INVESTIGATION OF CONTAMINATED LAND AT A FORMER SEWAGE TREATMENT WORKS, ITS REMEDIATION AND RETURN TO PUBLIC OPEN-SPACE, EXETER, DEVON

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Development of part of the Belle Isle Nursery site, at Trews Weir, Exeter for use as public open space required sampling for contaminated land assessment, due to its former use as a sewage treatment works. Once the site was confirmed to be contaminated, budgetary constraints necessitated a staged approach to its redevelopment. Government funding for remediation was also sought centrally through an initiative under English Partnerships. This is designed to assist in 'brownfield' site remediation where land is to be returned to public open-space. The sensitivity of the site due to its proximity to the River Exe required close liaison between the contractors, the City Council and the Environment Agency as the regulatory authority, throughout.

Eight trial pits were used initially to provide access for soil sampling. Soil was taken at near surface, 0.5 m and 1.0 m, whilst sub-samples were selected for inorganic and organic chemical analyses. Results from the initial survey showed contamination of surface soils by several metals, including lead. Consequently, detailed surface soil sampling by soil auger was initiated. Sample density was measured at 30 m intervals and additional samples were taken adjacent to the initial sample sites. At the end of the study, the sampling density for the 3 hectare site was 83 samples.

Contaminants comprised Pb, Zn, Cu, Ni and Cr with lead values dominant and reaching around 2500 ppm. Accordingly, mapping of the contamination employed Pb as the marker heavy metal, and using 1000 ppm Pb as the action level identified areas for remediation. Clean inert topsoil was imported to produce a barrier of some 600 mm depth over residual contaminated areas. This would provide a sufficient depth plus safety margin to ensure that members of the public would not come into contact with the underlying contamination. Hard standing (paths and seating) was also employed over contaminated areas where the engineered barrier would prove intrusive. Neutral to slightly alkaline soil pH made it unlikely that metal migration would occur in the future. The area was landscaped and opened up for public use providing access to the River Exe running through the city of Exeter.

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INTRODUCTION

In 1993 when this project was initiated, the new statutory regime dealing with contaminated land had yet to come into force in England, but provisions were contained in Section 57 of the Environment Act 1995 and were to be inserted into the Environmental Protection Act 1990 as Part IIA (Anon, 1991; DETR, 2000). From the legislative perspective, land was to be considered contaminated if the presence of substances in, or on, or under it meant that significant harm was being caused, or that there was a possibility of harm being caused, or pollution of controlled waters was being caused, or likely to be caused (Mylrea, 1998). However, codes of practice for the identification of potentially contaminated land and its investigation had been developed and formalised as a series of Government Guidance and British Standards from the 1980s (ICRCL, 1987a, b, BSI, 1988). Since the project has been completed a new risk assessment model has been developed under *The Contaminated Land Exposure Assessment* (CLEA) by the Department of Environment, Food and Rural Affairs (DEFRA) and the Environment Agency (EA) which includes a series of toxicological documents in support (DEFRA/EA 2002a, b, c, d). The British Standards have also been updated with regard to the code of practice for site investigations (BSI, 1999) and for potentially contaminated sites (BSI, 2001).

For development purposes, contaminated land investigations are directly concerned with establishing what the contamination is, where it is and how it can be dealt with. They are based on the source-pathway-receptor principle. As such then, they are not approached on the scale of an academic research study, where mechanisms of transport and rates of pollutant migration would receive more emphasis and require more detailed, time consuming and costly application.

When this project was undertaken Exeter City Council planned to develop part of their Belle Isle Nursery site, Trews Weir, Exeter, U.K. for use as a public open space (Figure 1). In view of part of its present-day use as a nursery and former uses which included a sewage works that could have contaminated the site, a contaminated land survey was deemed necessary prior to redevelopment. The main aim of the survey was to ascertain whether the site was, or was not, chemically contaminated. Additionally, as it seemed likely that the land contained some contaminated areas, the then Earth Resources Centre (University of Exeter) called in Frank Graham (consulting engineers) with experience in remediation of such 'brownfield' sites. This site is approximately 5 hectares and is bordered to the west by the River Exe in a valley which has seen extensive industrial activity (Environment Agency, 1998). Geologically, it is underlain by alluvium and river terrace deposits. Adjacent higher ground on the eastern border is comprised of the Permian Alphington Breccias of the Exeter Group (Edwards *et al*., 1995). On-site and surrounding soils are largely unsurveyed and classed under the designation U or urban and industrial areas (Mackney *et al*., 1983; Soil Survey, 1983).

