliance obligations have become more stringent over the recent past, a large number of contaminated sites still prevail. Alongside this the demand for land (and groundwater) remains high, driven by population growth and continued commercial and industrial activity. Consequently, the need for remediation of contaminated sites to restore the land for future viable use is in high demand.

Deep and irregularly shaped contaminant sources typically produce widespread and dynamic plume zones that are difficult to monitor and difficult to remediate. Remedial actions often fail because of the inadequate characterization of the source zone.

Authorities and environmental consultants are well aware that it is not enough to know what is the current pollution beneath the earth surface, you also need to know how it is moving. The pollution that reaches a receptor (e.g. drinking water extraction, residential zone, river) determines the risks for that receptor and therefore should be measured. Only when this risk is in control, a risk-based management of the contamination is suggested, which is often the only BATNEEC option (Best Available Technology Not Entailing Excessive Cost).

"It is not only about the status of pollution in groundwater,
it is about where and how it moves."

The pollutant load or the mass of pollutant that is moving through the subsoil and the groundwater is called the *contaminant mass flux*. Current methods for the determination of mass fluxes in groundwater provide no direct in situ measures of flow.

The monitoring and management of soil and groundwater is a challenge. These methods involve individual measurements of Darcy water fluxes and contaminant concentrations. This indirect approach entails large uncertainties, especially in complex, heterogeneous aquifers and under temporally varying flow conditions. These uncertainties cause more remediation failures and higher costs for contaminated site owners. On top of that, the lack of useful data makes it difficult to get approval for a *risk-based management* approach which completely avoids costly remedial actions.

2. Contaminant mass flux

Contaminant mass flux is defined as the total amount of contaminant, expressed as mass, passing per unit area per unit time through a well-defined control plane or plane of compliance that is orthogonal to the mean groundwater flow direction (Basmadijan, 2004; Bear, 1988; Newman et al., 2005). $J_c = C.v = \frac{m}{A.t}$

where Jc is the contaminant mass flux [g m^{-2} day^{-1}], C is the mean concentration of the contaminant in the groundwater [g m^{-3}], v is the Darcy groundwater flux [m^3 m^{-2} day^{-1}], m is the mass of contaminant [g], A is a well-defined plane of compliance, orthogonal to the groundwater flow direction [m^2] and t is the time [day].

Contaminant mass discharge (M_d) is the spatial integration of the contaminant mass fluxes (i.e., the sum of all mass flux measures across an entire plume) and thus represents the total mass of any contaminant transported by groundwater through a defined plane. Contaminant mass discharge is expressed as mass per time.

$$M_d = \int_A J_c dA$$

where A is the area of the plane of compliance [m^2] and J_c is the spatially variable contaminant flux [g m^{-2} day^{-1}].

3. Technology

The iFLUX technology includes an *in situ* measurement device for capturing dynamic groundwater quality and quantity, and an associated interpretation and visualization method. Currently, two iFLUX designs have been developed: 1. the iFLUX Sampler for installation in existing monitoring wells, and 2. the iFLUX Prospector for direct installation in the saturated subsoil.

The basics of the three designs are the same. They all are modular systems that include catridges, specific to measuring water flux or capturing the contaminants of interest. The catridges, when exposed to the groundwater flow, provide in situ point determinations of a time-averaged target compound mass flux and water flux.

iFLUX cartridges

The iFLUX catridges are permeable cartridges which are each packed with a specific sorbent matrix. The sorbent matrix of the water flux cartridge is impregnated with known amounts of water soluble resident tracers. These tracers are leached from the matrix at rates proportional to the groundwater flux. The measurements of the contaminants and the remaining resident tracer are used to determine groundwater and target compound fluxes. Exposure times range from 1 week to 6 months, depending on the expected concentration and groundwater flow velocity. Four types of cartridges are currently available: volatile organic compounds, metals & heavy metals, nutrients and water flux. Several cartridges can be superimposed to realize vertical flux differentiation

iFLUX Sampler

The iFLUX Sampler is the device that can be installed in existing monitoring wells. The cartridges are superimposed on rods (typically on waterflux catridge combined with one or more contaminant cartridges) that can be connected to form a long sampling chain. The ease of use and installation is the main advantage of this design.

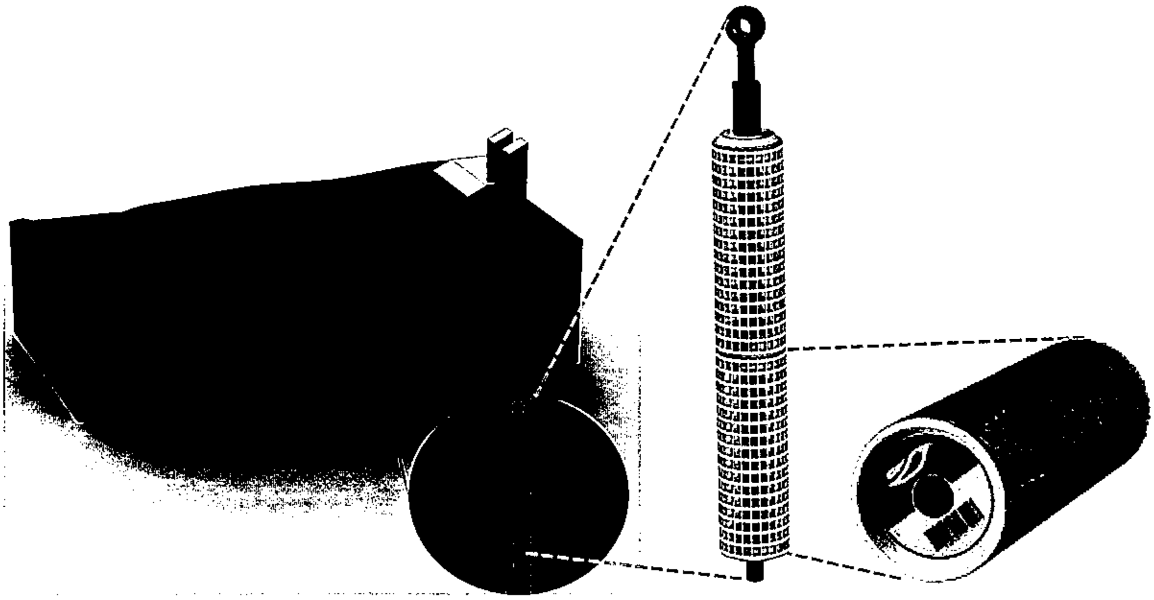


Figure 1 - iFLUX sampler: Field concept – sampler assembly – sampler cartridge

iFLUX Prospector

The iFLUX Prospector modules are designed to create a string of stainless steel modules to install into the soil by the use of machine drilling rig or by hand drilling. The weight and dimensions are designed to make the installation a one man job. Every sampling module can contain several iFLUX cartridges. Figure 2 shows the installation of the iFLUX Prospector system using a machine drilling drig. Advantages of this system are the no need for monitoring tubes where it is not desired and the minimum groundwater flow field distortion as the cartridges are in direct contact with the surrounding soil material.

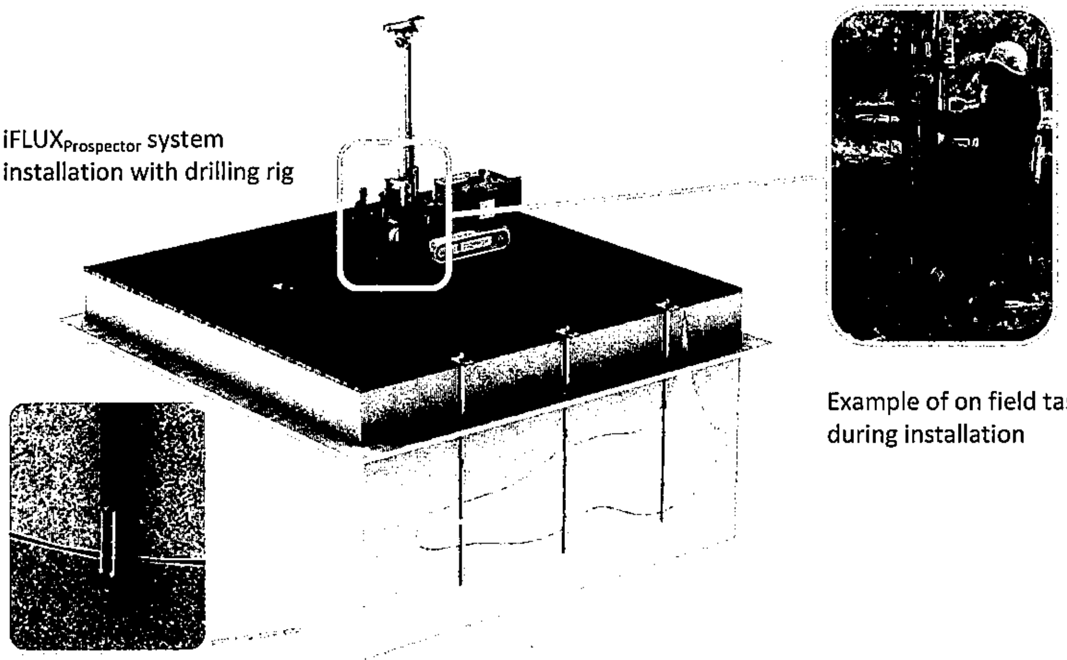


Figure 2 – iFLUX Prospector installation

4. When to apply?

- *More accurate characterization*
  Executing the remediation based on accurate data that can also indicate the mobility of contamination is of invaluable importance. Therefore it is crucial to map out clearly the spreading risks of groundwater contamination.
- *Design remediation plan*
  High flux zones can be indicated and in situ remediation techniques can be dimensioned based on the actual and local pollutant load.
- *Determine remediation urgencies and priority source zones*
  Differences in source strength can be determined from the flux results, which localizes the most hazardous sources. This can be put to immediate use in the remediation plan.
- *Follow up of remediation efficiency*
  Follow-up of the efficiency of these remediation measures is more accurate as well. This can be done by following the decrease in pollutant load and pollutant flux, typically downstream from the treated source or plume zone.
- *Monitoring of Natural Decomposition*
  The natural decomposition or the decrease in pollutant loads can be calculated by the difference in total pollutant load between two cross sections of the contamination plume. Monitoring of decomposition parameters, nutrients and fluxes to subsidiary products also results in highly valuable information.
- *Risk-based management of contamination*
  Flux sampling offers a reliable basis for risk management. The actual mass and speed with which a contamination reaches a receptor, evaluates precisely the risks for this receptor.

5. Reference projects

Multiple reference projects within different application scopes have been and are still being perfomed. As an example, we will show some results of two recent projects: 1. Vertical stratification of VOCs in groundwater (Czeck republic), and 2. PASSIFLUX phase 1-2 (Switzerland).

Reference 1: Vertical stratification of VOCs in groundwater (Czechia, March-May 2017)

Background

It concerns an active industrial site in Czechia. The site is contaminated with petroleum hydrocarbons, chlorinated solvents and pharmaceutical products. The flux field campaign focuses on the vertical spreading of mainly the chlorinated solvent compounds.

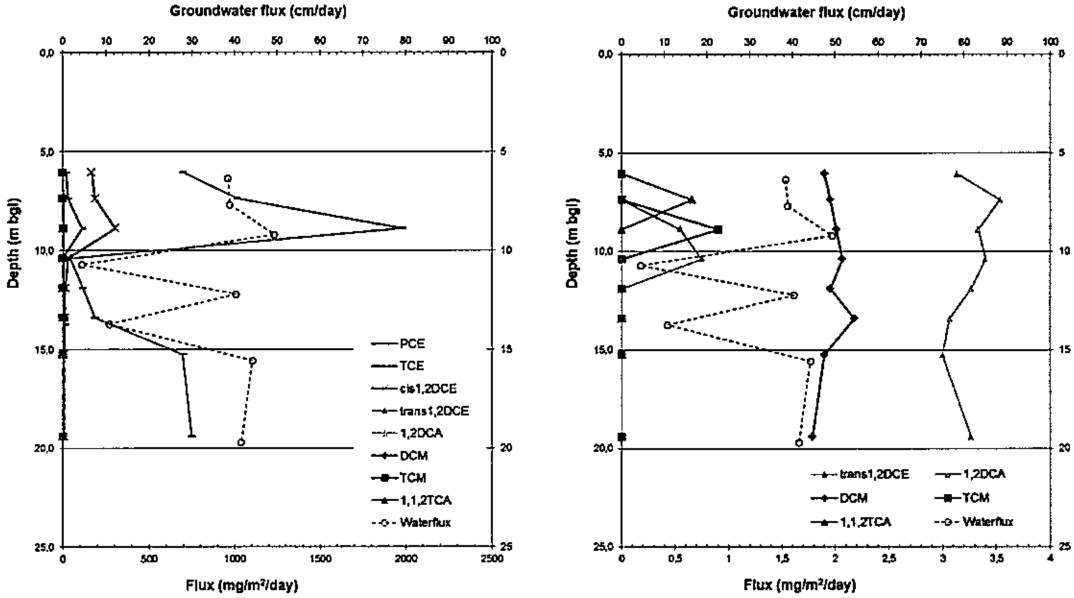
Challenge

The challenge within this project is to determine the vertical stratification of the residual deeper pollution in a very heterogeneic subsoil. A fully screened deep large diameter well is used for the measurements.

Solution

16 iFLUX cartridges were installed in one large diameter well between 6 and 19 meter below ground level. The mass flux data determine the vertical spreading and therefore stratification of the residual VOCs in the subsoil.

Results



Figures 3 a & b - iFLUX mass flux results in one monitoring well, showing different scales

Reference 2: PASSIFLUX phase 1-2 (Switzerland & France – 2015/2018)

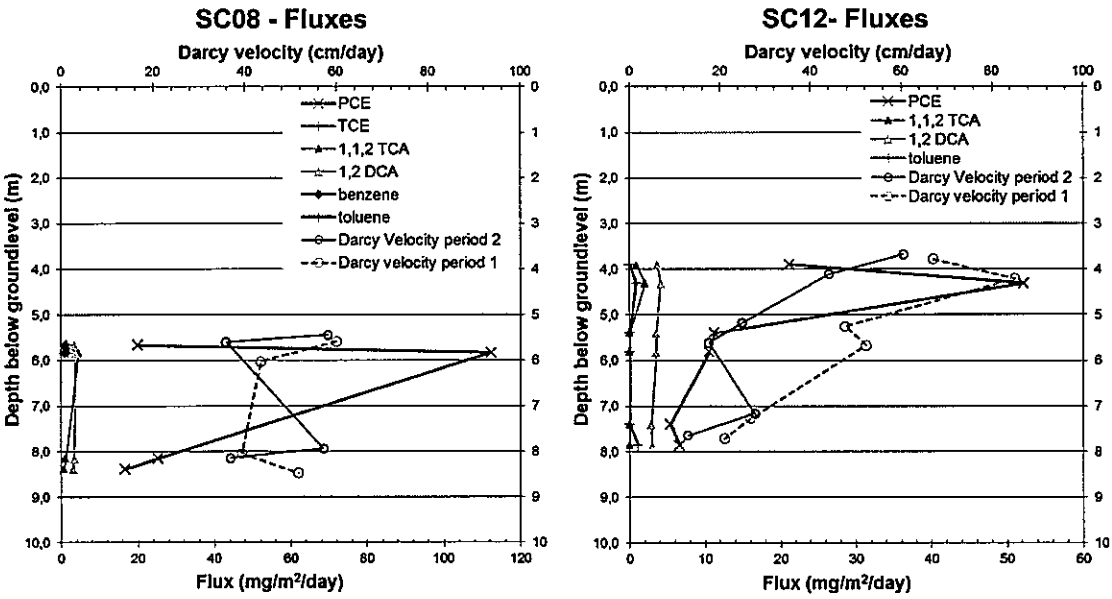
Background

This study comprises the application of passive flux samplers for the measurement of halogenated volatile organic compound mass fluxes and Darcy water fluxes in groundwater at a field site in Switzerland and in France. It frames in the PASSIFLUX project which aims the preparation of a 'Code of Best Practices for Passive Flux Samplers', that includes the evaluation and testing of the performance of several types of passive flux methodologies for groundwater.

Challenge

Flux samplers are installed in different situations, with different target pollutions, in source and plume zones, under low and high water fluxes and varying contaminant mass flux loads.

Results



Figures 4 a & b - iFLUX mass flux results in two monitoring wells

Solution

The project consists of four phases. In the first two phases we installed 22 flux samplers (2 cartr./sampler) in 6 different monitoring wells. After retrieval (1-3 months exposure), the cartridges were analyzed for VOCs and tracers. Results are compared with other passive sampling methods and traditional soil and groundwater sampling methods.

6.Prospects & discussion

The in situ monitoring of the movement of the groundwater pollution is unique and very promising in contaminated soil and groundwater management.

The proposed technology fits within the procedures and principles formulated in the proposed EU Soil Framework Directive, the EU Water Framework Directive, the Industry Emissions Directive and the Flemish Soil Decree. The implementation of this flux-based strategy requires the participation of the local authorities to accept mass flux measurements as an additional or in some cases better alternative monitoring method to conventional concentration measurements.

The Flemish, French and Suisse authorities have already taken the first step toward possible mass flux targeting instead of concentration targeting by implementing the iFLUX technology and by performing pilot studies to validate the technology and pubish it for the environmental sector as a Code of Best Practice for passive flux measurements in groundwater (Pilootstudie Polluentfluxen – OVAM, 2017, PASSIFLUX Project – ADEME & INERIS, 2015-2018).

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Ultra-resolution analysis of coal tars
NICOLE Innovation Award

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Entered for the following:

NICOLE innovation Award - Where we think we have answered a specific judging criteria[i], we have put the letter marking that criteria in brackets e.g. (a)

Executive summary

This project's achievements, include: **1)** the development of an analytical method providing a single stage analysis for fingerprinting coal tars **(a,c)**; **2)** the application of this method to fingerprint a diverse range of coal tars from the UK and abroad **(a,c)**. **3)**; the modification of the original analytical method to identify further groups of compounds in coal tar **(a,c)**, **4)** the application of this methods to produce the world's first ultra-resolution analysis of coal tar and creosote samples **(a, d)**; and **5)** Eight journal papers have been published **(d)**. The research has proven the applicability of the analytical method for fingerprinting coal tars **(c)**. It has identified a diverse range of over 2300 detectable compounds, with only 173 of these compounds found in all coal tar types **(b)**. It has greatly improved our knowledge of coal tar composition, beneficial in understanding it's remediation and fundamental in its risk assessment, where so much is dependent on benzo(a)pyrene and its relationship to coal tar **(a,b,c,d)**. The technique is available from the University and can be implemented by suitably equipped commercial laboratories **(b)**.

Introduction

"Coal tar" is a catch all term used by the contaminated land community worldwide to describe the viscous tarry substance generated by gas and coke manufacturing processes. Whilst it is often assumed all coal tars are similar, they are not. A point recognised by the US National Institute of Health[ii]. Any process which causes the thermal breakdown of organic matter in an oxygen limited environment will produce tar. In the US Coal tar is also used to describe tars from oil based gas manufacturing processes, adding to the confusion, especially as in the North Eastern and Pacific coast USA, oil based gas making processes started to predominate..

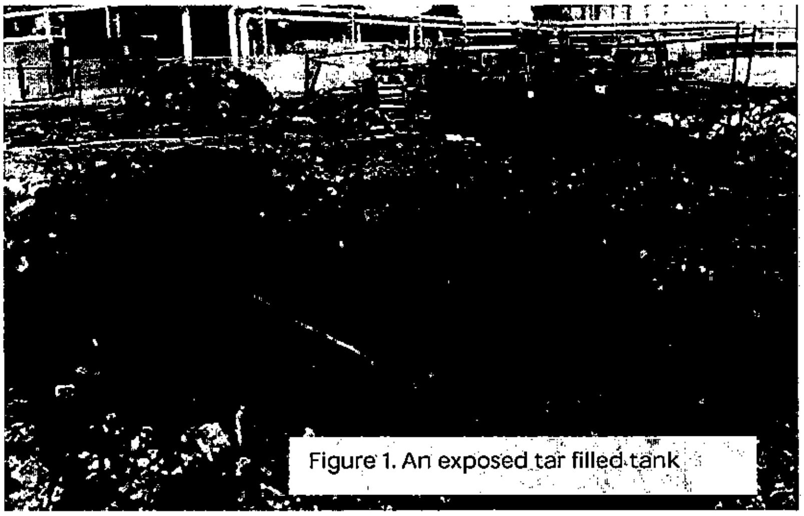


Figure 1. An exposed tar filled tank

During the 160 year history of gas manufacture, starting in the early 19^{th} century, the processes evolved, becoming more efficient and using new feedstocks, such as oil. Whilst the gas industry started in the UK, it soon spread across Europe, leading to the construction in excess of 10,000 former gasworks across the European continent and numerous coking works, so the manufacture of coal tar has been very intensive. It has left behind a considerable environmental legacy.

The composition of coal tar remains a long standing issue, even recent key documents such as European Commission's draft guidance document on the definition and classification of hazardous Waste, describe it incorrectly. They refer to it as "a viscous material composed of complex, high-molecular-weight, compounds derived from the distillation of petroleum or the destructive distillation of wood or coal", evidently this may describe tar, but not specifically coal tar.

The topic of the 2017 NICOLE Innovation Award is: Innovative remediation, monitoring and control technologies to deal with challenging contaminants leading to time and/or cost efficient sustainable remediation solutions. Whilst our research project focusses on the monitoring aspect, it this can equally be applied innovatively to look at both remediation and risk assessment.

This entry includes two phases of research which have been undertaken over the past eight years, primarily covering the PhD's of Laura McGregor and Chris Gallacher, under the supervision of Robert Kalin, Caroline Gauchotte-Lindsay and Russell Thomas. The work has been undertaken at the University of Strathclyde, with funding provided by WSP, National Grid and Scottish Funding Council (SFC) Glasgow Research Partnership in Engineering.

The problem

Our research has sought to answer some fundamental questions: what is coal tar composed of and does the composition of coal tars produced by different processes vary and do they have unique finger print. By answering these questions, it has allowed us to move away from making assumptions about this complex substance, providing a both a detailed analysis and a specific fingerprint for the different types of tar investigated. Whilst coal tar tends only to be found on former gas or coking works, similar substances such as soot from a fire, contain the same substances. The coal tar studies undertaken by Culp et al [iii] form a fundamental part of the surrogate marker approach used to assess the human health risks posed by Polycyclic Aromatic Hydrocarbons (PAH) and complex mixtures of organic compounds found on many brownfield sites. This approach was supported by the UK Health Protection Agency in 2010[iv] and other regulatory systems globally. Whilst these approaches take account of some of the diversity of PAH, they do not account for any other groups of compounds. To date the commercial analysis of coal tar has been limited to simple forensic identifications and the analysis of selected components such as Polycyclic Aromatic Hydrocarbons (PAH), using methods such as GC-FID or GC-MS. This project has sought to provide a more powerful analytical tool, to fingerprint tars for source apportionment and provide a detailed analysis to support risk assessment and remediation decision making.

The research

The first phase of the project was undertaken by WSP, who researched whether different gas manufacturing processes would produce tars of differing composition. The evidence obtained supported this hypothesis as described below (**a**).


Figure 2. The GCxGC-TOFMS

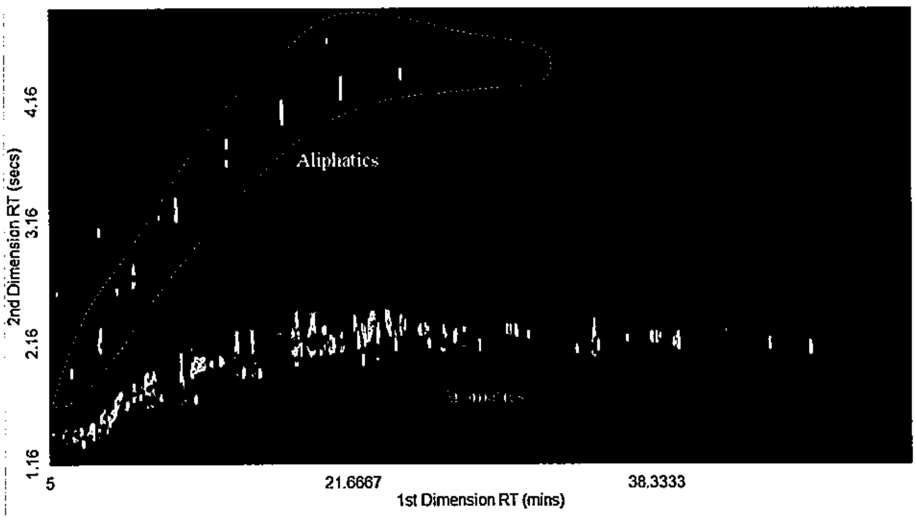
The retort systems used for the carbonisation of coal evolved from low temperature horizontal retorts through to high temperature coke ovens. Their shape and operation (static, intermittent or continuous) also changed as the industry evolved. These changes had an impact on the coal tar produced. The variation in the coal used was limited due to the fact that only certain coal types were used for gas manufacture. In all cases, during carbonisation a primary tar was formed initially. Depending on the process, the extent to which the tar was further degraded was reliant on the temperature of the retort, its orientation, its shape, the depth of coal charge and availability of hot surfaces. Another process used on gasworks from 1880s onward was carburettor water gas (CWG), which made gas from steaming hot coke to produce a poor quality of gas of hydrogen and carbon monoxide, this was enriched through injecting oils into the gas in a hot chamber called the carburettor. The tars produced by the CWG process were sourced directly from the gasification of the oil, rather than coal.

The second phase of this research was to develop an analytical method to enable the finger printing of coal tar samples. The analytical method had to be able to detect a significant number of the diverse groups of compounds found in coal tar. These ranged from aliphatic compounds to sulphur heterocycles. The analytical method chosen used two dimensional gas chromatography coupled with time of flight mass spectrometry (GCxGC-TOFMS, Figure 2). The GCxGC was operated in 'reverse—phase' using a polar primary column with a non-polar secondary column, this enhanced the resolution of aromatic and aliphatic compounds, enabling it to detect thousands of diverse compounds within a single sample run (**a,c,d**, Figure 3)[v].

In order to produce a fingerprint for the tar, the large amount of data generated required the use of the statistical technique "Principal component Analysis" (PCA). PCA was used to extract the variations from the large dataset by reducing raw sample data for selected compounds into smaller uncorrelated variables known as principal components (PC). The score plots of the two different PC describe the most variation in the data, allowing the relationships between the peak areas of the identified compounds within the samples to be evaluated (**a,c,d**).

During this phase of the research the project partners started to amass a diverse range of coal tar samples from different sites from across the UK. The tar library now contains over 40 different coal tar samples, a unique resource, accessible to researchers (**d**). For each site we collected tar samples from we undertook a separate phase of forensic industrial archaeology, so that we could be certain of the method used to produce the coal tar (**a,c**).

Figure 3. Typical scan produced by the GCxGC-TOFMS, showing the separation of aliphatic and aromatic compounds.



Fingerprinting coal tars

From the library of coal tars, 23 samples were chosen for fingerprinting via the method described above. These 23 samples had been identified as having been produced by 5 distinct production processes for detailed investigation[vi]. The gas making processes investigated included: Low Temperature Horizontal Retorts; Horizontal Retorts; Vertical Retorts; Carburettor Water Gas (CWG) and Coke Ovens. The result of this analysis can be seen in Figure 4. The result clearly showed that the CWG tars which are oil derived have a very different signature to "true" coal tars. This has its implications as experimental work undertaken on US coal tars (e.g. Culp et al, 1998), may well have been such oil derived CWG tars and not those more likely to be encountered in European gasworks.

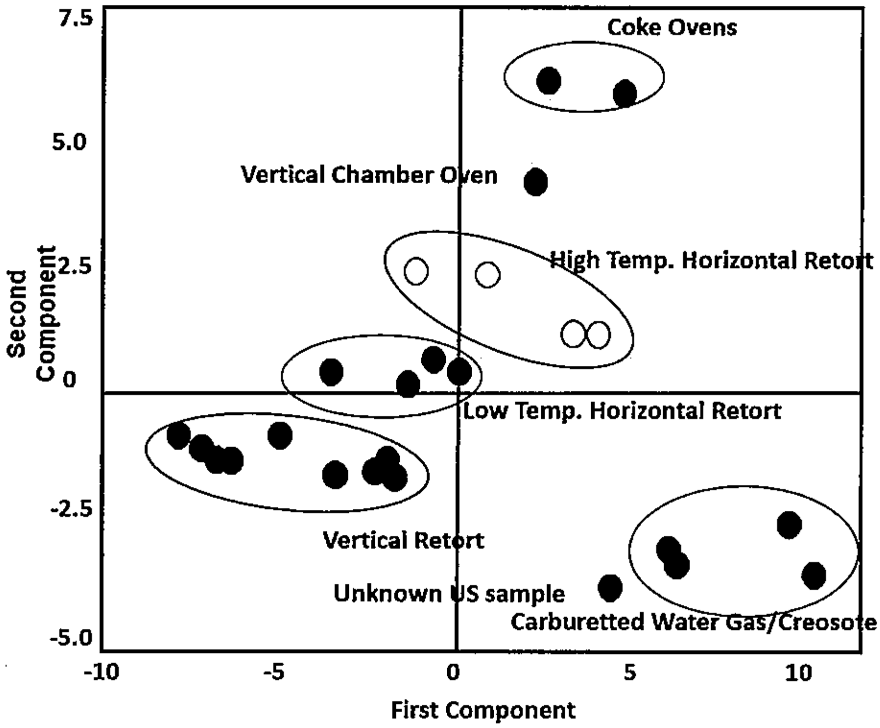
To expand the international utility of this work, samples were obtained from abroad (**c,d**). Working with the consultants in the field, we developed a tar sampling methodology, which was used to obtain samples and ship them to the UK (**c**). Two examples are given below.

Ultra-resolution analysis of coal tars

NICOLE Innovation Award

Samples of tar were obtained from the Arnhem gasworks in the Netherlands. Similar to many on the continent, Arnhem gasworks used chamber ovens, a process developed in Germany and seldom used in the UK. It was ideal for continental coals, which were primarily coking coals. The analysis of these samples provided a forensic signature for chamber ovens. Extending the capability of the method to a widely used gas making process on the European continent (**c,d**). When plotted against other characterised samples, the tar was positioned between high temperature horizontal retorts and coke ovens (Figure 4). This would have been the expected position, confirming the capability of the method as a forensic tool (**c**).

Figure 4. Plot of the principal components generated from the analysis of coal tar samples from the database, showing the position of the Vertical Chamber Oven tar (dark red) and US CWG tar (purple) samples (e).



Suspected coal tar samples from a waste dump were provided on behalf of the authorities of a city in southern USA. The dump had once been used to dispose of tars from the city gasworks. The authorities had provided the samples with the hope that our method could identify the process which had produced the tar and whether it could be linked to the gasworks (**a,b,d**). Such investigations in the US are common within legal cases to assign liability, but they depend upon simple forensic ratios. Our analysis detected 865 compounds within the tar, using PCA to interpret the data it showed the tar (Figure 5) grouped closely with UK CWG tars (**a,c,d**), but not identically. The difference being explained due to the CWG plants in Southern US using cheap soft coals in preference to more expensive coke, as used in the UK. This research has been submitted to the Journal Environmental Forensics (**d**). The method has in one attempt managed to prove the origin of the samples, which had previously taken years of expensive field and laboratory investigation without proving a conclusive answer (b).

Composition of coal tar and creosote

With the confirmation of the fingerprinting methodology. Attempts were made to improve the range of compounds which the analytical method could detect. The same analytical equipment was used (GCxGC-TOFMS), but the method was altered with the addition of a derivatisation step. Derivatization chemically changed compounds making them more amenable to detection. A number of different approaches were tried[vii], but eventually a post extraction derivatisation step was chosen. As with the previous method, it was designed so that it could be carried out in a suitably equipped commercial laboratory (**b**), but is also available from the University for at a cost of £800/sample, whilst this is costly, it provides a uniquely powerful tool (**b**). Details of the method are available in the references provided.

The research then focussed on detailed analysis of what constitutes both creosote and coal tar.

Detailed analysis of Creosote

Creosote, a distillation fraction of coal tar, has been widely used as a wood preservative and is commonly found in the ground of sites formerly used for this purpose. Detailed analysis of creosote has not extended beyond 160 compounds typically. The new method was able to detect 1505 compounds, which included 231 compounds only detectable with the new method (**a,c,d**). Many of the 231 compounds were high molecular weight phenolic compounds. These include octyl and nonyl phenols, suspected endocrine disruptors, previously undetected in coal tar or its distillates. This demonstrates the value of this research (**c,d,**) which has been published in the journal Chemosphere[viii]

Detailed analysis of coal tar

Sixteen samples produced by the 5 distinct production processes were selected from the 23 samples which had previously been fingerprinted as described above, In total the 16 samples contained 2369 unique compounds (**a,b,c,d**), these included:

- 948 aromatic compounds;
- 198 aliphatic compounds;
- 380 sulfur-containing heterocyclic compounds (PASH);
- 209 oxygen-containing heterocyclic compounds (Oxy-PAH);
- 262 nitrogen-containing heterocyclic compounds (NPAC); and
- 15 mixed heterocycles.

The derivatisation method allowed 359 more unique compounds, primarily hydroxylated PAH, to be detected (**a**). An important feature of the 2369 compounds detected, were that only 173 compounds were found to be present within all tar samples (**a,b,c,d**). This list includes the US EPA 16 PAH and the more recently designated US EPA 34 PAH. The latter includes 16 groups of C1 to C4 alkyl PAH. The detection of the alkyl PAH confirmed the benefits of the US EPA 34 PAH approach (**c**). Alkyl PAH can contribute between 35-45% of the total PAH composition and accounted for 74 of the 173 compounds found in all the tar samples (**c**).

Alkyl cyclohexanes are markers of oil (petrogenic material), they were only detected in samples of CWG tar or tar from sites that had operated a CWG plant. The CWG process used oil to enrich poor quality "water gas". It however, produced a tar which had a high water content and tar distiller would not accept. Blending the CWG tar with coal tar, diluted the water content, enabling it to be sold. The results demonstrated that the mixing of CWG tar and coal tar was common and goes towards explaining why UK gasworks do not tend to have the same large plumes of CWG tar in groundwater, as found in the USA (**a,b,c,d**). The presence of CWG tar in coal tar, would enhance its mobility, through reducing both its density and viscosity and increasing co-solvency of the tar (**g**).

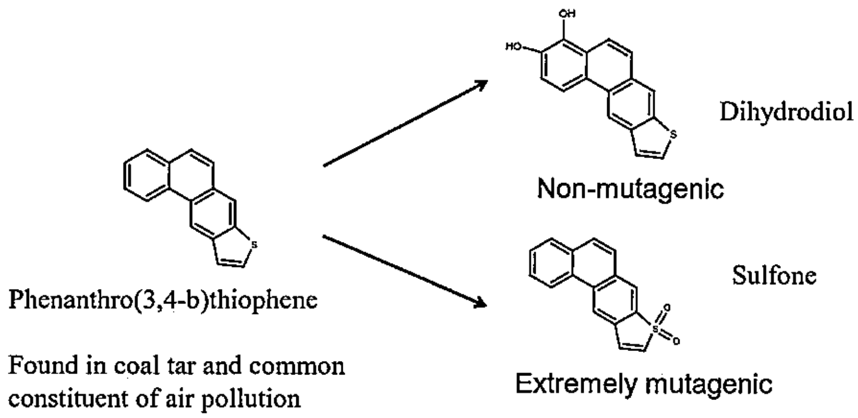
The most important of the PASH compounds detected were the thiophenes and dibenzothiophenes, some of which are carcinogenic and mutagenic. Whilst readily biodegradable, the metabolites can have increased carcinogenicity, such as shown in Figure 5 (**a,c,d**).

A small number of NPACs were detected in all samples, this included the acutely toxic 1-Naphthonitrile. The addition of nitro & amino groups to PAH can enhance toxicity by up to 100-fold. NPAC are also special concern in groundwater at gasworks due to their increased water solubility over PAH (**a,c,d,**).

Benzofuran and a number of its derivatives were the oxy-PAH present in all samples, phenolic compounds were not. Phenolic compounds can provide useful markers for the degradation of coal tars, as they are readily degradable and soluble. This analytical method can provide a useful tool to establish whether the tar would have originally had a high phenol content. The method can also detect compounds indicative of biological activity within the tar samples. Fluoren-9-one is of particular interest, as it is produced as a metabolic breakdown product of both fluorene and fluoranthene. It was abundant in some tar samples whilst missing from other comparable samples (**b,c,d**).

The results also demonstrated that as you transitioned from lower temperature processes (low temperature Horizontal retorts) to high temperature processes (coke ovens), the concentration of parent PAH, NPAC, PASH and OxyPAH would increase whilst the concentration of their alkylated forms and aliphatic compounds would simultaneously be lost (**d**). Such important changes demonstrate the variation in coal tar composition, with the risks of coal tars from low temperature processes (as found on small town gasworks) likely to be underestimated, as a greater portion of the PAH are present in their alkylated form which are not analysed. This research has been published as 3 separate papers (**d**)[ix,x,xi].

Figure 5. Potential biodegradation intermediates of Phenanthro(3,4-b)thiophene.



In all cases the impacts of alkylated PAH and heterocyclic compounds are overlooked in soils affected by coal tars. The aim is that knowledge gained from this project can be used to focus future attention on those alkylated PAH and heterocyclic compounds to better inform both risk assessment and remediation of site affected by both coal tar and PAH (**b,c,d**).

Conclusions

This project has delivered an analytical methods providing a single stage analysis of coal tar for fingerprinting coal tars or analysing them in detail (**a,c**). It has been applied to fingerprinting a diverse range of coal tars from the UK and abroad (**a**). The modification of the original analytical method to identify further groups of compounds which has allowed the world's first ultra-resolution analysis of coal tar and creosote samples (**a**), in total eight journal papers have been published (**d**). It has greatly improved our knowledge of coal tar composition (**a**), beneficial in understanding it's remediation and fundamental in its risk assessment, where so much is dependent on benzo(a)pyrene and its relationship to coal tar (**a,c**).

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[i] Judging Criteria: (**a**) innovation, (**b**) potential contribution to cost savings,, (**c**) technical applicability, (**d**) plans for communication and market availability, - applicable to contaminated land.
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[x] Gallacher, C., Lord, R., Taylor, C., Thomas, R., and Kalin, R., Comprehensive database of Manufactured Gas Plant tars – Part B Aliphatic and Aromatic compounds, Rapid Communications in Mass Spectrometry, 10 May., 2017.
[xi] Gallacher, C., Lord, R., Taylor, C., Thomas, R., and Kalin, R., Comprehensive database of Manufactured Gas Plant Tars - Part C Heterocyclic and hydroxylated PAHs, Rapid Communications in Mass Spectrometry, 10 May., 2017

NICOLE INNOVATION AWARD 2017:

INNOVATIVE in-Situ Injection Technology- i-SAV©

Uwe Dannwolf & Gordon Bures, RiskCom GmbH

SUMMARY

This entry describes the i-SAV© (in Situ AdVantage) technology, an innovative, *in situ* reagent emplacement technology with optional permeability enhancement possibilities to improve subsurface flow enabling a targeted distribution of treatment reagents in challenging geological conditions.

The i-SAV© technology creates cost savings as it is applicable while drilling and does not require the construction of injection wells. The technology achieves large radii of reagent distribution ranging from 4 m in shallow clays to more than 20 m in deeper sediments from one borehole. The technology allows reagents to be injected as suspensions with up to 80% reagent concentrations, thereby avoiding the requirement for repeated injections leading to further cost savings. Its technical applicability ranges from the unsaturated zone to the saturated zone, from shallow depths (usually below 4 m bgs) to depths up to 100 m, and from unconsolidated sediments to bedrocks. No groundwater extraction is usually necessary.

Moreover, the i-SAV© technology is independent of the subsurface' permeability as it is chiefly dependent on the at-rest pressure and the overconsolidation ratio.

Monitoring of subsurface remediation effectiveness is significantly improved through the use of proven non-intrusive geophysical mapping techniques to verify the areal and vertical extent of remedial amendments emplaced within contaminated subsoils. The application of i-SAV© technology is extremely adaptable, in that it can be used in a "treatment train" approach, whereby challenging contaminants can be treated by in sequence by physical, chemical, and biological processes on any given remedial project.

Furthermore, the i-SAV© approach requires only a small footprint making it ideally suited for operational sites with significant above- and below- ground infrastructure where ex situ treatment options are limited.

The technology is sustainable because it has proven to decrease the time required to meet remedial goals. I-SAV© requires only little energy and has a low water consumption resulting in a positive ecological balance compared to other remediation technologies.

The technology has been successfully applied in various configurations with physical extraction (e.g. enhanced pump & treat), chemical oxidation and reduction, and biological treatment processes across North America, Europe, and Asia.

The-i-SAV© technology is an innovative approach in the European remediation market, and many countries are trying to establish similar practices. Currently, the technology is available through RiskCom for the European market.

