(사) 한국 지하수토양환경학회
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토양 및 지하수 Investigation 과 Remediation 에 대한 현장적용

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ABSTRACT

Situated close to Heathrow Airport, and adjacent to the M4 and M25 Motorways, the site at Axis Park is considered a prime location for business in the UK. In consequnce two of the UK's major property development companies, MEPC and Redrow Homes sought the expertise of Intergeo to remediate the contaminated former industrial site prior to its development.

Industrial use of the twenty-six hectare site, started in 1936, when Hawker Aircraft commence aircraft manufacture. In 1963 the Firestone Tyre and Rubber Company purchased part of the site. Ford commenced vehicle production at the site in the mid-1970's and production was continued by Iveco Ford from 1986 to the plant's decommissioning in 1997.

Geologically the site is underlain by sand and gravel, deposited in prehistory by the River Thames, with London Clay at around 6m depth. The level of groundwater fluctuates seasonally at around 2.5m depth, moving slowly southwest towards local streams and watercourses.

A phased investigation of the site was undertaken, which culminated in the extensive site investigation undertaken by Intergeo in 1998. In total 50 boreholes, 90 probeholes and 60 trial pits were used to investigate the site and around 4000 solid and 1300 liquid samples were tested in the laboratory for chemical substances.

The investigations identified total petroleum hydrocarbons in the soil up to 25,000mg/kg. Diesel oil, with some lubricating oil were the main components.

Volatile organic compounds were identified in the groundwater in excess of 10mg/l. Specific substances included dichloromethane, trichloromethane and tetrachloroethene. Both the oil and volatile compounds were widely spread across the site. The specific substances identified could be traced back to industrial processes used at one or other dates in the sites history.

Slightly elevated levels of toxic metals and polycyclic aromatic hydrocarbons were also identified locally.

Prior to remediation of the site and throughout its progress, extensive liaison with the regulatory authorities and the client's professional representatives was required. In addition to meetings, numerous technical documents detailing methods and health and safety issues were required in order to comply with UK environmental and safety legislation.

After initially considering a range of options to undertake remediation, the following three main techniques were selected: ex-situ bioremediation of hydrocarbon contaminated soils, skimming of free floating hydrocarbon product from the water surface at wells and excavations and air stripping of volatile organic compounds from groundwater recovered from wells.

The achievements were as follows:

1) 350,000m3 of soil was excavated and 112,000m3 of sand and gravel was processed to remove gravel and cobble sized particles;
2) 53,000m3 of hydrocarbon contaminated soil was bioremediated in windrows;
3) 7000m3 of groundwater was processed by skimming to remove free floating product;
4) 196,000m3 of groundwater was processed by air stripping to remove volatile organic compounds.

Only 1000m3 of soil left the site for disposal in licensed waste facilities. Given the costs of disposal in the UK, the selected methods represented a considerable cost saving to the Clients. All other soil was engineered back into the ground to a precise geotechnical specification.

The following objective levels were achieved across the site:

1) By a Risk Based Corrective Action (RBCA) methodology it was demonstrated that soil with less that 1000mg/kg total petroleum hydrocarbons did not pose a hazard to health or water resources and therefore, could remain insitu;
2) Soils destined for the residential areas of the site were remediated to 250mg/kg total petroleum hydrocarbons; in the industrial areas 500mg/kg was proven acceptable.
3) Hydrocarbons in groundwater were remediated to below the Dutch Intervention Level of 0.6mg/l;
4) Volatile organic compounds/BTEX group substances were reduced to below the Dutch Intervention Levels;
5) Polycyclic aromatic hydrocarbons and metals were below Inter-departmental Committee for the Redevelopment of Contaminated Land guideline levels for intended enduse.

In order to verify the quality of the work 1500 chemical test results were submitted for the purpose of validation.

Quality assurance checks were undertaken by independent consultants and at an independent laboratory selected by Intergeo.

Long term monitoring of water quality was undertaken for a period of one year after remediation work had been completed. Both the regulatory authorities and Clients representatives endorsed the quality of remediation now completed at the site.

Subsequent to completion of the remediation work Redrow Homes constructed a prestige housing development. The properties at "Belvedere Place" retailed at premium prices.

On the MEPC site the Post Office, amongst others, has located a major sorting office for the London area. Exceptionally high standards of remediation, control and documentation were a requirement for the work undertaken here.

1. Introduction

Situated close to Heathrow Airport, and adjacent to the M4 and M25 Motorways, the site at Axis Park is considered a prime location for business in the UK. In consequnce two of the UK's major property development companies, MEPC and Redrow Homes sought the expertise of Intergeo to remediate the contaminated former industrial site prior to its development.