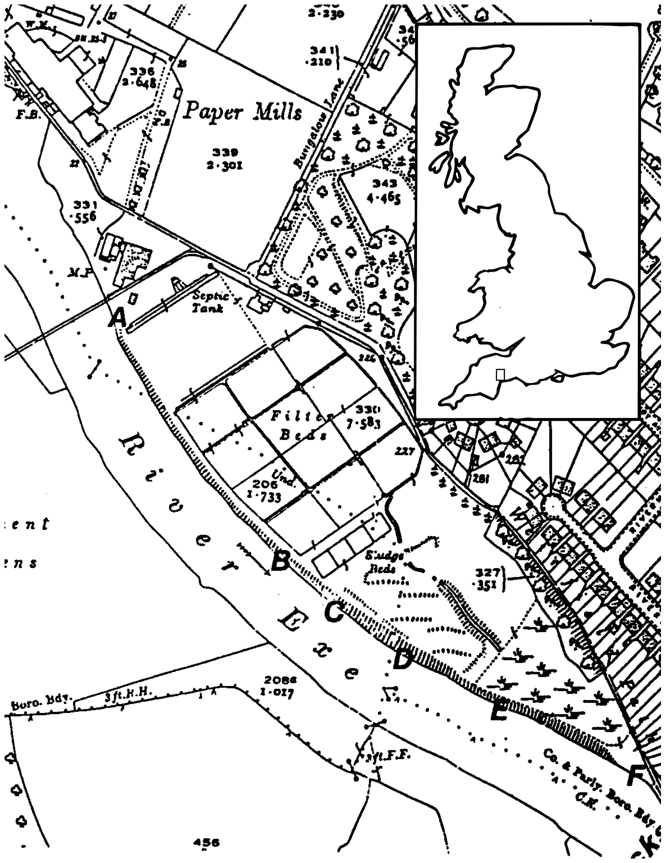

Figure 1. *Location map of the Belle Isle site with details of former sewage works. Letters A-E refer to points identified by the Environment Agency and referred to in the text as requiring special attention.*

Methodology

Site walkover

After an initial meeting with officers of Exeter City Council at Belle Isle Nursery a site walkover was conducted during May 1993. This enabled planning for the site investigation in order to meet the conditions laid down for the identification of potentially contaminated land. The U.K. guidance at that time issued by Her Majesty's Government was in the form of reports from the Interdepartmental Committee on the Redevelopment of Contaminated Land (ICRCL, 1987a, b; BSI, 1988) and these were used as the project rationale.

At this early stage, it was recommended that eight shallow (1 m depth) trial pits were dug to permit sub-surface soil sampling. A ninth sample was to be taken from a soil mound at the SE end of the site. Chemical analyses comprising Pb, As, Zn, Cu, Ni, Cr and Cd were to be carried out on all the samples and an organic screening on three more, selected to represent the site as a whole.

Sampling

For administrative reasons, the decision to proceed with the survey was delayed until October 1995. However, the sampling plan was retained with the addition of one sample from a new heap of compost deposited by the owners. Exeter City Council dug the pits by JCB and sampling was conducted. During the course of this work, an additional pit was dug, as local knowledge confirmed this to be the centre of the former sewage operations. Seventeen samples were taken from the trial pits near surface and sub-surface and two samples from the two spoil mounds by means of a screw soil auger (Table 1). They were sealed in labelled plastic bags for subsequent analysis of soil chemistry. The three samples for organic-screening were collected separately in acid/organic solvent washed glass bottles and stored in a cool bag prior to analysis.