A demonstration project is planned for autumn 2017 in Germany. Significant amounts of materials about the technology can be found on the "Clu-In" website.

1 TECHNOLOGY DESCRIPTIION

1.1 INNOVATION

The i-SAV© in-situ efficiency technology („in-situ advantage") is used to target specific contaminant zones and facilitate the hydraulic emplacement of treatment reagents at problem sites with limited access, or where difficult, low permeability soil and hard bedrock conditions are encountered. The i - SAV© technology enables a large contact of the treatment reagents with contaminants which significantly enhances their in-situ treatment. The technology can be adjusted so that sand layers are injected generating significant permeability enhancements of the subsurface allowing the technology to be coupled with other pre-existing technologies (e.g. hot or cold soil vapour extraction).

1.2 POTENTIAL FOR COST SAVINGS

The i-SAV© technology creates cost savings because:

- it is applicable while drilling and does not require the construction of injection wells;
- It facilitates large radii of reagent distribution even in low permeable soils and enables targeted emplacement requiring fewer injection wells;
- It allows the injection of extremely concentrated remediation reagents at very high rates (tons per day) avoiding the requirement for repeated injections;
- Unless the Authorities insist of an additional safety layer, no groundwater extraction is usually necessary.

The technology is sustainable because it has proven to decrease the time required to meet remedial goals. I - SAV© has a positive ecological balance compared to other remediation technologies because of its low energy and water consumption. Further advantages compared to conventional remediation approaches (e.g. dig & dump) are:

- Significantly lower energy requirements due to minimal equipment/transportation requirements;
- Negligible production of potentially harmful fugitive emissions compared to ex-situ removal/treatment of contaminated soils and groundwater. No disruption to off-site municipal infrastructure (roads, utility lines, pipelines, etc.);
- No excessive land use due to the avoidance of landfilling.

1.3 TECHNICAL APPLICABILITY

i-SAV©'s technical applicability ranges from the unsaturated zone to the saturated zone, from shallow depths (usually below 4 m bgs) to depths up to 100 m, and from unconsolidated sediments to bedrocks.

The technology involves the pressurized injection (3 to 15 bars) of slurry containing either high permeability substrates and/or treatment reagents into contaminated zones in the subsurface. A network of interbedded, hydraulically connected flow pathways is created which enables the distribution of treatment amendments over large radii of influence extent (4 to 20 m).

While using the i-SAV technology highly concentrated suspensions (up to 80%) for almost all reagents can be injected whereas regular injection methods allowing only low concentrated fluids (< 5% to a maximum of 40% for Na-permanganate) to be injected.

The reagents can be formulated in such a way to establish a treatment train, i.e. a series of oxidation or reduction and stabilising steps making the remediation successful. Thereby the success of the remediation can be easily increased in one step.

One key factor of differentiation to other in-situ injection techniques is that the i-SAV© technology is not dependent on the permeability of the subsurface. Instead the technology is depending on the pressure distribution of the subsoils. One important geo-mechanical factor determining the distribution of amendments emplaced into subsoils is the coefficient of earth pressure at rest, K_0, which is defined as the horizontal pressure, σ'_h divided by the vertical pressure, σ'_v at a given depth and for a particular soil type. The other main factor which determines the distribution pattern of amendments is the overconsolidation ratio (OCR).

The i-SAV© technology can be applied in contaminant source areas or distal plume areas, as a stand-alone remediation technology, or in combination with other in-situ remediation methods.

1.3.1 Visualising the distribution of remediation reagents

One of the most problematic aspects of in-situ remediation is the verification of its effectiveness, because of the inability to visually observe the effects on contamination in the subsurface. This is particularly important when treatment reagents are injected into the subsurface. This is especially so, if the reagents are emplaced as low concentrated solutions with large amounts of water. When injected as highly concentrated slurries, soils from liner bores show the distribution in a vertical bore. A better way of reagent mapping by a non-intrusive, accurate and verified method exists for determining the distribution of reagent layers is called a tiltmeter geophysical survey. This method relies on ground surface sensors to monitor nano/micro-displacements induced by reagent emplacement into subsoils.

Typically, an array of 10 to 16 surface-mounted geophysical tiltmeters is set up around each injection borehole location. During an injection event, ground surface "tilt" is measured at each tiltmeter station and the information is stored wirelessly in a data store, which allows live visualisation on field laptops. For interpretation purposes, the tiltmeter data is subsequently analysed by dedicated geophysical modelling software. Three dimensional graphical representations are subsequently generated. Such 3D pictures can assist the interpretation of the effectiveness of the reagents and the hydrogeochemical patterns found after the injection event. It would also allow optimising long term remedial performance modelling. Furthermore, it tremendously aids in the communication to the regulating Authorities.

1.4 PLANS FOR COMMUNICATION

A demonstration project is planned for autumn 2017 in Germany. Significant amounts of materials about the technology can be found on the "Clu-In" website.

The i-SAV© process was initially developed in response to an USEPA initiative for developing technology to overcome the limitations of in-situ remediation in low permeability soils[1], and has evolved over the past two decades to a proven and accepted remedial technology with hundreds of successful commercial applications worldwide.

1.5 MARKET AVAILABLIITY

The-i-SAV© technology is an innovative approach in the European remediation market, and many countries are trying to establish similar practices. Currently, the technology is available through RiskCom for the European market.

2 CASE STUDY – ITALIAN GAS STATION PILOT TEST

Two highway retail fuel service stations near Chieti, Italy have significant petroleum hydrocarbon related impacts (TPH, BTEX, MTBE) in groundwater and in low permeability soils in the saturated and unsaturated zone. Efforts to remediate contamination using pump & treat and dual phase extraction have proven ineffective. An initially planned dig&dump approach was also considered to be cost prohibitive.

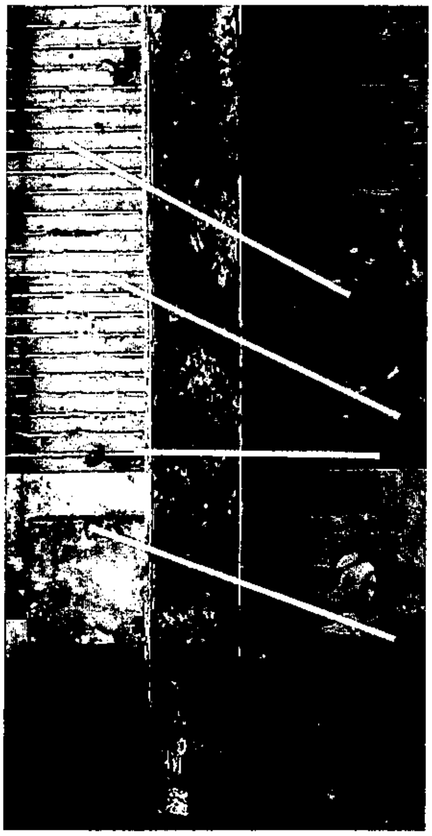
An alternative ISCO *in situ* remedial strategy using the i-SAV© technology was developed and a field pilot test was carried out at two service station sites which involved:

- The use of activated dual-oxidant slurries to aggressively mitigate contaminant impacts;
- Formulation of high viscosity slurry enabling high oxidant concentrations to be injected (upwards to 40% by wt.);

[1] https://clu - in.org/techfocus/default.focus/sec/Environmental_Fracturing/cat/Overview/

- Targeted emplacement of large oxidant volumes at 0.3 m depth increments into contaminated unsaturated and saturated zone silty clay soils to 10 m depth;
- Verification of subsurface oxidant distribution using tiltmeter geophysics and soil coring;
- Long term ISCO performance monitoring and assessment.

Persulfate-ferric iron and persulfate-calcium peroxide dual component oxidants were successfully emplaced in significant quantities within each of the pilot test boreholes (3.000 kg and 3.500 kg per borehole, respectively) using the i-SAV© technology. For five injection boreholes emplacing 14 tons of reagents two weeks of field work were required.



Elevated concentrations of indicator parameters in groundwater monitoring wells (sulfate, redox, dissolved oxygen, calcium, iron) indicated that oxidant distribution of at least 6 metres in radius was achieved at each of the injection boreholes.

The results of soil coring and geophysical mapping of subsurface oxidant distribution indicated that oxidants were emplaced as distinct, sub-horizontal layers, with evidence of more steeply inclined secondary layers (see 3D distribution schematic and summary table below).

Initial increases in groundwater TPH and BTEX concentrations due to displacement effects immediately after oxidant injection were followed by order of magnitude declines two months after emplacement. The primary oxidant (persulfate) appears to have been exhausted 4 months after emplacement, whereas the secondary treatment components (ferric iron and calcium peroxide) show evidence of continued contaminant degradation (see graphic of results below).

Figure 1: ***Soil core with sub-horizontal persulfate-ferric iron oxidant layers (reddish brown) emplaced into silty clay***

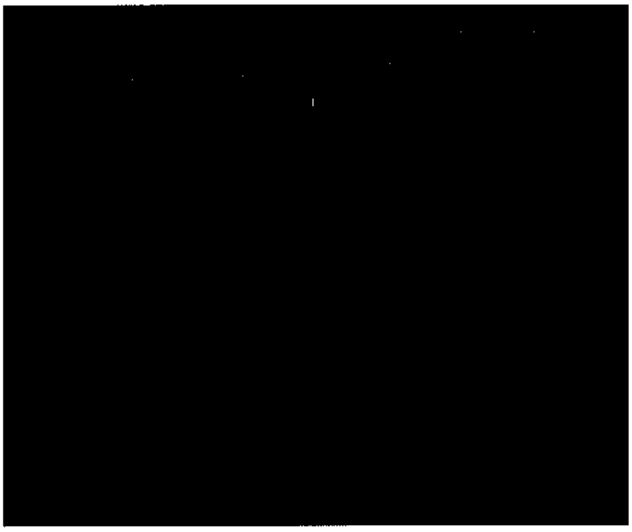


Figure 2: ***Oblique view of six distinct oxidant layers emplaced in subsoils during individual injection events, based on analysis of tiltmeter data at injection borehole IP1***

ID	Depth of [illegible] (m bgs)	[illegible]	[illegible]	[illegible]	Inclination of [illegible] (degrees)	Direction of [illegible]	Fracture [illegible]
i-2	4.3	90°	60°	South	-	-	Strongly ascending
i-5	5.5	110°	25°	North	80°	South	Moderately ascending (P) [6]
							Near vertical (S) [7]
i-8	6.4	105°	25°	North	80°	South	Moderately ascending (P)
							Near vertical (S)
i-9	6.7	160°	20°	West	-	-	Slightly ascending
i-11	7.3	100°	20° to 25°	North and South	80°	South	Moderately ascending (P)
							Near vertical (S)
i-12	7.6	93°	75°	North	-	-	Strongly ascending

Notes:
1. Depth of fracture (m bgs)
2. Orientation of Fracture Axis
3. Angle of inclination from horizontal ("Dip Angle")
4. Direction of inclination perpendicular to fracture axis

Figure 3: ***Summary of geophysical tiltmeter results for 6 of 13 oxidant injection events between 4 and 8 m depth below ground surface at injection borehole IP1.***

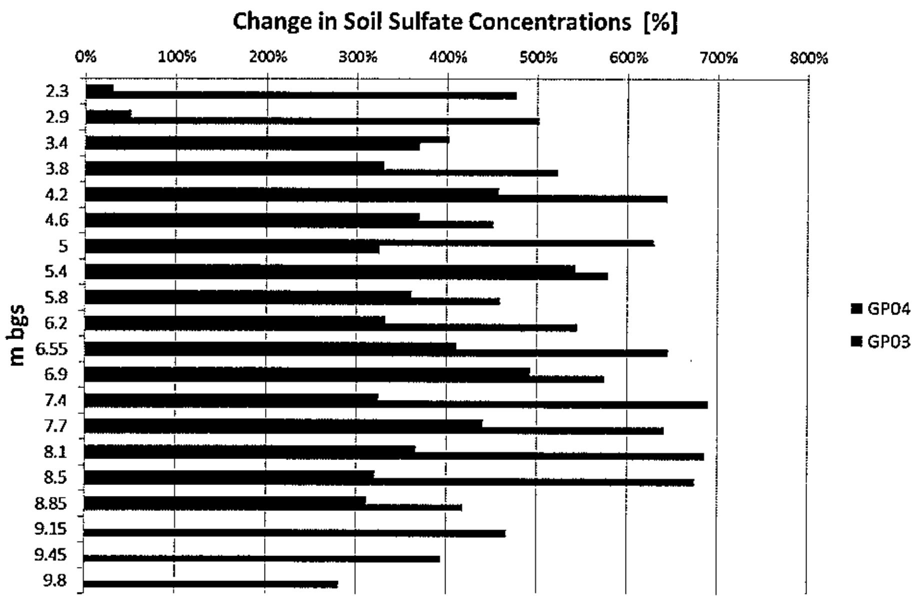


Figure 4: Results from 37 soil samples from two soil liner verification boreholes indicating a homogenous distribution of the persulphate reagent by an increase of sulphate concentrations by several 100%

Implications of Remediation Approach:

Further work is planned to optimize ISCO injections based on results to date, but so far it has been shown that:

- Massive oxidant delivery and homogenous oxidant distribution (i.e. establishing contact") leading to long term treatment at highly contaminated sites can be achieved using very few injection boreholes – no wells are required;
- High resolution geophysical mapping and selective soil coring enable verification of subsurface oxidant distribution in contaminated subsoils for injection optimization;
- ISCO can be employed in both saturated, and unsaturated low permeability soils;
- Remediation can be safely achieved without the need for replacing site infrastructure.

A brief example from a Canadian site outlines an approach where the permeability enhancement through sand emplacement was applied:

- Increasing the bulk permeability of clay soils by emplacing a network of 120 permeable subsurface sand layers (>100 tonnes sand) within the contaminated zone;
- Incorporation of non-ionic, biodegradable surfactant into sand pathway network for improving contaminant availability during subsequent oxidant treatments;
- Completion of 30 injection wells in boreholes with hydraulically connected sand pathways at 0.5 m vertical depth increments;
- 5 rounds of chemical oxidant injection through permeable sand pathways into surrounding clay soils using activated sodium and potassium persulfate, modified Fentons Reagent, calcium peroxide, and oxygen diffusers; total dry mass of 60.000 kg oxidant was injected as solution.
- An iterative remediation approach was used whereby the results of continuous remedial performance monitoring (" CRPM feedback loop") was used to adjust and optimize the ISCO remedial strategy during the lifecycle of the remediation project.

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ICCL – NICOLE Conference – Groundwater Management on Contaminated Sites – 5 - 6 October 2017

Call for Abstract:

Improving Cost-Benefit and Sustainability Assessments by Estimating Groundwater Resource Loss

Tim Bartlett, Principal Hydrogeologist, Advisian UK

Introduction

The sustainable management of land contamination is a key objective considered during the regeneration of brownfield sites in Europe. The assessment of sustainability is commonly made via a process of cost-benefit analyses (CBA) and requires that the benefits of remedial action, across a range of environmental factors, are explicitly quantified and valued.

The proposed presentation discusses an innovative approach to quantify the loss of groundwater resource due to contaminant impact in scenarios where the economic consequences are difficult to assess.

This innovative approach has been developed by Advisian to support the regeneration of UK brownfield sites as part of a cost-benefit approach both in determining sustainable remedial strategies; and to achieve site closure and resolution of land contamination liabilities where remedial action is not warranted. This approach accords with procedures advocated by the Sustainable Remediation Forum (SURF-UK) and provides an advance in the assessment process applicable to a commonly encountered scenario.

Assessing the Benefits of Groundwater Remediation

Where brownfield land has impacted groundwater quality, the process of risk assessment is used to assess unacceptable risks to human health and environmental receptors. A decision then has to be made about the strategic value of the groundwater resource and how much effort is appropriate to address the residual water quality impacts. Here, sustainability and CBA Appraisal (the process of assessing the relative sustainability of different options) can be used to identify an optimum remedial strategy.

When an existing human, ecosystem, good or service (e.g. a groundwater abstraction well or a surface water body that supports a commercial fishery) has been impacted, the lost resource can be assigned a value relatively easily. Commonly, such estimates are determined based on the costs incurred to replace or protect the damaged asset, or otherwise compensate those who have been affected. However, when groundwater contamination is currently not having this type of impact to an easily identified receptor, evaluation becomes more difficult with a large degree of uncertainty.

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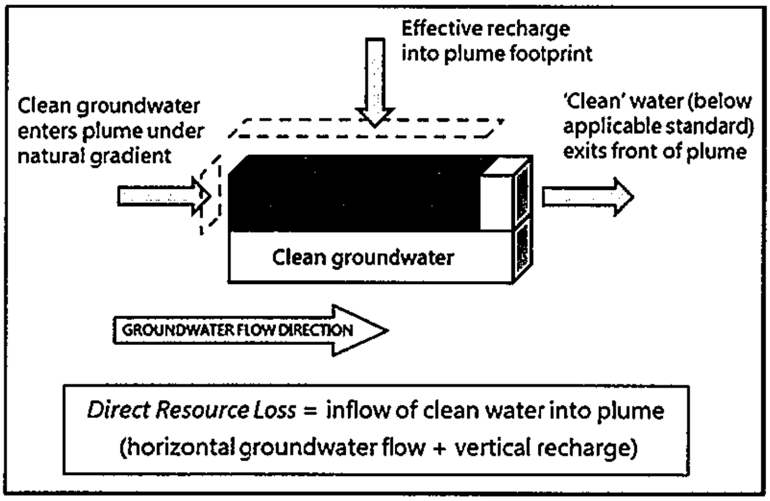
The presentation will present an innovative Groundwater Loss method developed by Advisian to reduce this uncertainty and estimate the groundwater resource loss due to land contamination to inform a robust assessment of the benefits and sustainability of remedial action.

Groundwater Loss

'Option value', representing the value placed on groundwater for possible future use, provides a way to quantify the loss due to contamination.

Calculation of the overall loss requires consideration of both the spatial (physical) extent of an aquifer where groundwater use is constrained by the presence of contamination, and the economic element (local water value).

An approach has been developed for estimating the spatial element, represented as the annualised abstraction loss of available groundwater resource. Two distinct components have been identified based on the potential restriction on location of a new abstraction well: (1) the *direct resource loss*, which relates to the contaminated zone of the aquifer within which a new abstraction is no longer an option, and (2) *the indirect location loss*, which relates to the loss of an opportunity to site a new abstraction well in the surrounding uncontaminated aquifer due to the presence of the plume.



The total loss of groundwater associated with the contamination in the aquifer is the sum of the indirect location and direct resource loss components.

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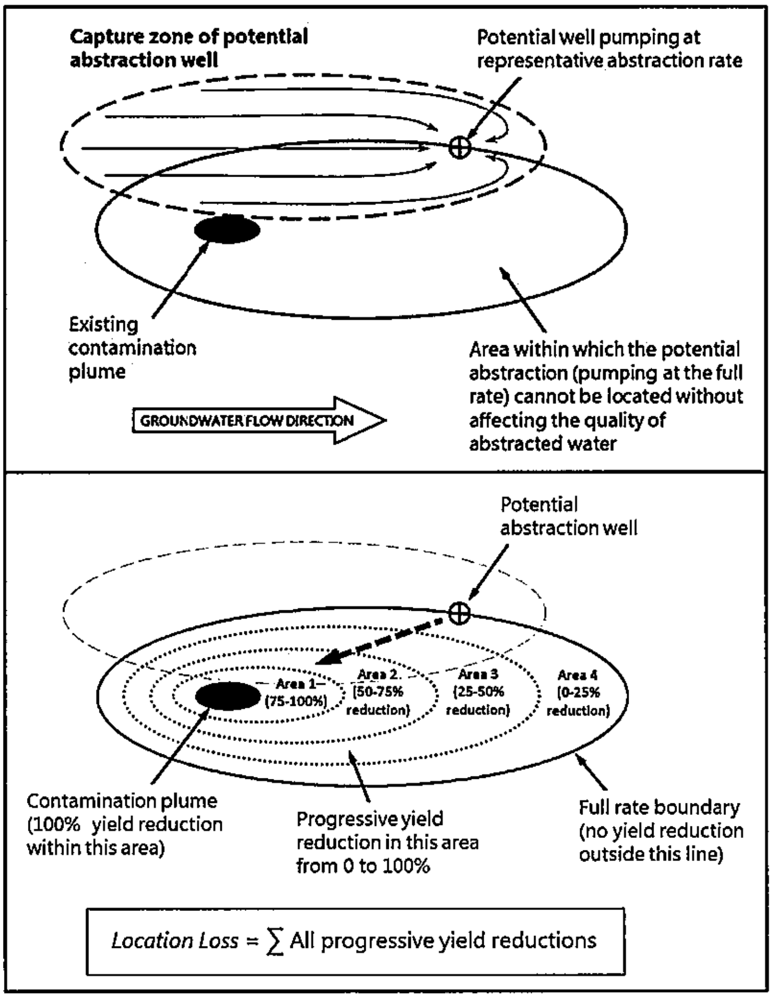
The Groundwater Loss model represents an important innovation and advancement of best practice within the process of cost-benefit analysis and sustainable decision making for the redevelopment of brownfield sites. The presentation describes the concepts underlying this approach to estimating loss of available groundwater resource, presents some methods for their calculation, and illustrates the approach with a UK based case study applied to a remediation cost benefit analysis.



Biography

Tim Bartlett is a Principal Hydrogeologist with Advisian based in the UK.

Tim has over 30 years' professional experience as a hydrogeologist and specialises in the conceptualisation of complex groundwater flow and transport systems, together with contaminated land risk assessment and modelling.

Tim has specific expertise in groundwater valuation as applied to monetised Cost Benefit Analysis and developed the innovative groundwater loss method presented in this paper to resolve problematic sites where the cost of remediation works has proved to be disproportionate to the potential benefit delivered.

From cost-benefit to impact-benefit analysis in sustainability appraisals

Why this makes sense and an illustration with two cases

Hans Slenders 1, Arne Alphenaar 2, Kathy Verhelst 3, Allan Thomas 4

1: Arcadis, 2: TTE consultants, 3 Bekaert 4 ERM

Cost-benefit becomes Impact-benefit analysis

During the early 2000s in the Netherlands the ROSA project was executed to define cost-effectiveness for making decisions for mobile contaminants in groundwater, and an elegant twist was given to change this into an impact-benefit decision; balance the impacts and benefits of a remedial action. This methodology and tool for weighing options (pair-wise comparison) was developed with a consortium of 30 municipalities and provinces (Slenders et al.) and made part of Dutch legislation. The methodology was later on adapted and made part of the Dutch Road Map for sustainability (SURF-NL). It is also art of some cases that are part of the NICOLE portfolio on Sustainable Remediation.

In this presentation we would like to go back to why the decision was made in 2004 to shift from cost-benefit to impact-benefit analyses (costs are not the only impacts, Impact on the environment etc. also need to be taken into account and balanced), and we will explain the changes to make it fit in the current sustainability appraisals. It is a very easy to use tool and robust in its decision, unfortunately still not used by many.

We will illustrate the elegance of this methodology in two big complex cases that were relatively recently executed in the Benelux, for Dutch Railroads and for Bekaert in Belgium.

Case 1: The TERRA project in Zwevegem

The extensive impacts with chlorinated solvents at the Bekaert site initially demand very expensive remedial actions. In 2014 Bekaert starts the TERRA project in order to find a more cost-effective and sustainable solution. Technical solutions were detailed by Arcadis and ERM and sustainability indicators selected by a stakeholder panel, and sorted as benefits and impacts. In a workshop the two remaining options were compared on impacts and benefits and a significantly cheaper and more sustainable option selected. This case was used as an example in the sustainable remediation working group in Amsterdam.

Case 2: The impact-benefit evaluation at a Railroads site in Amersfoort

Since 2007 SBNS (the Remediation Foundation of Dutch Railways) has been looking for a finite solution for her site in Amersfoort. In 2015 things were speeded up because SBNS will cease to exist and responsibility for the site will be transferred to the Ministry of the Environment and Infrastructure. Both parties feel responsibility for sustainable land stewardship and invited Arcadis and TTE to develop scenarios and to structure the appraisal process towards a sustainable finite solution. An impact-benefit analyses was used.

In a series of meetings with a group of stakeholders of NS Vastgoed, Prorail, Municipality, the Ministry and competent authorities scenarios and sustainability indicators were discussed and selected. A process similar to NICOLEs Road Map or SURF UKs Framework was used. The tool of pairwise comparison and reduction of choices proved to be strikingly simple and robust. And in the end a comparison was made between the extra impacts of one alternative against the other, and compared with the extra benefits. Although the basic scenario (2 mln€) is sufficiently protective, an additional scenario (4 mln€) was unanimously selected that *in situ* removes 80% of the contaminant load and is considered by all to have the best balance between impacts and benefits.

Finding ways to implement sustainability in remediation through procurement. Experiences from stakeholder engagement in a complex multisite 'design-build' tender for CHC contaminated urban groundwater remediation in the Finnish Contaminated Land Demonstration Program.

Jarno Laitinen, MSc., Project Manager, Centre for Economic Development-, Transport and the Environment

The Finnish Contaminated Land Demonstration Program is one of the strategic priority projects of the Finnish Government Program that facilitates the necessary reforms in 'circular economy and clean solutions' towards more sustainable resource management. Purpose of the Demonstration Program is to operate as an innovation platform for contaminated land risk management and remediation. To achieve this, the Demonstration Program facilitates various innovation and development activities within private and public sectors and executes site investigations and remediation projects at orphan sites, showcasing best-practice approaches.

A multisite 'design-build' tender for CHC contaminated groundwater remediation was announced in January 2017 by the Demonstration Program. The tender consisted of five contaminated sites with a widespread groundwater CHC contamination (plumes > 1km) that had, or was currently threatening to, cause closure of the cities' municipal drinking water extraction as acute risk management. Many of the sites had been investigated for over a decade and a many had prior remediation history with varying success.

The procurement process had multiple intrinsic goals. Besides the environmental and health (risk) aspects and the political emphasis on GW resource management, the tender process was designed to 1) facilitate a stakeholder driven process for sustainable remediation design, 2) develop and disperse know how on managing complex brownfield sites throughout the stakeholders, 3) showcase opportunities and benefits of state-of-the-art in situ remediation methods and 4) enhance the national remediation market dynamics for futures benefit.

During procurement a number of negotiation rounds and workshops between the main stakeholders: client, municipalities, land owners, consultants, contractors, research institutes and regulators were arranged to define the technical, environmental, economic and social expectations of the remediation projects.

Parallel to the procurement, a collaborative regulatory group between the five municipalities and corresponding regional authorities was formed to ensure timely and coherent environmental remediation permit process. A thorough political decision process was conducted on the five regional municipalities supported by a detailed communication program to engage the decision makers and include the directly affected citizens to the process.

- **Session 2:** Innovation in investigation, remediation and source removal technologies
- **Chair:** Jim Wragg – Geosyntec Consultants

Poster pitches:

Irene Jubany - CTM
Mohamad Sakizadeh - University Teheran, Iran
Jeremy Birnstingl - REGENESIS
Hans-Peter Koschitzky - VEGAS, Versuchseinrichtung zur Grundwasser- und Altlastensanierung, Universität Stuttgart

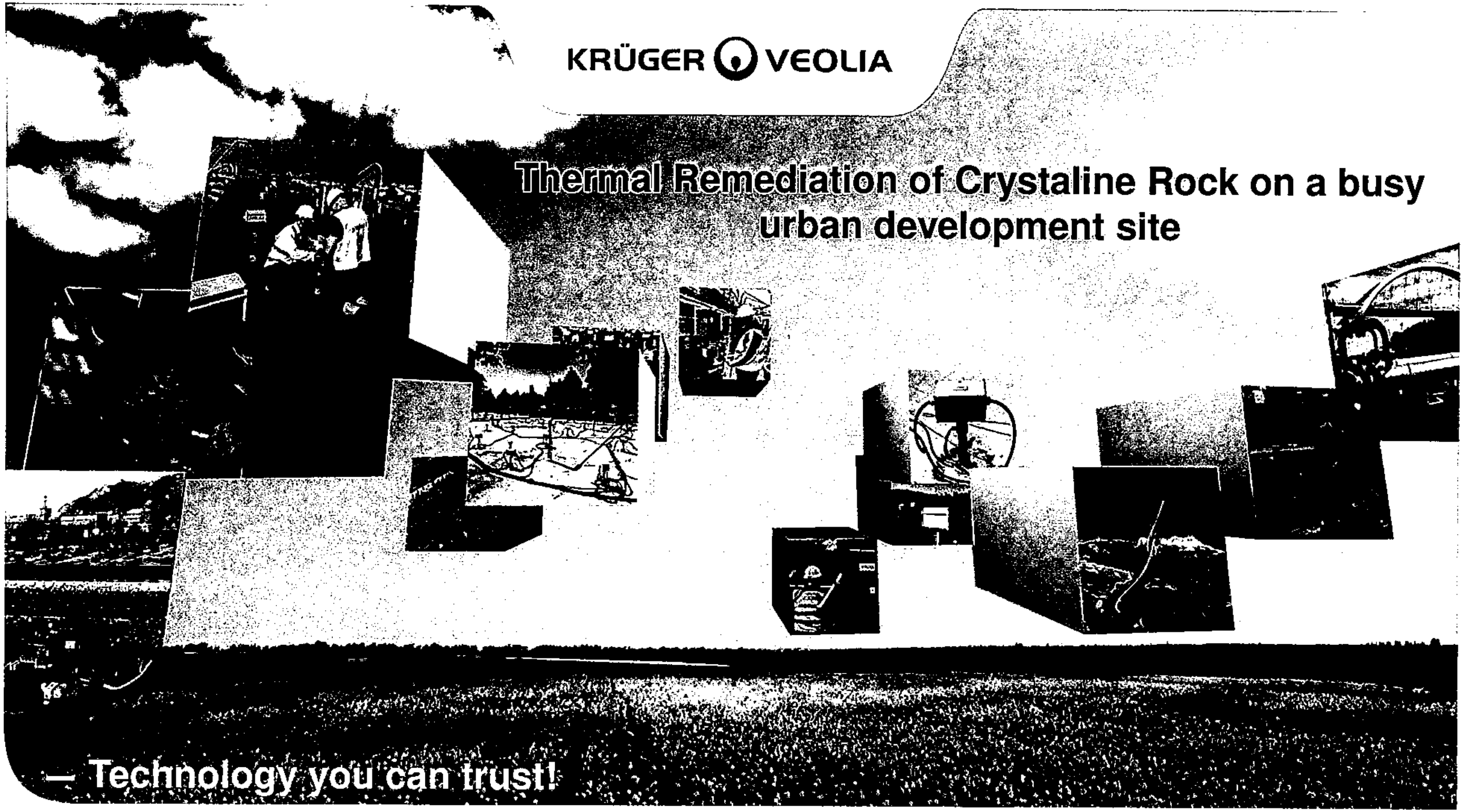
Presentations:

- **Anne Northway - Environment Protection Agency Australia / Victoria**
  Australia's Regulatory Journey: Cross jurisdictional collaboration towards nationally consistent approaches to environmental regulation of PFAS.

- **Niels Ploug - KRÜGER A/S**
  First European Thermal Remediation of Crystalline Rock on a busy urban development site

- **James Baldock - ERM**
  Sustainable Low Temperature Thermal Remediation of Pesticides

- **Dirk Paulus - Tauw België N.V.**
  In-Situ Metal Precipitation of a mercury impacted aquifer


KRÜGER VEOLIA
Thermal Remediation of Crystaline Rock on a busy urban development site
– Technology you can trust!

The team behind the remedy

Client

- *Developing Kvarnholmen*

Consultant

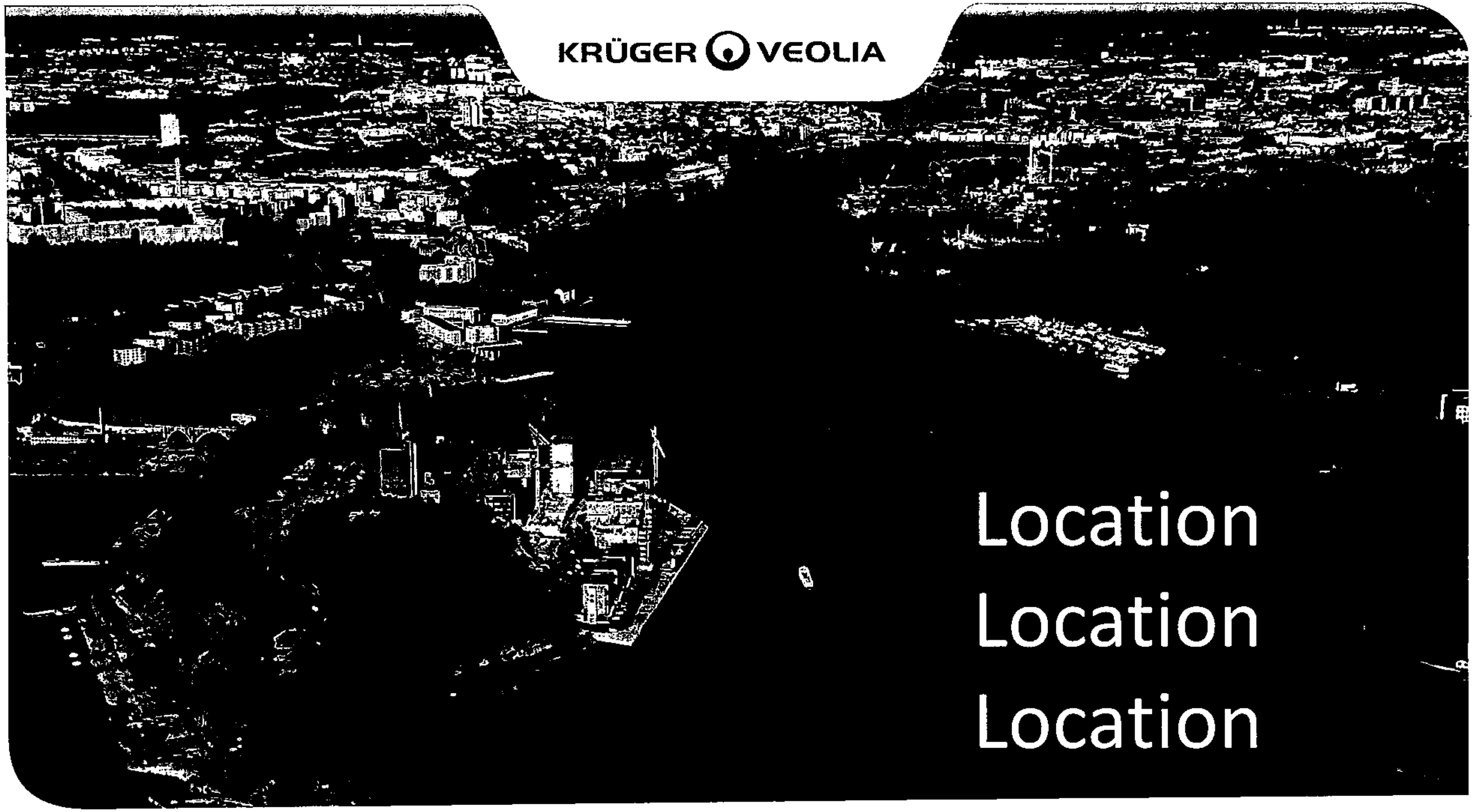
- *Investigations*
- *Delineating target area*
- *Client support during remediation*
- *Sampling*

Thermal service provider

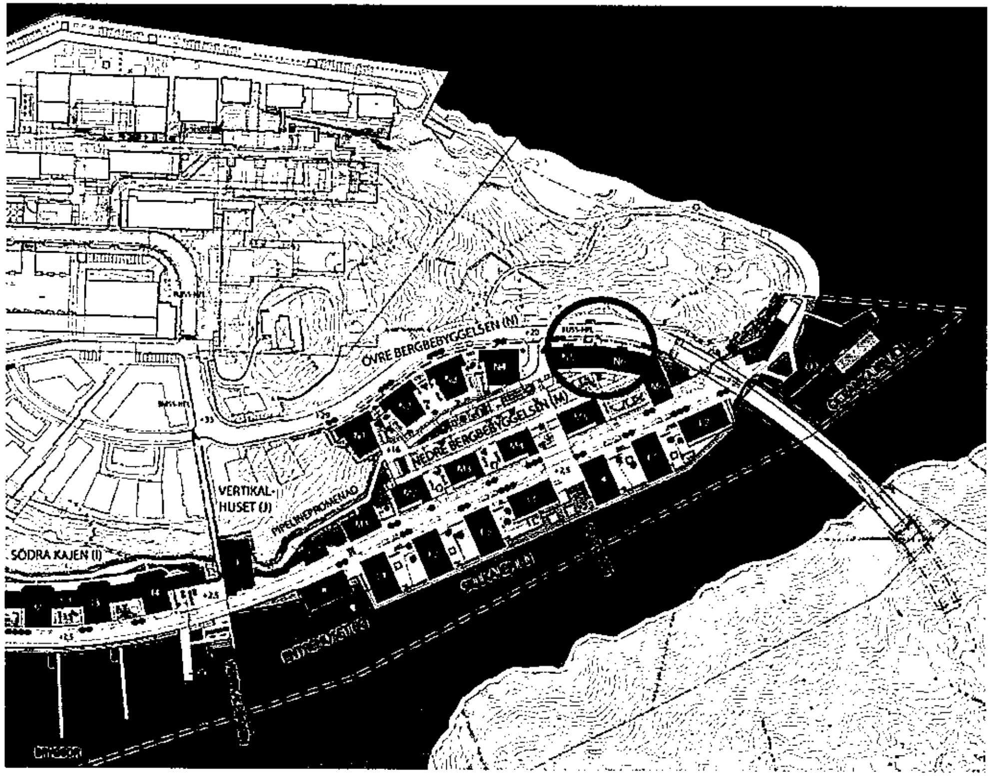
- *Design*
- *Installation*
- *Execution*

Agenda

- **Site background/drivers**
- **Challenges**
  - *Client*
  - *Consultant*
  - *Contractor/Service provider*
- **Evaluation and choice of technology**
- **Installations**
- **Operation and results so far**