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The investigations identified total petroleum hydrocarbons (TPH) in the soil up to 25,000mg/kg. Hydrocarbon compounds in the range diesel oil were determined, with some lubricating oil. Volatile organic compounds were identified in the groundwater in excess of 10mg/l. Specific substances included dichloromethane, trichloromethane and tetrachloroethene. Both the oil and volatile compounds were widely spread across the site. The specific substances identified could be traced back to industrial processes used at one or other dates in the sites history. Slightly elevated levels of toxic metals and polycyclic aromatic hydrocarbons were also identified locally.

Prior to remediation of the site and throughout its progress, extensive liaison with the regulatory authorities and the client's professional representatives was required. In addition to meetings, numerous technical documents detailing methods and health and safety issues were prepared in order to comply with UK environmental and safety legislation.

After initially considering a range of options to undertake remediation, the following three main techniques were selected: ex-situ bioremediation of hydrocarbon contaminated soils, skimming of free floating hydrocarbon product from the water surface at wells and excavations and air stripping of volatile organic compounds from groundwater recovered from wells and excavations.

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* 350,000m3 of soil was excavated and 112,000m3 of sand and gravel was processed to remove gravel and cobble sized particles;
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* 7000m3 of groundwater was processed by skimming to remove free floating product;
* 196,000m3 of groundwater was processed by air stripping to remove volatile organic compounds.

2.Excavation

Where contamination was identifie during the investigations in total 350.000 m^3 of soil was excavated at and/or below the water table, pumping from dewatering wells was undertaken to effect a drawdown of the water level to expose the contaminated soils and permit their removal. The wells were located at strategic positions around and within the plumes of contamination, such that the cones of depression created encouraged any mobile contamination to run in towards the excavation and thus enhance the removal of free product and dissolved phase hydrocarbons.

The water extracted as part of the dewatering process was passed through the treatment plant and returned to the ground via discharge points which were located beyond and up-gradient of the zones of contamination, thereby assisting in flushing through any mobile contaminants.

The excavated contaminated material was transported to the screening area by dumptruck. In order to prevent generation of leachate, the material was screened immediately into threee stockpiles which were located either under the cover of available pre-demolition buildings or outside on an impermeable surface, but within a bunded area. The stockpiles comprised the following materials.

- Sand and material less than 15 mm
- Material between 15 mm and 40 mm in size
- Material greater than 40 mm in size

The material less than 15 mm in size was stockpiled inside of a bunded area until it was moved to bio-piles for bio-remediation. The material between 15 mm and 40 mm in size and with TPH contamination not exceeding 500 mg/kg was removed from site as an aggregate, or re-screened to a sized aggregate for a select market.

The material greater than 40 mm in size was stockpiled for backfill or crushed and removed from site.

Any soils containing significant proportions of sand or clays was directed to the bio-remediation stockpile without the need for screening.

3.Bioremediation

The bioremediation process involves stimulating the indigenous microbial population to degrade organic waste into biomass and harmless by-products of microbial metabolism such as carbon dioxide, water and inorganic salts. In most cases, the process relies on the aerobic metabolism of micro-organisms already present at the site.

The materials contaminated with TPH at Axis Park were excavated and placed on an impermeable concrete or tarmac surface. The area was bunded to prevent lateral migration of leachate.

The excavated soil was conditioned by using shredding and sieving equipment up to three times per week. Supplements such as inorganic nutrient and micro-nutrients were added to soil to stimulate microbial growth.

The sampling of the biopiles took place once a week. One representative sample was taken for every 250 tonnes: a 20 kg bulk sample was taken, mixed and then from this a 1 kg sample was cut and analysed. Every tenth sample was sent away to a third party accredited laboratory for independent analysis for TPHs. This sampling methodology was devised with the cooperation of the Environmental Health Officer.

The time taken between setting out the soil and removing the bioremediated soil to the "clean" stockpile varied according to the degree of contamination and weather conditions. Generally, it took between two and five weeks to reduce hydrocarbon levels to below the 500 mg/kg maximum acceptable level for reengineering of the material on the proposed industrial part of the site. A slightly longer period was required to achieve the 250mg/kg level required of the proposed residential part of the site.

The groundwater monitoring points within the bioremediation area were carefully protected from the biopiles by bunding to prevent the escape of hydrocarbons into the underlying soils, particularly during periods of inclement weather.