Sample no.	Depth (m)	Comments
TW 01a	0.2	brown clay-rich soil
01O**	0.2	
01b*	0.8	gravel horizon 0.5 m
TW 02a*	0.1	crumbly soil
02b	0.7	large stone (limestone) W end of trial pit dark bands, red brick remains
TW 03a*	0.1	clay-rich surface soil
03b	1.0	pebbles/cobbles with light red clay
TW 04a*	0.1	evidence of bonfires, dark humus-rich layer down to 0.5 m., red zone >0.5 m depth
04b	0.6	red clay-rich zone
TW 05b	0.5	dark humus-rich surface soil down to 0.3 m red oxidised zone >0.3 m, red clay bricks, wall remains
05O**	0.5	
TW 06a	0.2	dark black humus horizon, fine
06b	0.6	red-stained pebbles and red clay sub-soil
TW 07a*	0.1	dark black humus top-soil
07b	0.5	red clay-rich sub-surface zone
TW 08a	0.1	dark black fine humus topsoil
08b*	0.6	red clay, bottles, New Red Sandstone cobble
TW 09	top	tip site, brown humus, leaves, plastic bags
TW 10	2 m from top	recent above-ground level mound of light brown soil with pebbles and cobbles
TW 11b	0.5	site of sewage settling area
11O**	0.5	
11c	1.0	thin light brown surface soil & red oxidised clay-rich zone below

Table 1. *Description of the trial pit soil samples from Belle Isle Nursery. *Denotes sampled but not analysed. **sampled for organic screening only*

Analyses

Soil samples were oven-dried overnight at 50°C and ground in a TEMA tungsten carbide disc mill for 4 minutes. Five grams of the powder were mixed with 4 drops of 2% aqueous polyvinyl-pyrrolidone in an agate pestle and mortar, backed with boric acid and pressed at 3 tons for 3 minutes to provide a pellet for X-ray fluorescence spectrometry (XRFS). The sample was then analysed for inorganic chemistry using a Philips PW1400 sequential X-ray spectrometer with reference to an international set of calibration standards. Certified reference materials were also run against the calibrations. Values from this are expressed as parts per million (ppm) with an analytical error of around ±10%.

Approximately 30 g (fresh weight) of soil were transferred to a 100 ml glass bottle. Deuterated (d8)-napthalene was added to the soil as an internal standard to a final concentration of 4.7 ppm (mg/kg) and mixed thoroughly to ensure homogeneous distribution throughout the soil matrix. Fifteen ml pentane and 5 ml acetone were added and the sample sonicated for 2 hours to maximise contact between solvent and soil particles. After sample acidification with 2 ml 10% nitric acid, clearing by filtration, cleaning through activated flurosil and elution with a 95:5 mixture of pentane:toluene, a small volume of 1-bromonapthalene was added as a marker to enable accurate determination of the final volume of the extract. Extracts were analysed by gas chromatography with mass spectrometry (GC-MS) using a Hewlett Packard 5890 series gas chromatograph linked to an HP 5972 mass selective detector.

Results

Trial pit results

Results from the initial organic screening (Table 2) and inorganic chemical analyses (Table 3), showed some contaminant organic compounds to be present in the soils and that concentrations for lead proved particularly high in some of the near-surface samples, 6a (exceeding 2318 ppm Pb) and 8a (1520 ppm Pb), and in sub-surface samples 2b (1054 ppm Pb) and 5b (1259 ppm Pb). Thus all parts of Belle Isle Nursery were contaminated with lead to some degree. As ICRCL threshold

Sample no. TW 01 Depth (0.2 m) Compounds identified to better than 90%
Naphthalene, 1,5-dimethyl-
Naphthalene, 1-methyl-
Naphthalene, 2,6-dimethyl-
Naphthalene, 2,3,6-trimethyl-
P-hydroxyphenyl phenylsulphone
(+-)-3,3,7-Trimethyltricyclo[5.4.0.0(2,9)]undecan-8-one
(Z)-1,3,4,5-Tetrahydro-3,3,3',4'-tetramethyl-5-oxo-2,2'-pyrromethane
Chrysene
Naphthalene, 1,6,7-trimethyl-
Anthracene, 1,4-dimethyl-
Anthacene, 2-methyl-
Pyrene, 1-methyl-
9H-Fluorene, 1-methyl-
Dibenzothiophene
Acepyrene (3,4-Dihydrocyclopenta(cd)pyrene)
9H-Fluorene
Azulene
Benzo[b]naphtho[2,3-d]furan
Dibenzofuran
Dibenzofuran, 4-methyl-
Phenanthrene, 2,7-dimethyl-
Pyrene, 4-methyl-