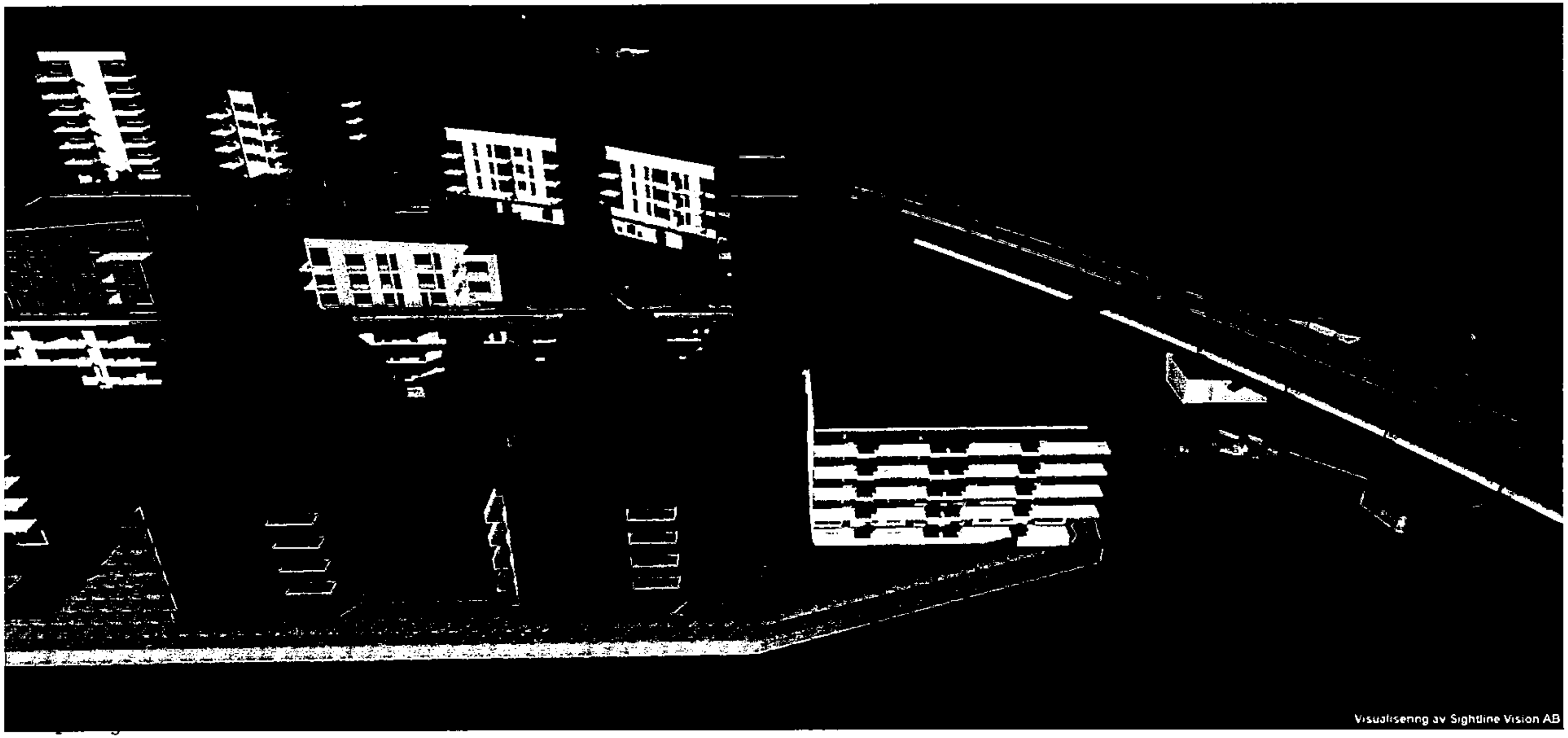

KRÜGER VEOLIA
Location
Location
Location

Clients challenges

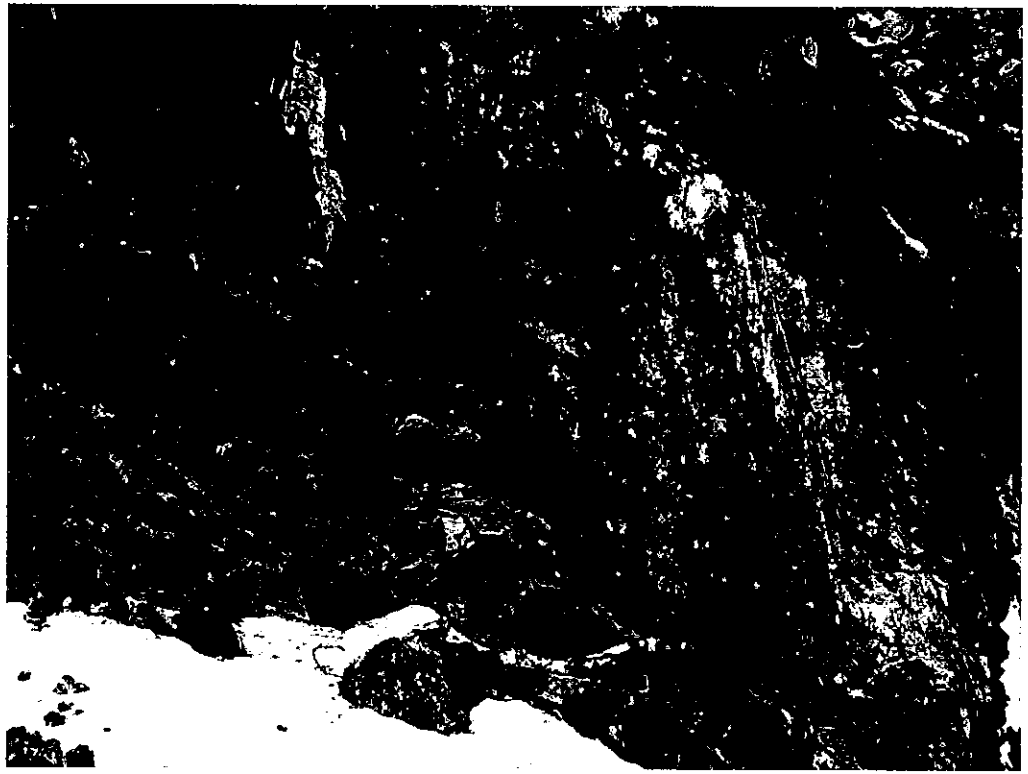


- On-going development
- High priorities: Bridge and road
- Need of high probability of success of remediation

Development plans

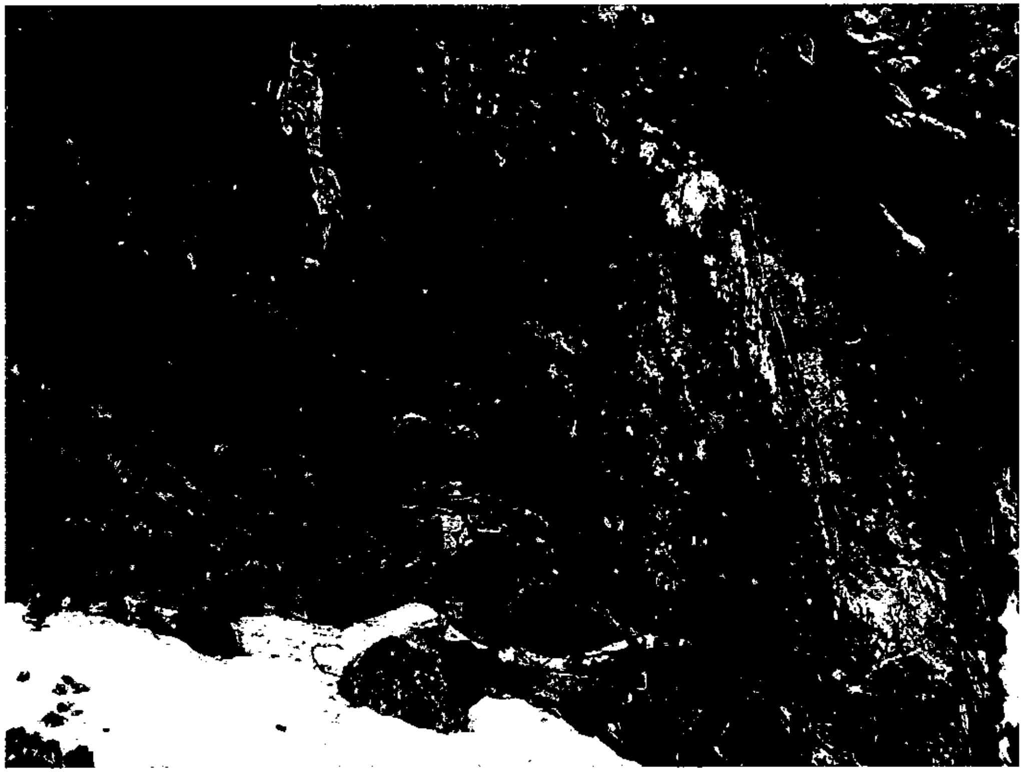


Consultants challenges



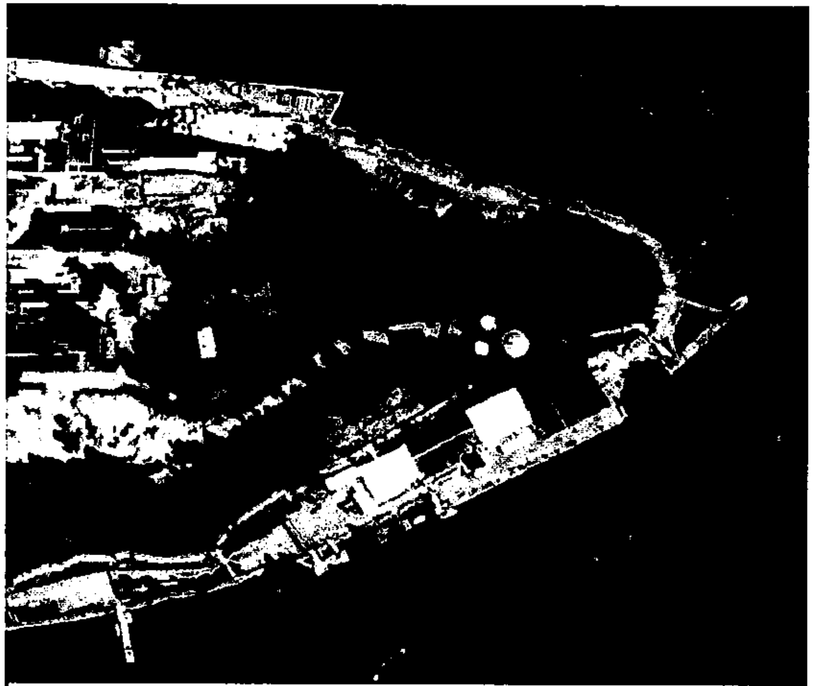
- Investigation in fractured rock
- Understanding fracture zones and contaminant migration
- Delineating target zone

Contractors challenges



- Dealing with a low porous and low fractured rock
- Installing and operating a site while road construction takes place
- Remediating in a public accessible area using a forceful technique

Site background



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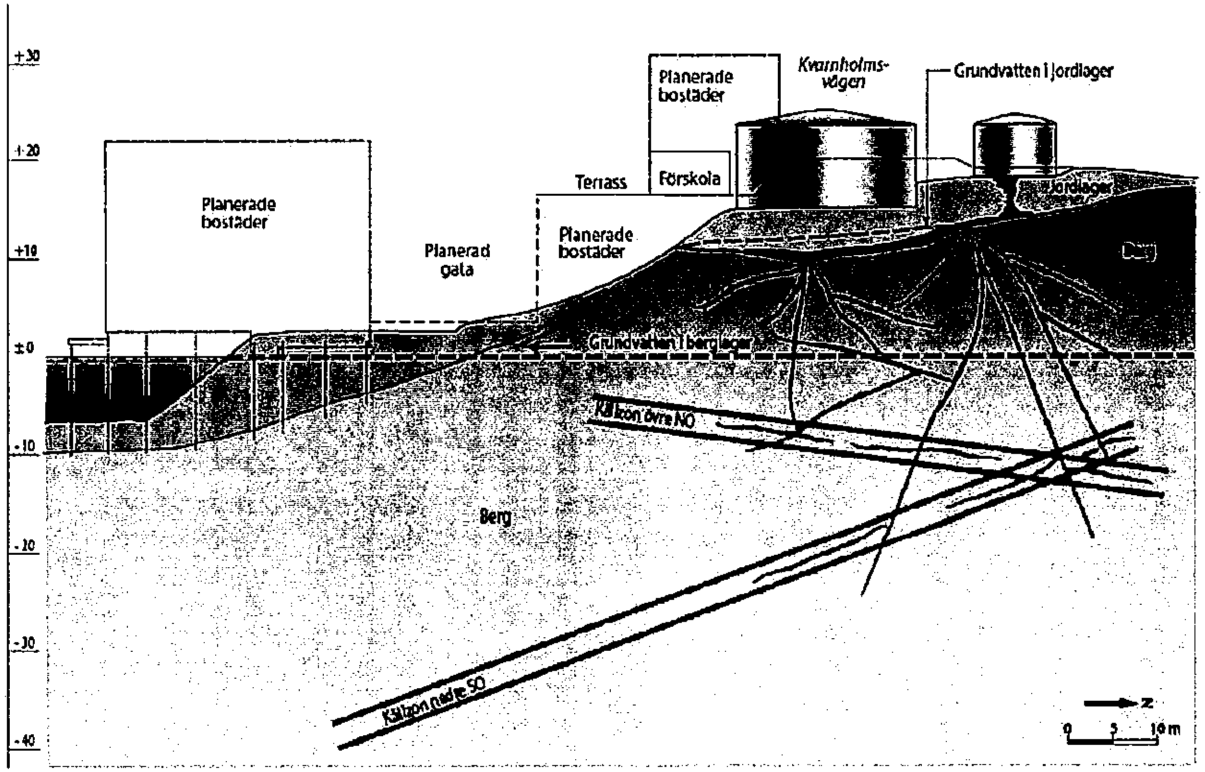
Aerial photo 2009

- Three storage tanks
- Used for storage of chlorinated compounds
- Removed in 2012

Conceptual understanding (simplified)



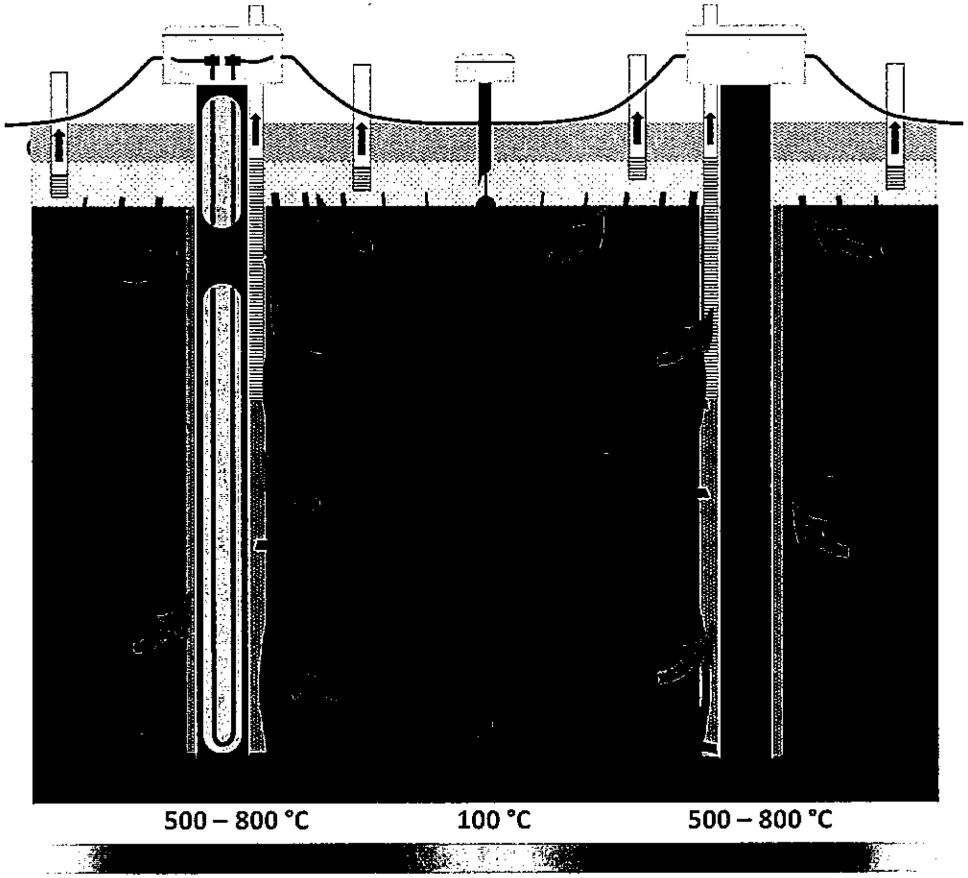
- Top soil excavated
- Bedrock porosity incl. fractures <2%
- <u>Max conc of CAH:</u>
  - Water: 163 mg/l
  - Pore gas: 13.000 mg/m^3
- <u>Remedial goals:</u>
  - Water: PCE 5 mg/l
  - Pore gas: PCE 30 mg/m^3

Choice of technology

Technology must be able to:

- Address both unsaturated and saturated zone
- Overcome the challenge of a fractured low porosity media like granite
- A reasonable time frame
- Robust and high probability of success

Thermal Conductive Heating (electrical)



Principle of TCH

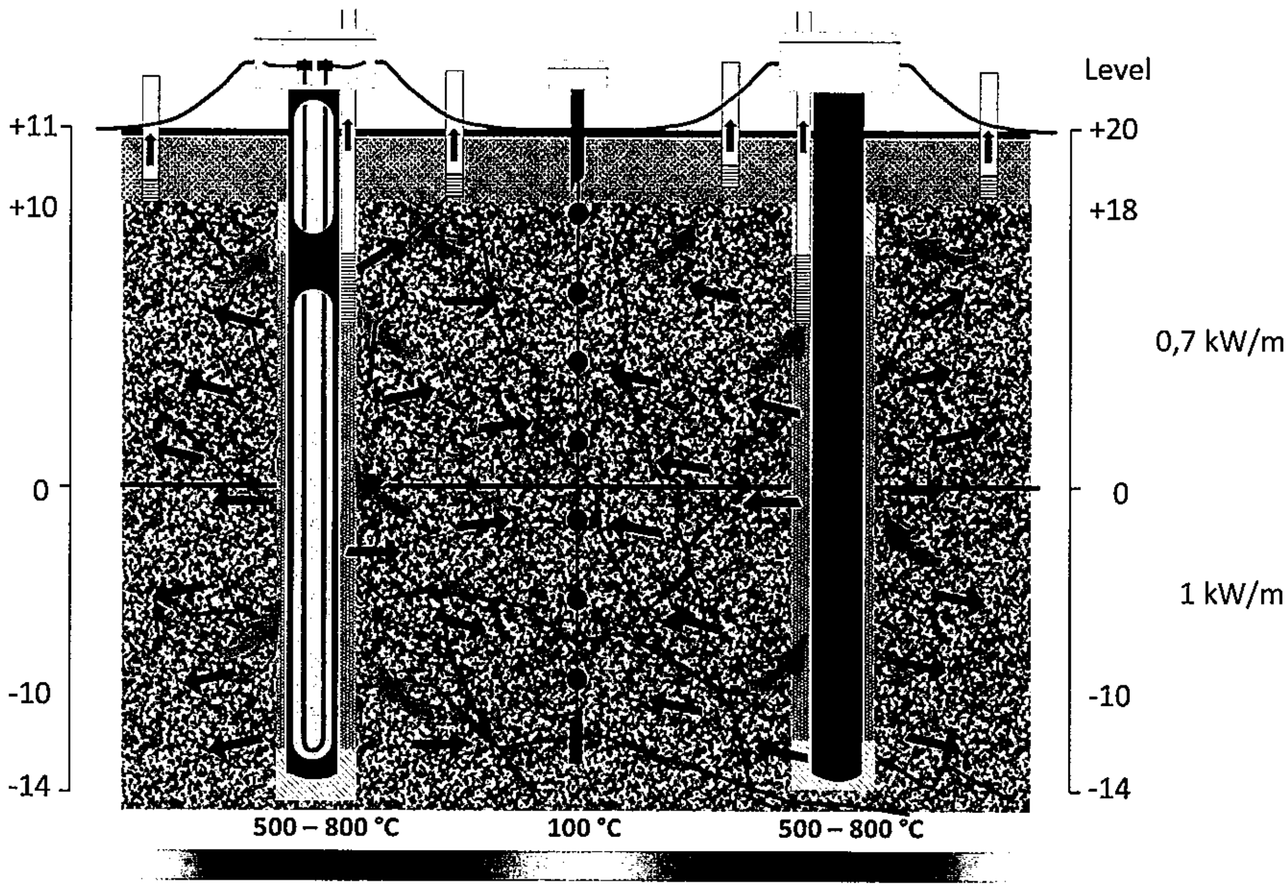
Uniform heating because thermal conduction for the entire soil range varies very little

Insensitive to permeability

Applying a temperature gradient > 100 °C

Using electrical powered heating elements it is possible to differentiate power input

TCH – extraction approach



Extracting in fractures

Creating extraction pathways along heaters with individual extraction

Possible vapor migration to surface, controlled by permeable crushed rock layer ventilation

14 m below water table

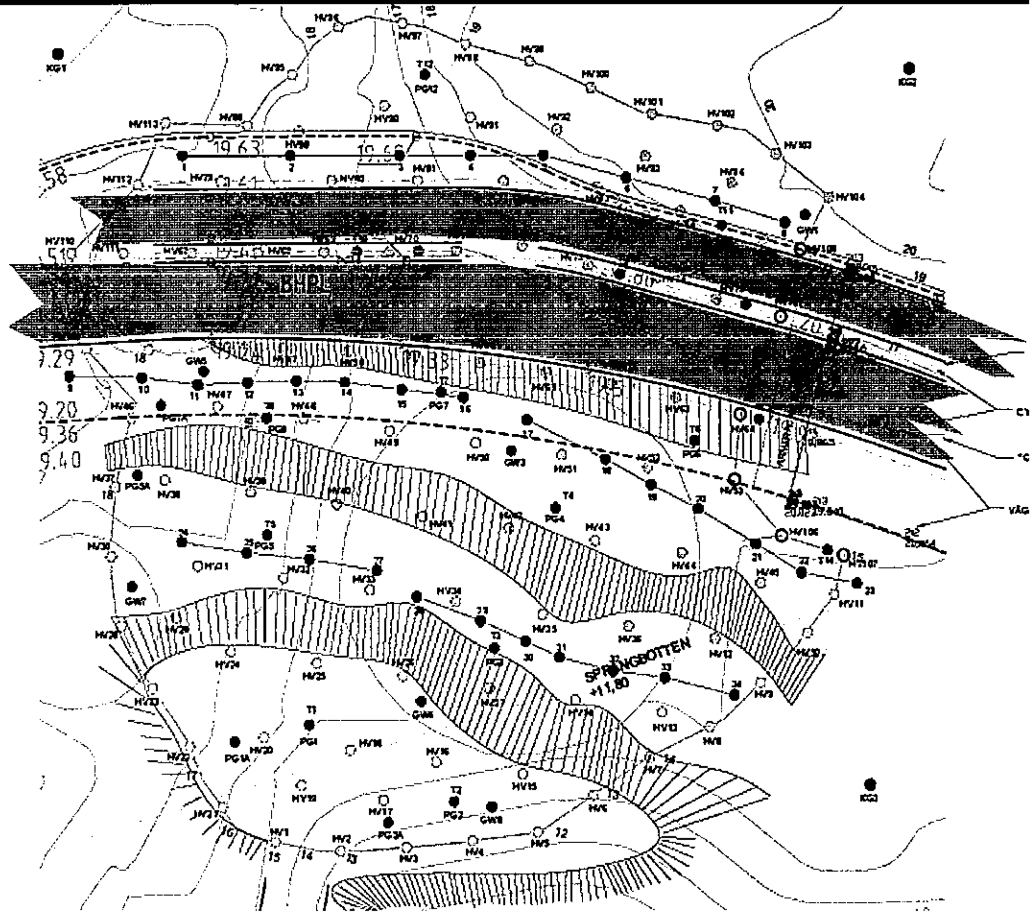
Target 10 m below water table

Uneven target at surface

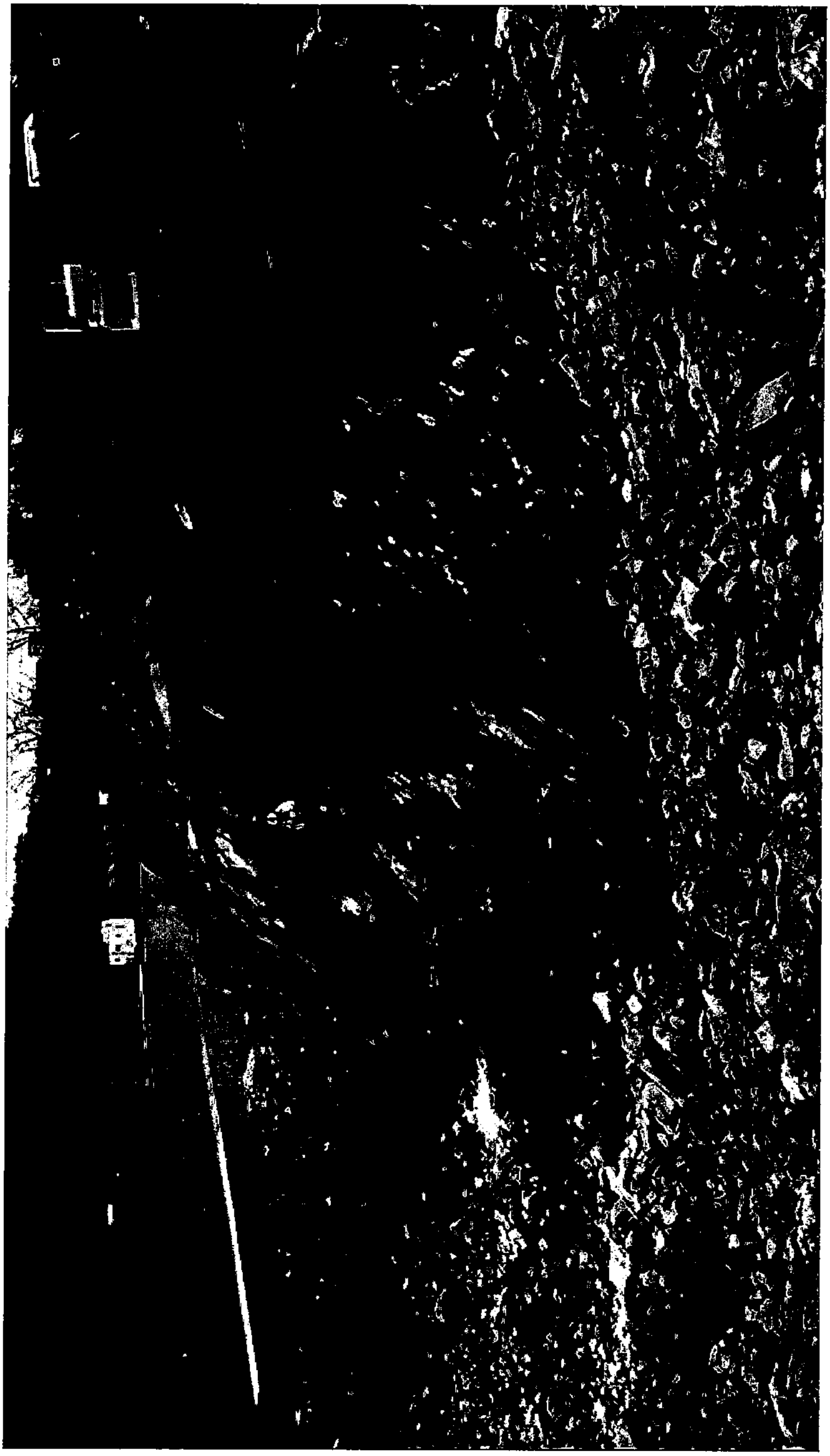
Differentiated power input

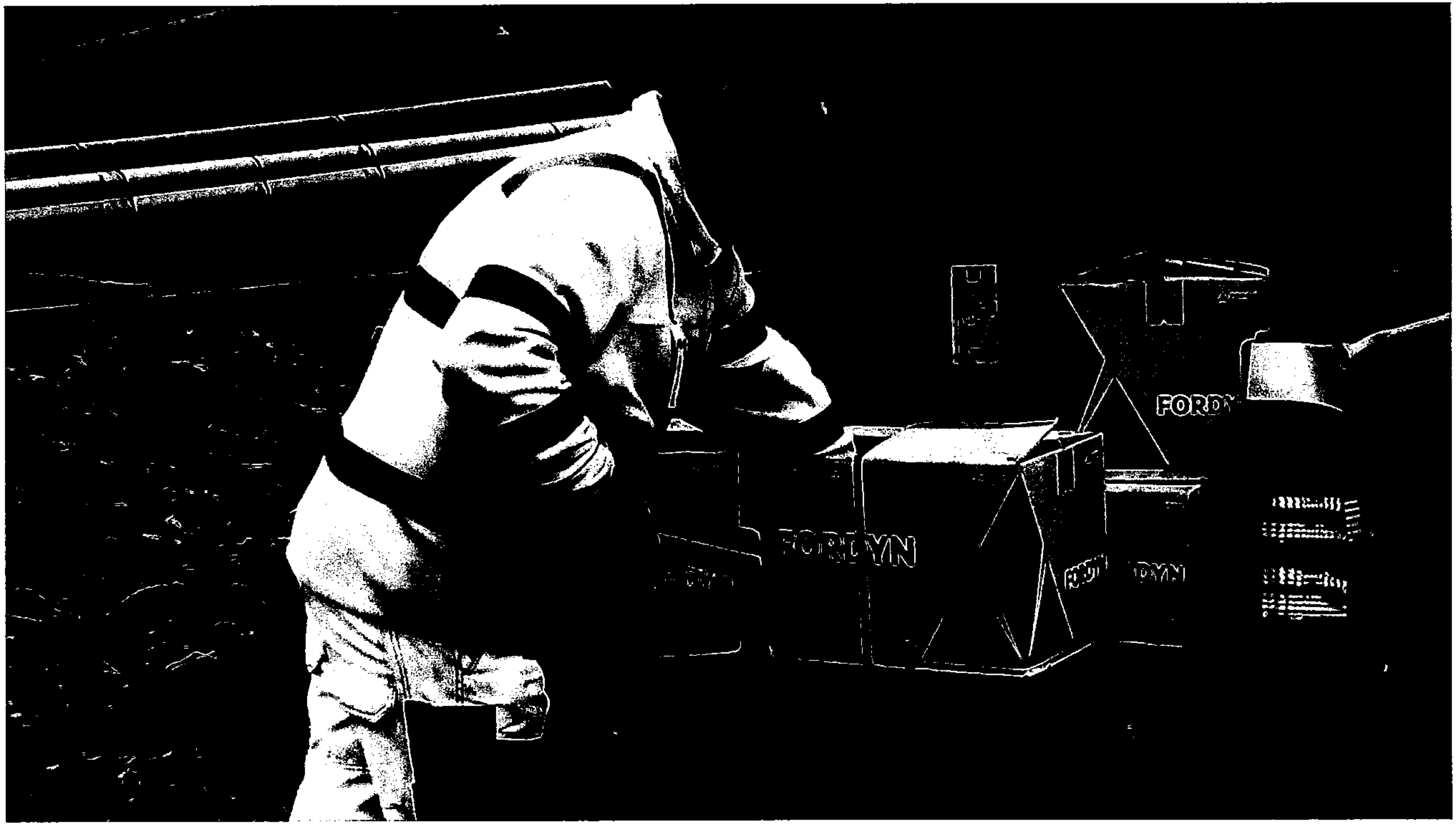
Well field layout

- Target Treatment Zone (TTZ): 1.238 m^2
- Top of TTZ: Top of bedrock
- Bottom of TTZ: -10
- Target volume: 29.600 m^3
- Number of heater wells: 105



Krüger Soil Remediation

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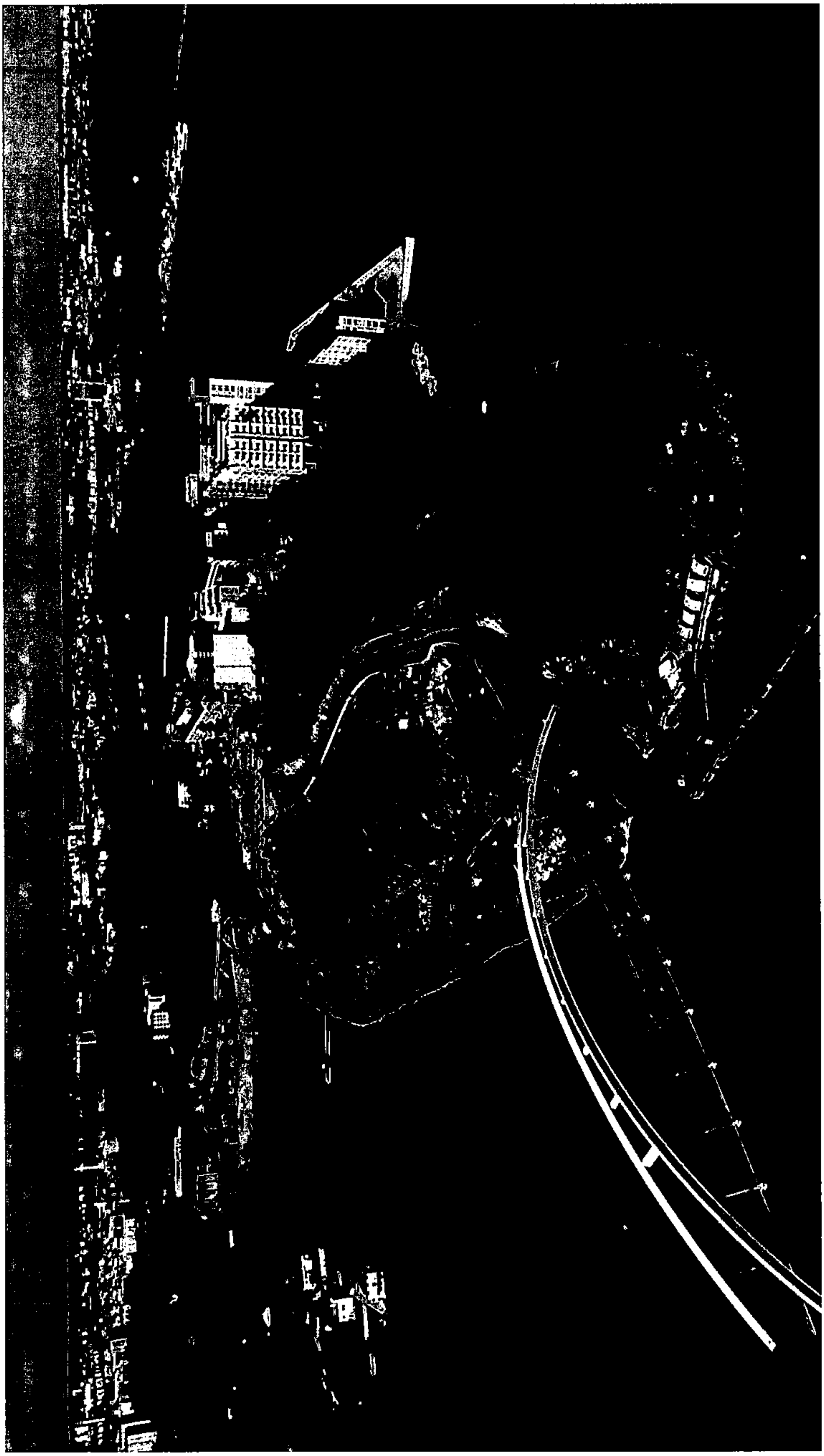
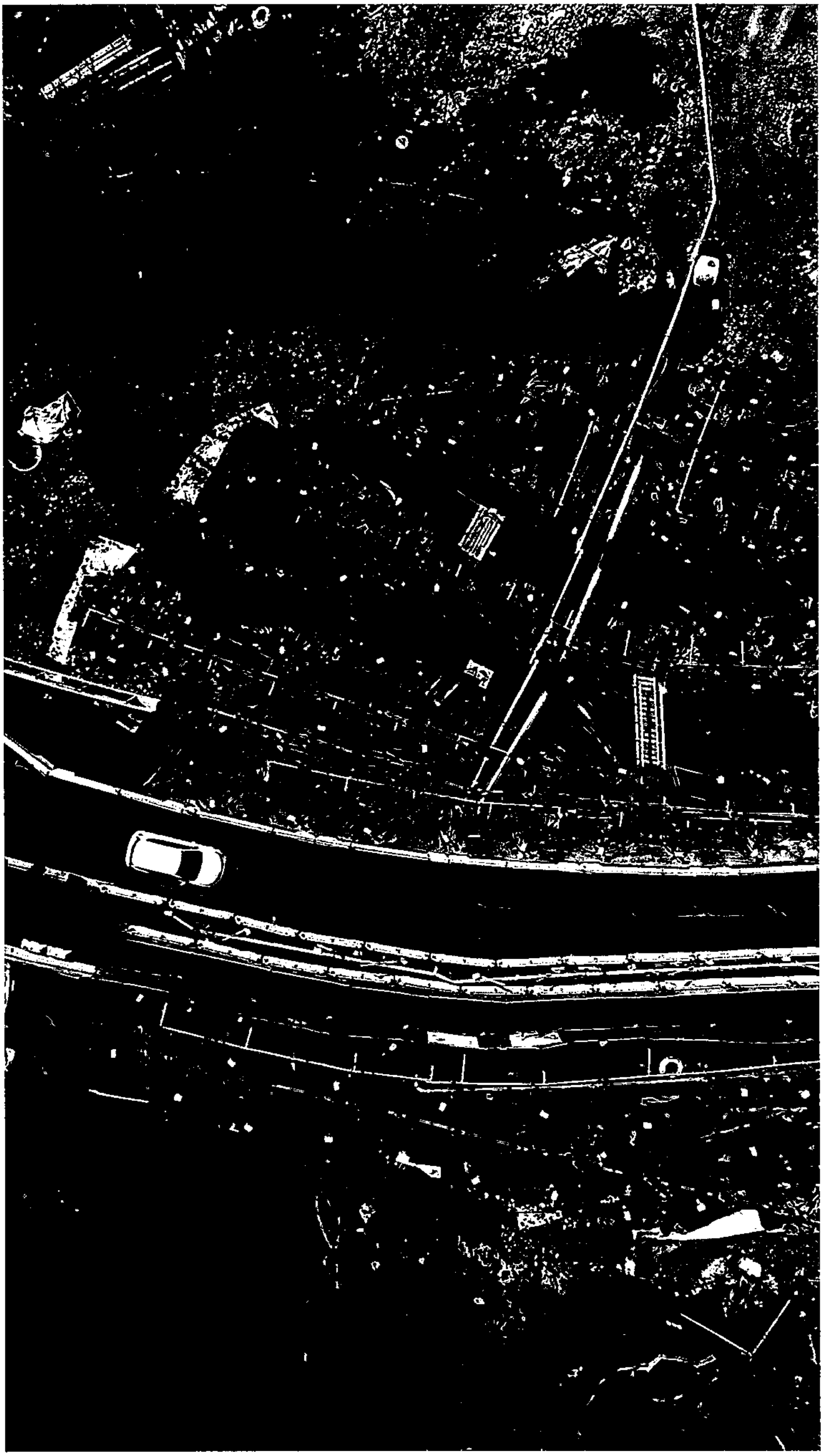
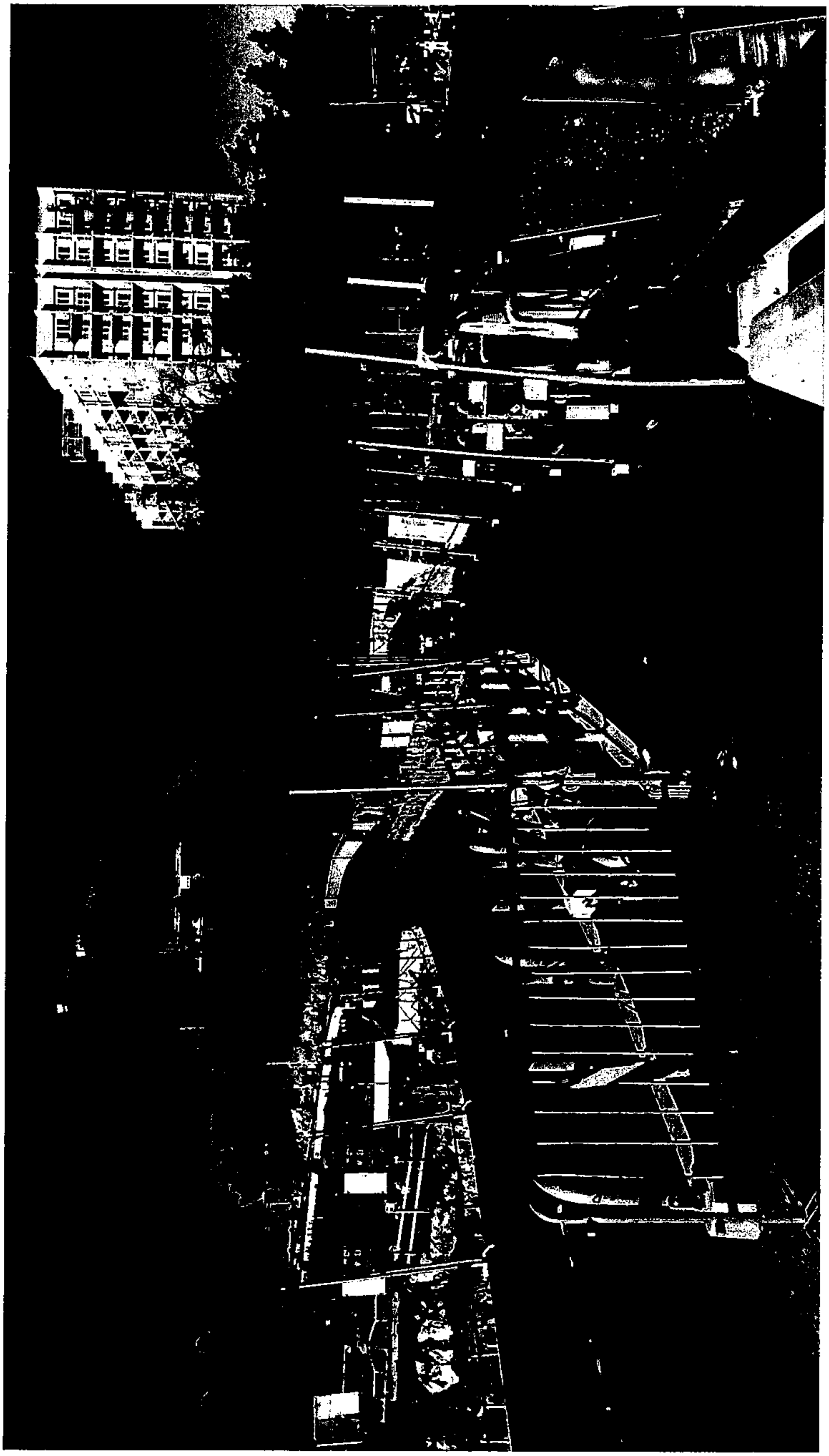
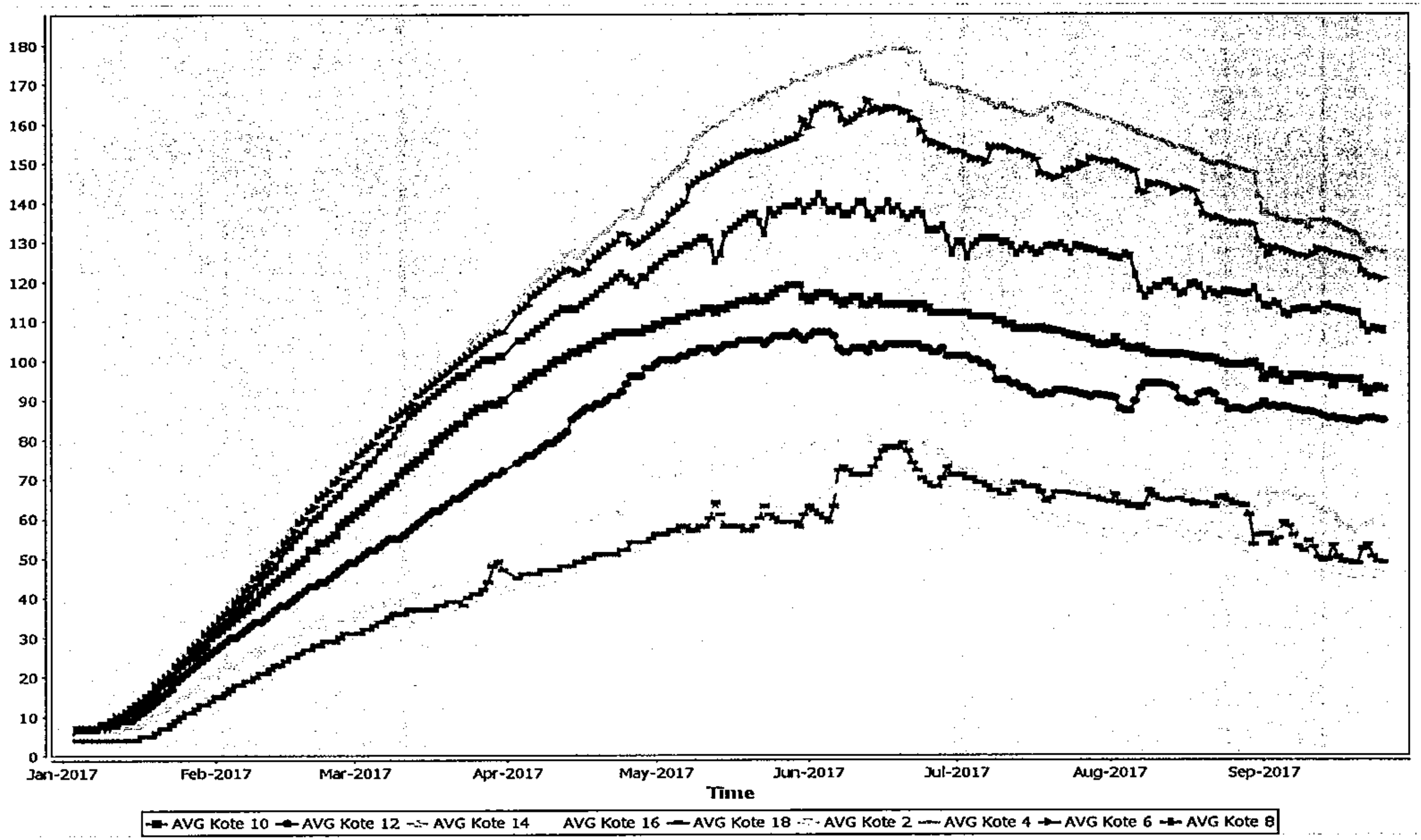