The size and configuration of the biopiles was determined by the machines used for oxygenating the pile. Each pile had a maximum dimension of 3m width at the base and 1.5m height, but was the maximum length possible within the limits of the remediation area. Because of the nature of the processing machine, a minimum distance of 3m was allowed between each biopile to give easy access for the oxygenating/turning equipment. If the material from the excavation area was very fine grained, then it was mixed with a coarser material to increase the porosity, to allow ingress of the oxygen necessary for the bacteria to be effective.

In some circumstances biopiles can be sheeted with plastic to retain warmth and prevent the ingress of moisture. At Axis Park this was not generally considered necessary. Every week samples were taken from the biopiles in order to document the progress of the brekdown of mineral oil hydrocarbons.

The anticipated rate of production of soils bioremediated to the target levels was 3,000 m^3 per week after an initial lead in period of 3 weeks.

4. Groundwater remediation

Groundwater was extracted as part of the dewatering process and was treated prior to being returned to the ground. In addition, oil skimming pumps were operated within excavations and within dewatering wells in the plume areas. The water from the depression pumps and the skimmer pumps was processed by passing the contaminated water through an oil/water separator. In some cases, two or three separators were used in series to expedite the remediation process For treatment of the VOC' s (BTEX, chlorinated solvents), air stripping techniques, in conjunction with oil separators, were adopted in localised areas.

Air stripping is an established technology in which volatile organic compounds are partitioned from the groundwater by greatly increasing the surface area of the contaminated water exposed to air. It results in the mass transfer of volatile contaminant from water to air. For groundwater remediation, this process is typically conducted in a packed tower of approximately 5m height. The typical packed tower air stripper includes a spray nozzle at the top of the tower to distribute contaminated water over the packing in the column, a fan to force air counter−current to the water flow, and a pump at the bottom of the tower to collect decontaminated water. Today in the UK carbon filters are placed in the air stream to collect volatile compounds. At the date of the work at Axis Park, this was not a legal requirement.

Groundwater contaminated with BTEX and chlorinated compounds was pumped by mineral oil resistant submersible pumps to the stripping towers, from trial pits, concrete wells and standpipes placed in boreholes. The clean water resulting from processing methods was returned to the groundwater at wells. To monitor the effectiveness of the air stripping process and functioning of the tower, water was tested regularly on entry to, and exit from, the towers. Where necessary, groundwater was circulated a further time through the towers in order to achieve objective levels for groundwater quality.

5.Backfilling and compaction

As the validation of the remediated material was completed, backfilling operations started. The material when used for backfilling had to meet a precise geotechnical specification. In consequence crushed demolition material, bioremediated soils and unremediated soils were blended together to form a backfilling material appropriate to the area of the site where it was to be placed. For example, it was specified by the Clients that the foundations to residental dwellings should be placed on a coarser backfill than that specified below the floor slab of industrial units.

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6.Environmental Control

The management and implimentation of environmental control measures was an important duty set out in the contract for remediation work. The remediation process necessitated the following measures:

- Setting up of clean and dirty areas;

- Control of dust;
- Control of vehicles;
- Wheel washing;
- Control of surface water in contaminated areas.

As the excavation of contaminated areas across the site progressed, separate clean and dirty areas were defined. Orange Netlon bi-visibility fencing was placed along the boundary between each clean and dirty area and the positions revised daily in agreement with the Employer's Agent's site representative.

Stockpiles and exposed working areas were inspected on a daily basis to confirm that the surface of the stockpile or working area was not in a dry condition, such that it could give rise to wind generated dust. If the inspection indicated dry surface conditions, water was sprayed onto the dry material to damp down the surface.

The stockpiles were bunded to prevent any excess, potentially contaminated water from running onto the surrounding area. Water sprayed onto working areas was carefully controlled so as to not over-saturate the soils and cause migration of contaminants.

The frequency of inspection increased during sunny and windy periods as necessary. The plant used to screen and separate materials prior to transferring to stockpiles was, when necessary, adequately shrouded to prevent dust generation.

All vehicles entering or leaving the site were logged at the gatehouse for the following information;

- Date / time;
- Weight of load empty and full;
- Haulage company & registration number;
- Driver name;
- Type of load;
- Tip destination.

Separate record logs were kept for each type of material taken off–site. All vehicles were sheeted–up in a designated area on the site, which was provided with facilities for the sheeting of vehicles without exposing workers to contaminated soil and so that the video cameras linked to the Clints office by Internet could view the loads on exit. In part this was necessary because of the extensive associated work on site, which included demolition of buildings an highways realignment.

7.Monitoring

Monitoring was required throughout the works in order to confirm that the remediation was progressing as planned and that no significant migration of mobile contaminants was occurring.

Groundwater monitoring was a requirement of the Environment Agency Scientific Support Division to ensure that no deterioration of groundwater quality occured as a result of activities associated with the works. In this connection groundwater monitoring took place in boreholes placed around the perimeter of the site and down–gradient of excavations.