Table 2. *Results of organic screening. Analysis by GC-MS.*

Sample no.	Pb	As	Zn	Cu	Ni	Cr	Cd
TW 01a	303	<3	189	66	49	75	<3
02b	1054	<3	412	79	51	72	<3
03b	160	<3	139	44	45	66	<3
04b	91	<3	57	29	48	82	<3
05b	1259	<3	258	54	157	195	<3
06a	2318	<3	1209	285	56	214	<3
06b	178	<3	231	41	40	67	<3
07b	310	<3	181	72	45	80	<3
08a	1520	<3	742	261	70	168	<3
09	86	<3	153	41	44	62	<3
10	184	<3	137	38	30	57	<3
11b	25	<3	67	24	37	67	<3
11c	70	<3	99	29	59	103	<3

Table 3. *Geochemical analyses of soils from first survey, Belle Isle Nursery. All results given in parts per million (ppm).*

trigger levels for lead are 2000 ppm Pb for parks and open space, these values gave cause for concern. This was because similar guidance from the Greater London Council (Kelly, 1980) classes lead concentrations between 500-1000 ppm Pb as slightly contaminated and 1000-2000 ppm Pb as contaminated. Importantly, highest chromium values correlated with highest lead values. This strongly suggested residual material from the former sewage works to be the likely source of this contamination. As industrial waste was not separated from domestic waste during the life of this sewage works a complex cocktail of chemical pollutants would have been received by the site. Chromium is used for tanning, for example, and a tannery operated nearby. Guidance on the likely contaminants to be encountered from specific industrial operations is given in the ICRCL series, such as that in 23/79 on the redevelopment of sewage works and farms.

Results of the organic screening showed surface sample TW01O, from 0.2 m depth yielded a wide range of organic contaminants, some at relatively high concentrations. Of 76 compounds isolated, 51 were identified and 22 gave match qualities of greater than 90% (Table 2). The majority of those identified were polycyclic aromatic hydrocarbons (PAHs) or their derivatives (25 compounds), or derivatives of the bicyclic molecule naphthalene (7 compounds). Biphenyls, furans and thiophene derivatives were also prominent. Very few aliphatic (long-chain) compounds were identified. The three most prominent peaks were identified as phenanthrene, fluoranthene and pyrene and were present in concentrations significantly above that of the standard (approximately 7 ppm, or mg/kg, wet weight) in the original soil sample. The other compounds identified were present in the high parts per billion (ppb) to low parts per million (ppm) range. The predominance of bicyclic and polycyclic aromatics and near absence of long-chain aliphatic hydrocarbons suggested that the contamination did not result from spillage or seepage of motor or other lubrication oils. Additionally, these organics decreased with depth unlike the Pb contamination which generally increased downwards. Thus, contamination from creosote or other wood preservatives which may have been used on the site during its time as a plant nursery appeared more likely. Subsurface samples TW05O and TW11O were much less contaminated with organics, both in the number of compounds isolated and their relative concentrations. Nevertheless, there was some evidence of historic contamination at site 5 with low levels of aromatic hydrocarbons including the PAH pyrene. Fourteen compounds were isolated from sample TW11O including alcohol, 2 ketones and a complex organic acid additive. These compounds can be of biogenic origin and could have related to the former use of the site as a sewage treatment works.

Soil auger survey

Budgetary constraints dictated a phased approach to sampling and analysis with each outcome dictating the next step. Initially, thirty near-surface (to a depth of 30 cm) soil samples were taken in July 1996, by means of a screw soil auger. The samples were from strategic locations across the area destined for new end-use as a public open space (Figure 2 and Table 4). An additional set of 5 samples from soil stored at nearby Trood Lane landfill site and intended for cover at Belle Isle, were also analysed to assess its status (Table 5). The five (3 from brown silty soil and 2 from red sandy soil) were taken for lead analysis. Two more were sampled in July for organic screening.