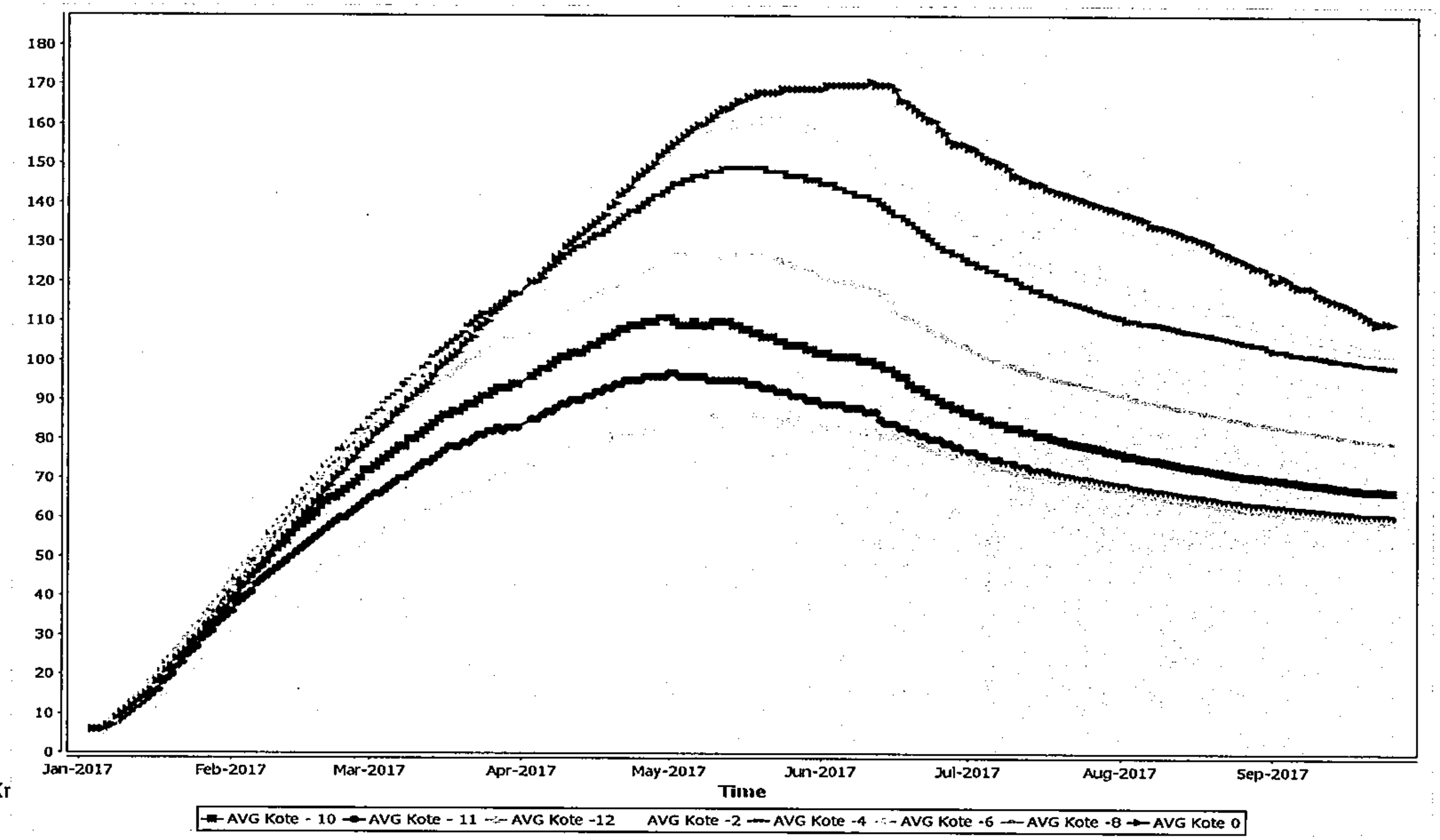


Average temperature above sea level



Kr

Average temperature below sea level



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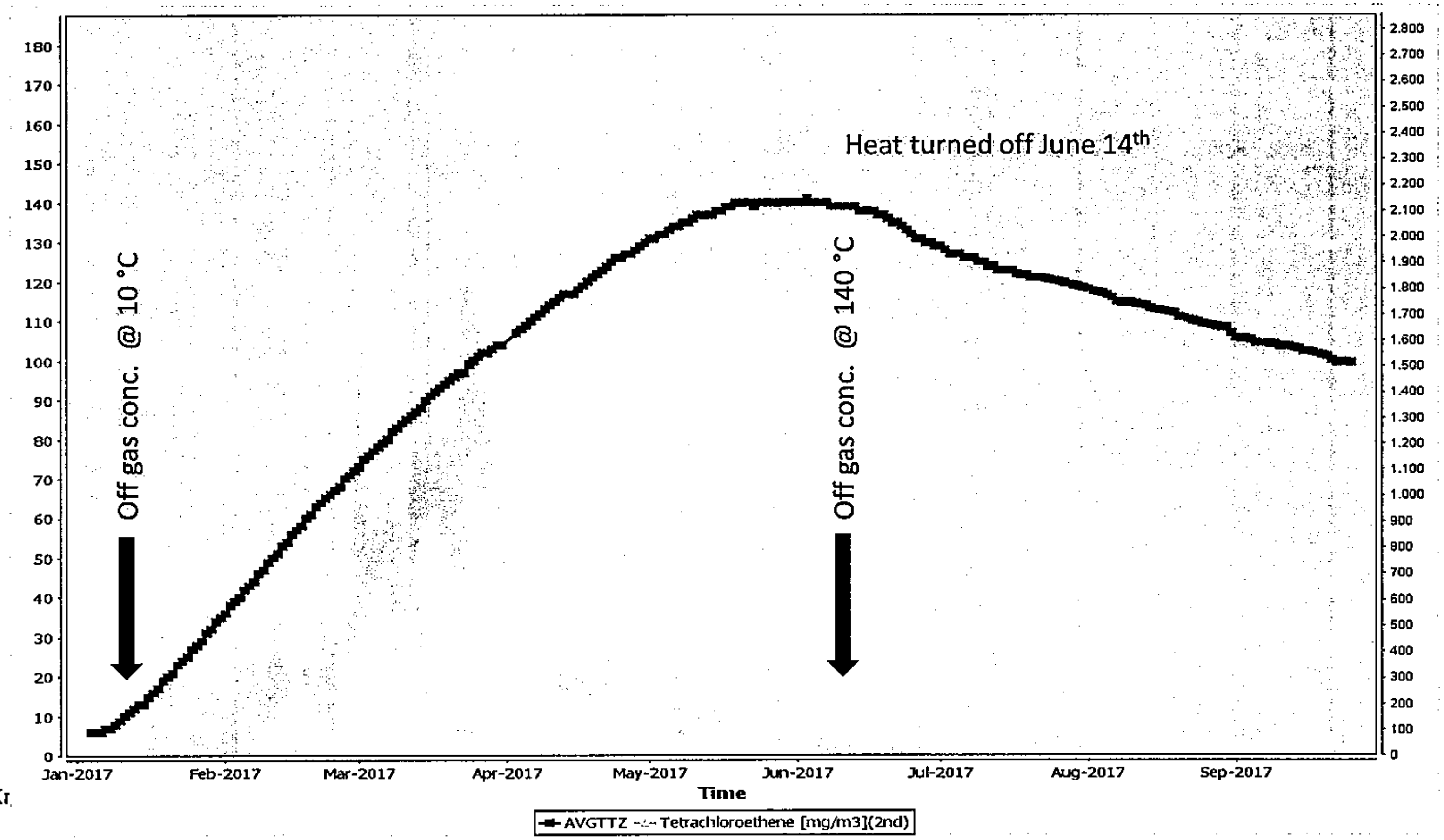
Average TTZ temperature



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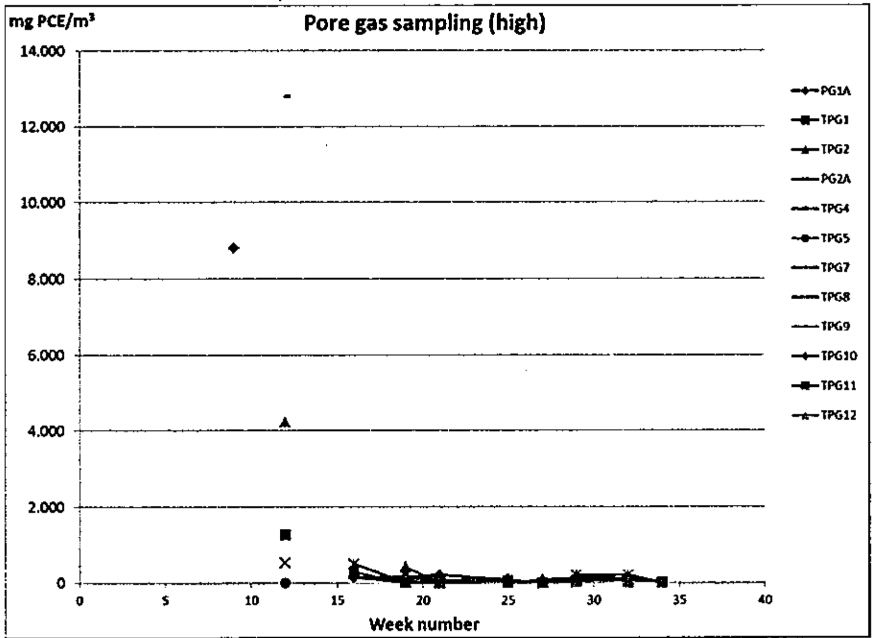
Status of remediation

- Groundwater sampling has been challenging due to little or no water in wells
- Max concentration 0,33 mg/l PCE (based on 4 wells)
- Pore gas sampling is on-going
- Today Target Treatment Zone average temperature is 100 °C (3½ month after shutdown)

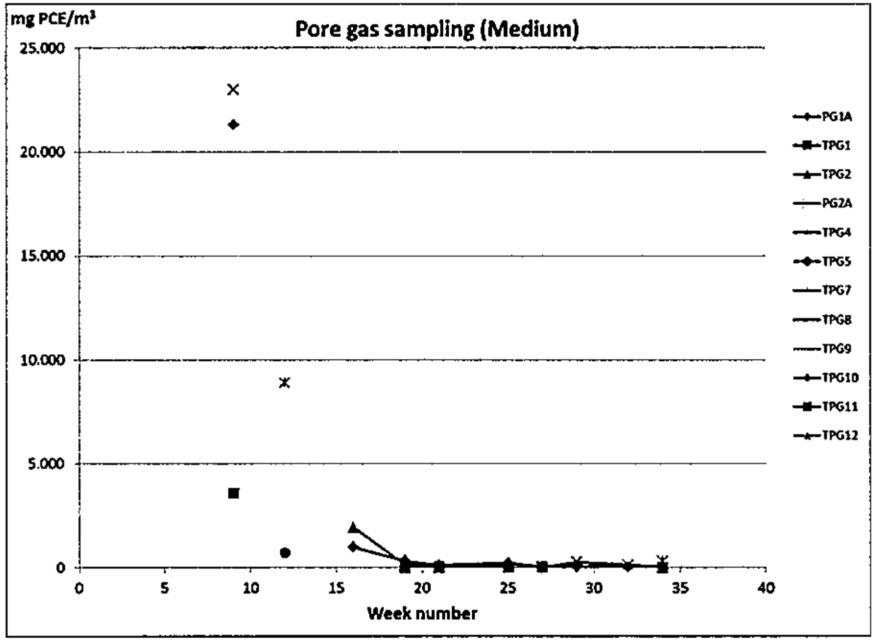
Pore gas sampling

- Comparison between two sampling methods

1,8 m below bedrock surface



5 m below bedrock surface



Krüger Soil Remediation

Take home message!

- TCH can heat granite thoroughly
- Thermal remediation can be executed within public accessible areas
- Confirmatory sampling in granite is more complex and a line of evidence approach is needed

Speaker Biography

James Baldock is a Technical Director within ERM UK and has more than 20 years of experience in the fields of environmental site investigation, design, implementation and management of a wide variety of contaminated soil and groundwater investigation, remediation projects and hydrogeological assessments. He has extensive experience of all major in-situ and ex-situ remediation technologies from design to strategy negotiation with regulatory authorities and is a thermal technology specialist. He plays a key role in ERMs global remediation team and has presented numerous papers at national and international technical conferences on the sustainable application of these technologies.

Sustainable Low Temperature Thermal Remediation of Pesticides

James Baldock, Joanne Pennell and Kathryn Johnson (ERM UK) and Jay Dablow (ERM US)

Site investigation activities at a former pesticide manufacturing plant in the UK, identified impacts from kerosene (TPH) and high boiling temperature dieldrin, within saturated gravels that overlie Chalk bedrock. A total contaminant mass of several thousand kilograms was estimated to be present in the target source zone. The TPH was present mainly as Light Non-Aqueous Phase Liquid (LNAPL). Dieldrin was shown to present a potential risk to a nearby river and the Chalk groundwater below. In order to mitigate these risks a source zone remediation strategy was developed and implemented.

A remedial options appraisal was undertaken using a holistic approach, where environmental, social and economic indicators were evaluated to determine the most sustainable option. The results showed thermal remediation could address both the TPH and pesticide impacts, although high temperatures of circa 350°C would be required to volatilize the dieldrin and achieve a predicted 95 - 99% mass removal. Initially this high temperature strategy using In-Situ Thermal Desorption (ISTD) as the heating methodology was modelled and evaluated using *Petrasim* PC based software, but attaining the target temperature was identified to be wholly unsustainable in terms of energy consumption and cost.

Therefore a more innovative strategy of using Steam Enhanced Extraction (SEE) to mobilize, rather than volatilize, the TPH at lower temperatures was developed and bench tested. The bench-scale treatability study was conducted to determine the effectiveness of thermal remediation activities to reduce combined concentrations of TPH and dieldrin. The results of the bench testing demonstrated that dieldrin was likely solubilized in the TPH LNAPL and could be removed at lower temperatures of between 70 and 100°C, although total mass removal was expected to reduce to circa 90%.

ERM further engaged with the UK regulatory authority (Environment Agency) to agree a change in the heating methodology from ISTD to SEE; this reduced predicted energy requirements by 80%. Whilst the anticipated mass recovery was also expected to decrease by 5 - 10%, it was recognized by the regulator, via the modelling and bench testing, that the risk could still be reduced to an acceptable level in a manner that factored in cost benefit for the client, substantial indirect reduction in environmental impact (avoidance of large energy requirement) and achieved sustainable land management. The regulators also recognized the recalcitrant nature of pesticides and difficulty of remediation and an endpoint objective was therefore agreed on an asymptotic recovery basis, rather than concentration or mass derived target.

Steam injection, together with simultaneous vapour and liquid recovery commenced on 4 April 2017. The target source zone was slowly brought up to temperature through controlled injection of steam. Mobilization of LNAPL was observed as temperatures approached 70°C and dieldrin concentrations were detected at concentrations greater than had been observed in the laboratory. The majority of the mass was removed as NAPL at average soil temperatures between 70 and 80°C, confirming success suggested at bench scale. TPH mass removed by mobilization to date is circa 4,000kg.

This innovative approach is likely to have applicability to other chemical and pharmaceutical sector sites.

In situ metal precipitation of mercury

A Belgian case study

Tauw

11th Soil Seminar
September 2017, Tarragona

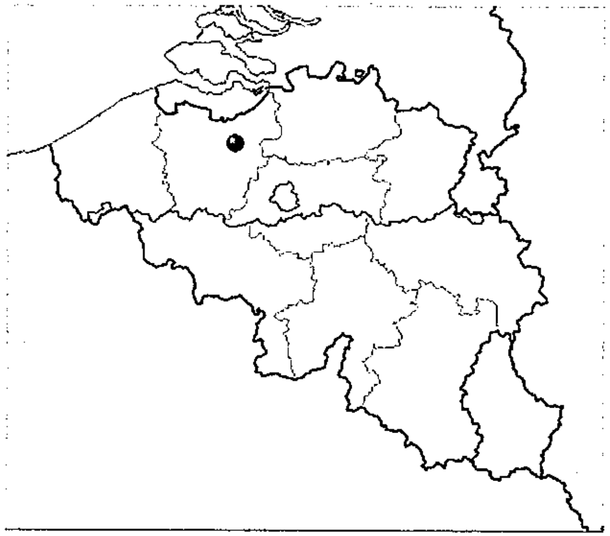
Overview of the presentation

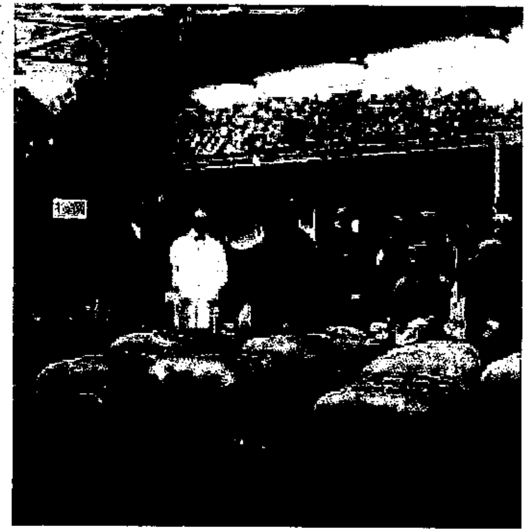
1. Introduction to the case study
2. Labtest: design and results
3. Field test: design and results
4. Lessons learned
5. Conclusions

Introduction to the case study

- The region around Lokeren was known for its felting industry

  → Rabbit fur was used as the raw material for the production of felt, which was afterwards used in the production of hats.

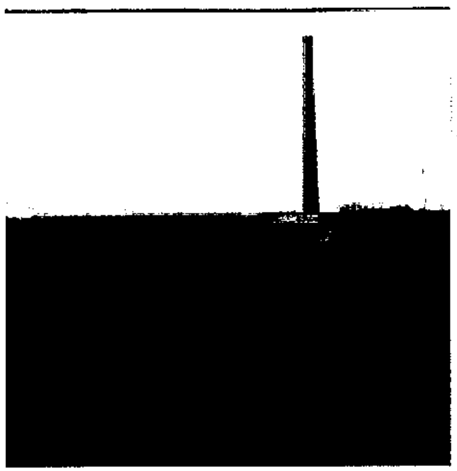


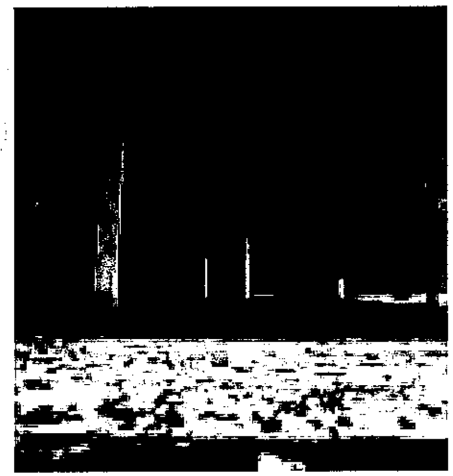


Introduction to the case study

- The industrial production process involved dissolving metallic mercury in nitric or chloric acid for the treating the rabbit fur. Industrial activities ceased in the ‘60’s.

→ Heavy mercury contamination in local soils and aquifers





Introduction to the case study

- Flemish competent authority (OVAM) remediated the *"Jourdes"* site in 2002 – 2003 with an excavation of the Hg contaminated soils.

- Pump and treat (P&T) was used for the remediation of the aquifer

    - P&T turned out to be long lasting and expensive

    - Alternative remediation technique(s)?

        → Tauw idea: ISMP of mercury possible?

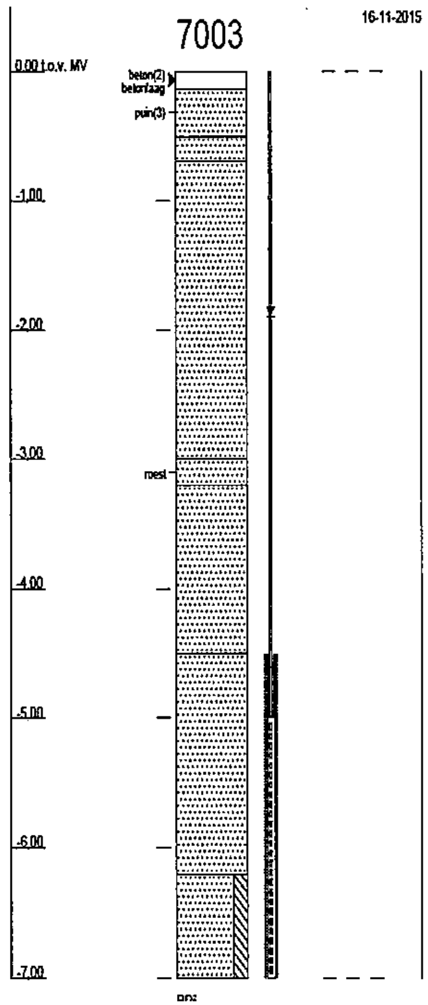
Labtest

- Local soil and groundwater:
  - Loamy fine sand
  - Groundwater between 1,5 and 2 m-bgl
  - Groundwater contamination of mercury,
    - Initial Hg concentrations range between 10 and 1100 µg/l

    at a depth between 2 and 8 m-bgl

    ↔ remediation objective for Hg = 1µg/l

  - Original pH = 6,8
  - Oxygen rich in the upper part of the aquifer
    - <5m-bgl
  - Poor in oxygen in the deeper parts of the aquifer



Labtest

Four test conditions to test the adsorption and precipitation processes:

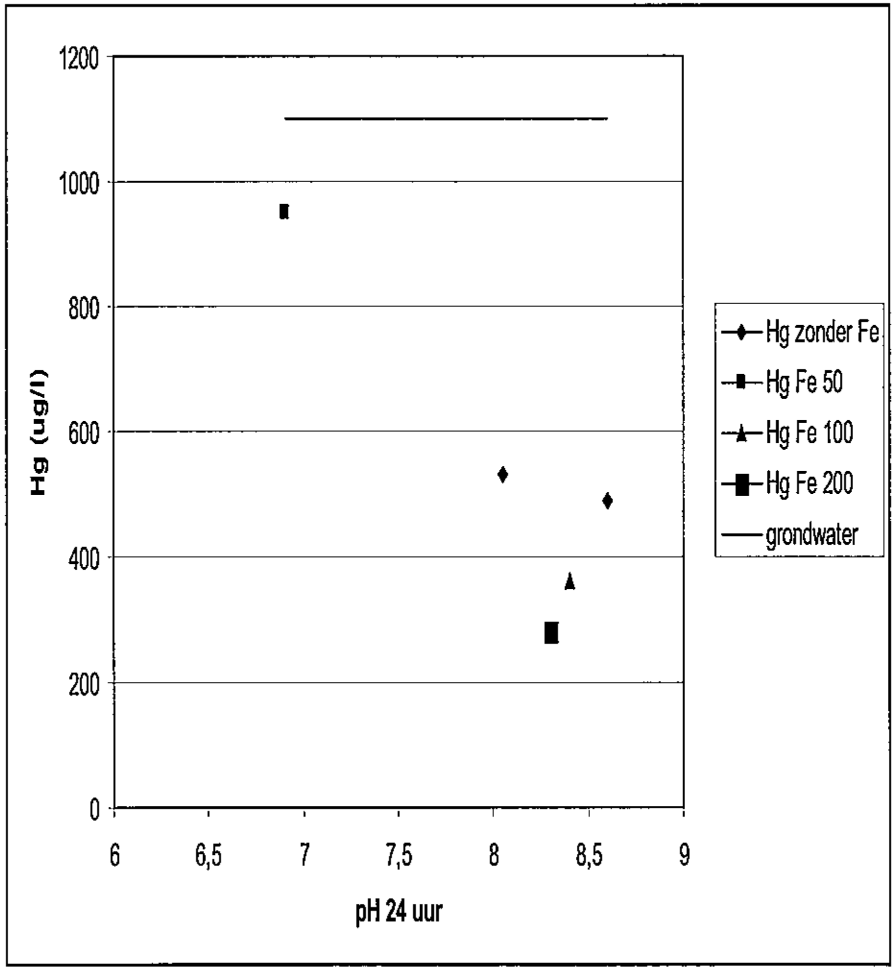
- Adsorption of Hg on ferric oxide by an injection of a solution of iron salts:
  a) $FeCl_3$
  b) $FeSO_4$
- Precipitation as α-HgS under reductive conditions
  a) Ethanol
  b) Protamylasse

Lab test results

$FeCl_3$:

- Increase of pH during the test from pH 6,8 to 8,4

- Good result with high pH and high iron dose (200 mg Fe/l)
  - Hg concentration dropped from 1100 µg/l to 280 µg/l



Labtest results

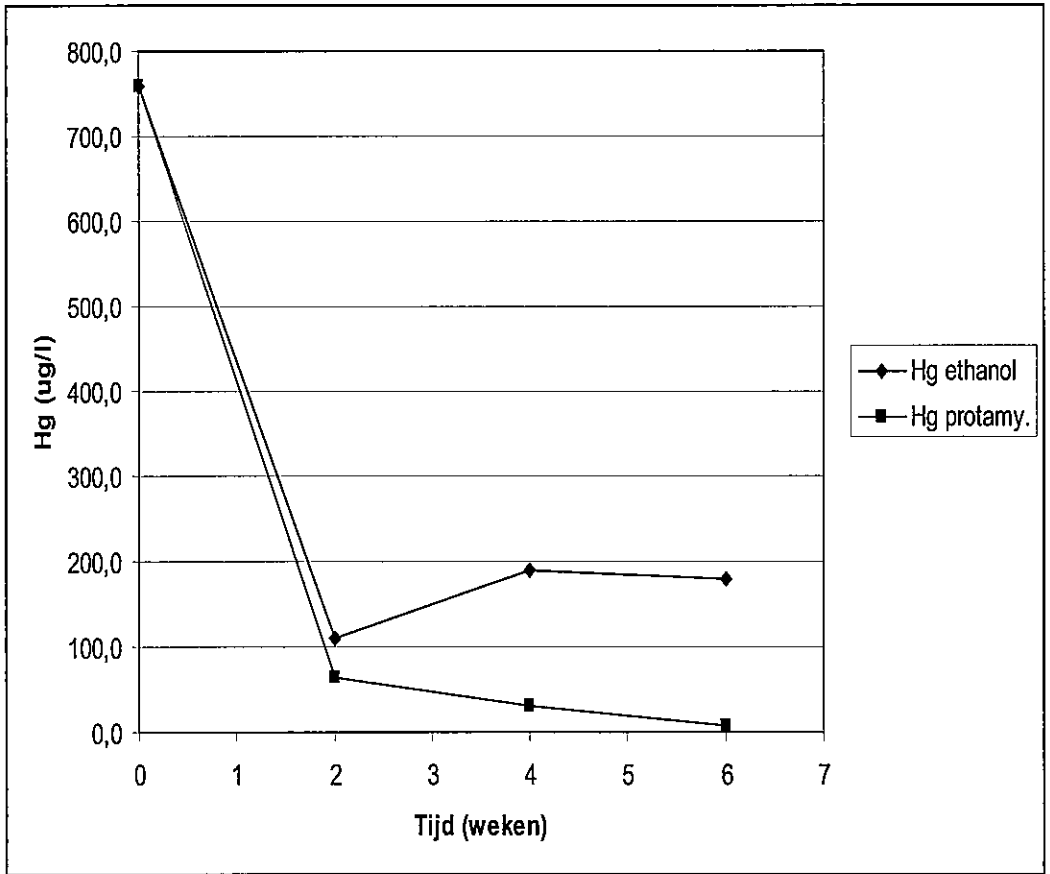
$FeSO_4$

Parameter	Test 1	Test 2	Test 2 + pH correction
Dosage	200 mg Fe	400 mg Fe	400 mg Fe/l + pH correction
pH 24 uur	8,3	8,3	6,8
Hg (µg/l)	150	97	280

Labtest: Ethanol and protomylasse

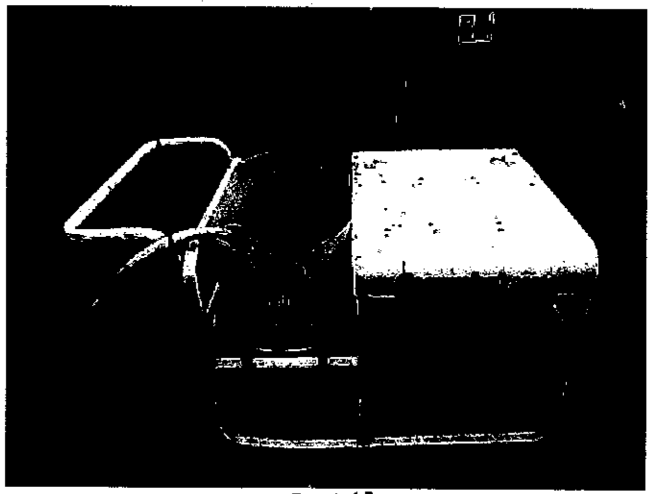
Protomylasse:

Best result : drop in Hg-concentrations from 760 µg/l to <8 µg/l

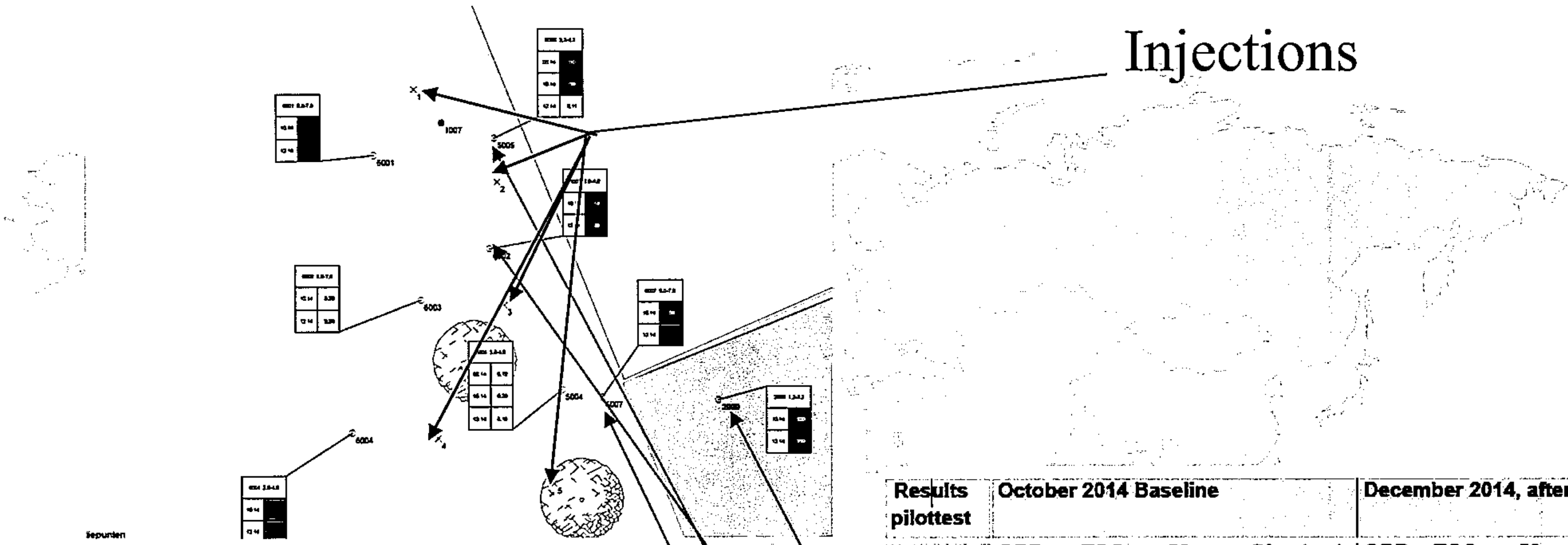


Field test

- First injection campaign (#5), protomylasse (1:1) solution
  - Injection in October 2014
  - 55l of protomylasse /0,5 m depth interval (top-down)
  - Injection between 2 and 8 m-bgl
- Second injection campaign (#8), protomylasse (1:2) solution
  - Injection in January 2016
  - 90l of protomylasse/ 0,5 m depth interval (top –down)



Results the field test (phase 1)

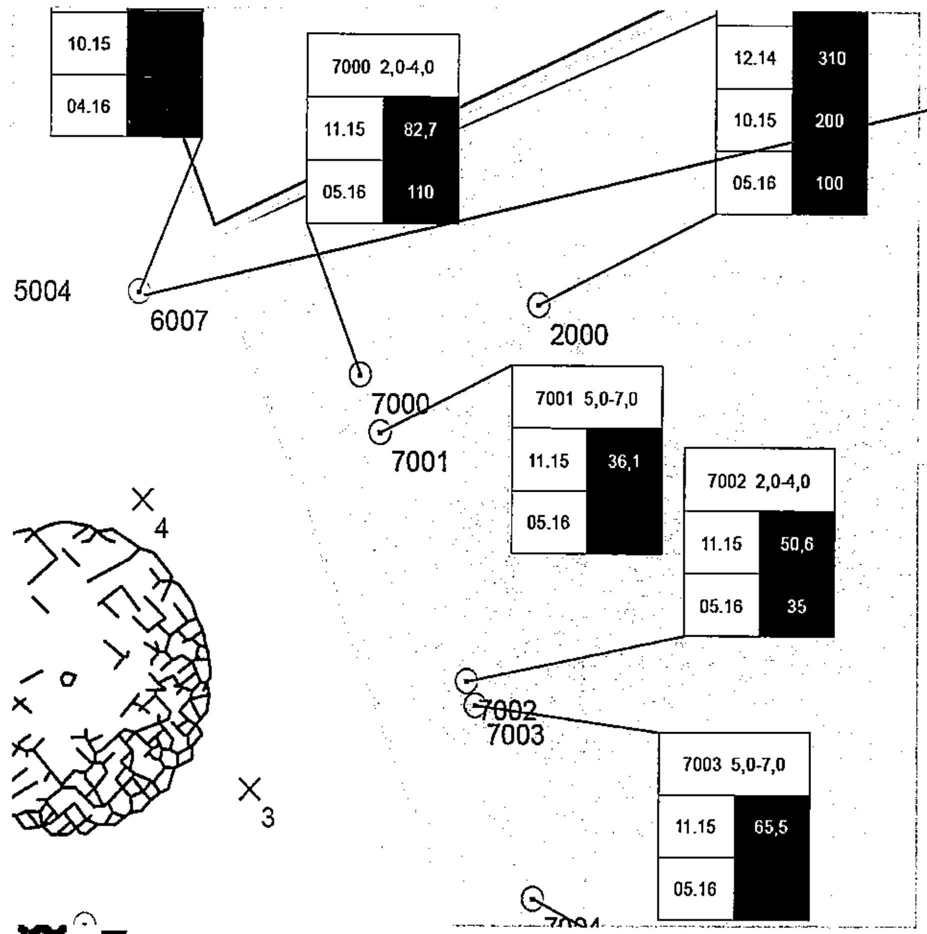


Results pilottest	October 2014 Baseline				December 2014, after injection			
Parameter Monitoring well	ORP (mV)	TOC (mg/l)	S^{2-} (mg/l)	Dissolved Hg (µg/l)	ORP (mV)	TOC (mg/l)	S^{2-} (mg/l)	Dissolved Hg (µg/l)
				No Influence				
2000	+165	9,8	0,1	320	+155	10	0,1	310
6002	+64	4,2	0,1	14	+125	4	0,1	29
				Influence				
5005	+90	6,3	0,1	110	-195	9,9	3,4	0,11
6007	+38	6,6	0,1	59	-178	3700	0,4	0,63

a) Heterogeneous spreading of the injected carbon source
b) In case the substrate arrives, reduction of ORP, formation of S^{2-} and decrease of dissolved Hg conc.

Tauw

Results of the field test (phase 2)

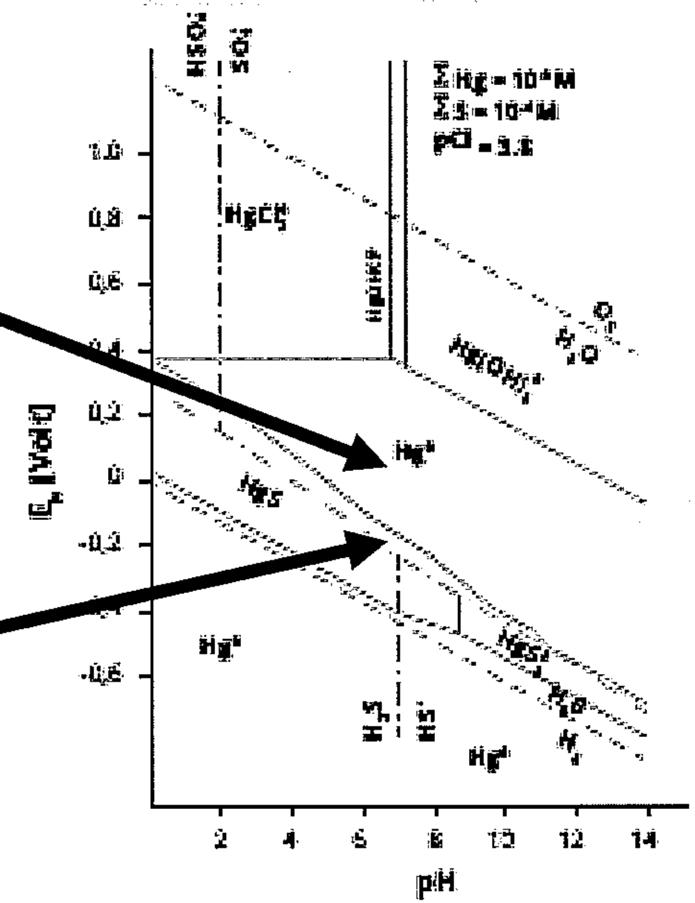


- MW 6007
  - Stable situation in October 2015, one year after the first injection
- Under the building
  - Shallow wells no influence
  - Deeper wells influence of the injections with significant drop of the Hg conc.