Perimeter boreholes were monitored for groundwater quality at least once before any excavation of the soils took place. The determinants included the following contaminants:

- Mineral oils (TPH)
- BTEX
- Chlorinated hydrocarbons

Post remediation monitoring was undertaken from key monitoring points agreed with the Environment Agency and the Employers Agent. The period of monitoring was 1 year with samples being taken at monthly intervals.

Soil gas monitoring was undertaken at monitoring points along the south and south east boundaries to the site to determine the presence or otherwise of migrating landfill gases from an offsite source. For a number of documented reasons no significant gas was detected.

In addition further soil gas sampling points were located in areas where mineral oil contamination had been removed in order to confirm that no methane gas assiciated with hydrocarbons was present. Monitoring for methane, carbon dioxide and oxygen was undertaken on a fortnightly basis during the works and was continued on a monthly basis for 1 year after completion of site works.

8.Summary

The following objective levels were achieved across the site:

- By a Risk Based Corrective Action (RBCA) methodology it was demonstrated that soil with less that 1000mg/kg total petroleum hydrocarbons did not pose a hazard to health or water resources and therefore, could remain insitu;
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Subject: Bioslurping LNAPL (Light Non-Aqueous Petroleum Liquid) Contamination-

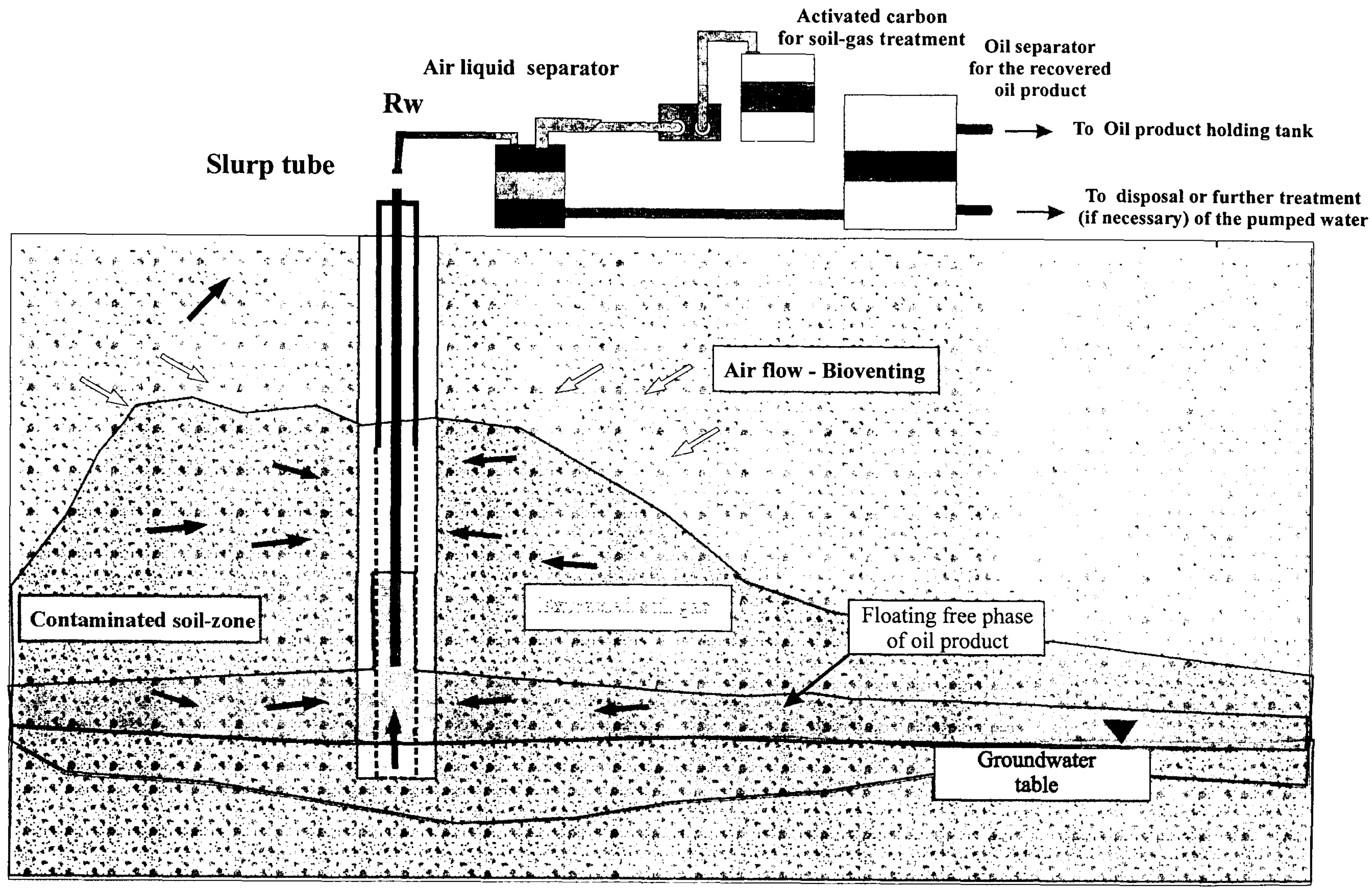
Treatment of contaminated soil and groundwater with petroleum hydrocarbons