Soils were pH tested in the field at Belle Isle using a Solomat portable pH/Eh metre and equal volumes of soil and de-ionised water. They were returned to the laboratory for repeat analysis at the end of the day. Additionally, a further set of 23 soil samples were collected from the site during August for lead analysis along margins where soil remediation would necessitate construction of retaining walls, and to confirm the most elevated levels of contamination. Lead was selected as the key indicator of metal contamination at this site, based on the initial analyses and enabled the more detailed analyses to be targeted with reduced costs.

The lead results gave a range from 61 ppm to 2437 ppm Pb. The highest result was similar to that from the initial survey location 2 at 2318 ppm Pb, whilst lead concentrations of 2006, 1848 and 1747 ppm Pb further confirmed the contamination at the southern half of the Belle Isle site. Samples analysed from the central section better defined the hotspot there, the new values giving between 900 and 1397 ppm Pb. Attention was paid to the area supporting 3 lines of trees south of the E-W aligned path crossing the centre of the site. Concentrations of lead in the soils there proved relatively lower (271 to 860 ppm Pb) except for one area away from the trees (1493 ppm Pb) at the junction with a riverside path. Attention was also paid to the north of the site as the desk study had uncovered previous structures related to the site's former use as a sewage works. Values here proved relatively low, from 99 to 207 ppm Pb.

A small plantation of trees ran along the southern boundary of the nursery and as much as possible of the valuable flora was to be retained. Additional soil samples were collected from this area for Pb analysis. These ten samples yielded generally lower concentrations of lead (271-803 ppm Pb), making this additional survey particularly cost effective in sparing the tree plantation. It also provided additional data for delimiting the main 'hotspot' of pollution.

In order to plot the area of contamination, these Pb values plus the 30 obtained from the third soil survey were contour plotted using Kriging interpolation based on a linear variogram model. Results from this are illustrated in Figure 2. Areas above 1000 ppm Pb and 2000 ppm Pb are shaded to indicate the key sectors requiring remediation. The three sites tested for soil pH, representative of low, intermediate and high levels of lead,

Figure 2. *Present-day contour lead plotting and remediation works. The Pb plotting identifies the general extent of contamination with 'hotspots' above 1000 ppm Pb shaded.*

Sample No. Survey 2	Pb ppm	Sample No. Survey 3	Pb ppm
TW 1/1	260	TW 0/1	195
1/2	468	0/2	193
1/3	174	1.5/1	207
2/1	465	1.5/2	99
2/2	137	4.9/1	930
3/1	447	5.25/1	1397
3/2	331	6.5/1	900
4/1	532	6.5/2	826
4/2	816	7.25/1	1493
5/1	881	7.25/2	271
5/2	900	7.25/3	593
6/1	1163	7.25/4	512
6/2	2159	7.25/5	578
7/1	628	7.25/6	622
8/1	676	7.5/1	508
8/2	770	7.5/2	492
8/3	706	7.5/3	479
9/1	252	7.5/4	350
9/2	1820	7.5/5	803
9/3	1705	8/1	447
10/1	2350	8/2	796
10/2	1560	8/3	860
10/3	58	8.5/1	1349
11/1	1023	10.5/1	61
11/2	888	10.5/2	2006
12/1	306	10.5/3	2437
12/2	903	10.5/4	1747
13/1	86	11/1	186
13/2	386	11/2	1848
14/1	216	11.5/1	455

Table 4. *Lead results from second and third soil surveys at Belle Isle.*

proved neutral giving a range from pH 7.33-7.60. Samples from Trood Lane identified for remediation at Belle Isle gave low lead values from 17-28 ppm Pb. The organic screening of the topsoil indicated traces of long aliphatic side chain benzene derivatives, which might have been derived from fuel oil (Table 5). As a precautionary measure, therefore, a further sample was tested for quantitative analysis of benzene, toluene and xylene which all proved below 0.02 milligrams per kilogram (parts per million).

Consideration of remedial measures

The soil surveys revealed that the site was slightly contaminated, probably as a result of its past use as a sewage works. For the intended use as parkland with public access, it was recommended that remedial works should be carried out in order to separate the public from soils containing lead concentrations exceeding 1000 ppm Pb. This figure was chosen on the basis of an assessment of risk; although the ICRCL TTV for parks is 2000 ppm Pb, the choice of a lower threshold value provides a safety margin to allow for limitations and possible anomalies. The suitability of various methods of remediation were considered as follows.