Results of the field test

Prior to injection
pH = 6,8
ORP = 100 to 200 mV
→ Hg^0
$Hg^0 \leftrightarrow Hg_2^{2+} \leftrightarrow Hg^{2+}$

After injection
pH = 6,8
ORP = -150 to -200 mV
→ HgS



Hg Pourbaix Diagram with Cl and S

Lessons learned

- 1:2 protomylasse/water solution easier to inject + better distribution in the soil compared to a 1:1 solution
- Reflux in the top layers (50% of the injections)
  → more difficult to inject in the top layer
- Top layer more difficult to treat:
  - Higher initial ORP
  - Difficult distribution of protomylasse mixture
  - Increase the pH → $Hg(OH)_2\downarrow$?

Conclusions

ISMP of Hg is possible:

→ Formation of a stable precipitation (SP of HgS = 2 X 10^{-53})

→ Dissolved Hg concentrations decreased significantly in the aquifer

→ HgS precipitation remains stable over a wide pH range

→ ISMP is a technique with a lower environmental impact (CO_2 emissions) compared to a P&T

Conclusions

→ ISMP of Hg is a <u>cost effective alternative</u> with an estimated 70% budget saving compared to a P&T

→ Applicable in other industrial activities than the production of felt e.g. chloro-alkali or gold mining industry

<u>Acknowledgements:</u>

- *Jaap Steketee: <u>jjs@tauw.com</u> : Expert, responsible for the design and realization of the labtest*
- *Herwig De Wilde: <u>Hwi@tauw.com</u>: Projectleader, coordinator of the project*
- *Dirk Paulus: <u>dpa@tauw.com</u>: Senior expert, technical responsible of the project*

- **Session 3:** **Innovation in investigation, remediation and source removal technologies**
- **Chair:** **Dietmar Müller-Grabherr – EA Austria**

Poster pitches:
Giovanni Buscone - Tauw Italia S.r.l.
Phil Studds - Ramboll Environ
Erwin van der Pol - Witteveen + Bos

Presentations:

- **Hans-Peter Koschitzky - VEGAS, Versuchseinrichtung zur Grundwasser- und Altlastensanierung, Universität Stuttgart**
  Nanoremediation for Soil and Groundwater Clean-up
  What can we learn from NanoRem: possibilities and Future Trends

- **Olivier Sibourg - Enoveo**
  Real-time and in situ monitoring of aquatic environments using indigenous microbial community - based biosensors

Nanoremediation for Soil and Groundwater Clean-up
What can we learn from NanoRem: Possibilities and Future Trends

Hans-Peter Koschitzky, Alexandra Gens, Joachim Roos

VEGAS

Versuchseinrichtung zur Grundwasser- und Altlastensanierung
Institut für Wasser- und Umweltsystemmodellierung, Universität Stuttgart
vegas@iws.uni-stuttgart.de; www.vegas.uni-stuttgart.de

Joint ICCL – NICOLE conference
Groundwater Management on Contaminated Sites
5th to 6th October 2017, National Museum, Copenhagen, Denmark

NICOLE
Network for Industrially Co-ordinated Sustainable Land Management in Europe

ICCL

What is NanoRem?

NanoRem – Taking Nanotechnological Remediation Processes from Lab Scale to End User Applications for the Restoration of a Clean Environment

University of Stuttgart
VEGAS

NanoRem

NanoRem is a € 14 million international collaborative project with 29 Partners from 13 countries, and an international Project Advisory Group (PAG) providing linkages to the USA and Asia.

- **Industry, research, SMEs, public agencies, technology providers**
- **01.02.2013 – 31.01.2017**

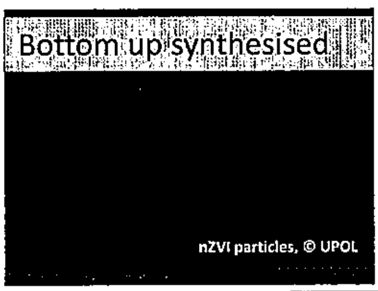
KIT, aquatest, The University of Manchester, Ben Gurion University of the Negev, Geoplano, ctm, HelmholtzZentrum münchen German Research Center for Environmental Health, DTU, universität wien, CL:AIRE, Verfahrenstechnik für Rohstoffe, NANOIRON FUTURE TECHNOLOGY, SciDRE Scientific Instruments Dresden GmbH, Universität Duisburg Essen, brgm, VEGAS, University of Stuttgart Germany, tecnalia, Helmholtz Centre for Environmental Research - UFZ, NIBIO, Deltares, SOLVAY, LQM, Golder Associates, environmental technology

University of Stuttgart
VEGAS

VEGAS

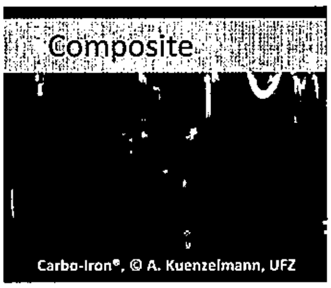
What is nanoremediation?

- The use of nanoparticles (NPs) for treatment (remediation) of contaminated soil and groundwater
- Depending on the use of different particles types nanoremediation processes generally involve reduction, oxidation, sorption or a combination
- NPs usually defined as particles with one or more dimensions <100nm
- Can include larger composite particles with embedded nanoparticles



nZVI particles, © UPOL

Milled nZVI particles, © UVR-FIA

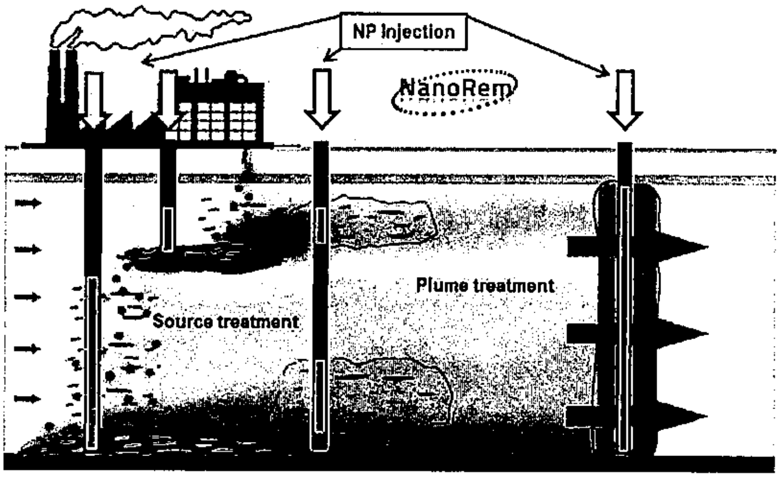


Carbo-Iron®, © A. Kuenzelmann, UFZ

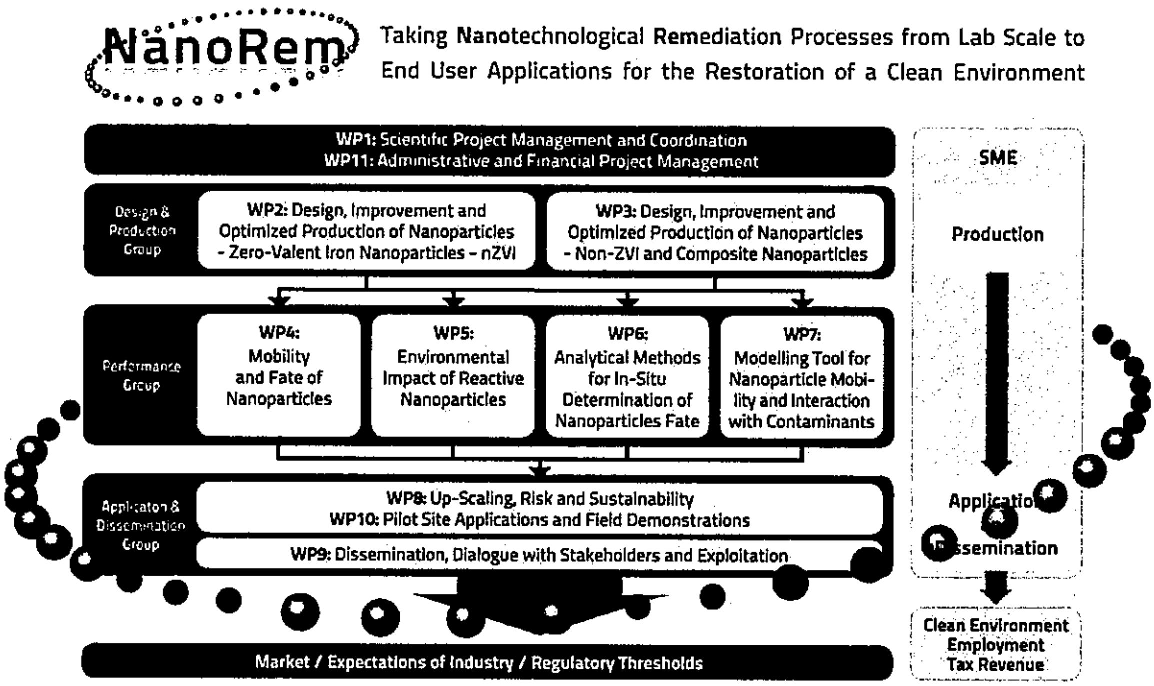
Advantages of NPs for in situ remediation

- Small size
  ➔ higher surface area
  ➔ very reactive
- Applicable below buildings
- "independent" of application depth
- different NPs
- for various contaminants
- innovative technology

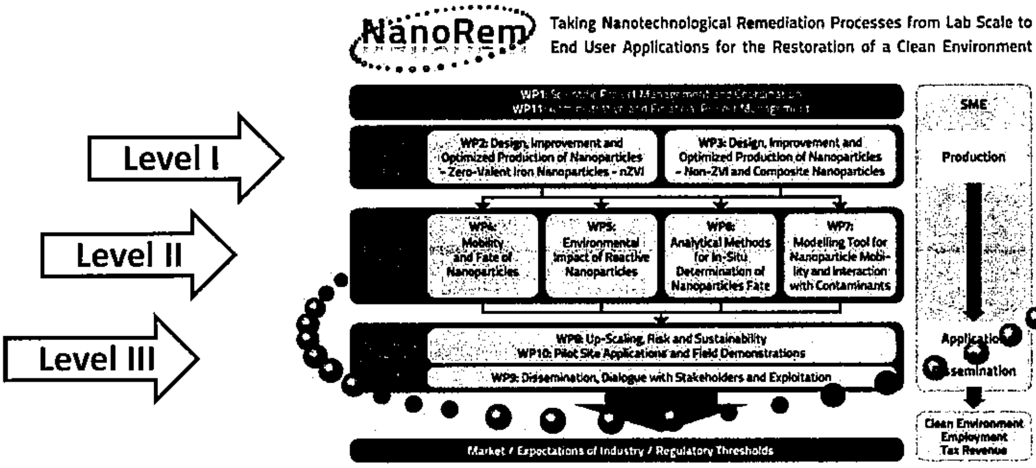
- NPs (in a carrier fluid) injected into saturated zone via wells
- Focus on source treatment



NanoRem Structure



NanoRem‘s three level approach



I Development and production: **WP2** and **WP3**

II Properties and behavior in the environment: **WP4** to **WP7**

III Application, permission (approval) and promotion
- Large scale experiments and pilot sites: **WP8** and **WP10**
- Dissemination, communication and exploitation: **WP9**

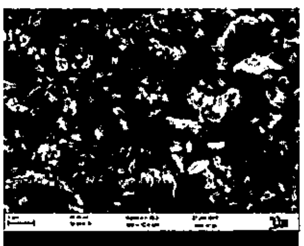
NanoRem Main Results (1)

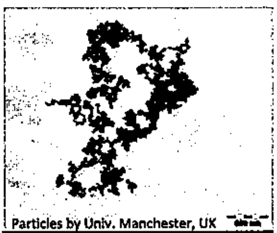
(1) Identify the **most appropriate nanoremediation technological approaches** to achieve a **step change** in remediation practice

- Model systems have been used to investigate mobility, reactivity, functional lifetime and reaction products
- For NP optimisation, the influence of size, surface chemistry, structure and formulations was investigated

✓ Results led to enhanced NPs and novel NP types

✓ Step change: Extension of practically treatable contaminants


Particles by CTM, ES © Techn. Univ. Liberec, CZ



© M. Kleiven NMBU, NO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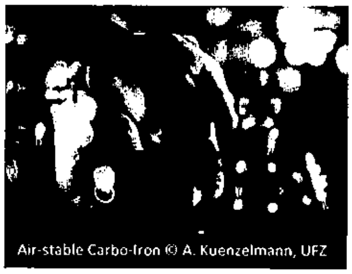
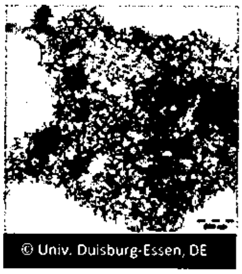
NanoRem Main Results (2)

(2) Develop **lower cost production techniques** and production at **commercial scales** for nanoparticles

- ✓ Laboratory scale production processes were up-scaled to the industrial level, resulting in a commercially available and economically competitive technology
- ✓ nZVI particles have been improved: Surface coating allows for a more convenient handling regarding transport and storage (air-stable)

More information: *Bulletin no 4: "A Guideto Nano particles for the Remediation of Contaminated Sites"*


Air-stable Carbo-Iron © A. Kuenzelmann, UFZ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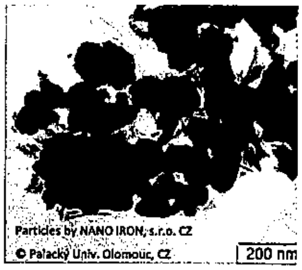
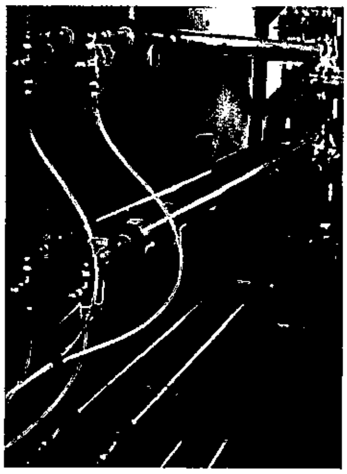

Particles by NANO IRON, s.r.o. CZ
© Palacký Univ. Olomouc, CZ

NanoRem Main Results (3a)

(3) Determine the **mobility and migration potential of nanoparticles** in the subsurface, and relate these both to their **potential usefulness** and also their **potential to cause harm**

- Experiments for mobility and migration potential ranged from laboratory scale (columns), over large-scale contained laboratory systems to field tests

✓ More information:
- *Generalized Guideline for Application*
- *Stability, Mobility, Delivery and Fate of optimized NPs under Field Relevant Conditions* and
- NanoRem site bulletins


Reactivity studies (©VEGAS/Univ. Stuttgart, DE)

NanoRem Main Results (3b)

- Investigations included unintended secondary effects of NPs application on environment and ecosystems

✓ In the lab, no significant toxic effects were observed on soil and water organisms (tests included effects on earthworms, radish roots, green algae and bacteria)

✓ In three out of four field sites investigated, no toxic effects were observed up to nine months after NP injection. The remaining one was transient.

Radish seeds (© Claire Coutris, NIBIO, NO)

Commercially Available NanoRem Particles

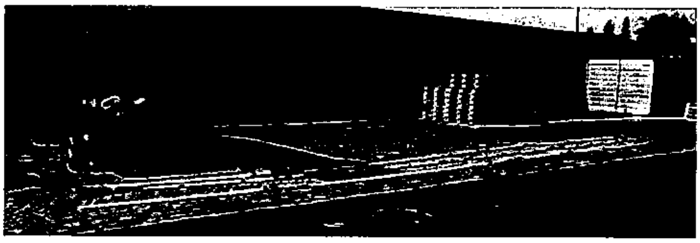
Particle name	Type of particle	Manufacturer	Process of contaminant removal	Target contaminants
Carbo-Iron® (industry)	Composite of Fe(0) and activated carbon	SciDre GmbH, Germany	Adsorption + Reduction	Halogenated organics (contaminant spectrum as for NZVI)
FerMEG12	Mechanically ground nZVI particles	UVR-FIA GmbH, Germany	Reduction	Halogenated hydrocarbons
NANOFER 25S	Nano scale zero valent iron (nZVI)	NANO IRON s.r.o., Czech Republic	Reduction	Halogenated hydrocarbons and heavy metals
NANOFER STAR	Air stable powder, nZVI	NANO IRON s.r.o., Czech Republic	Reduction	Halogenated hydrocarbons and heavy metals
Nano-Goethite	Pristine iron oxides stabilized with HA	University of Duisburg-Essen, Germany	Oxidation (bioremediation) + Adsorption of HM	Biodegradable (preferably non-halogenated) organics, such as BTEX; heavy metals

NanoRem Particles under Development

Particle name	Type of particle	Manufacturer	Process of contaminant removal	Target contaminants
Trap-Ox Fe-zeolites	Nanoporous alumosilicate loaded with Fe(III)	UFZ Leipzig, Germany	Adsorbent + Oxidation (catalyst)	Small molecules (dep. on pore size of zeolite) - e.g. BTEX, MTBE, dichloroethane, chloroform, ...
Bionano-magnetite	Produced from nano-Fe(III) minerals	University of Manchester, UK	Reducing agent and adsorption of heavy metals	Heavy metals, e.g. Cr(VI)
Palladized bionano-magnetite	Biomagnetite doped with palladium	University of Manchester, UK	Reduction (catalyst)	E.g. Halogenated substances (contaminant spectrum broader than for nZVI)
Abrasive Milling nZVI	Milled iron	Centre Tecnològic de Manresa, Spain	Reduction	Halogenated aliphatics and Cr(VI)
Barium Ferrate	Fe(VI)	VEGAS, University of Stuttgart, Germany	Oxidation	BTEX?, nitroaromatic compounds? (under investigation)
Mg/Al particles	Zero valent metals	VEGAS, University of Stuttgart, Germany	Reduction (reagent)	Halogenated hydrocarbons
Nano-FerAl	Composite of Fe and Al	UVR-FIA GmbH / VEGAS, Germany	Reduction (reagent)	Halogenated hydrocarbons

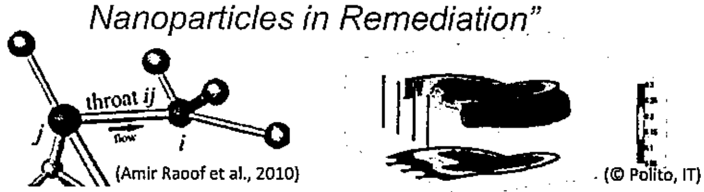
NanoRem Main Results (4)

(4) Develop a comprehensive **set of tools for design, application and monitoring practical nano remediation performance and determine the fate** of nanoparticles in the subsurface



Monitoring equipment on pilot site (© VEGAS/Univ. Stuttgart, DE)

- ✓ Bulletin No 2: *"Appropriate Use of Nanoremediation"*
- ✓ Bulletin No 3: "*Generalized Guideline for Application*"
- ✓ Bulletin No 5: "*Development and Application of Methods for Monitoring Nanoparticles in Remediation*"



Numerical modeling of nanoparticle transport: From the pore scale to the field scale

- ✓ Bulletin No 6: "*Forecasting NP Transport for Soil Remediation*"
- ✓ Risk Screening Model

NanoRem Main Results (5)

(5) Engage in **dialogue with key stakeholder and interest groups** to ensure that research, development and demonstration meets their needs, is most sustainable and appropriate whilst balancing benefits against risks

- Address real market and regulatory interests
- Communicating findings regarding renegade particles and relative sustainability over the life cycle of a typical remediation project

✓ *"Exploitation Strategy, Risk-Benefit Analysis and Standardisation Status"* available on www.nanorem.eu
✓ *"NanoRem Case Study Sustainability Assessment Background and Workbook"* to provide background, context and procedures for a sustainable remediation

NanoRem Main Results (6)

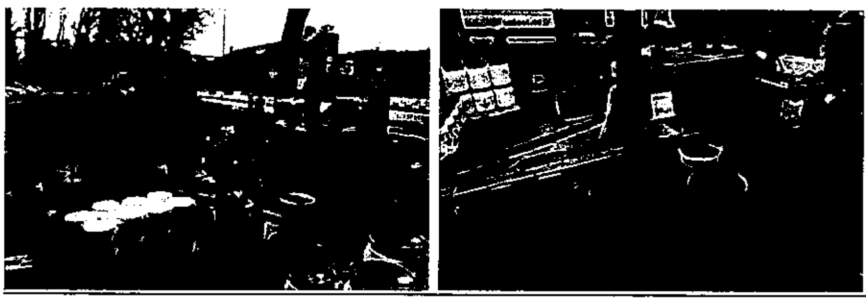
(6) Carry out a **series of full scale applications in several European countries** to provide cost estimations and performance, fate and transport findings

✓ NPs were applied in both large-scale containers and on pilot sites to provide on-site validation of the lab-scale results
✓ Site results can be found in the site bulletins on www.nanorem.eu
✓ All field trials were carried out within a risk management regime that gained the required regulator approvals
✓ Qualitative sustainability assessment for one NanoRem pilot site and an external one
✓ NANOFER STAR, FerMEG12 and Carbo-Iron® led to a (partial) degradation of CHC sources. Nano-Goethite particles were shown to "polish" a remaining BTEX contamination (groundwater plume) after a primary source removal.

NanoRem Pilot Sites

Site	Country	Site Primary Investigator	Target Cont.	NP-Type	Reaction Principle	Aquifer
Solvay	CH	Solvay	CHC	FerMEG12 (milled nZVI)	Reduction	porous / unconfined
Spolchemie 1	CZ	Aquatest	CHC	NANOFER 25S / NANOFER STAR	Reduction	porous / unconfined
Spolchemie 2	CZ	Aquatest	BTEX	Nano-Goethite (Iron-Oxide)	Oxidation / microbial enhancement	porous / unconfined
Neot Hovav	IS	Negev, BGU	TCE, cis-DCE, toluene	Carbo-Iron®	Adsorption / Reduction	fractured
Balassagyarmat	HU	Golder	PCE, TCE, DCE	Carbo-Iron®	Adsorption / Reduction	porous / unconfined
Nitrastur	ES	Tecnalia	As, Pb, Zn, Cu, Ba, Cd	NANOFER STAR	Reduction	porous / unconfined

Large Scale Flume
(© VEGAS / University of Stuttgart, DE)



Injection of FerMEG12 (nZVI) into the Solvay site
(© VEGAS / University of Stuttgart, DE)

www.nanorem.eu

NanoRem

Nanotechnology for contaminated land **Remediation**

Home | Toolbox | Project Aims | Project Description | Project Partners | News | Search | Intranet

NanoRem (Taking Nanotechnological Remediation Processes from Lab Scale to End User Applications for the Restoration of a Clean Environment) is a research project, funded through the European Commission FP7. It focuses on facilitating practical, safe, economic and exploitable nanotechnology for in situ remediation. This is being undertaken in parallel with developing a comprehensive understanding of the environmental risk-benefit for the use of nanoparticles (NPs), market demand, overall sustainability, and stakeholder perceptions.

The project is designed to unlock the potential of nanoremediation processes from laboratory scale to end user applications and so support both the appropriate use of nanotechnology in restoring land and water resources and the development of the knowledge-based economy at a world leading level for the benefit of a wide range of users in the EU environmental sector.

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Quick Links

- NanoRem Toolbox now available
- NanoRem Bulletins 05/02/17
- The NanoRem Toolbox will be available in full from February 2017, 08/12/16
- NanoRem final conference 31/05/16
- Possible amendments of Annexes to REACH for registration of nanomaterials 05/02/16
- NanoRem Newsletter Autumn 2015 16/11/15
- No significant toxicological effects for nanoparticles 05/06/15
- NanoRem at AquaConsoil 2015 01/06/15
- Nanoscale Zerovalent Iron (nZVI): Risk-Benefit and

NanoRem

Nanotechnology for contaminated land **Remediation**

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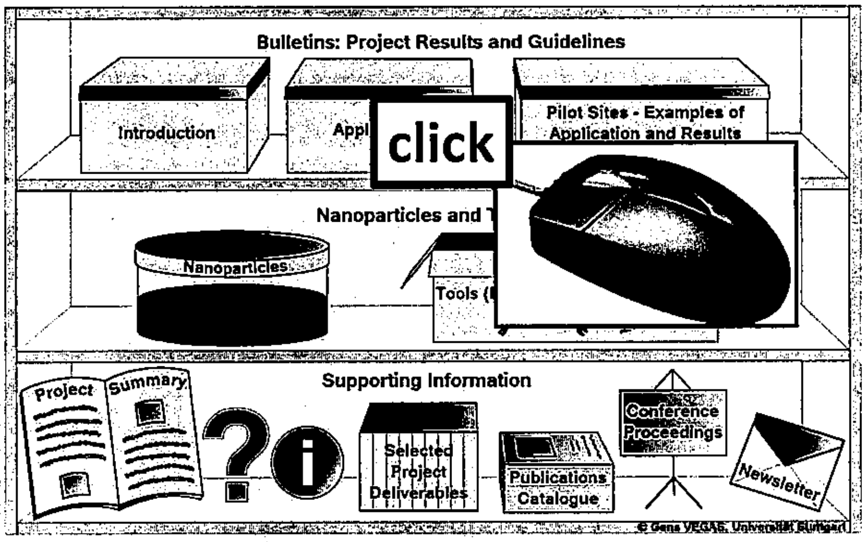
*Nano*Rem Toolbox



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List of NanoRem bulletins

No.	Title
1	Nanotechnology for Contaminated Land Remediation - Possibilities and Future Trends Resulting from the NanoRem Project
2	Appropriate Use of Nanoremediation
3	Generalised Guideline for Application of Nanoremediation
4	A Guide to Nanoparticles for the Remediation of Contaminated Sites
5	Development and Application of Methods for Monitoring Nanoparticles in Remediation
6	Forecasting Nanoparticle Transport for Soil Remediation
7-12	Site-Bulletins

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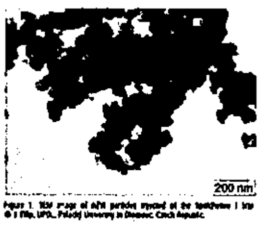
NanoRem 1

NanoRem Bulletin

Nanotechnology for Contaminated Land Remediation – Possibilities and Future Trends Resulting from the NanoRem Project



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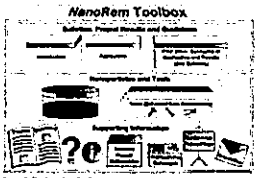

NanoRem Bulletin

Thanks to

NanoRem

& the team

University of Stuttgart
VEGAS

And thank you for your interest

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This presentation reflects only the author's views. The European Union is not liable for any use that may be made of the information contained therein.

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NanoRem: Nanoremediation for Soil and Groundwater Clean-up - Possibilities and Future Trends

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Keywords: nanoremediation, soil and groundwater remediation, nano iron, nZVI, nanoparticles, composite particles, NanoRem toolbox

1 Introduction

NanoRem was a research project, funded through the European Union's Seventh Framework Program for research, technological development and demonstration under grant agreement no. 309517. NanoRem focused on facilitating a practical, safe, economic and exploitable nanotechnology for *in situ* remediation of soil and groundwater. This was undertaken in parallel with developing a comprehensive understanding of the environmental risk-benefit for the use of nanoparticles (NPs), their market demand, overall sustainability, and stakeholder perceptions. The project was designed to unlock the potential of nanoremediation processes from laboratory scale to end user applications and to support both the appropriate use of nanotechnology in restoring land and water resources as well as the development of the knowledge based economy at a world leading level for the benefit of a wide range of users in the EU environmental sector.

The NanoRem consortium was multidisciplinary, cross-sectoral and transnational. It consisted of 29 partners from 13 countries (Fig. 10) organised in 11 work packages. The consortium included 19 of the leading nanoremediation research groups in the EU, 9 industry and service providers (7 SMEs (small and medium sized enterprises)) and one organisation with policy and regulatory interest. The consortium was co-ordinated by the VEGAS team (Research Facility for Subsurface Remediation) from the University of Stuttgart in Germany.

The overall aim of the NanoRem project was to demonstrate that the application of NPs is a practical and reliable method for the treatment of contaminated soil and groundwater. NanoRem provided a direct link between SMEs on the production side and SMEs on the application side of groundwater remediation using NPs.

2 What does Nanoremediation mean?

Nanoremediation means the use of nanoparticles (NPs) for treatment (remediation) of contaminated soil and groundwater. Depending on the use of different particles types nanoremediation processes generally involve reduction, oxidation, sorption or a combination of these. NPs are usually defined as particles with one or more dimensions <100nm, but they can include larger composite particles with embedded nanoparticles. The main focus is on source treatment in the saturated zone, but plume treatment is also an option (Fig. 1). It is applicable below buildings, "independent" of application depth. Different NPs can be used for various contaminants. But it is still an innovative technology.

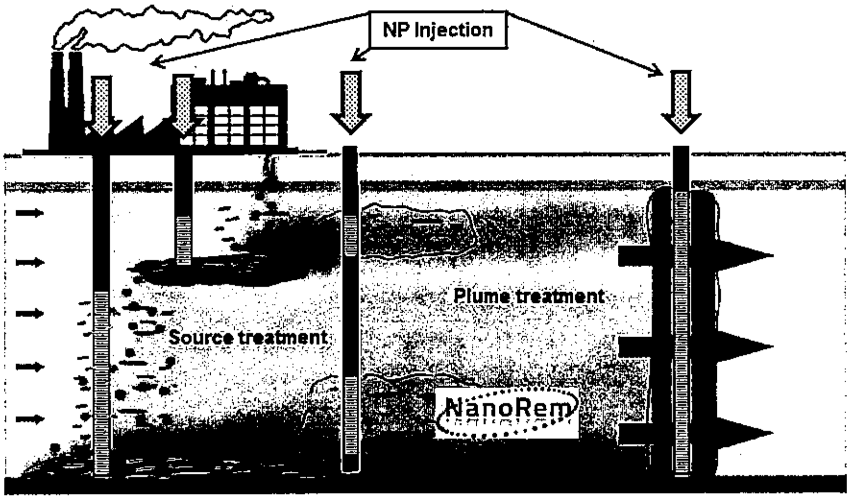

Figure 1: Possibilities for Nanoremediation

3 Project Structure

The project structure is depicted in Figure 2.

The *Design and Production Group* was comprised of two work packages (WP2 & WP3) to facilitate the focus on different NPs and their corresponding production and application strengths.

The Performance Group was established to bridge the gap from production to application (WP4-WP7), to work closely together to ascertain potentials and limitations of NPs, and to extend the limits of economic and ecological NP application.

The *Application and Dissemination Group* was responsible for successfully transferring the technology to the end-user. This comprised the proof of concept in large scale indoor experiments (WP8), the demonstration at a number of pilot sites (i.e. field tests, WP10), risk assessment and sustainability and lifecycle assessment considerations (WP8 & WP9).

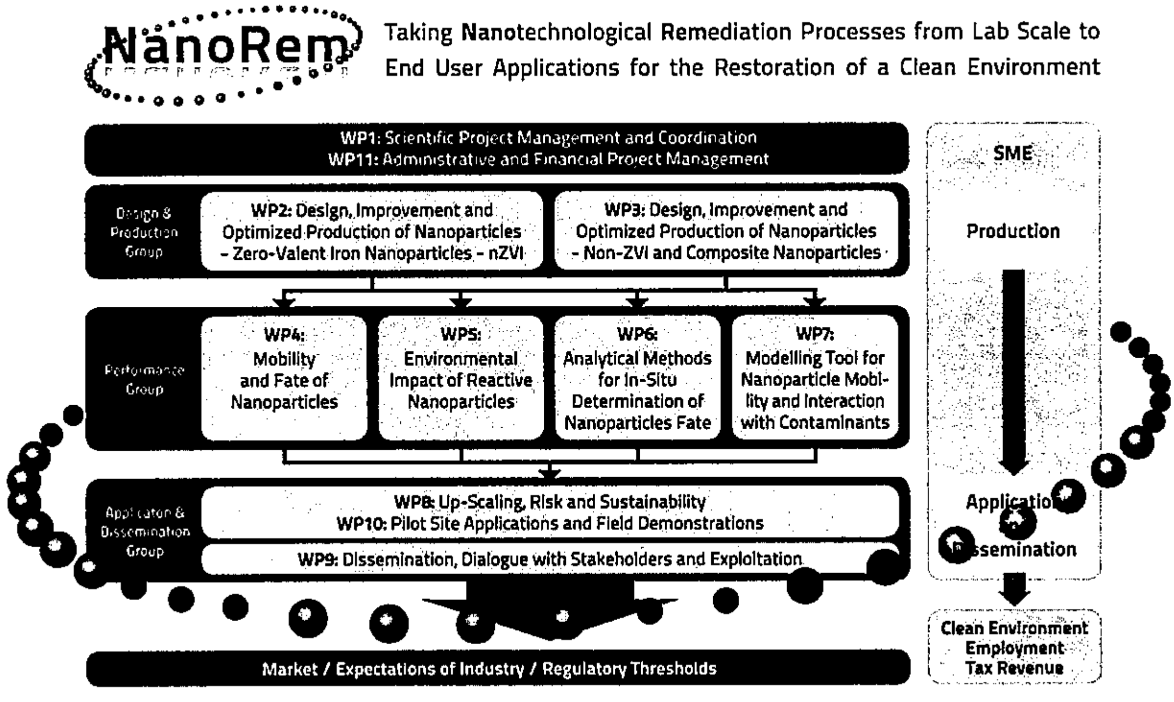

Figure 2: NanoRem's project structure

4 NanoRem Project Goals and Main Results

Six project goals were identified at the project outset. These are listed below along with a brief text describing how these goals were met.

Goal (1) Identify the most appropriate nanoremediation technological approaches to achieve a step change in remediation practice.

Model systems (NPs + conditions mimicking real environmental conditions), both existing and novel, have been used to investigate mobility, reactivity (destruction, transformation or sorption of contaminants), functional lifetime and reaction products. For NP optimization the influence of size, surface chemistry, structure and formulations on the performance were investigated leading to enhanced NPs as well as novel NP types. The step-change focus was to extend the range of practically treatable contaminants.

✓ Available NPs are listed in Table 1 and Table 2, some examples are shown in Figure 3. More information can be found within the Bulletin No 4 "A Guide to Nanoparticles for the Remediation of Contaminated Sites" and at www.nanorem.eu.

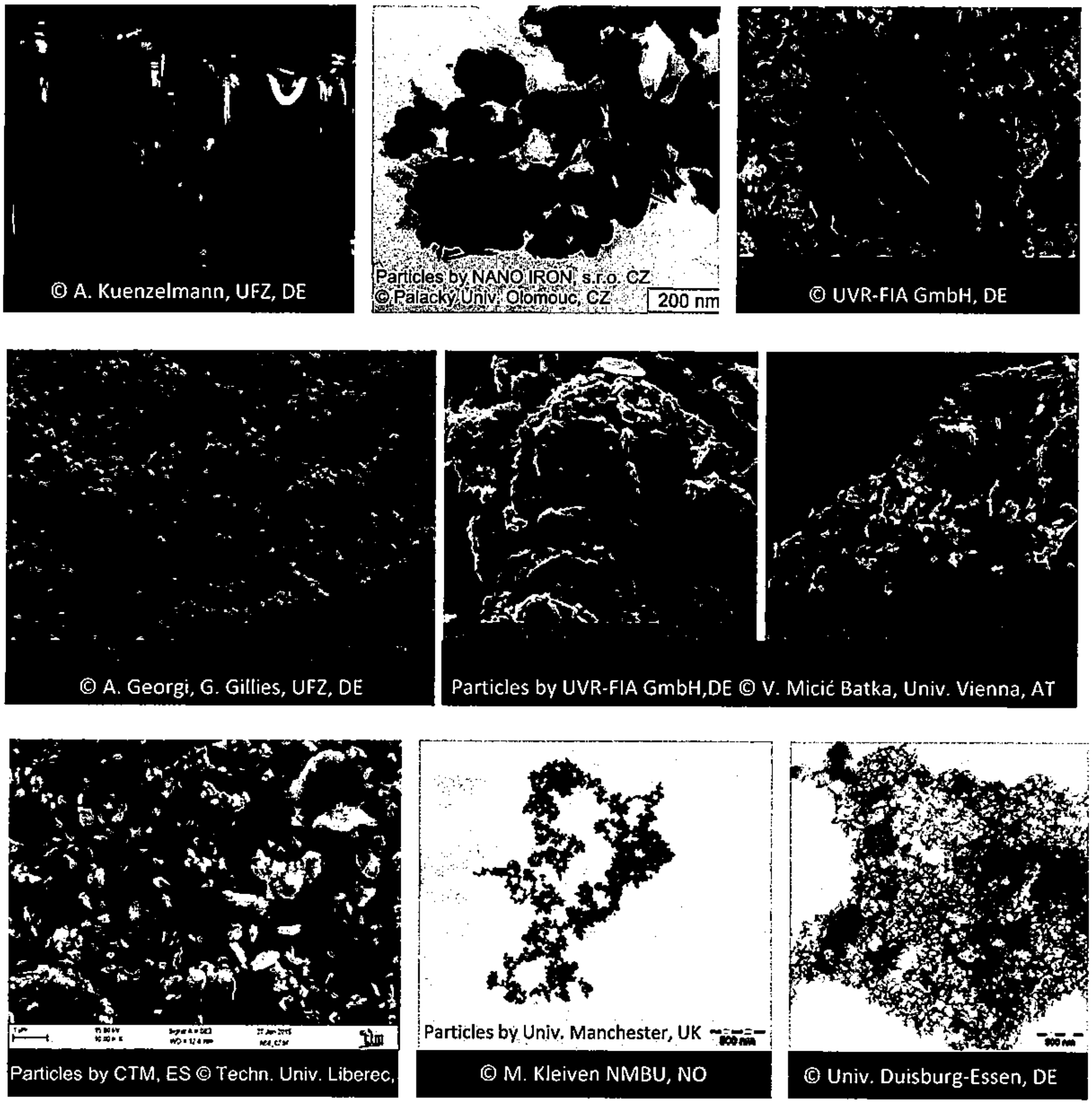

Figure 3: Different NPs from left to right: upper row: Carbo-Iron®, NANOFER (nZVI), milled nZVI particles; middle row: Trap-Ox Fe-zeolites, milled nZVI particles; lower row: milled nZVI particles, palladized bionanomagnetite, Nano-Goethite

Table 1: Commercially available NanoRem Particles

Particle name	Type of particle	Manufacturer	Process of contaminant removal	Target contaminants
Carbo-Iron® (industry)	Composite of Fe(0) and activated carbon	ScIDre GmbH, Germany	Adsorption + Reduction	Halogenated organics (contaminant spectrum as for NZVI)
FerMEG12	Mechanically ground nZVI particles	UVR-FIA GmbH, Germany	Reduction	Halogenated hydrocarbons
NANOFER 25S	Nano scale zero valent iron (nZVI)	NANO IRON s.r.o., Czech Republic	Reduction	Halogenated hydrocarbons and heavy metals
NANOFER STAR	Air stable powder, nZVI	NANO IRON s.r.o., Czech Republic	Reduction	Halogenated hydrocarbons and heavy metals
Nano-Goethite	Pristine iron oxides stabilized with HA	University of Duisburg-Essen, Germany	Oxidation (bioremediation) + Adsorption of HM	Biodegradable (preferably non-halogenated) organics, such as BTEX; heavy metals

Table 2: NanoRem Particles under Development

Particle name	Type of particle	Manufacturer	Process of contaminant removal	Target contaminants
Trap-Ox Fe-zeolites	Nanoporous alumosilicate loaded with Fe(III)	UFZ Leipzig, Germany	Adsorbent + Oxidation (catalyst)	Small molecules (dep. on pore size of zeolite) - e.g. BTEX, MTBE, dichloroethane, chloroform, ...
Bionano-magnetite	Produced from nano-Fe(III) minerals	University of Manchester, UK	Reducing agent and adsorption of heavy metals	Heavy metals, e.g. Cr(VI)
Palladized bionano-magnetite	Biomagnetite doped with palladium	University of Manchester, UK	Reduction (catalyst)	E.g. Halogenated substances (contaminant spectrum broader than for nZVI)
Abrasive Milling nZVI	Milled iron	Centre Tecnològic de Manresa, Spain	Reduction	Halogenated aliphatics and Cr(VI)
Barium Ferrate	Fe(VI)	VEGAS, University of Stuttgart, Germany	Oxidation	BTEX?, nitroaromatic compounds? (under investigation)
Mg/Al particles	Zero valent metals	VEGAS, University of Stuttgart, Germany	Reduction (reagent)	Halogenated hydrocarbons
Nano-FerAl	Composite of Fe and Al	UVR-FIA GmbH / VEGAS, Germany	Reduction (reagent)	Halogenated hydrocarbons

Goal (2) Develop lower cost production techniques and production at commercial scales of nanoparticles.