Case study: Decontamination of soil and groundwater at an oil product terminal in south Europe

Authors: Dr. Stylianos A. Papadopoulos-INTERGEO Thessaloniki
Dr. Christos Vatseris- INTERGEO Thessaloniki

Abstract: Bioslurping is an innovative technology for the remediation of sites contaminated with petroleum hydrocarbons (LNAPLs). For certain sites, it promises to be a fast, less costly and effective cleanup solution. This technology should only be selected based on a thorough understanding of the site's characteristics, including geology and hydrogeology.

Figure 1: Concept of combined decontamination techniques for the subsoil and the groundwater (Oil product recovery) by means of BIOSLURPING (Vacuum-enhanced free product recovery plus bioventing)



Bioslurping2.cdr

Subject: Treatment of contaminated soil with sulfuric acid.

Case study: Decontamination of 43,000 m^3 subsoil in Cyprus

Authors: Dr. Stylianos A. Papadopoulos-INTERGEO Thessaloniki
Dr. Christos Vatseris- INTERGEO Thessaloniki
Dr. Armin K hler-INTERGEO Augsburg

Abstract: In 1996, after the end of the operation of a Fertilizer Factory an amount of about 600 to 1000 m^3 of pure sulfuric acid was disposed in natural lagoons nearby that were coated with natural clay. To coat the natural material and deposits, the entire area was covered with limestone soil that represented together with claystone, the natural soil of the area.

The decision to build a new power plant in that area created the necessity of the decontamination project.

INTERGEO was assigned to neutralize the contaminated soil of the site and dispose it in a special prepared encapsulation cell.

The decontamination measures in the contaminated site were carried out in 4 different phases:

- Phase I: Investigation
- Phase II: Pumping and Neutralization of the liquid sulfuric acid
- Phase III: Solid phase Neutralization
- Phase IV: Disposal of the neutralized soil

The total amount of the pumped sulfuric acid during the pumping procedure reached 645 m^3.

The total amount of the neutralized soil finally reached 43.020 m^3

Distribution of the pH-value of the soil in the depth of 0 - 1.3 m b.g.l.