Removal and replacement

Removal of the contaminated soils and replacement by importation of clean soils would provide the best level of clean-up because the more highly contaminated material would be taken off-site. However, contaminated material would have to be disposed of at a special licenced landfill and transport and disposal costs were likely to be high. Further testing would be necessary to ensure removal of all of the more highly contaminated material. In addition, this operation might expose previously buried contamination possibly leading to increased leaching of

Sample No.	Pb ppm	As ppm	Zn ppm	Cu ppm	Ni ppm	Benzene mg/kg	Toluene mg/kg	o-Xylene mg/kg	m-Xylene mg/kg	P-Xylene mg/kg
TL 01	23	6	34	12	14	na	na	na	na	na
02	27	5	30	11	12	na	na	na	na	na
03	28	5	30	11	11	<0.02	<0.02	<0.02	<0.02	<0.02
06	17	6	29	10	17	na	na	na	na	na
07	18	6	32	12	16	na	na	na	na	na

Table 5. *Soil chemistry from material stored at Trood Lane site, Exeter na: not analysed.*

pond feature. This would add to the environmental value of the site. Again, however, contaminated material would have to be disposed of at a special licensed landfill, further testing would be required and precautions taken to protect the adjacent river from pollution by contaminated leachate.

Encapsulation

The most appropriate and cost effective remediation option for this site, given its proposed end use as parkland amenity, was considered to be encapsulation. Encapsulation involves the placing of a low permeability capping layer on top of the contaminated soil to physically separate the contaminants from surface and subsurface targets and to limit the infiltration of rainfall into the contaminated soil. The main advantages of encapsulation are that the high costs of excavation, removal and disposal are avoided, the cover improves the existing situation by reducing infiltration and the contaminated soils are not disturbed.

Remediation plan and encapsulation works

Before the commencement of works a letter was sent to each household of nearby residents informing them of the nature of the scheme, its benefits and duration. This also contained contact details. The adopted remediation plan and encapsulation works subsequently contained the following elements. Areas lying within the 1000 ppm Pb contour were encapsulated by the importation and placement of clean soils to create a slightly raised/domed profile feathered out to paths. The deepest cover was to be approximately 1000 mm and the shallowest no less than 300 mm depth.

A haul-road of sand was laid across the site from the access road at the north end to the southern end where works were to commence. This enabled lorries to cross over the contaminated soils without disturbing them (Figure 3).

The cover soils were topsoiled (around 150 mm thick, minimum 75 mm) and seeded immediately to prevent the possible erosion of surface soils. Given the elevated levels of phytotoxic metals detected in the soils, planted areas were seeded with grass as it has relatively shallow roots and is more resistant to phytotoxic effects. Planting of shrubs or trees was avoided as deep root systems in these contaminated areas could result in the upward migration of contaminants to the surface and the plants themselves could be affected by the phytotoxins present in the underlying soils. Hardstanding comprising a relatively impermeable layer of tarmac or concrete was also used in some areas (e.g. park benches) as an effective method of encapsulation.