Laboratory scale production processes were upscaled to the industrial level. The step-change focus was to produce substantially cheaper and more sustainable NPs.

✓ The production was upscaled successfully resulting in a commercially available and economically competitive technology.

- ✓ Nano-scale zerovalent iron particles (nZVI) have been improved via a new surface coating so that they are available as an air-stable dry powder in spite of a large specific surface. This allows for a more convenient handling (transportation to the site, storable). More information can be found within the Bulletin No. 4 "A Guide to Nanoparticles for the Remediation of Contaminated Sites" and at: www.nanorem.eu.

Goal (3) Determine the mobility and migration potential of nanoparticles in the subsurface, and relate these to their potential usefulness and also their potential to cause harm.

Experiments for mobility and migration potential ranged from laboratory scale (columns), over large-scale contained laboratory systems to field tests. Furthermore, investigations included unintended secondary effects of NPs application on environment and ecosystems (Fig. 4).

Figure 4: Nanoparticles developed during the project were tested for their potential effects on plant root elongation. The picture shows an overview of the test after a 6-day exposure of radish seeds *Raphanus sativus* to (from front to back) Fe-Zeolite, activated carbon, aged Carbo-Iron®, and Carbo-Iron® at 0.01, 0.1, 1 and 10 g/L. © Claire Coutris, NIBIO, Norway

- ✓ All NPs were intensively tested and optimized with respect to *mobility* and *reactivity* in column experiments; the three nZVI particles, Carbo-Iron® and Nano-Goethite additionally in large scale experiments and at different field sites. In lab-scale studies, the migration potential of some types of NPs was optimized by using special additives. Other NPs types were shown to form stable suspensions as delivered by their producers.
- ✓ Further information on "*Stability, Mobility, Delivery and Fate of optimized NPs under Field Relevant Conditions*" can be found in the respective project deliverable.
- ✓ *Large Scale Experiments* (LSE, Fig. 5) transferred the results from the lab scale (homogeneous condition) to technical scale (homogeneous or controlled heterogeneous condition). For more information, please see goal (6).

Figure 5: Large scale flume (LSF) experiment, University of Stuttgart, © VEGAS, Germany

- ✓ With regard to ecotoxicological aspects it was found that no significant toxic effects were observed on soil and water organisms when ecotoxicological tests were undertaken for a range of nanoparticles available for remediation (including with respect to the particles' interaction with contaminants and the resulting products).
- ✓ A suite of standard and non-standard ecotoxicity tests, covering both terrestrial and aquatic organisms, did not lead to any hazard classification according to EU regulation for any of the tested particles. All particles, except the FerMEG12, can be considered non-toxic to organisms living in aquatic and terrestrial ecosystems. Effects on selected soil and water organisms were monitored for up to one year after NP injection at the pilot sites. In three out of four sites, no toxic effects were observed. A temporary increase in toxicity was observed right after NP injection at only one pilot site. More information can be found at www.nanorem.eu.

Goal (4) Develop a comprehensive set of tools for design, application and monitoring practical nanoremediation performance and determine the fate of nanoparticles in the subsurface.

The bulletins and tools described below can be downloaded from www.nanorem.eu.

- ✓ *Appropriate Use of Nanoremediation* (Bulletin No 2). The aim of this "position paper" is to provide a concise and easily read overview of NanoRem's views on the appropriate use and application of nanoremediation technologies, and provide some clarity about how they are regulated in comparison with other forms of *in situ* reduction and oxidation remediation technologies.
- ✓ The *Generalised Guideline for Application* (Bulletin No 3 and Tool) gives a comprehensive overview on the implementation of nanoremediation. The aim of this guideline is to assist practitioners and consultants in screening nanoremediation as a possible remediation option for a given site and facilitate the communication between regulators and consultants.
- ✓ Numerical tools for *Forecasting NP Transport for Soil Remediation* (Bulletin No 6) include a 1D modelling tool (MNMs)[1] for the assisted quantitative analysis of laboratory-scale column tests and the preliminary design of pilot NP injections in simplified geometry (radial 1D simulations), and a full 3D transport module (MNM3D)[2] for the simulation of particle injections (in one or more injection points) in heterogeneous domains and prediction of NP fate and transport at the field scale. The Bulletin gives details on how the tools can support the various stages of the design, implementation and evaluation of a nanoremediation.
- ✓ Analytical methods and field measurement devices (Bulletin No 5 "Monitoring Methods") are needed to follow the fate of nanoparticles during and after a injection, and to evaluate the efficiency of remediation. A variety of methods have been developed and tested at NanoRem field injections, ranging from on site sampling and measurement to in situ tracking using magnetic susceptibility (Fig. 6).
- ✓ The *Risk Screening Model* (Tool) is used to establish whether NanoRem particles can be injected without causing pollution of groundwater or surface water.

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[1] Micro- and Nano-particles transport, filtration and clogging Model Suite, www.polito.it/groundwater/software

[2] Micro and Nanoparticle transport Model in 3D geometries
Bianco, C., Tosco, T., Sethi, R. (2016) A 3-dimensional micro- and nanoparticle transport and filtration model (MNM3D) applied to the migration of carbon-based nanomaterials in porous media. *Journal of Contaminant Hydrology, 193, pp. 10-20.* DOI: 10.1016/j.jconhyd.2016.08.006

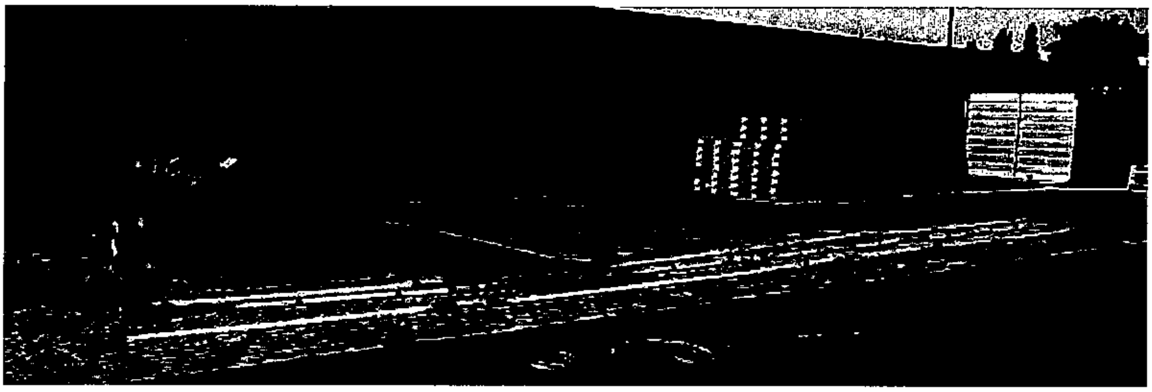

Figure 6: Preparation of the monitoring equipment at the Spolchemie Site 1 © VEGAS, University of Stuttgart, Germany

Goal (5) Engage in dialogue with key stakeholders and interest groups to ensure that research, development and demonstration meets their needs, is most sustainable and appropriate whilst balancing benefits against risks.

The main focus was on ensuring that the research addresses real market and regulatory interests. Communicating findings regarding renegade particles and the relative sustainability of nanoremediation over the life cycle of a typical remediation project was vital. Information and knowledge was being shared widely across the Single Market so that advances in nanoremediation can be properly exploited.

- ✓ NanoRem's *Exploitation Strategy, Risk-Benefit Analysis and Standardisation Status* summarises NanoRem's findings regarding dissemination and exploitation.
- ✓ NanoRem applied an internationally recommended approach to the *Life Cycle Assessment* (LCA) on the production process of three nanoparticles. *Life Cycle Inventories* (LCI) and impact assessments were applied to the production process of three zero valent iron nanoparticles being used at the pilot sites. Results from the impact assessment show the steps in the process that have major environmental impacts, for example energy consumption during the production. However, the boundary of the study has not gone beyond the production premises.
- ✓ The *NanoRem Case Study Sustainability Assessment Background and Workbook* has two broad purposes: to provide a background and NanoRem context for sustainable remediation and to provide a procedure to carry out a qualitative sustainability assessment of the nanoremediation technologies to be used at the field test sites.

Goal (6) Carry out a series of full scale applications in several European countries to provide cost estimations and performance, fate and transport findings.

NPs were applied both into large-scale contained laboratory systems and during field trials on the pilot sites, to provide on-site validation of the results on a representative scale both in terms of the effectiveness of nanoremediation as well as the environmental fate of the NPs and their associated by-products.

- ✓ In *field pilot tests* (see Table 3) the LSE results were verified under 3D heterogeneous field conditions. NANOFER STAR, FerMEG12 and Carbo-Iron® led to a (partial) degradation of CHC sources. Nano-Goethite particles were shown to "polish" a remaining BTEX contamination (groundwater plume) after a primary source removal. In the field trials on the pilot sites, the results of the LSE were validated in terms of effectiveness of nanoremediation and with respect to the environmental fate of the NPs and their associated by-products. It could be shown that nanoremediation works if the appropriate particles are selected for the conditions present at the site. Further information about the sites is given in the Site bulletins.

- ✓ A description of the applications and results can be found in the Site Bulletins on www.nanorem.eu. All field trials within the project were carried out within a risk management regime for nanoparticle release that gained the required regulators approvals and included where necessary a pre-deployment risk assessment protocol. Qualitative sustainability assessments have been conducted in a retrospective sense for one of the Czech pilot sites and as part of a remediation options appraisal for a separate UK based case study.

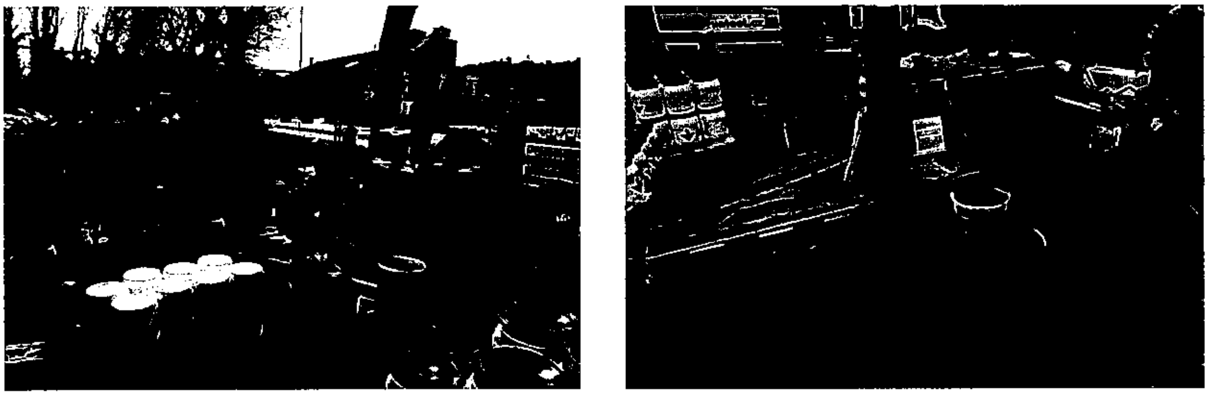

Figure 7: Injection of FerMEG12 (nZVI) into the Solvay site © VEGAS, University of Stuttgart, Germany

Table 3: NanoRem Pilot Sites

Site	Country	Site Primary Investigator	Target Cont.	NP-Type	Reaction Principle	Aquifer
Solvay	CH	Solvay	CHC	FerMEG12 (milled nZVI)	Reduction	porous / unconfined
Spolchemie 1	CZ	Aquatest	CHC	NANOFER 25S / NANOFER STAR	Reduction	porous / unconfined
Spolchemie 2	CZ	Aquatest	BTEX	Nano-Goethite (Iron-Oxide)	Oxidation / microbial enhancement	porous / unconfined
Neot Hovav	IS	Negev, BGU	TCE, cis-DCE, toluene	Carbo-Iron®	Adsorption / Reduction	fractured
Balassagyarmat	HU	Golder	PCE, TCE, DCE	Carbo-Iron®	Adsorption / Reduction	porous / unconfined
Nitrastur	ES	Tecnalia	As, Pb, Zn, Cu, Ba, Cd	NANOFER STAR	Reduction	porous / unconfined

5 Comprehensive Results - NanoRem Bulletins

An overview and the main results are condensed in twelve NanoRem-Bulletins which introduce the reader to NanoRem's research and provide an easy-to-read and useful information source for problem owners, consultants and decision makers. They can be downloaded free of charge from www.nanorem.eu.

(1) Nanotechnology for Contaminated Land Remediation - Possibilities and Future Trends Resulting from the NanoRem Project

(2) Appropriate Use of Nanoremediation

(3) Generalised Guideline for Application of Nanoremediation

(4) A Guide to Nanoparticles for the Remediation of Contaminated Sites

(5) Development and Application of Methods for Monitoring Nanoparticles in Remediation

(6) Forecasting Nanoparticle Transport for Soil Remediation

(7)-(12) NanoRem Pilot Site-Bulletins

6 Project Results online – the NanoRem Toolbox

The NanoRem toolbox (Fig. 9) is available on the NanoRem Web site www.nanorem.eu.

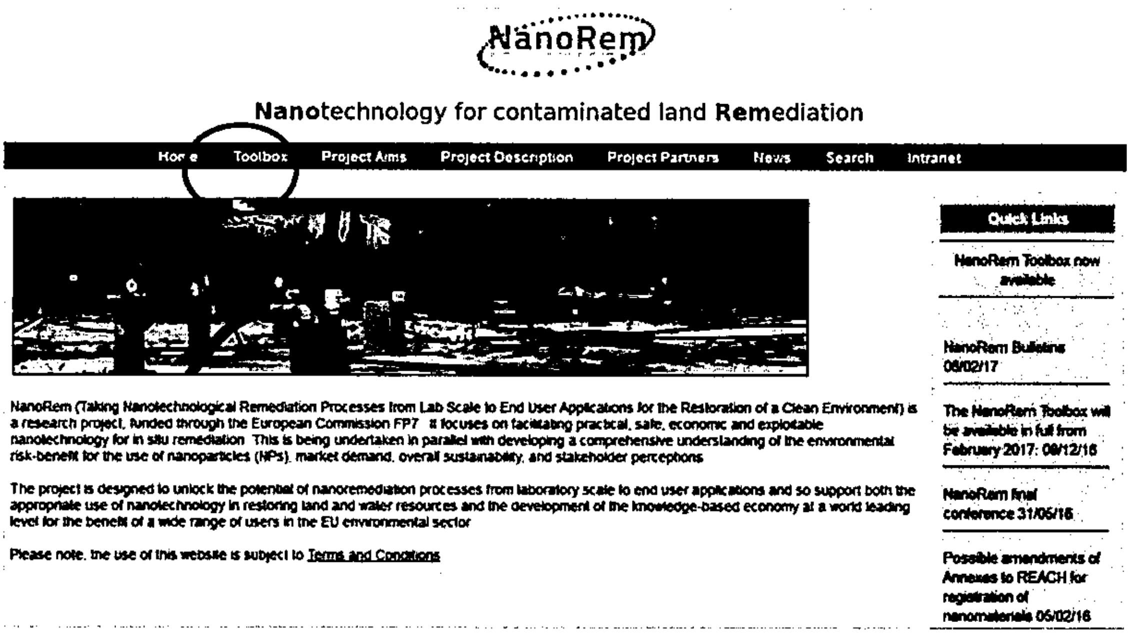

Figure 8: NanoRem website www.nanorem.eu

The NanoRem Toolbox (Fig. 9) focuses on the needs of decision makers, consultants and site owners. It provides the respective output of NanoRem in three levels:

(1) The bulletins include the most relevant information in a condensed and concise way.
(2) More detailed information on nanoparticles and tools are located in the "Nanoparticles and Tools" shelf.
(3) Other dissemination products and selected project deliverables can be found in the "Supporting Information" shelf.

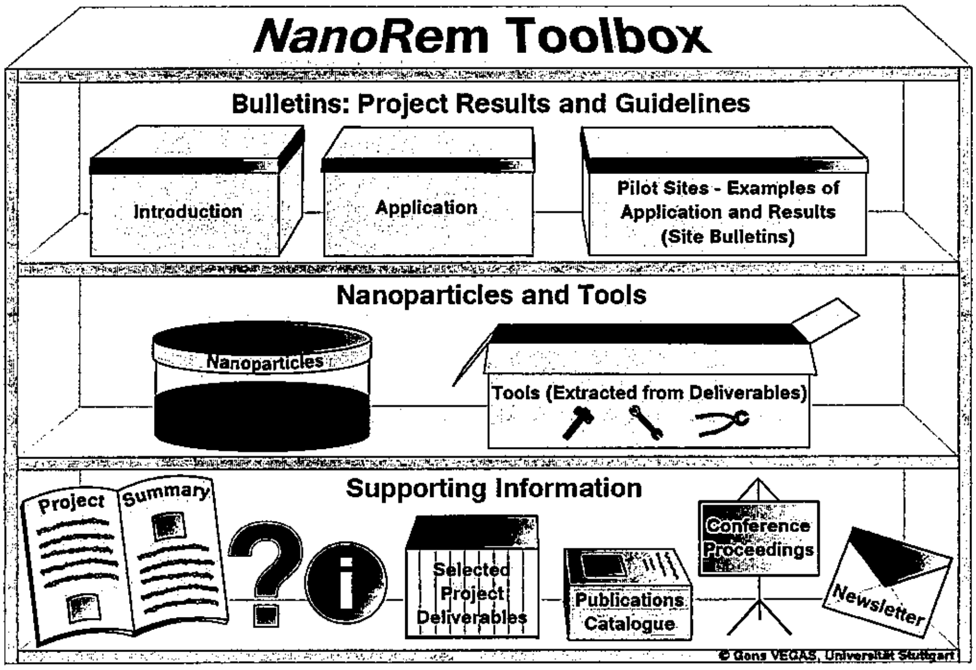

Figure 9: NanoRem Toolbox © VEGAS, University of Stuttgart, Germany

Figure 10: Project partners

Acknowledgement and Disclaimer

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Real-time and *in situ* monitoring of aquatic environments using indigenous microbial community - based biosensors

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Innovations in Investigation, Remediation and Source Removal Technologies

Innovations in technology for investigation & remediation

Keywords: Innovative monitoring, *in-situ* remediation, Detection, Pollution, Toxicity, Online measurement, Alarm.

Increasing contamination of aquatic environments by organic loads or toxic chemicals has resulted in the need for real-time monitoring tools to be used in pollution detection and risk assessment. While monitoring aquatic environments is critical to ensure their quality and sustainability, monitoring strategies often relies on the collection of individual spot samples followed by *ex situ* analyses under laboratory conditions. Such approach, usually costly and time-consuming, only provides a snapshot that may often fail to detect localized transient contamination events and describe the dynamic changes of the monitored environment. The objective of our work was to develop a cost-effective event detection system to monitor aquatic environment in real-time, inform targeted sampling by conventional means (ie spot sampling) and act as a decision support tool.

This novel biosensor uses microorganisms naturally occurring in the targeted environment as bioindicators and exploits their ability to convert chemical energy into an exploitable electrical signal. The electrical signal generated by the sensor is proportional to the organic load or affected by the presence of toxic compounds, as it directly reflects microbial activity at the surface of the colonized electrodes. Biosensors have been deployed at different sites in order to estimate either the organic load or BOD in real time (*eg*, groundwater, sewage networks...) or detect toxic compounds and assess their impact on their environmental sink (*eg*, industrial processes and wastewater treatment plants...). Through real case studies, the presentation will address the principle, information provided and advantages (*in situ*, autonomy, robustness, representativeness, sensitivity) of such devices and how they can provide unique information to act as a decision support tool (*eg*, targeted sampling, process optimization, process dysfunction identification, bioremediation treatment efficiency...). Work in progress regarding a metrological station that uses a combination of different monitoring devices developed to manage aquatic environments in real time will also be presented.

- **Session 4:** **GW management on Large Scale and Multisource sites: regulatory framework and adaptive approaches**
- **Chair:** **Christian Andersen – Danish Regions**

Presentations:

- **Dietmar Müller-Grabherr** - Environment Agency Austria
  Understanding WFD objectives in groundwater management
- **Corinne Merly** - BRGM
  Towards a less stringent groundwater body objective?
  Feedback from a French heavily industrial and urban study area
- **Johanne Urup** - Ramboll
  Water supply in an urban area with many well-known pollution sites – one case study in the Copenhagen area
- **Chiara Senzolo** - Advisian
  Integrated Water Resources Management in South America

Towards a less stringent groundwater body objective? Feedback from a French heavily industrial and urban study area

C. Merly, BRGM
with the contribution of P. Vigouroux, M. Gremont, M. Bouzit, B. Clozel, D. Hubé (BRGM)

NICOLE & ICCL joint conference, Copenhagen, 6th of October 2017

agence de l'eau RHÔNE MÉDITERRANÉE CORSE établissement public de l'État

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Context & Objectives

- Context: At the last reporting in 2013, Rhône River Basin Water Agency identifies 9 groundwater bodies presenting a risk of not achieving WFD environmental objectives, due to industrial pressures.

- Study objectives
  - Develop a methodology which provides sound technical and economical evidence to justify for a derogation for **less stringent objectives** for groundwater body quality – French case study
  - Highlight lessons learnt and future methodological recommendations for facilitating **future implementation of the methodology** to groundwater bodies being impacted by contamination originated from industrial activities
  - **Exploratory** approach, no set methodology among the Members of State

- Project details
  - Co-funding (255k€) : AERMC 80% / BRGM 20%
  - Multi-disciplinary team : Hydrogeologist, Environmental scientist, Contaminated land scientist, Environmental economists
  - Duration: 2015-2017

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Methodological approach

➢ <u>Regulatory framework</u>

- Exemptions under Article 4 of the Water Framework Directive
- **In our case, two possible mechanisms for exemption** to achieve the good groundwater status :
  - **Extension of the time limit**;
  - **Allowing the achievement of a less stringent objective**
- **Three criteria** to justify for an exemption:
  - **Natural conditions**
  - **Technical feasibility**
  - **Disproportionate cost**

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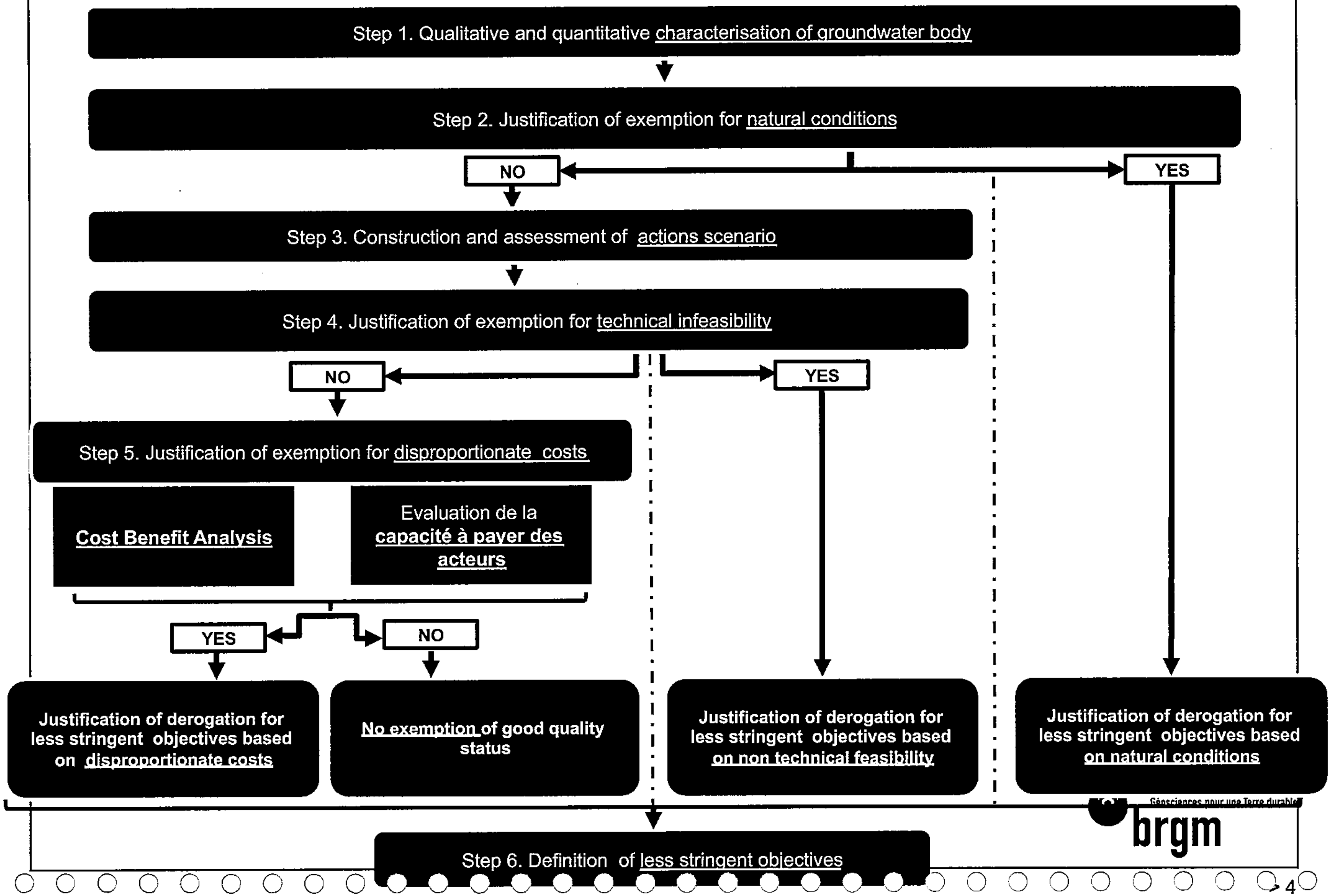
Methodological Approach



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STEP 1: Groundwater body characterisation

- Establishing **current groundwater status**:
  - Determine **substances** for which there is a risk of non achievement of environmental objectives and for which remedial actions shall be implemented.
  - Identify **sectors** which contribute to the groundwater quality degradation and for which remediation actions shall be implemented.

- Highlighting **incertitude** associated with this characterisation:
  - Recommendations for **future monitoring actions**.

- **Four main phases** :
  - Description of hydrogeological functioning
  - Qualitative status of the groundwater body
  - Identification of main contamination sources
  - Recommendations for future monitoring actions

➡ **Sound technical and environmental knowledge** to support the exemption

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STEP 2: Justification for natural conditions

➢ Justify that natural conditions of the groundwater body are such that it is **impossible** to reach the environmental quality objectives (strong inertia for example)

STEP 3: Construction and assessment of Actions scenario

➢ **Identify** management or remedial actions which improve groundwater body quality in order to combine them into **several scenario**.

- Exhaustive Inventory
- Various types of actions *(remediation, monitoring, knowledge, etc.)*
- Dimensioning in concertation with stakeholders (*duration, impact, cost, etc.)*

⚠ Two methodological decisions:

- **Additionality of** the actions
- **Temporality of** the actions

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STEP 4: Non-technical feasibility

- **Lack of methodological framework**
- Points of attention to consider:
  - Possibility for the substances to migrate in sub-surface
  - Groundwater vulnerability
  - Management measures according to BAT
  - Extension of groundwater plume
- Methodology to be developed according to **available data**

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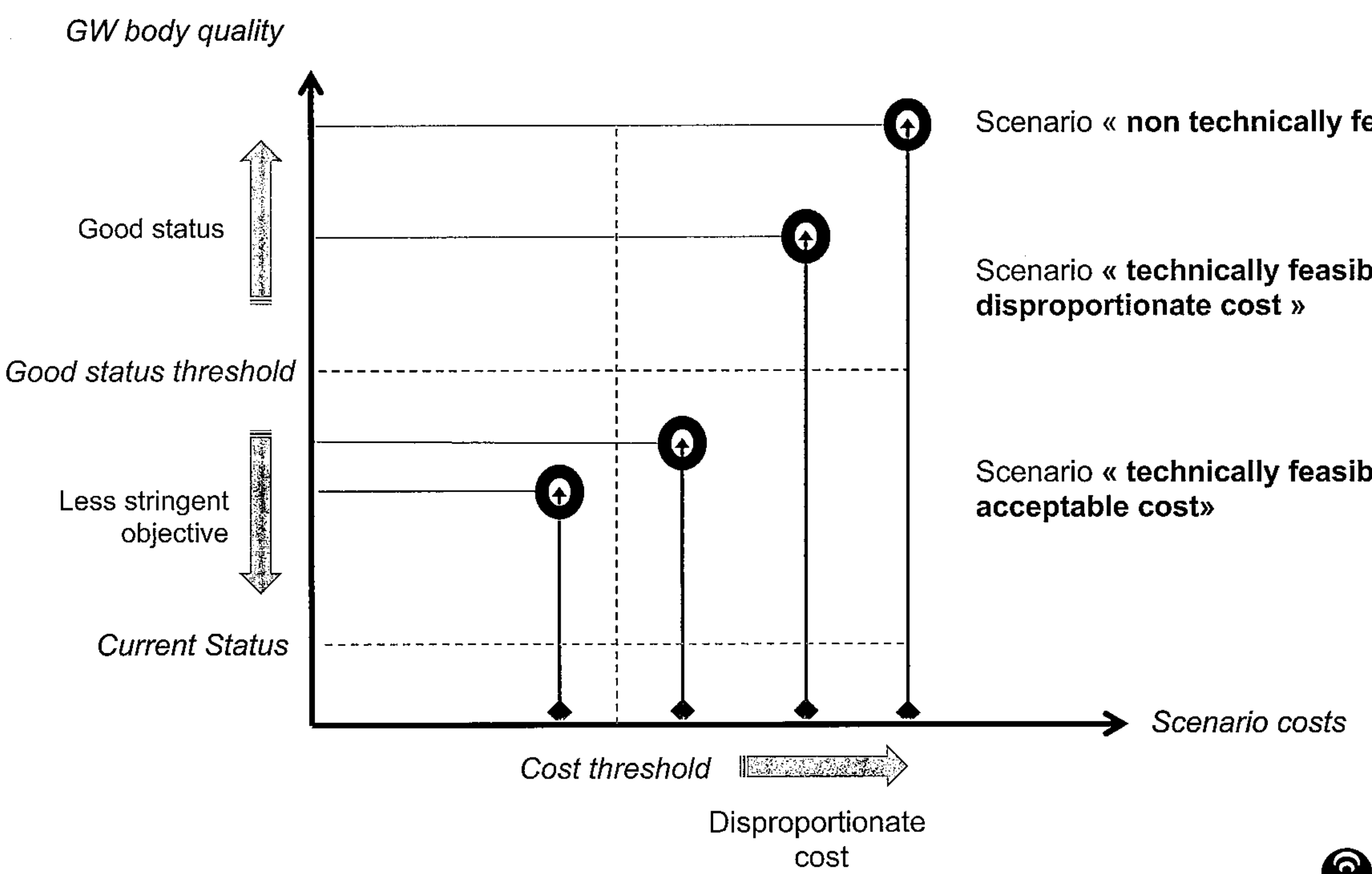
STEP 3: Actions scenario

➤ <u>Scenario</u> : **Combination** of actions which enables to reach the good GW body status or to improve the GW body quality



STEP 5: Disproportionate cost

1 Cost benefit analyses

Are the costs of actions **disproportionate with respect to benefits** associated with the implementation of these actions?

- Inventory of **current GW uses**
- Identify **future potential users**
- Assess good status **impact** on these uses
- Estimate the **additional economical benefits** from the good GW status

Assessment of actors affordability 2

Are the costs of **actions disproportionate with respect to funding capacity** of actors (in charge of financing the actions)?

- Identify **funders**
- Select **relevant financial indicators**
- Calculate indicators

- Set **threshold** for disproportionate cost in concertation with stakeholders
- **Compare** costs with benefits or with actors affordability

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STEP 6: Definition of less stringent objective

- Methodological propositions – not tested
- Define **the more ambitious environmental objective** which could be technically achievable at acceptable costs
- Objective to be revised every **6 years**

- Several types of objectives can be suggested

  - **Quantitative objectives**
    - **Decrease in concentration**
    - **Decrease of impacted surface area**
    - **Time delay beyond 2027**
    - Combination of the three above options

  - **Qualitative objectives**
    - **Decreasing trend** of the concentrations or of the impacted surface area

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Feedback & Recommandations

> **Project at the interface between Contaminated Land Management and Water Framework Directive**

- Site versus groundwater body
- Risk versus threshold
  - Substances associated with industrial activities / list of WFD substances
  - Management Measures / Actions

> **Necessary involvement of numerous actors (Regulatory bodies, Problem owners, Water Agency, Union, Non-governmental organisation, etc.)**

- Data accessibility (GW quality, remedial options, economic data, ..)
- Find consensus for scenario, their assessment and future involvement
- Interaction and validation processes

> **Maintain communication flow through rigor, transparency and equity**

- Strict study framing: Set objectives and limits
- Description of heterogeneous data through an homogeneous template

> **Perspectives**

- Results of the study to be translated by Water Agency in the WFD reporting
- Needs for methodological development (Working Groups?)
- Further to complete monitoring of the study area – Definition of less stringent objectives

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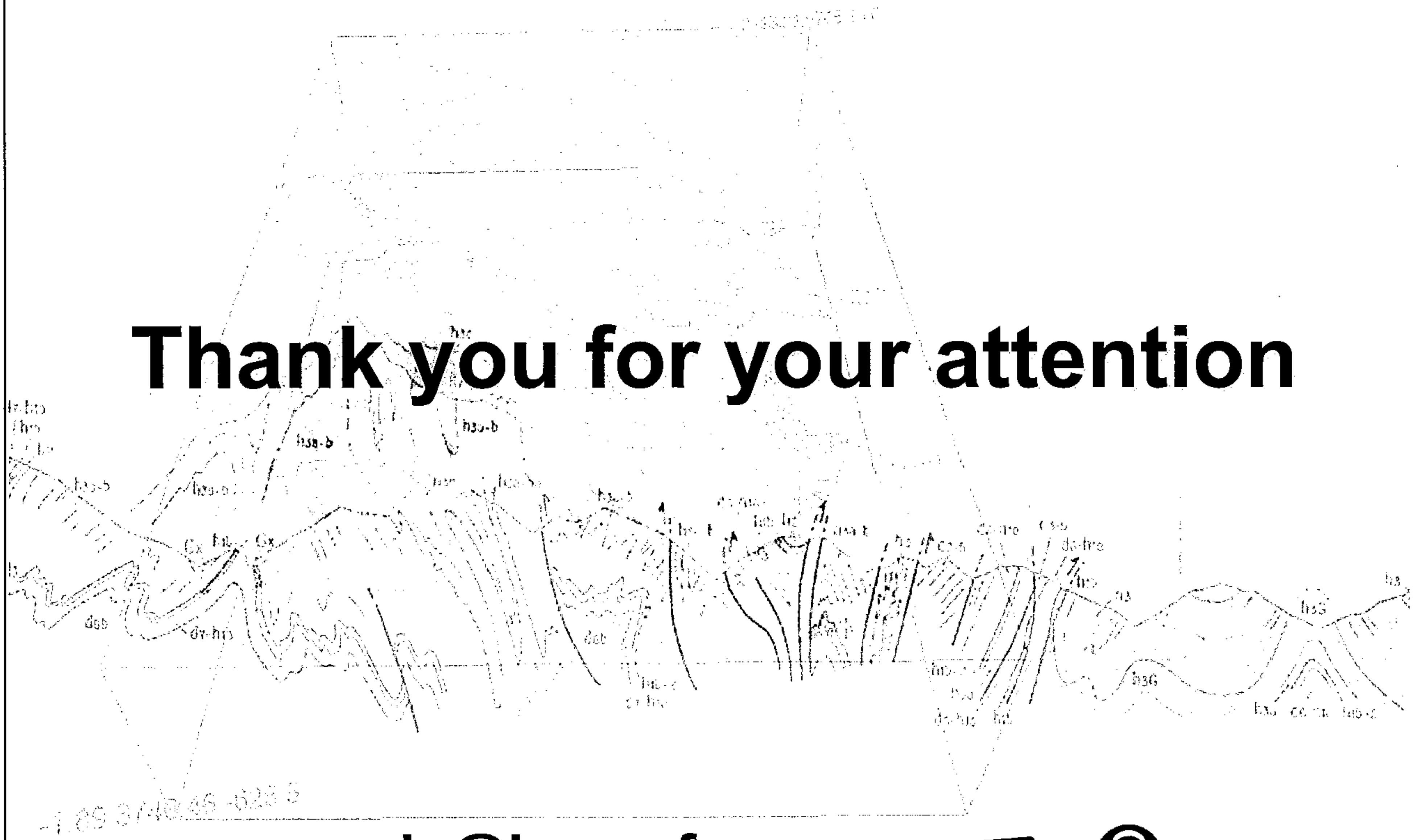

Thank you for your attention

c.merly@brgm.fr

agence de l'eau RHÔNE MÉDITERRANÉE CORSE établissement public de l'État

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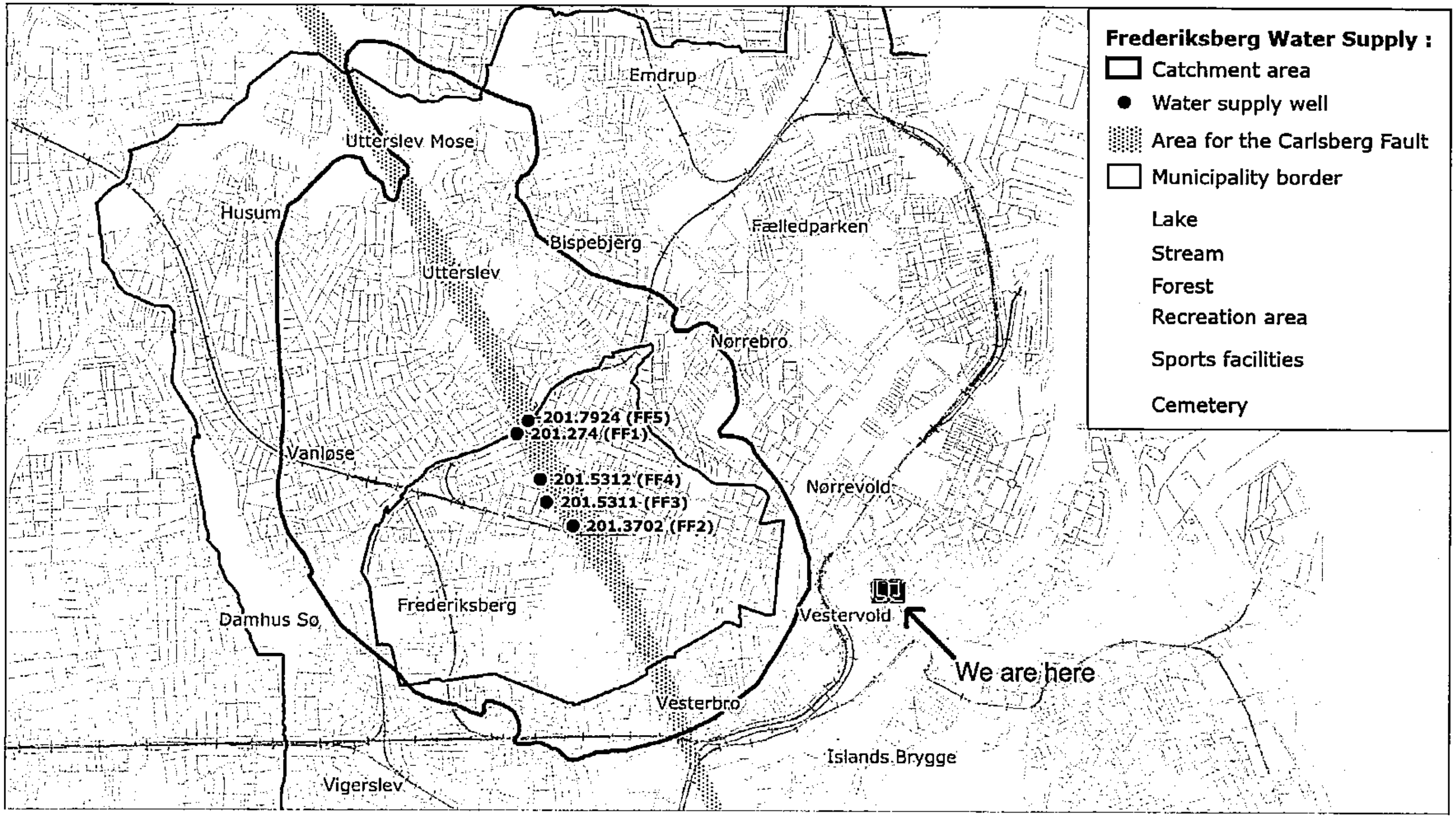
WATER SUPPLY IN AN URBAN AREA WITH MANY WELL-KNOWN POLLUTION SITES ONE CASE STUDY IN THE COPENHAGEN AREA