Figure 1: Distribution of soil pH in two levels

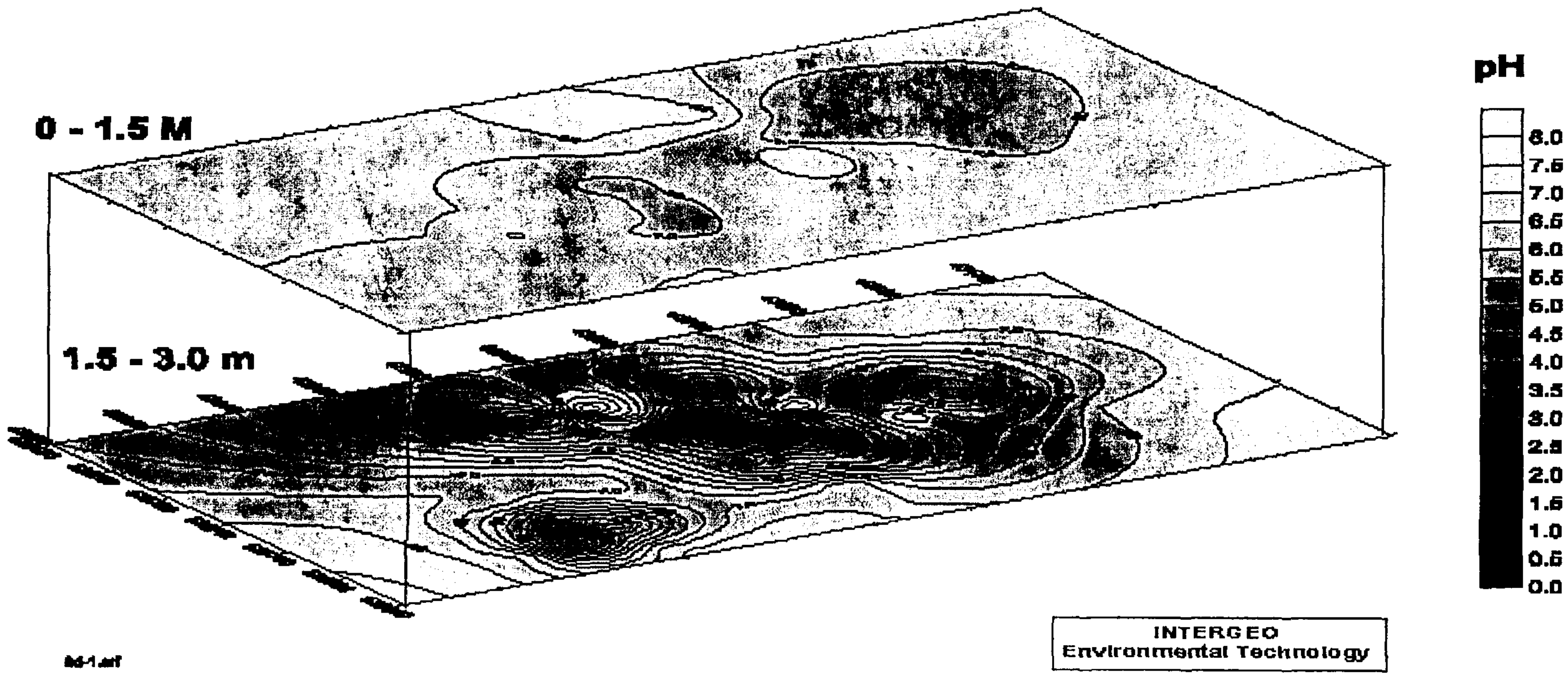


**Figure 2: Final location of the performed pumping wells and neutralization pits
Total amount of pumped sulfuric acid in the different groups.**