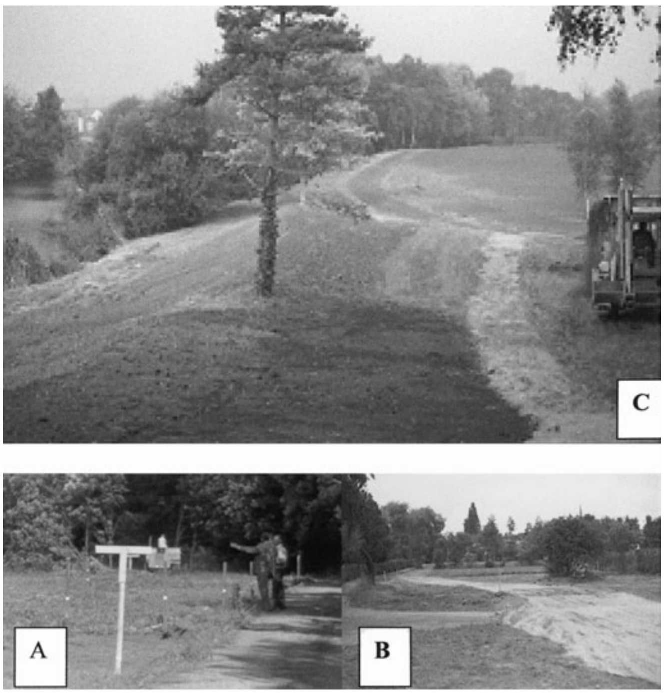

***Figure 3.** Geochemical mapping information is translated to the field where marker posts used to indicate position and levels of soil cover required are shown in the accompanying image (A). The sand haul-road preventing disturbance of contaminated soil is shown (B), along with the completed landscaping of the southern section (C).*

A source of available clean cover material was identified at the Exeter Trood Lane site and testing of this had shown the material to be uncontaminated with respect to heavy metals and organics and of similar pH to that at Belle Isle. Consultation with the Environment Agency prior to importation gained exemption from the need for a Waste Management Licence for this activity.

Stones and cobbles lying on the surface of the site were removed using a stoneraker which only penetrated the top 75 mm of soil. Stones and cobbles of less than 300 mm in diameter were added to the cover provided they were fairly clean and did not have clods of potentially contaminated soil attached.

Key elements of the works now comprised: consultations and approvals from regulatory authorities, a remediation plan defining methods, procedures and safety precautions; further sampling and testing to narrow the limits of excavation and to check new cover materials if won on site; construction (design management) requirements including a Health and Safety File, engineering design, specification, quantification and cost estimates; a letter drop to houses overlooking the site explaining works and timescale; the laying down of a haul-road to the southern section of the site; and damping down of the public access road by water-bowser.

Additionally, the Environment Agency required the following measures to protect the riverside wildlife interest and the integrity of the riverbank, namely:

(1). The public were to be excluded from the northwest boundary for safety reasons and to minimise disturbance to wildlife. Extending existing hedges at each end of this strip was recommended using native broadleaved shrubs and to maintain wildlife value, this section was to remain unmanaged (section A-B, Figure 1).

(2). Public access was to be managed along the remainder of the river boundary save for the southernmost section. This was to be achieved by ornamental fencing, hedging and judicious planting or leaving of tall grass through much of the year (sections B-C and D-E, Figure 1).

(3). Riverside seating was to be located towards the path to avoid trampling/erosion at the water's edge (section C-D, Figure 1).

(4). There should be no public access along the steeply banked section and no management apart from the control of the invasive Himalayan Balsam which grows there (section beyond B, Figure 1).

Conclusions

Taking the initial results of the inorganic and organic analyses together, soils of the Belle Isle Nursery site, Exeter, UK were proven to be contaminated. The selective survey indicated this pollution to be just above the UK ICRCL threshold guidelines and it was a matter of professional judgement as to whether action was needed. However, the site was unsuitable for direct development as a public open-space amenity without prior remedial action. A subsequent more detailed soil survey was thus undertaken based on Pb analysis to better define the limits and to assess the scale of this contamination. The feasibility of remedial action at Belle Isle was then assessed with reference to the scope, health and safety aspects, quality assurance and cost implications. Consultation with the Environment Agency won approval for the importation of cover soils in order to gain exemption from the need for a Waste Management Licence. Formal consent was also obtained from the Environment Agency for works within seven metres of the bank of the River Exe. The more highly contaminated soils lying within the 1000 ppm Pb contour were encapsulated by the importation and placement of clean soils (maximum 1000 mm, minimum 300 mm deep) uncontaminated with respect to heavy metals and organics. Encapsulation was also achieved by the placement of relatively impermeable features such as bench seat foundations and access paths. The soil cover layer was topsoiled and seeded immediately to prevent erosion and shrubs and trees were not planted within the areas of encapsulation.

Key elements of the survey comprised: a desk-top survey of previous use, a site walkover, examination using trial pits, organic screening of trial pit samples, inorganic analysis for heavy metals and, additional sampling and analyses to delimit 'hotspots' for remediation.