Johanne Urup, Rambøll, Kristian Bitsch, Rambøll, and Frederiksberg Municipality



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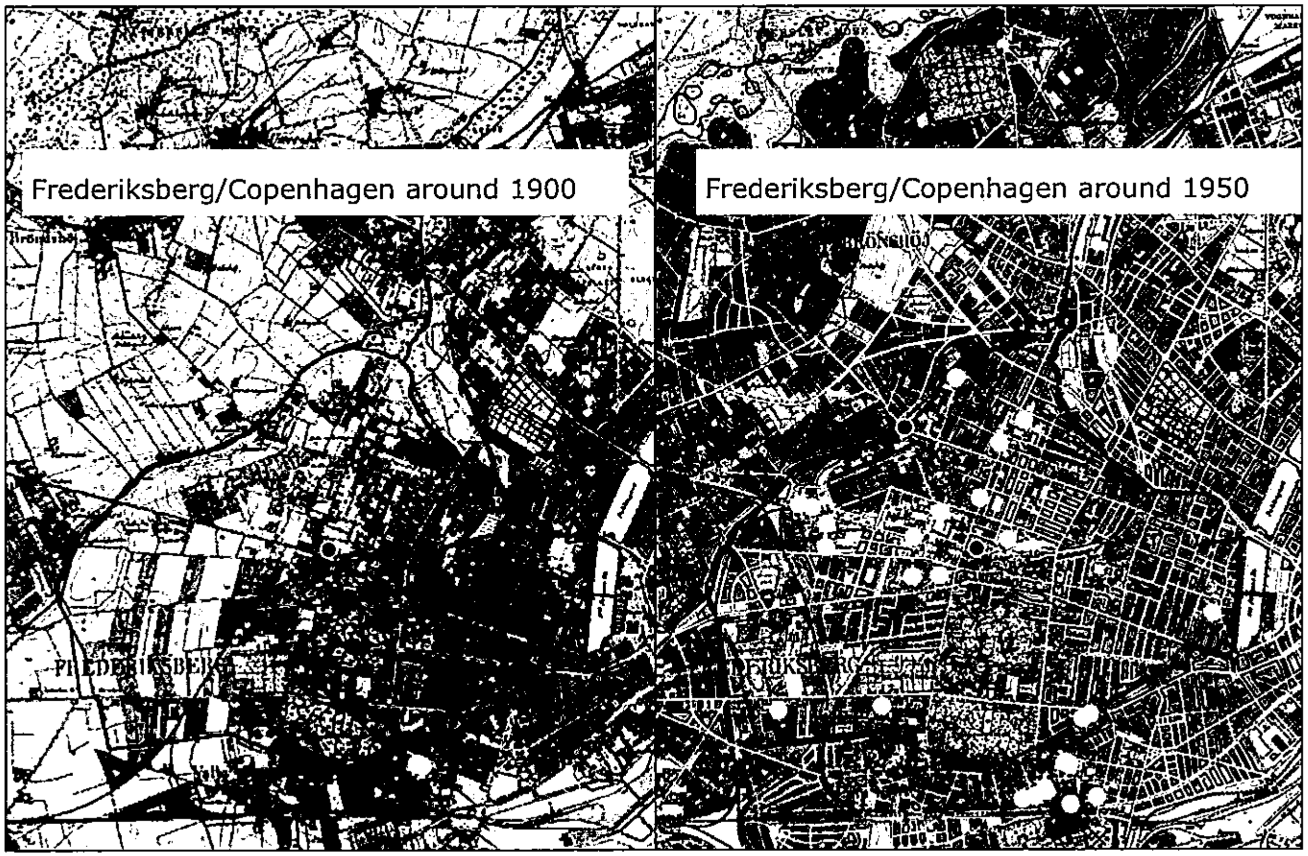
THE HISTORY OF FREDERIKSBERG

Abstraction in the Copenhagen area starts in 1847, where Carlsberg is founded

Abstraction for municipal water supply in Frederiksberg starts in 1869

Frederiksberg is developed from 1890-1950

Abstraction in the Copenhagen area peaks around 1930 – including abstractions for industries



POLLUTED SITES IN THE CATCHMENT AREA – MANY TYPES

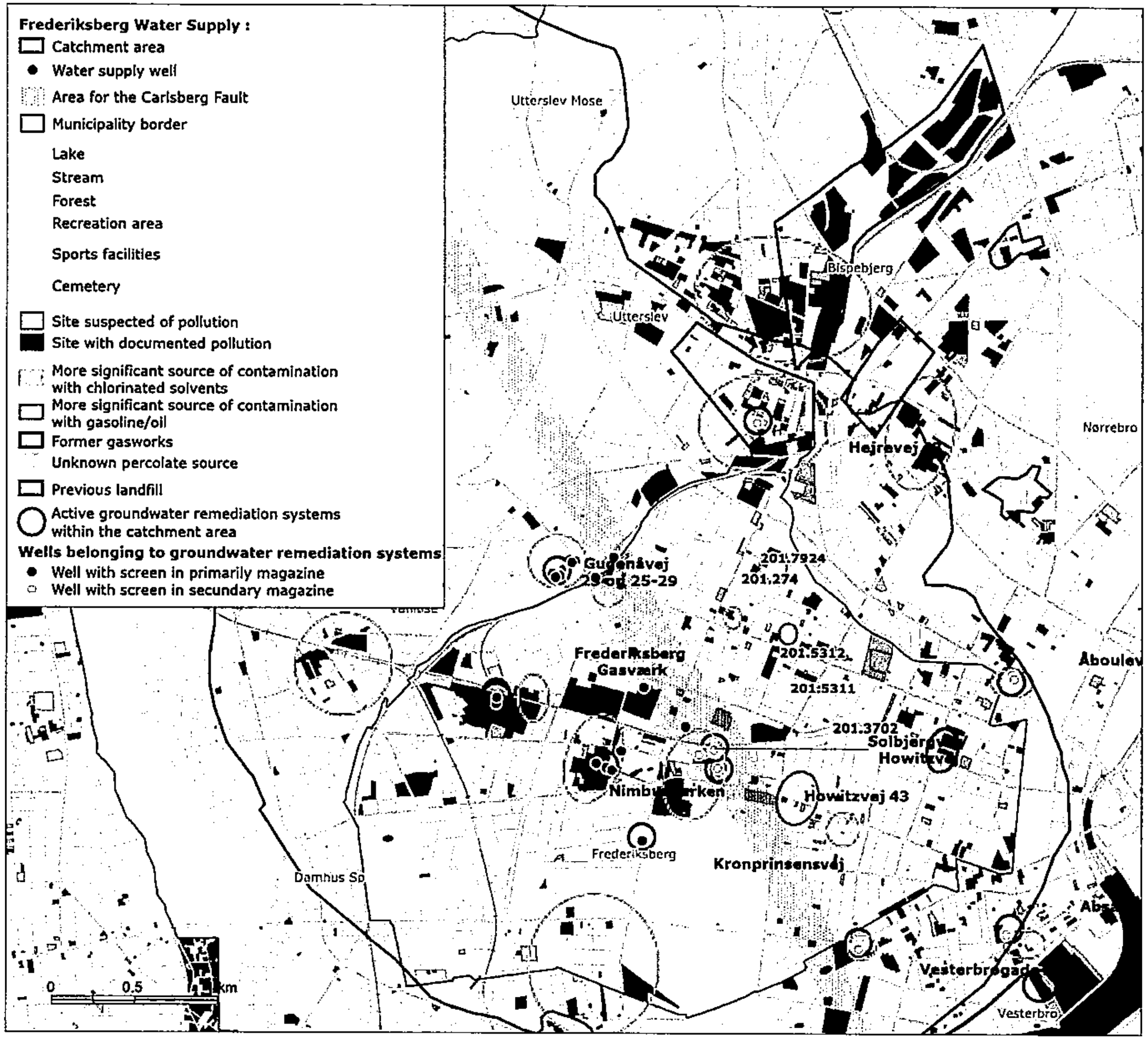
Industrial development 1900-1950 - Particularly metal processing, colour/ lacquer and chemical industry (degreasing and solvents)

Increased need for dry cleaners (solvents)

1950-1990 - Large use of chlorinated solvents

Industries are phased out 1980-2000

Today, residential and commercial but not industrial



WATER SUPPLY IN AN URBAN AREA WITH MANY WELL-KNOWN POLLUTION SITES – ONE CASE

06/10/2017

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CHLORINATED SOLVENTS IN THE GROUNDWATER

Content of chlorinated solvents is measured for the first time in the abstraction wells in 1987

A major mapping study initiated by Frederiksberg Municipality, Gas and Water Supply in 1987 – including development of a hydrological/ groundwater model

Active carbon filtration on Frederiksberg Waterworks starts in Autumn 1994

Implementation of a municipal strategy for the protection of groundwater resources that is still in use (Preventive, Proactive, Monitoring, and Groundwater remediation actions)

Frederiksberg Municipality's goal is to maintain groundwater extraction (2,5 mill. m^3 pr. year) and efforts are being made to improve the quality of groundwater to minimize the treatment of chlorinated solvents at the waterworks.

In this context it is important to know how the threat evolves and which sources of pollution are the most important to remediate now and in the future

OBJECTIVES AND STRATEGY

To develop a method to estimate the duration of chlorinated solvents in water supply wells.

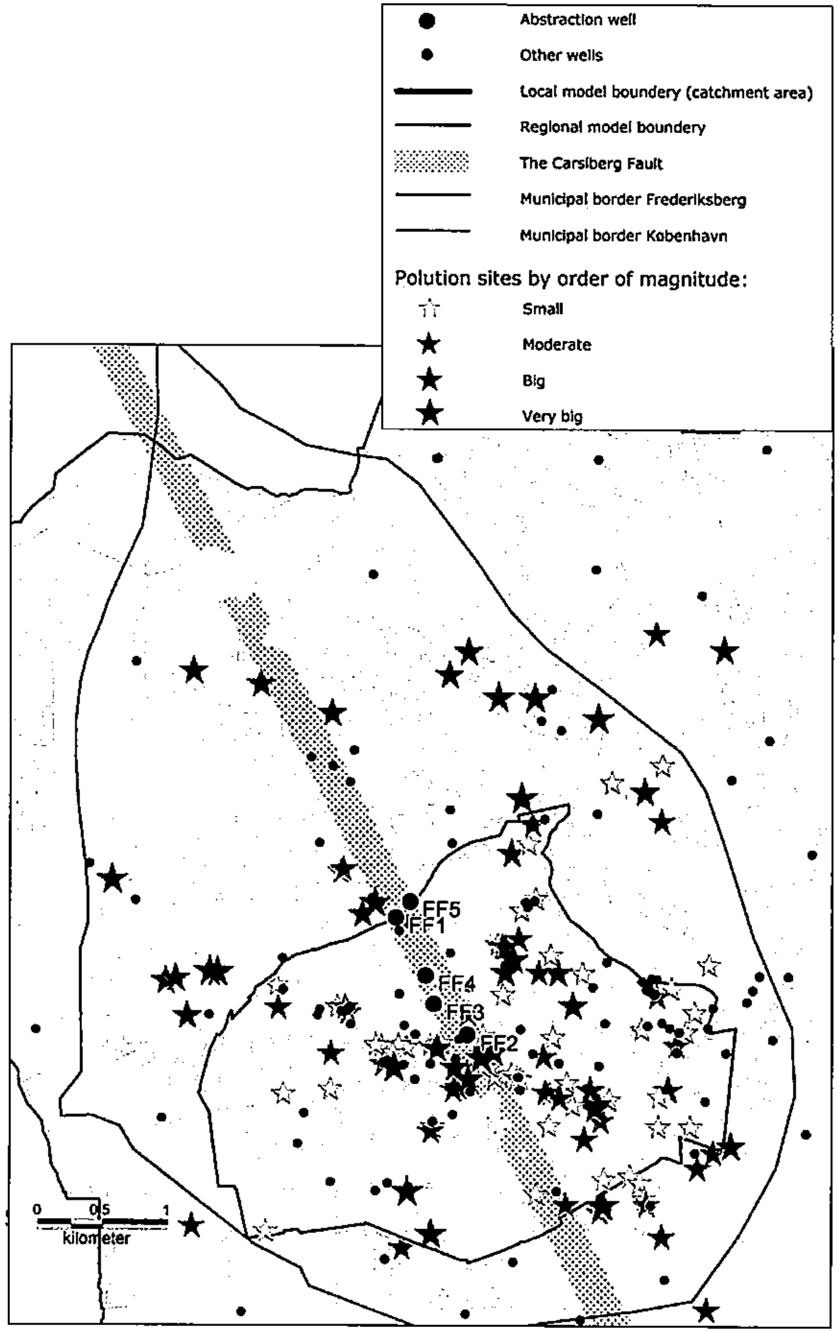
The strategy follows four steps:

I. Gather information on degradation and transport of chlorinated solvents from the literature

II. Gather existing knowledge on the polluted sites and estimate the amount of chlorinated solvents

III. Develop a model to estimate the flux of chlorinated solvents to the saturated zone (kg/year)

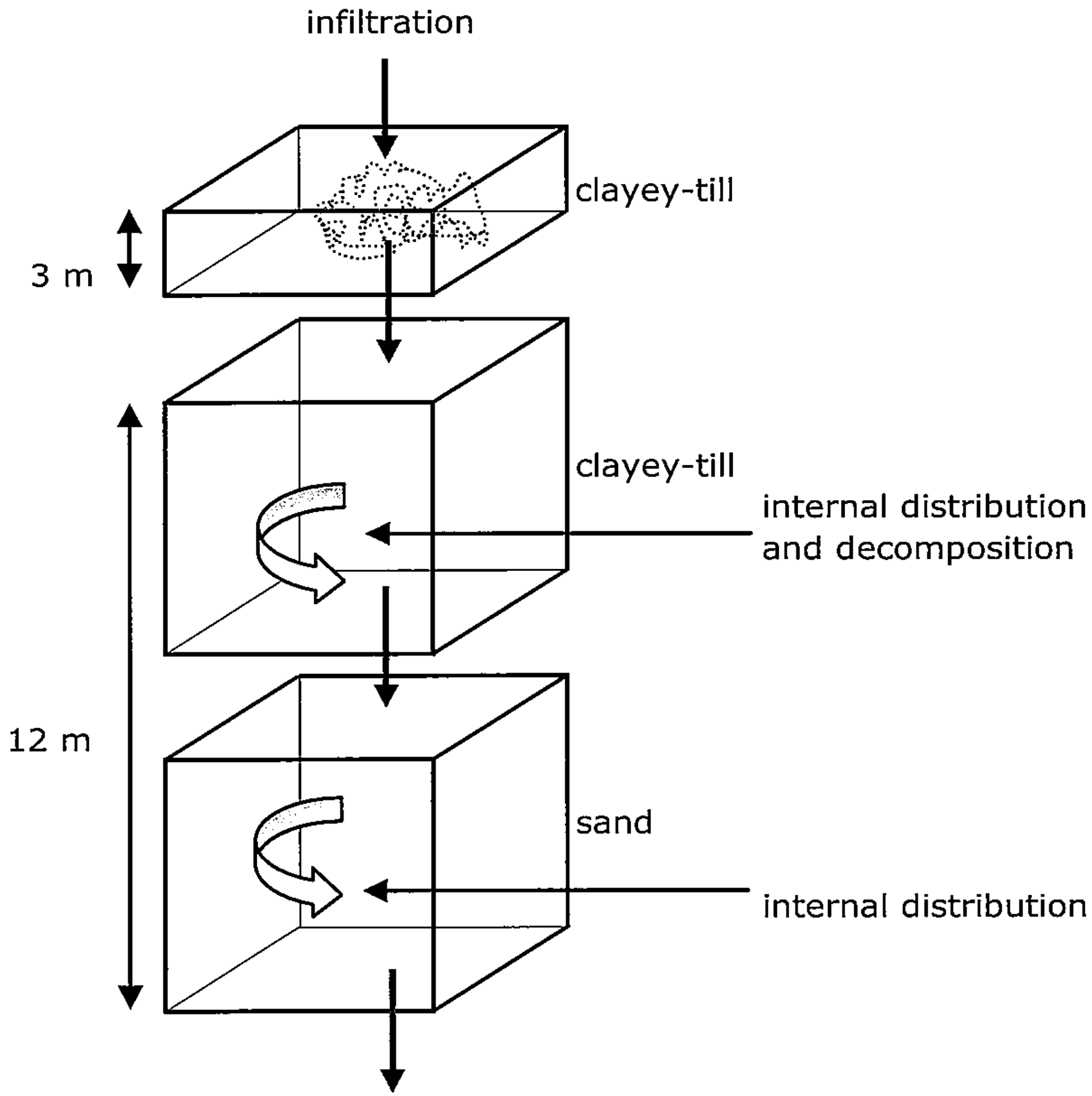
IV. Calibrate solute transport model against the observed concentrations of chlorinated solvents. Simulate duration of the chlorinated solvents in the aquifer and in the water supply wells



MODEL FOR FLUX OF CHLORINATED SOLVENTS

3 box model for the unsaturated zone

- Upper 3 m contains the source
- Clay – internal distribution + decomposition
- Sand – internal distribution



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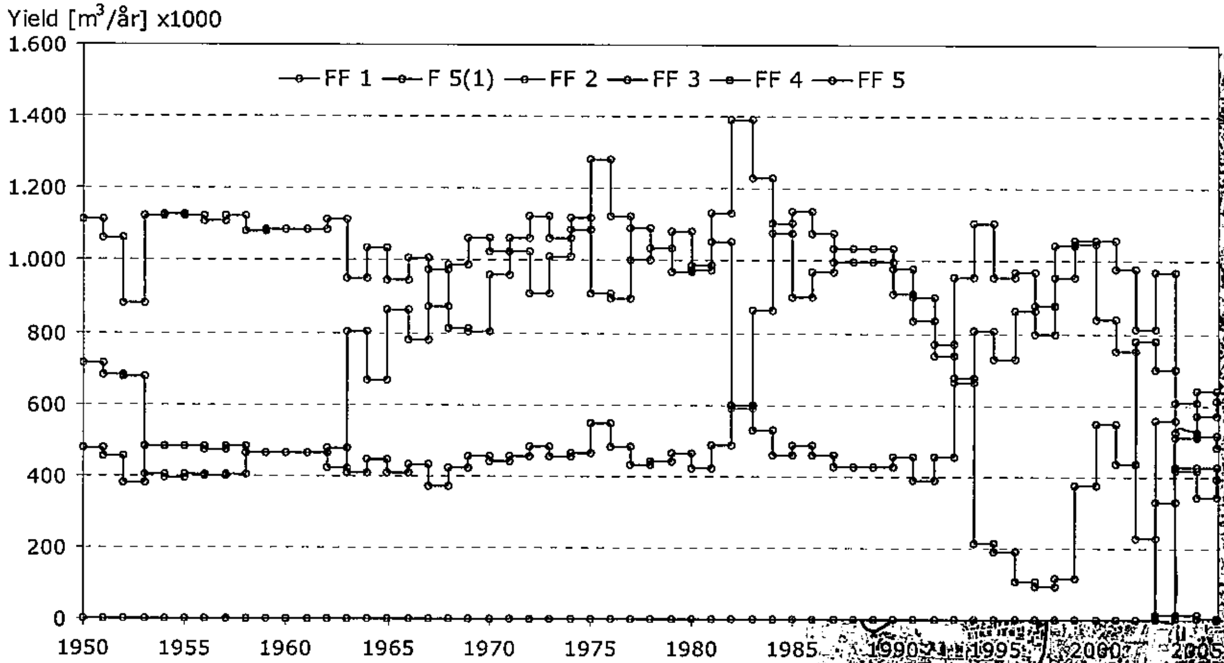
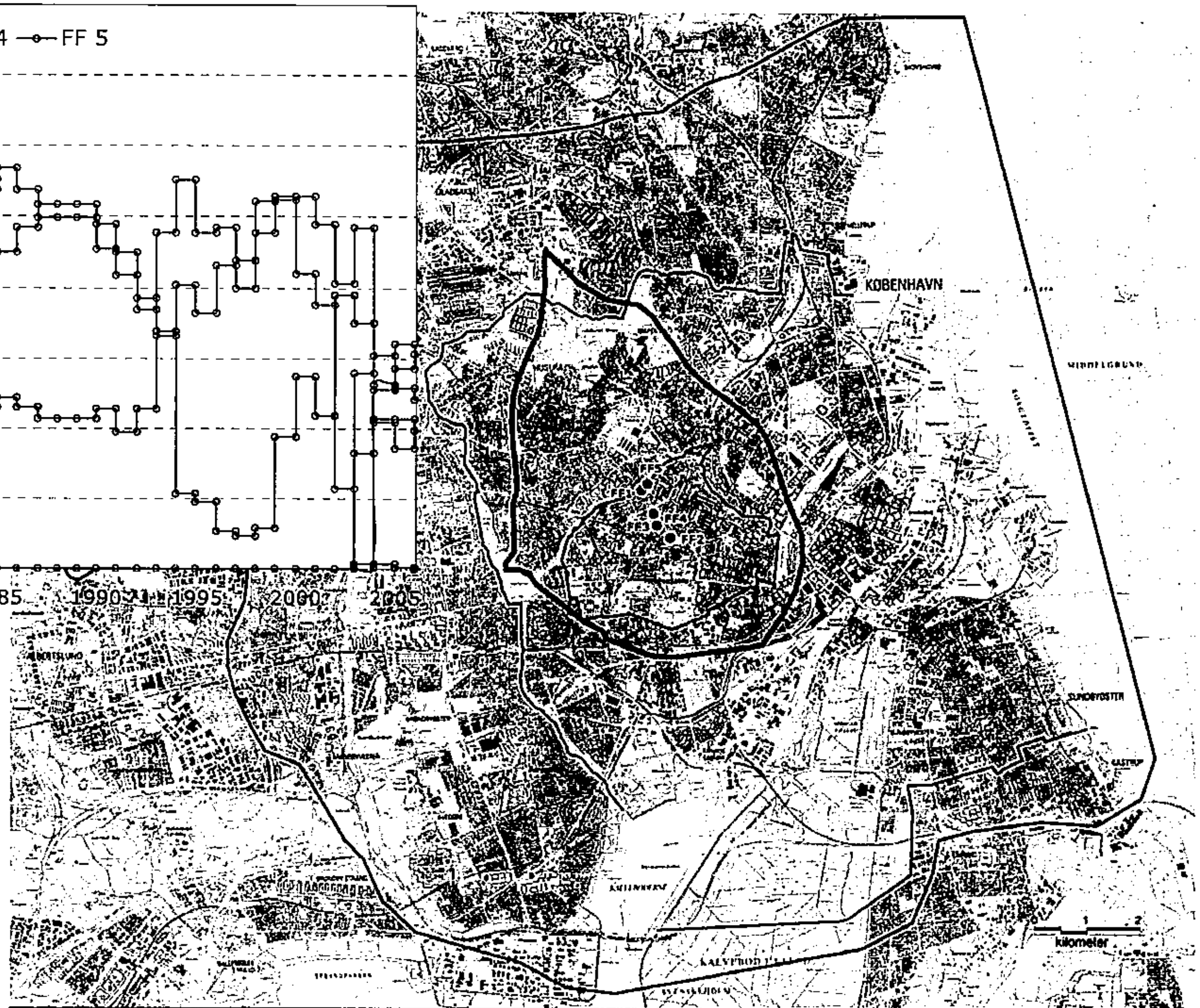
SETUP FOR GROUNDWATER MODEL – MIKE SHE





Simulation period:

1950 → 2150

Calibration:

1990 → 2005

Prediction:

2006 → 2150

Active water supply wells:
1950-2004/2005 : FF1, FF2 and F5(1)
2004/2005- : FF1, FF2, FF3, FF4 and FF5

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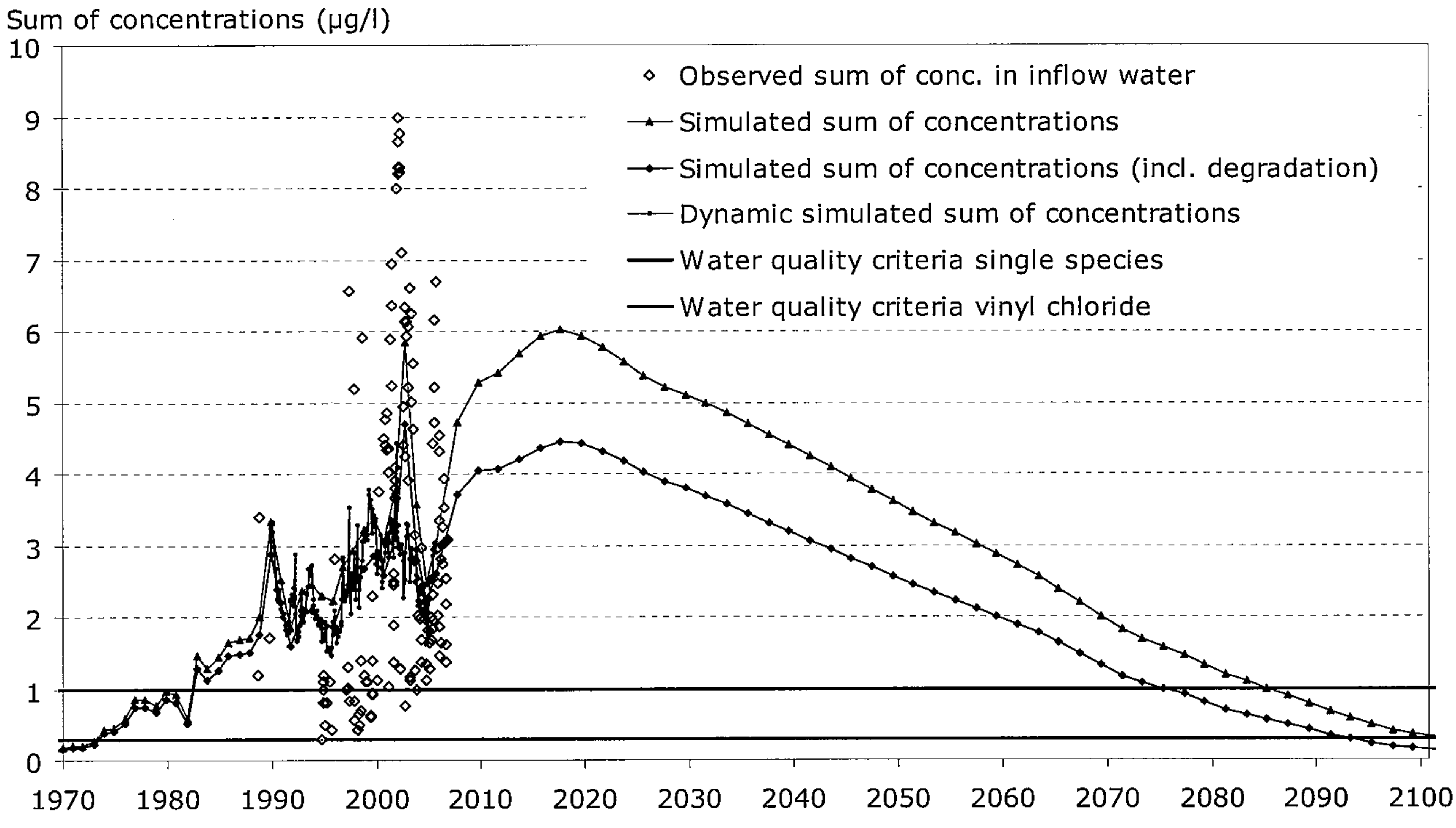
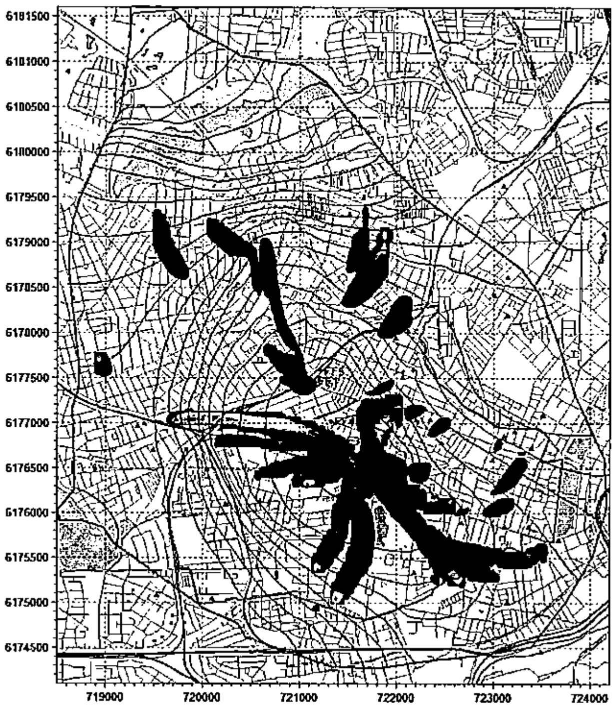
RESULTS

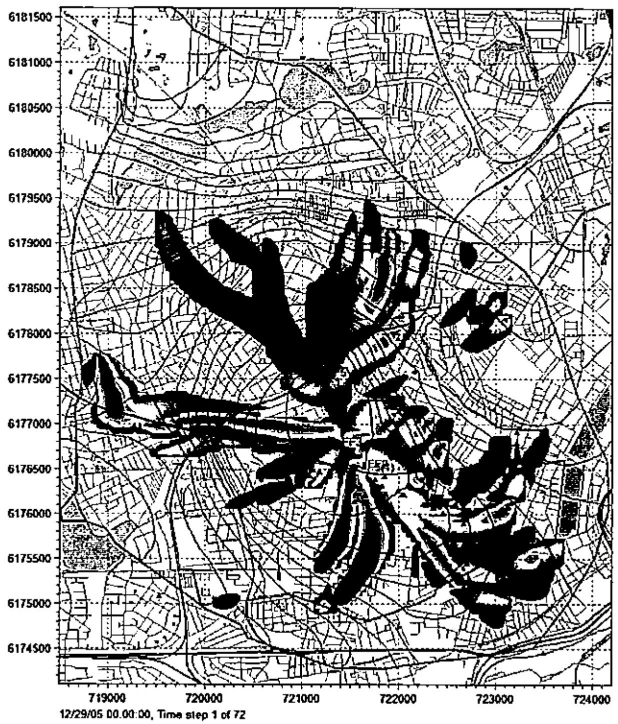

Sum of concentrations (µg/l)
10
9
8
7
6
5
4
3
2
1
0
1970
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
Observed sum of conc. in inflow water
Simulated sum of concentrations
Simulated sum of concentrations (incl. degradation)
Dynamic simulated sum of concentrations
Water quality criteria single species
Water quality criteria vinyl chloride

DEVELOPMENT IN CONCENTRATION IN THE AQUIFER

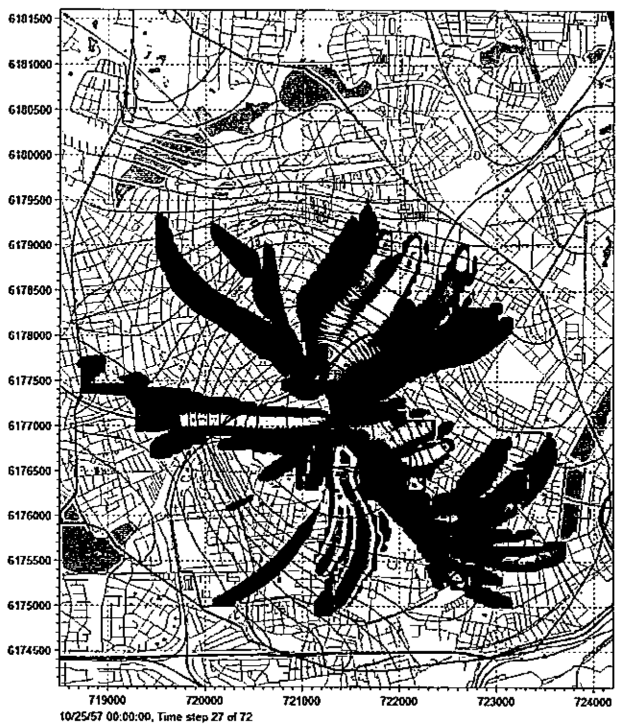
1974



2005



2057



Sum koncentration,[mu-g/l]

- Above 50
- 25 - 50
- 15 - 25
- 10 - 15
- 9 - 10
- 8 - 9
- 7 - 8
- 6 - 7
- 5 - 6
- 4 - 5
- 3 - 4
- 2 - 3
- 1 - 2
- 0.1 - 1
- 0 - 0.1
- Below 0
- Undefined Value

RAMBOLL

MAIN CONCLUSIONS IN 2006

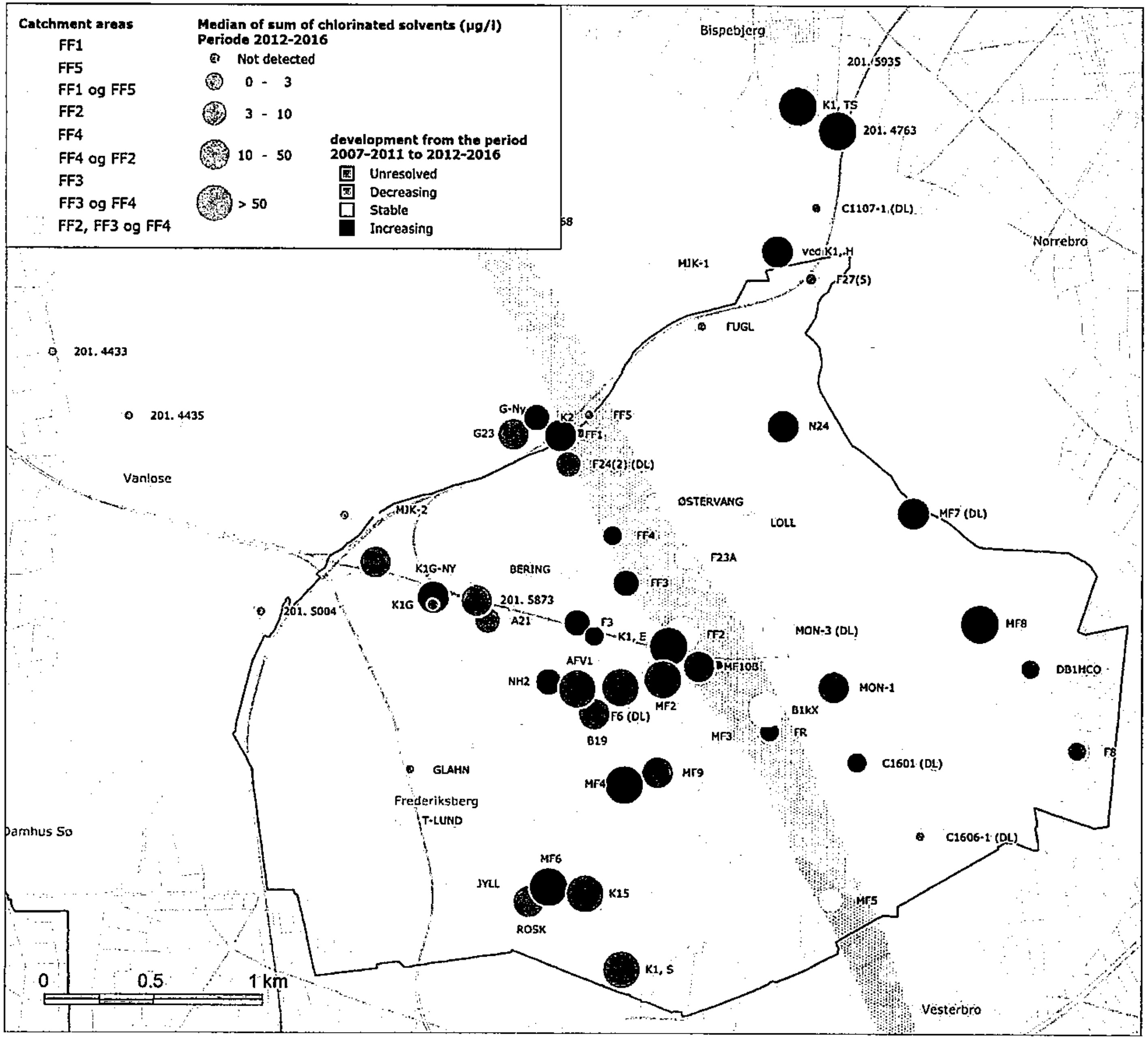
Duration of chlorinated solvents

- The concentration of chlorinated solvents is simulated to reach a maximum in 2016
- The concentration in the mixed water at the waterworks will not be under quality criteria (1 µg /l) before 2080-2090, depending on degradation rates

Model concept

- The use of model has shown to be a good tool to estimate the duration of chlorinated solvents
- Calibrating against observed concentrations has given important insight with respect of mass and leakage time from the polluted sites
- The model has been used to indicate and predict locations for unknown polluted sites

HOW IS THE PICTURE THEN TODAY?



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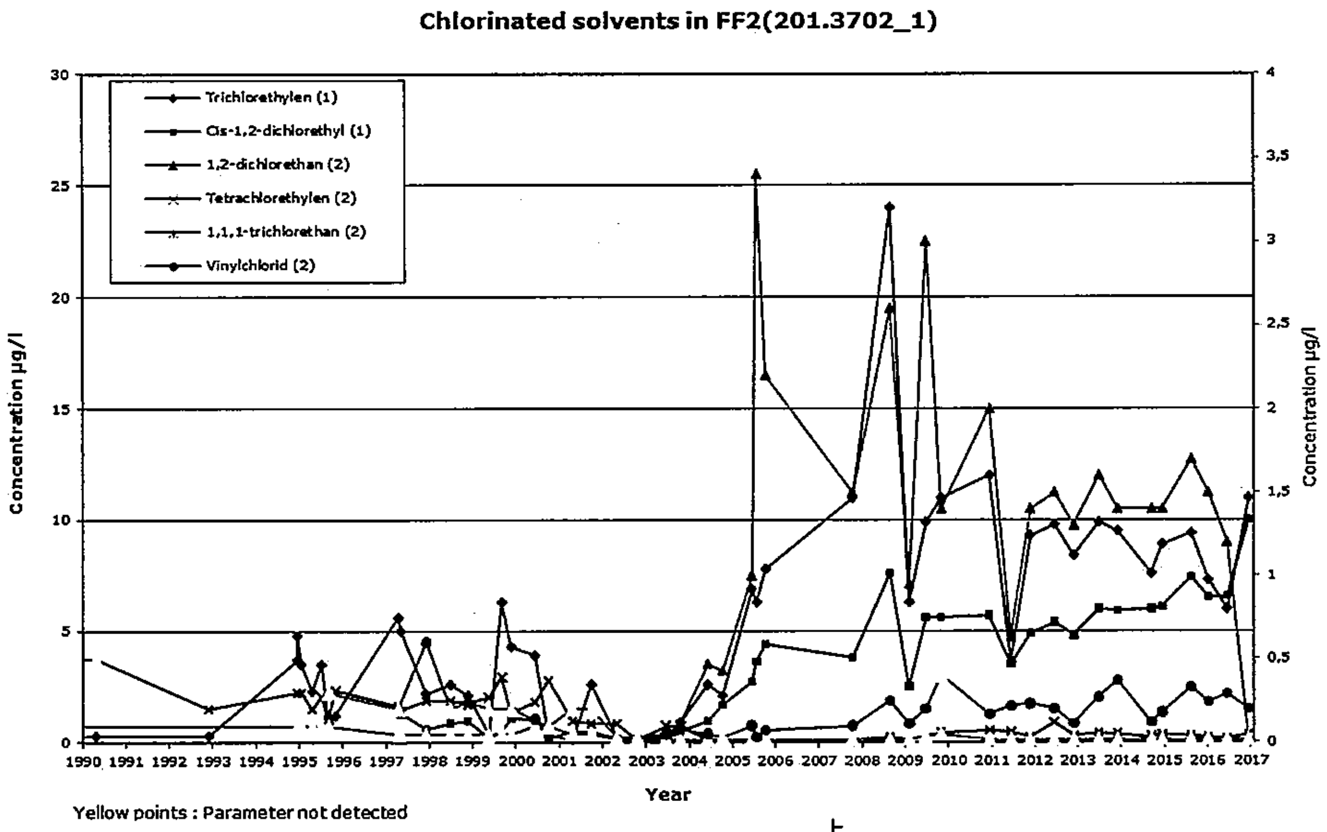
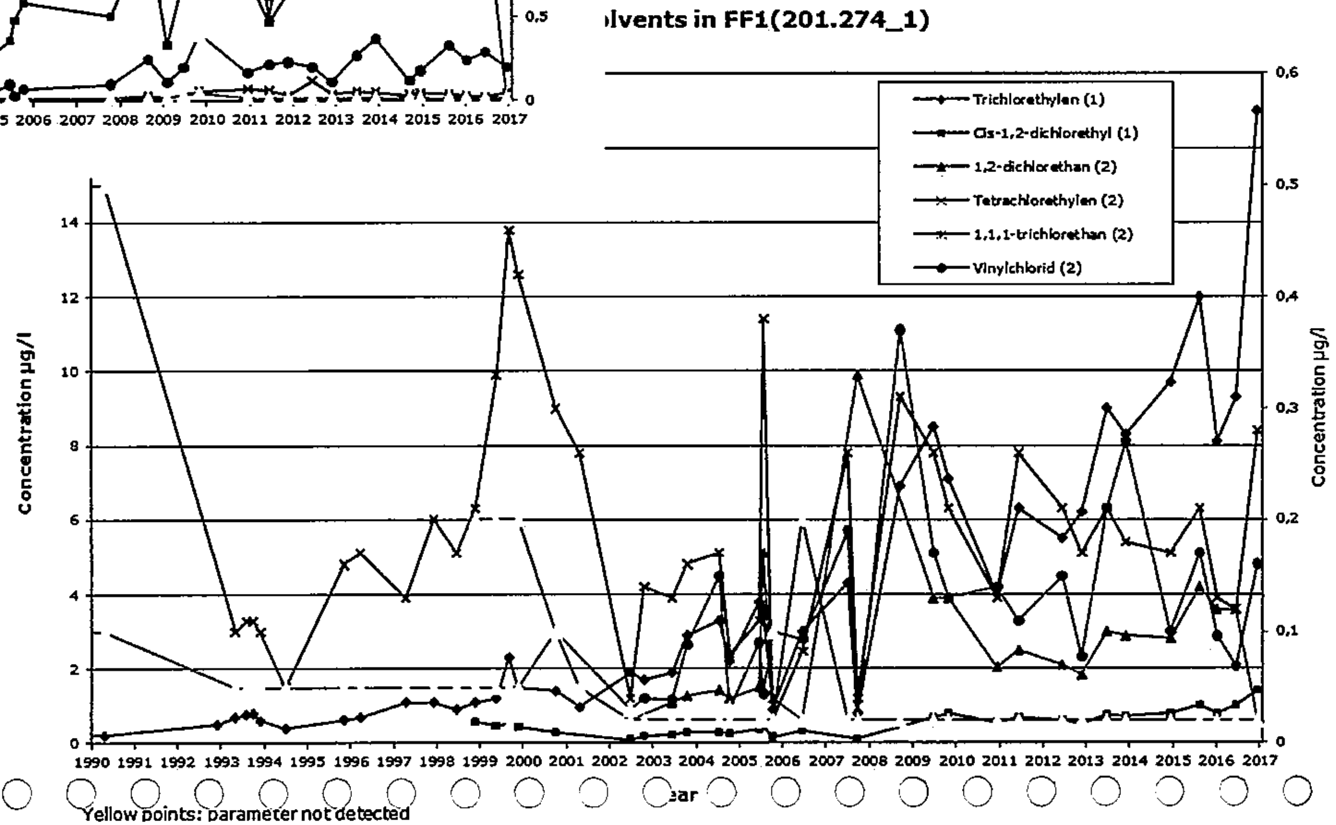
WATER SUPPLY IN AN URBAN AREA WITH MANY WELL-KNOWN POLLUTION SITES – ONE CASE

06/10/2017

EXAMPLES FROM ABSTRACTION WELL





RAMBOLL

FUTURE ACTIONS REGARDING PROTECTION OF THE WATER SUPPLY

- Continued monitoring of the development in chlorinated solvents
- Revaluation of existing groundwater remediation measures
- New groundwater remediation systems
- New monitoring wells/boreholes
- A possible change in the Frederiksberg Water supply's groundwater abstraction strategy
- Changing the strategy for water treatment at the water works

WHY NOT JUST STOP ABSTRACTING DRINKING WATER?