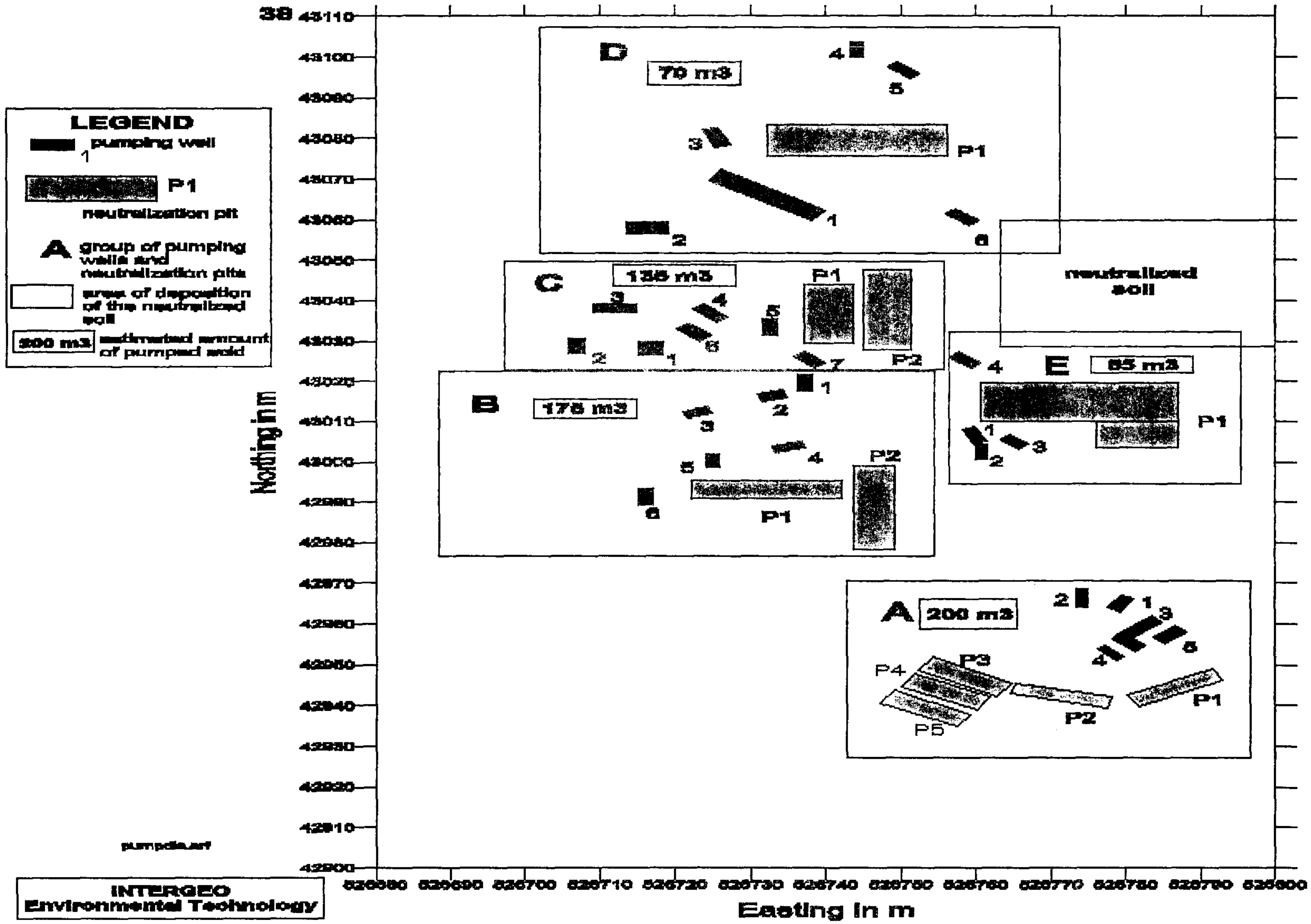


Figure 3 : Vertical profile of the encapsulation cell

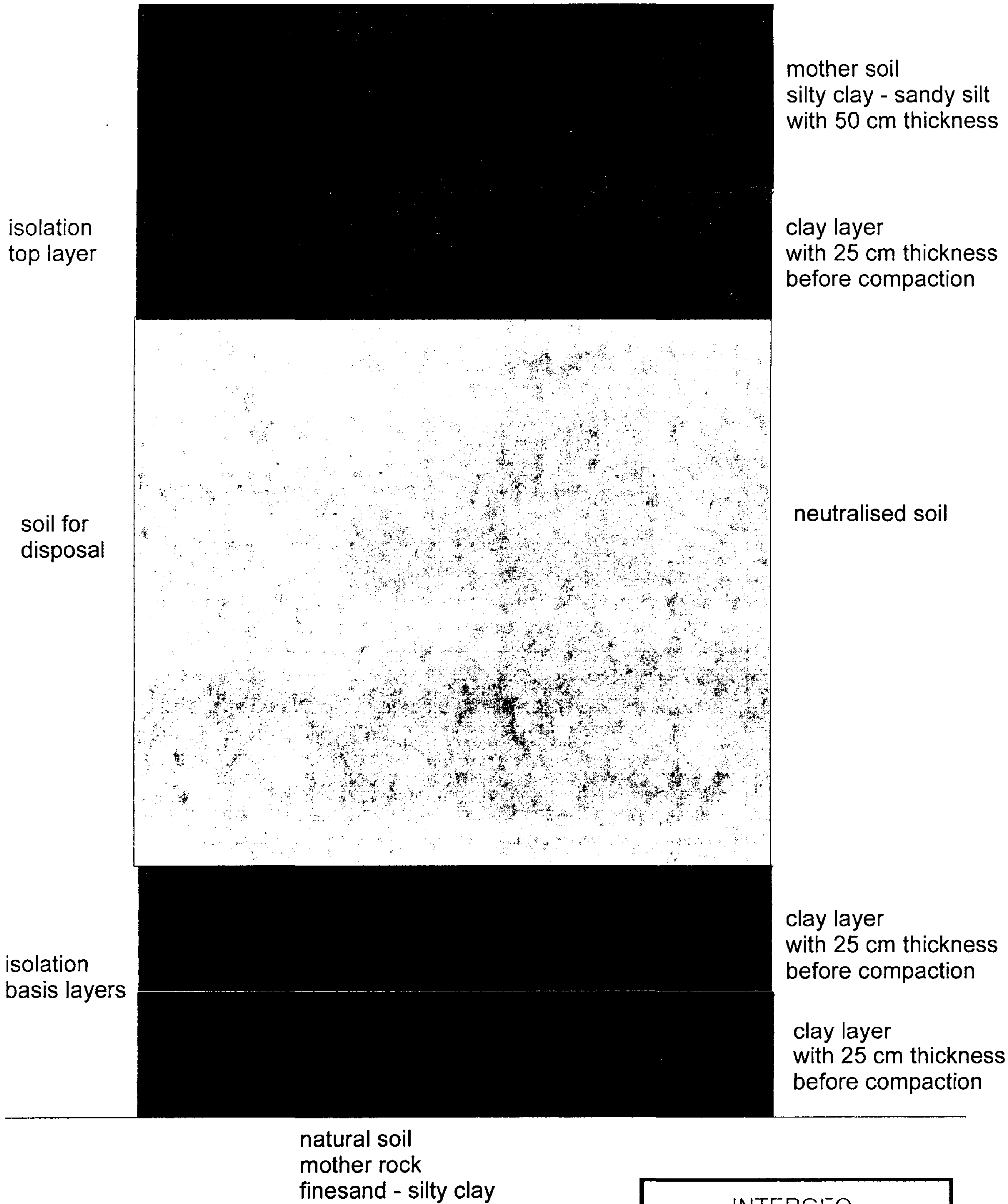


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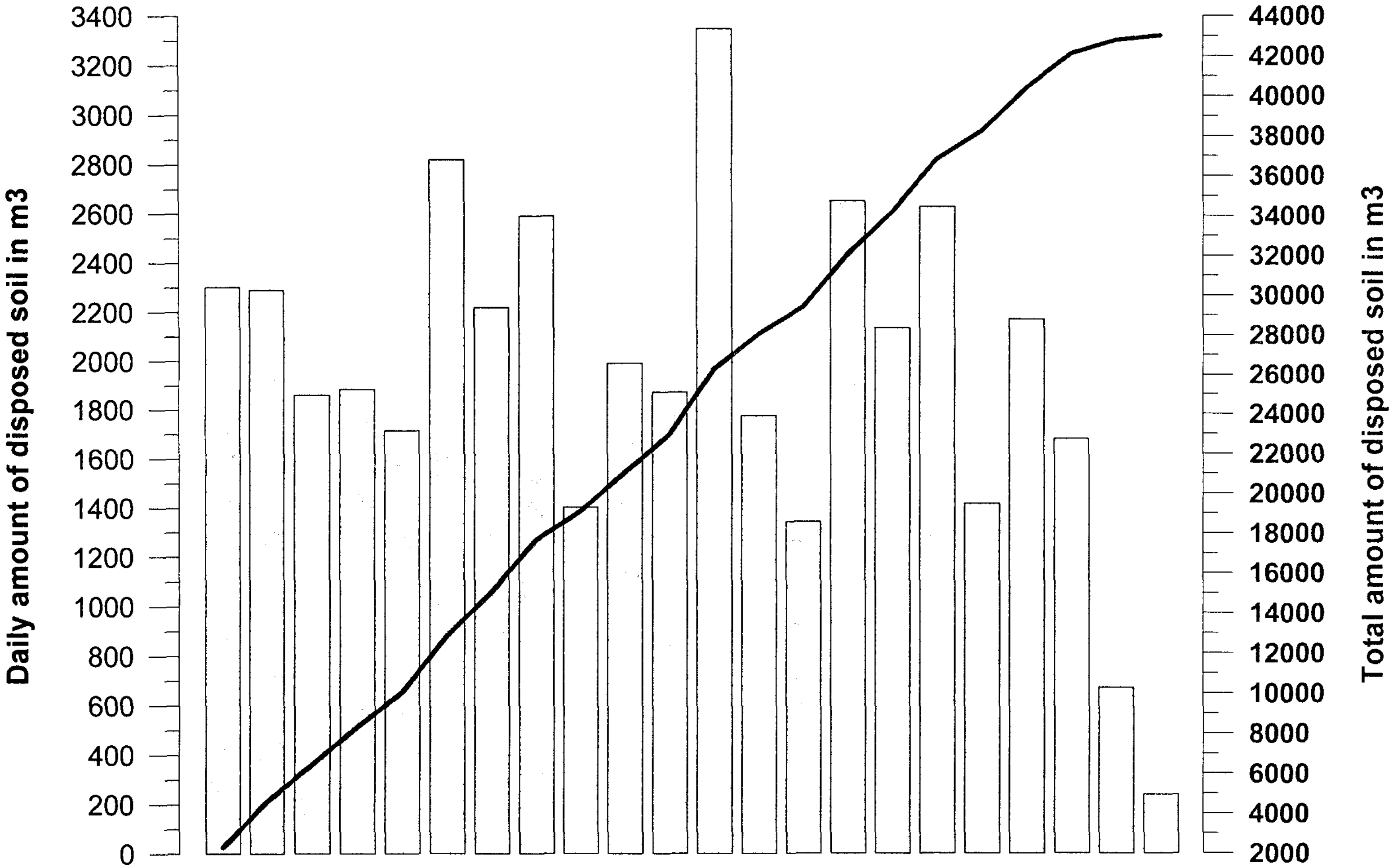
Figure 4 : Disposal of the neutralized soil in the encapsulation cell.
Daily amount and total amount of disposed soil from 2/5 till 28/5/1996



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