Key elements of the remediation comprised: use of lead contour plots to mark out areas requiring remediation, covering of the 'hot spots' by importation and placement of clean soils (up to 1 m depth) to a slightly raised/domed profile and analysis of imported soils before and after remediation.

On a wider perspective, the Belle Isle project suggests that a carefully phased approach such as this could prove equally valuable elsewhere when cost considerations are at a premium. The temptation to omit the trial pit stage should be avoided, however, as it provides an invaluable perspective on the status of the soil profile and the presence of any physical contaminants. The combination of soil augering with chemical analysis is also invaluable as it provides soil pollutant mapping which readily translates on the ground to remediation works.

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REFERENCES

ANON, 1991. Environmental Protection Act 1990. DoE. HMSO, London.

BSI. British Standards Institution. 1988. *Code of practice for the identification of* potentially contaminated land and its investigation. Draft for Development. DD 175, 1988.

BSI British Standards Institution. 1999. *Code of practice for site investigations*. BS5930, 1999

BSI British Standards Institution. 2001. *Investigation of potentially contaminated sites – Code of practice*. BS10175, 2001.

DEFRA Department for Environment, Food and Rural Affairs. 2002a. *The Contaminated Land Exposure Assessment Model (CLEA): Technical Basis and Algorithms.* CLR10, Department for Environment, Food and Rural Affairs, Environment Agency, Swindon.

DEFRA Department for Environment, Food and Rural Affairs. 2002b. *Assessment of Risks to Human Health for Land Reclamation: An Overview of the Development of Soil Guideline Values and Related Research.* CLR7, Department for Environment, Food and Rural Affairs, Environment Agency, Swindon.

DEFRA Department for Environment, Food and Rural Affairs. 2002c. *Potential Contaminants for the Assessment of Land.* CLR8, Department for Environment, Food and Rural Affairs, Environment Agency, Swindon.

DEFRA Department for Environment, Food and Rural Affairs. 2002d. *Contaminants in Soil: Correlation of Toxicological Data and Intake Values for Humans.* CLR9, Department for Environment, Food and Rural Affairs, Environment Agency, Swindon.

DETR Department of the Environment Transport and the Regions. 2000. *Contaminated Land*. DETR Circular 2/2000, Contaminated Land Implementation of Part IIA of the Environmental Protection Act 1990, HMSO, London.

EDWARDS, R.A., SCRIVENER, R.C., BRISTOW, C.R., WILLIAMS, B.J., BARTON, C.M., GOODE, A.J.J, GALLOIS, R.W., ALLEN, P.M. and WILLIAMS, B.J. 1995. *Exeter, England and Wales Sheet 325. Solid and Drift geology 1:50,000 Series*. British Geological Survey, HMSO, London.

ENVIRONMENT AGENCY. 1998. *Groundwater Vulnerability of South Devon, 1:100,000 Map Series.* Sheet 49 South Devon. Policy and Practice for the Protection of Groundwater, HMSO, London.

KELLEY, R.T. 1980. Site Investigation and Materials Problems. Proceedings of Conference on Reclamation of Contaminated Land, Eastbourne, 1979. *Society of the Chemical Industry*, London.

ICRCL. Interdepartmental Committee on the Redevelopment of Contaminated Land. 1987a. *Guidance on the assessment and redevelopment of contaminated land.* (ICRCL) 59/83, Second Edition, July.

ICRCL. Interdepartmental Committee on the Redevelopment of Contaminated Land. 1987b. *Notes on the redevelopment of sewage works and farms.* (ICRCL) 23/79: Second Edition, July.

MACKNEY, D., HODGSON, J.M., HOLLIS, J.M. and STAINES, S.J. 1983. Legend for the 1:250,000 Soil Map of England and Wales. *Soil Survey of England and Wales*, Harpenden.

MYLREA, K. 1998. Recent UK legal developments relating to pollution of water resources. In: MATHER, J., BANKS, D., DUMPLETON, S. and FERMOUR, M. (eds), *Groundwater Contaminants and their Migration.* Geological Society, London, Special Publication, **128**, 15-21.

SOIL SURVEY. 1983. Soils of England and Wales. 1:250,000 *Sheet 5, South West England*. Soil Survey of England and Wales, Rothamsted.