- Consequences for the sewage system
- Implications for possible climate change adaptation actions
- Consequences for basements
- Consequences for deep structures

THANK YOU FOR YOUR ATTENTION - QUESTIONS

Johanne Urup, Rambøll, Water and natural resources

jnu@ramboll.dk

RAMBØLL

Integrated Water Resources Management in South America

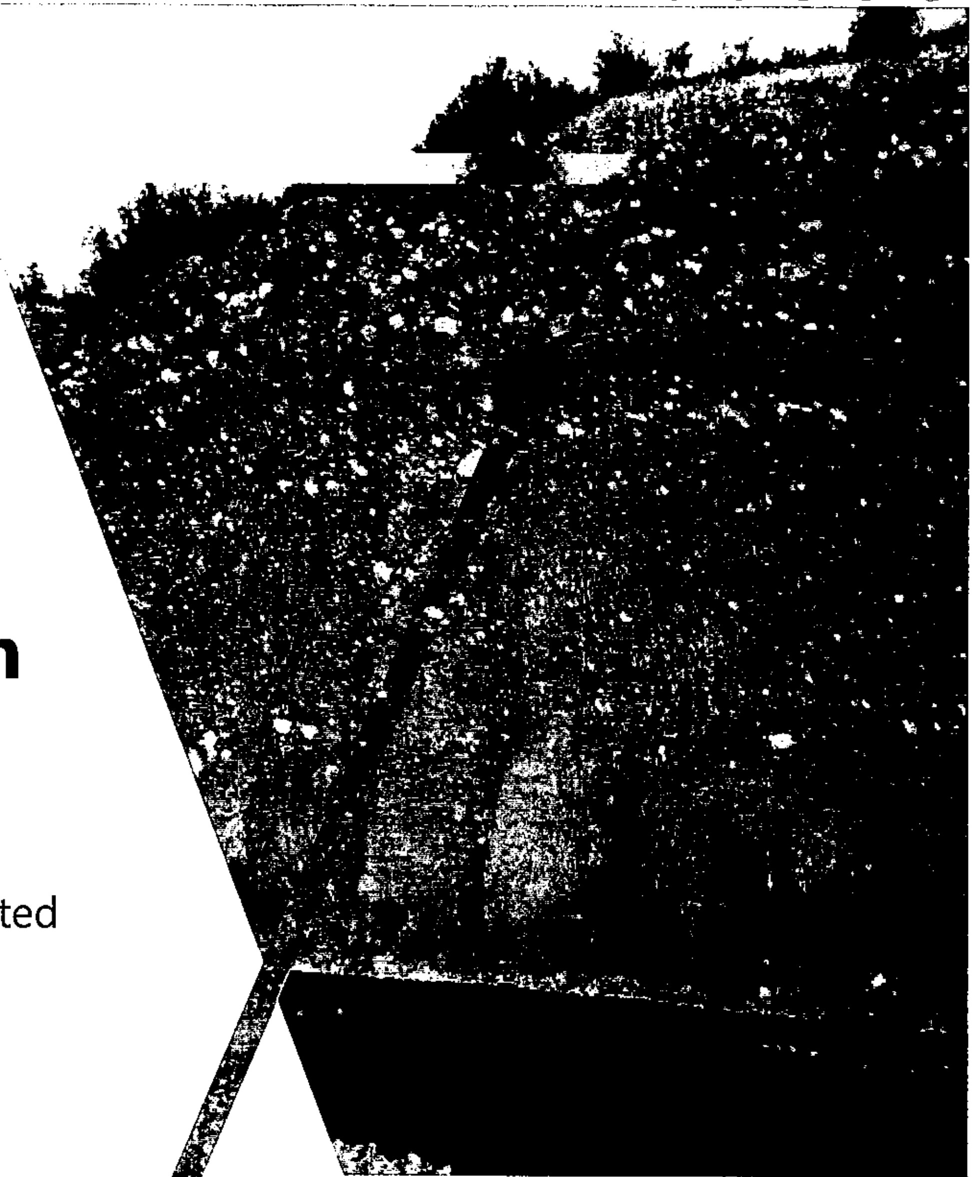
ICCL – NICOLE Conference

Groundwater Management on Contaminated Sites

Chiara Senzolo, Principal Consultant, Advisian

Guillermo Bonder, Senior Hydrogeologist, Advisian

06/10/2017



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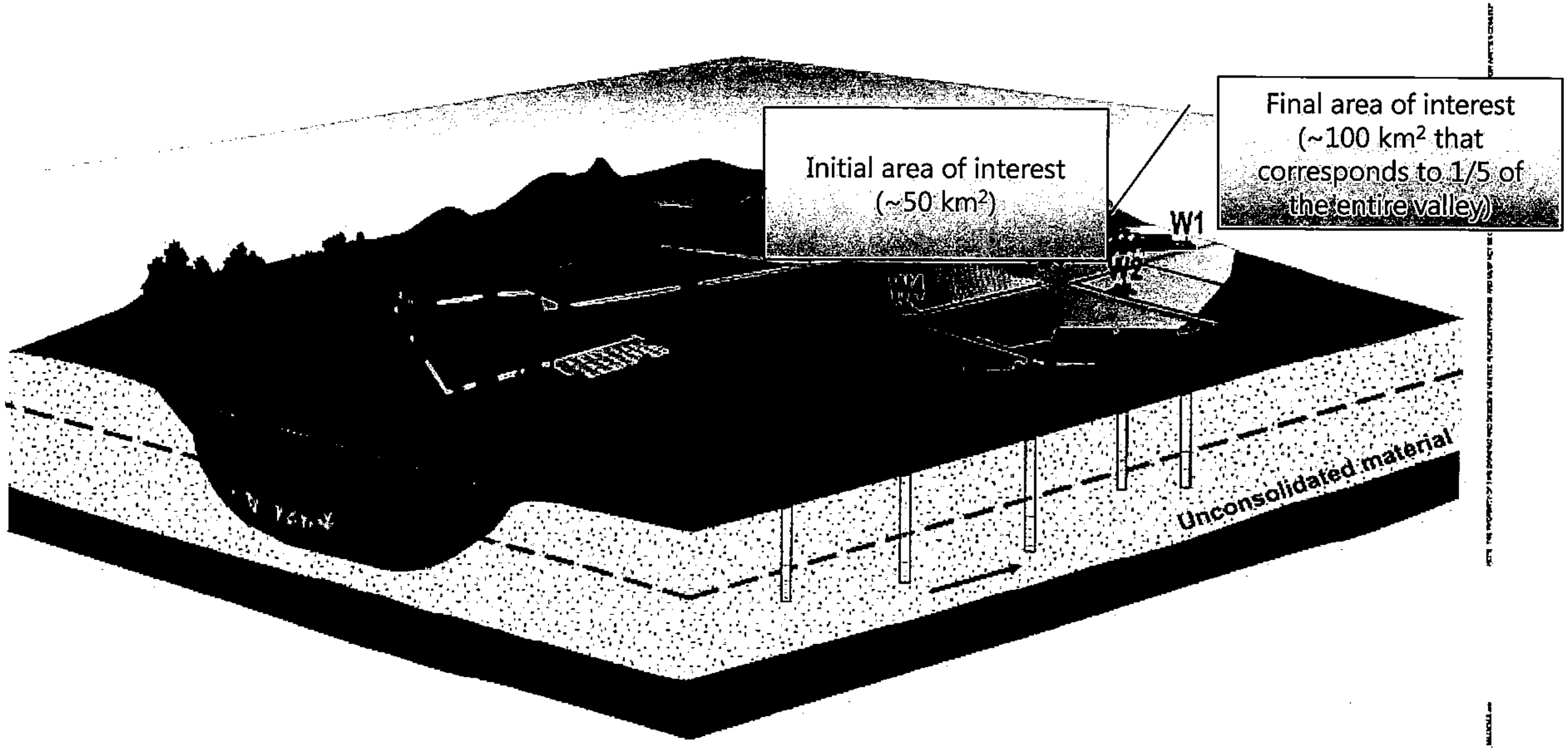
Contents

Site Description

Social Context & Regulatory Framework

Hydrogeological Modelling & Remedial Strategy

Site Conceptual Model



Site Conceptual Model | Elements

Sources → Migration Routes → Receptors

Loss of containment of...

Compounds of Concern (CoC)

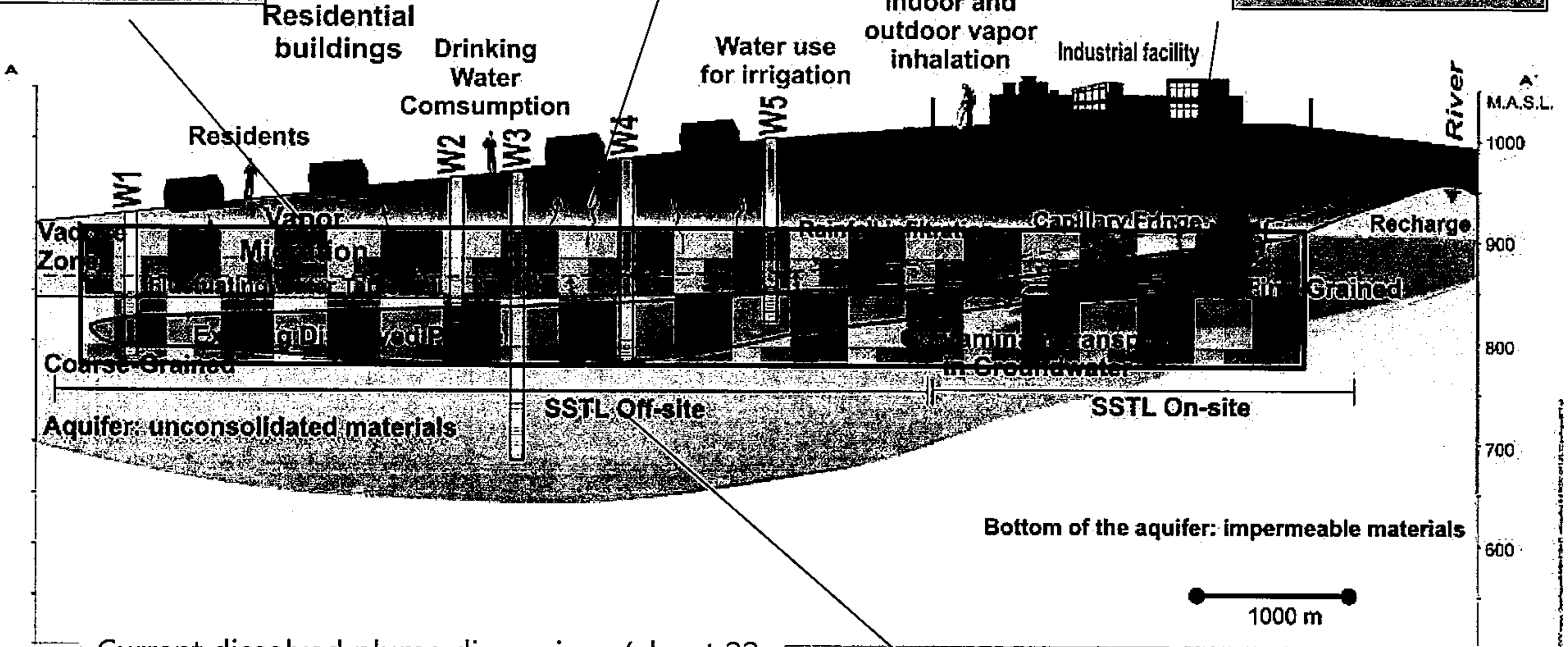
From	Through	To
Tanks / Containers	Soil and subsoil	Soil and subsoil
Pipes / Valves	Groundwater	Groundwater
		Landowners / Workers

Conceptual Model of Risks

Important water table variations

Different migration routes and receptors

Area affected by a highly soluble organic compound



Current dissolved plume dimensions (about 22 years after the loss of containment):

- Length: 7,000 m ~ 320 m/year
- Width: 2,000 m
- Thickness: 30 m (estimate)

Identification of Site Specific Target Levels (SSTL)

Social Context

- Water resources management involves the participation of **multiple stakeholders** with different interests

Populations

Industries

Agriculture

- The **agricultural activity**, the most relevant economic activity of the region, has been based on efficient, but **intensive** (with hundreds of active production wells), **utilization of groundwater resources**.
- Public Authorities are facing significant concerns about the **water scarcity** of the last 7 years that is causing the decrease in groundwater levels and the increase in competition amongst groundwater users.
- A **groundwater use restriction zone** was declared in the past, since estimated demand exceeded available resources.
- **Strong political interests** could influence decisions made by Public Authorities.

Regulatory Framework

- **Inadequate** regulatory framework:
  - Chemicals of Concern not included or regulated
  - Specific Standards are not available to define remediation objectives
  - Remedial alternatives and technologies are not defined
  - Water injection in the aquifer is not regimented

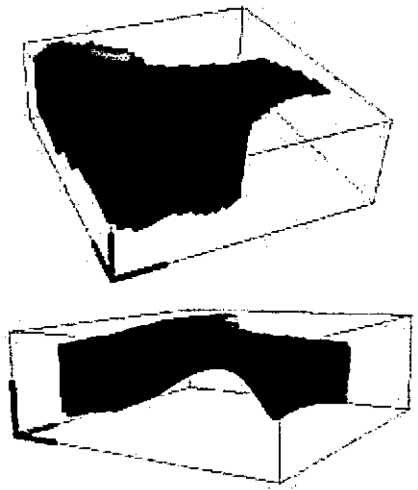
→ The Public Authorities needed to take decisions based on **US** experience and study cases.

- **Specific local regulations** to manage groundwater extractions:
  - Existing limitations for landowners of farms to use water not abstracted from their property.
  - Existing control on drilling of deeper wells and the volumes of abstracted water.
  - Currently, **new drilling** of production wells has been completely **suspended** in the entire area to allow time for checking and reviewing data characterizing existing concessions to guarantee the **water balance.**

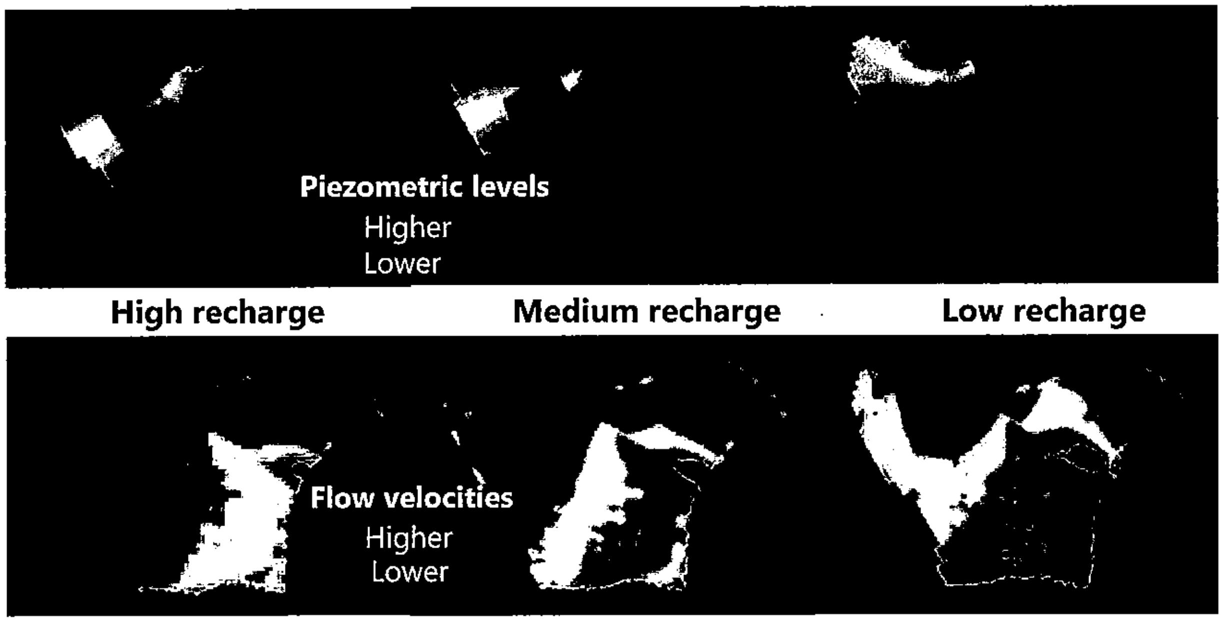
Hydrogeological Modelling (1)

3D Numerical Flow Model (MODFLOW AND MODPATH CODES)

- A **25-year flow model** was calibrated.
- The recharge volume affects the **direction** of groundwater flow lines, and thus different receptors potentially affected by the CoC.
- Significant differences in **flow velocities** occur between areas close to and far from the recharge zone.



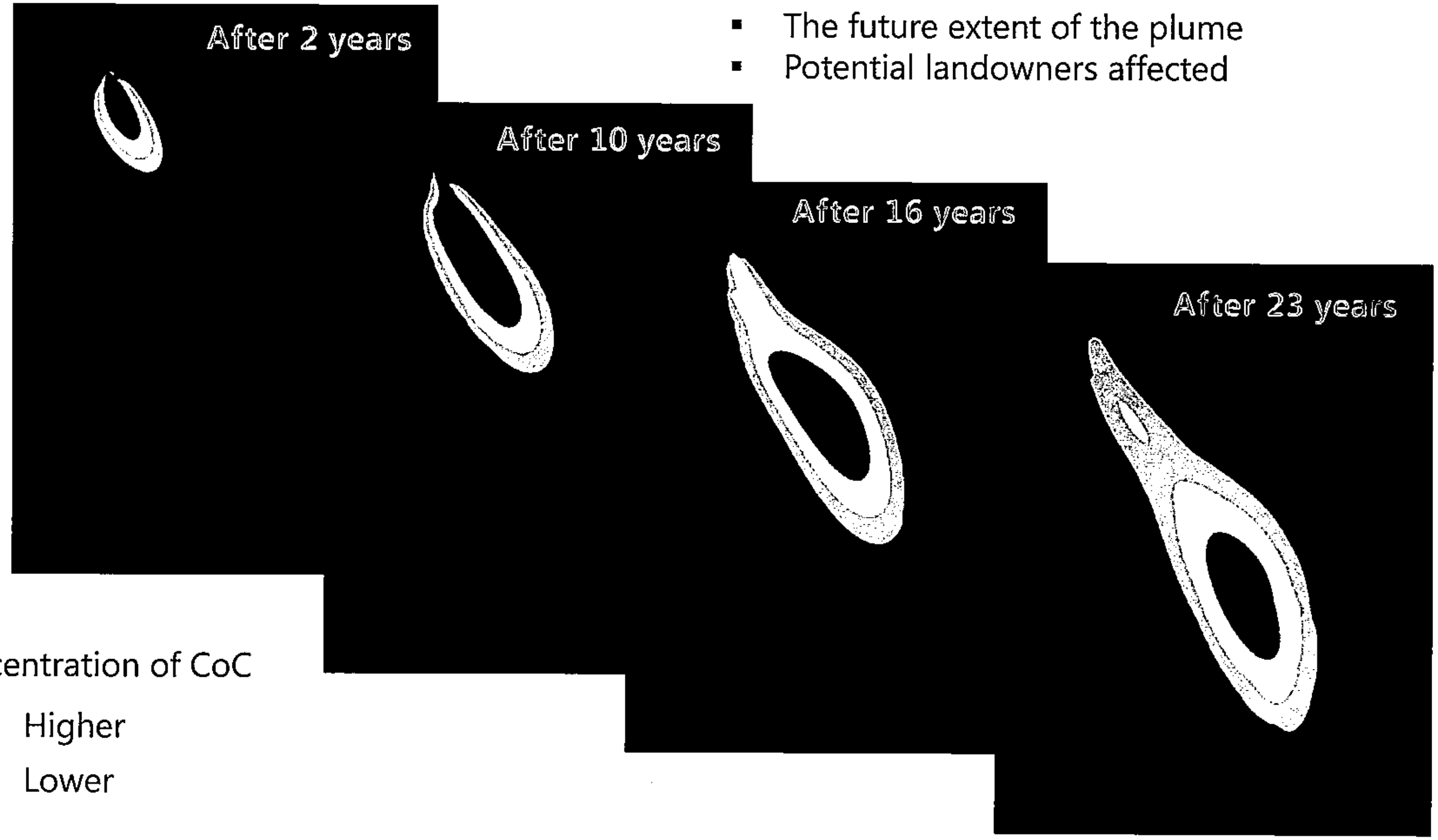
As a **conflict management tool**, a numerical flow and transport model was used to simulate past and future scenarios.



Hydrogeological Modelling (2)

3D Numerical Transport Model (MT3D CODE)

- Development of a **transport model** for the specific CoC to simulate the plume from 2 to 22 years after the spill.
- Model **calibrated** (time and concentrations) to estimate:
  - The future extent of the plume
  - Potential landowners affected

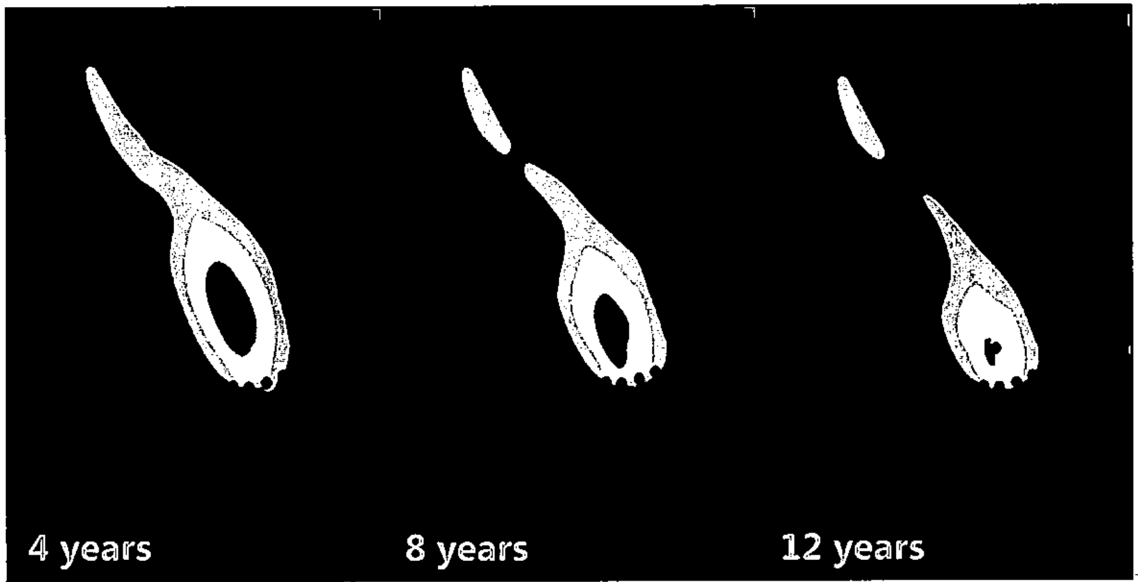


Concentration of CoC

- Higher
- Lower

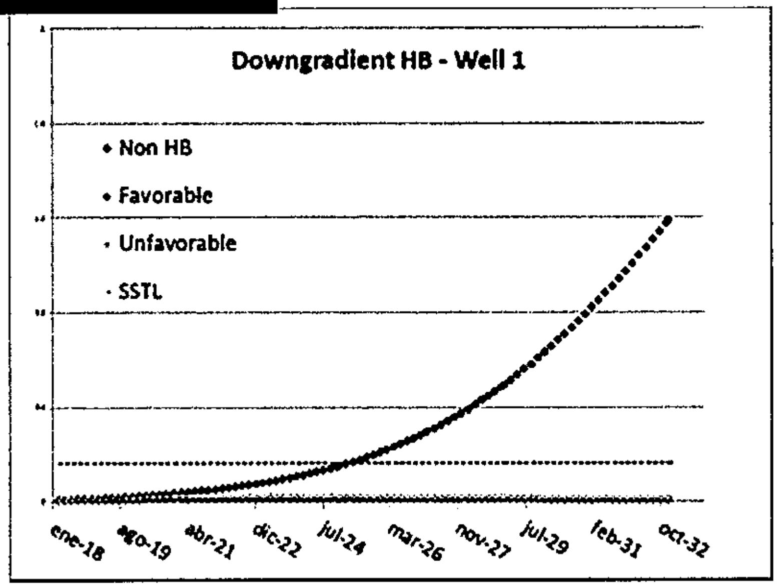
Remedial Strategy

CoC Migration Prediction



Modelling used to define and design the P&T System to:

- Control downgradient migration of the plume, preventing the plume from reaching new stakeholders.
- Reducing downgradient concentration of the CoC to SSTL, returning to full water use.
- Disposal of treated water through injection wells to maintain water balance of the aquifer.



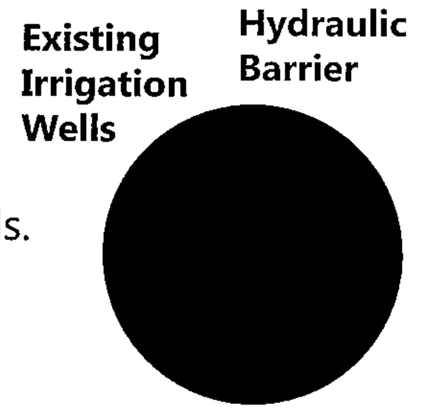
Hydraulic Barrier System Design

The Hydraulic Barrier modelling considers:

- Different future climatic scenarios

- 5 pumping wells abstracting up to **800 m^3/h** → 192000 m^3/day → **7 hm^3/year during 15 years**. Equivalent to 1200 trucks of 16 m^3 every day!

- According to the numerical model, the average water volume that recharges the entire valley is approx. 119 hm^3/year:
  - ✓ Current abstracted water for irrigation purposes $\simeq$ 16.8 hm^3/year → 14% of the annual recharge.
  - ✓ Abstraction for remedial purposes will be approx. **5%** of the annual recharge → Equivalent to more than 30 new irrigation wells.



- **Return of treated water to landowners** with affected wells.

- **Injection of excess water volume to the aquifer to maintain water balance.**

- Downgradient impacts on groundwater levels during extraction.

- Water treatment plant designed to comply with drinking water regulations.

Adaptive Approach

The **aquifer characterization** took 8 years and included: geophysical prospecting, drillings, hydrogeological tests, extensive monitoring of levels, and hydrochemistry. Drilling of remediation wells has started.

Behavior of the released organic compound was modelled, which allowed for key management factors to be identified and communicated to stakeholders.

The hydraulic barrier was designed to return the groundwater to the approved standards without reducing the volume available in the aquifer, taking into account that availability is decreasing over time.

Public authorities were involved in every step of the project and were extremely interested in maintaining both **quality standards** and the **water balance** of the area. **Agreements** and **conflicts management** with landowners were key to start operation.

Expectations management related to remediation:

- The minimum barrier operation time to meet water quality threshold values for irrigation and potable uses
- The overall cost of remediation.
- Ensuring **long-term sustainable development** of the water resource, taking into account **Climate Change** effects on the area.

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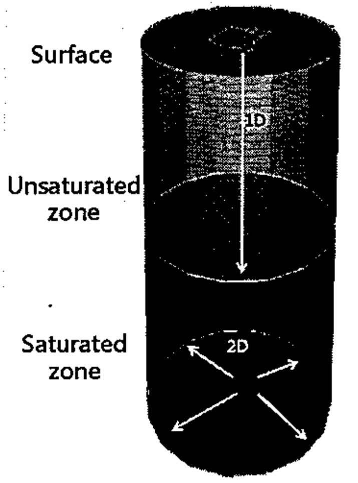
附錄 4

The Application of Pollution Transfer Model and Health Risk Map on the Brownfield Revitalization in Taiwan

Soil and Groundwater Pollution Remediation Funds, Environmental Protection Administration (Taiwan)

Environmental Engineering Research Center, Sinotech Engineering Consultants, Inc.

THE MODEL



Richards equation

$$\frac{\partial\theta}{\partial t}=\frac{\partial}{\partial z}\left[K(\theta)(\frac{\partial h}{\partial z}+1)\right]$$

K : hydraulic conductivity
h : matric head induced by capillary action
z : elevation above a vertical datum
θ : volumetric water content
t = time

Darcy's Law

$$Q=-KA\frac{(dh)}{dL}$$

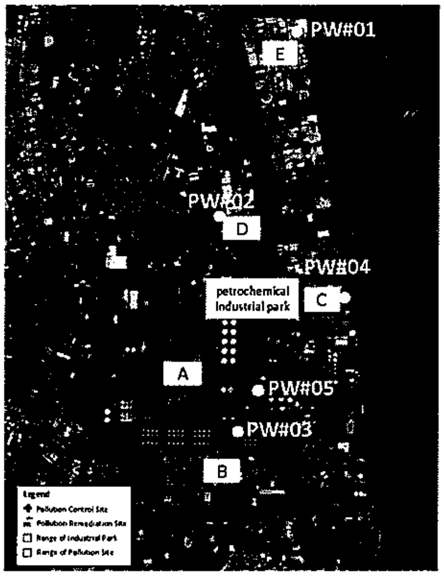
Q = discharge
K = hydraulic conductivity
A = surface area
h = piezometric head
L = distance in direction flow

The methodology

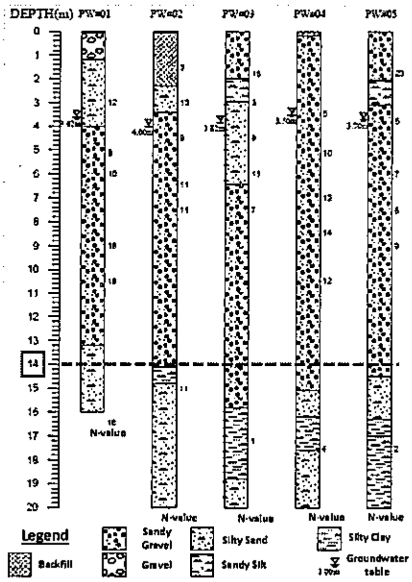
- Assuming hydrogeological condition as homogeneous media
- Take the highest contaminated concentration for risk assessment

Applying hydraulic model (HydroGeoChem) to demonstrate the groundwater flow and transport of individual contaminants so that a 2D dynamic health risk map is illustrated.

THE SITE



Geological condition



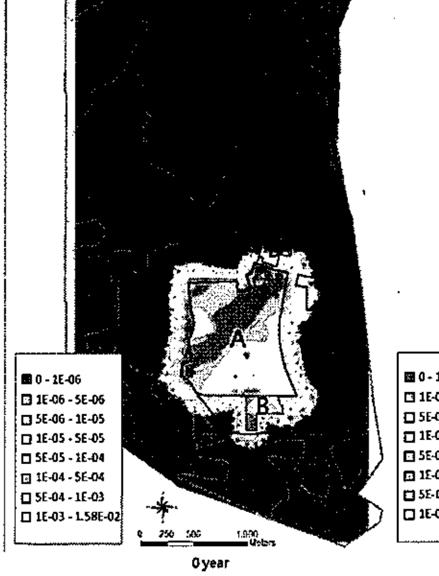
- The site is located in Southern Taiwan.
- The geological condition is composed of clay (14-20 m), sand and grit (0-14 m).

Pollution

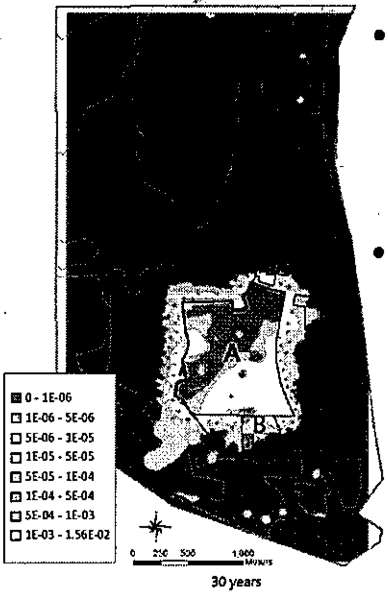
- The soil and groundwater are polluted by BTEX, CCl_4, 1,2-CH_2Cl_2 and CH_3Cl, mainly from the petrochemical factories in the neighborhood.

THE RESULTS

Risk Map



0 year



30 years

Risk Management for Revitalization of this site

- The site will be redeveloped as a shopping outlet in the near future, while the groundwater remediation of will proceed along with the service.
- According to the model, the vapor intrusion of BTEX from soil and groundwater will be the major health concern. The ground shall be covered by asphalt to avoid the contact with the human beings.

附錄 5

附錄5 丹麥污染土壤法律及整治現況簡介

丹麥四面環海，地表徑流少，地下水是丹麥最主要的淡水資源，丹麥居民的飲用水全部直接來自地下水。如果土壤資源遭到嚴重污染，蘊藏於土壤資源之下的地下水資源也會被破壞，這將動搖丹麥人的生存之本。在工業化的歷史進程中，丹麥不少土壤資源也遭到了破壞。丹麥高度重視土壤污染的問題，從 1971 年起成立丹麥環境部 (The Ministry of the Environment)，陸續制定相關的環保法規，在 2000 年發布「污染土壤法」 (Contaminated Soils Act)。

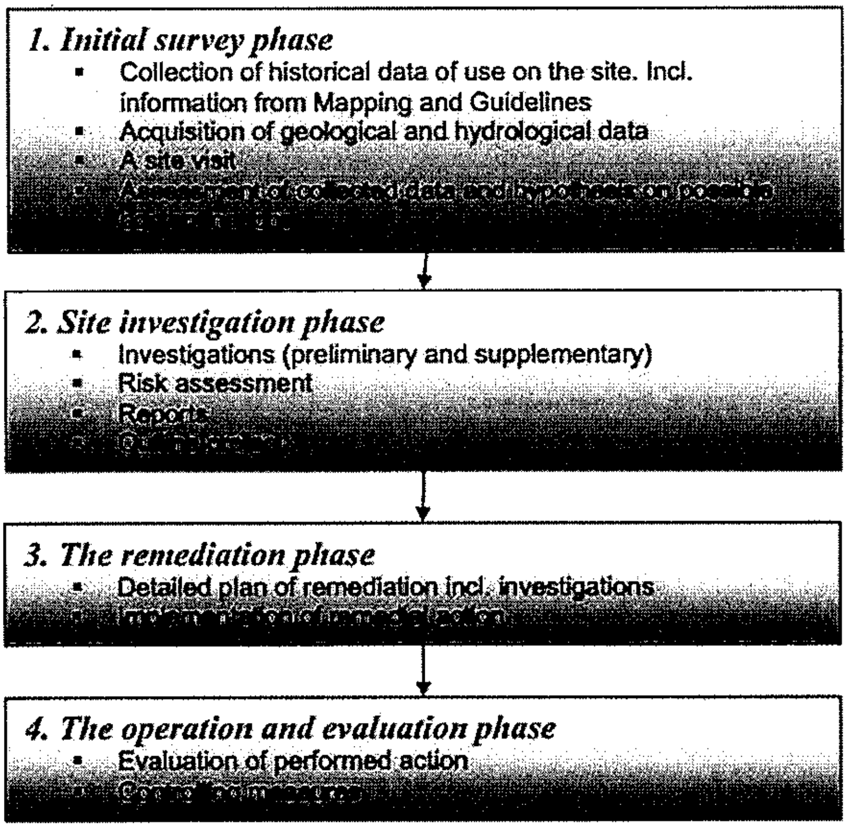
「污染土壤法」旨在協助防止、消除或減少土壤污染，以及阻礙或防止土壤污染對地下水、人類健康和環境之不利影響。尤其，法令目標是：

1. 保護飲用水資源
2. 防止因使用受污染地區導致之健康問題
3. 為組織有序的及指導公眾成果提供準則，用以避免從土壤污染造成之有害影響
4. 透過使用及處置土壤，防止對環境的進一步污染
5. 堅持污染行為人應採取必要措施以對抗土壤污染的影響，以及恢復環境原狀態之首要對象

「污染土壤法」適用於因為人為衝擊而對地下水、人體健康及環境有害之土壤，但不適用於因受農作目的產生之污泥、肥料及農藥等影響之土壤。如果已取得於某區域的實際活動或其他區域之活動可能為土壤污染源，則該區域應被指定列管為一級列管區 (knowledge level 1)。如果已獲得該區域極有可能含有可能對人類健康和環境造成不利影響之土壤污染種類與濃度之文件，則該區域應被指定列管為二級列管區 (knowledge level 2)。

也就是一級列管區 (knowledge level 1)包括所有潛在的可能污染場地，比如以前的化工廠區、加油站地下儲油罐等區域，級列管區 (knowledge level 2)為被證實的污染場地。環境部門對所有一級列管區 (knowledge level 1)之潛在污染場地進行初步調查 (preliminary investigation) 確認場址是否被污染，再進行詳細調查 (Further investigations)，包含風險評估 (risk assessment.)。此外，亦針對特殊目標地區，如飲用水重要性地區、供水廠的集水區、住宅、兒童機構或公共遊樂場地。如果污染物被證實超過土壤質量基準 (Quality

Criteria for Soil)，則被列為二級列管區 (knowledge level 2)，進入至整治階段。根據丹麥環保署 2002 年發布之污染場址整治指引 (Guidelines on Remediation of Contaminated Sites)，丹麥的污染土壤管理策略大致分為四個階段 (圖 1)，依序為初始調查階段 (The initial survey phase)、場址調查階段 (The investigation phase)、整治階段 (The remediation phase) 以及操作與評估階段 (The operation and evaluation phase)。於操作與評估階段為評估和記錄整治措施之效果，在開始整治措施前，必須基於風險評估設立停止標準 (stop criteria) 和監控程序 (monitoring programmes)。停止標準 (stop criteria) 可按照整治速率實效說明，整治過程緩慢的時候，可以暫時停止整治措施。其後的風險評估結果為決定是否應該永久停止整治措施或是需要繼續使用其他技術之依據。



附圖