Chapter 4

LAND CONTAMINATION

4 LAND CONTAMINATION

Introduction

4.1 As detailed in the *Theme Park EIA*, Cheoy Lee Shipyard (CLS) located on the north and eastern shores of Penny's Bay, was identified as the primary land use of concern for land contamination. Additionally, the decommissioning of CLS comprises a Designated Project under Schedule 2 of the *EIAO*. To allow the Theme Park and associated infrastructure development, CLS should be decommissioned and properly remediated. As such, site investigation (SI) at CLS is necessary.

4.2 Site investigation was split into two distinct phases (Advanced SI and Phase 2 SI) due to site access limitation in the earlier phase of the project. The advanced SI, which included the advancement of 13 boreholes, was carried out with the consent of shipyard occupier between November and December 2000 when the site was under private ownership and was yet to be resumed by HKSAR Government.

4.3 The advanced SI identified a number of locations at the shipyard site having signs of soil and groundwater contamination. Due to access restriction, the extent of contamination could not be quantified at that time. Detailed Phase 2 SI was recommended be carried out throughout the whole site after resumption of the shipyard.

4.4 After the resumption of the subject shipyard in April 2001, the Phase 2 SI at the former CLS site for the preparation of the EIA report was commenced in June 2001 and was completed in November 2001. The Phase 2 SI was carried out in accordance with the Contamination Assessment Plan (CAP), which had been approved by EPD.

4.5 The primary area addressed by the SI is the former location of the CLS, situated at the head of and along the eastern shore of Penny's Bay. The CLS site comprises approximately 18.7 hectares of primarily reclaimed land along the bay waterfront. The CLS used the site for construction and repair of fiberglass (also known as glass reinforced plastic or GRP), wooden, aluminium, and steel-hulled ships from 1963 until 2000.

4.6 The outlines of the approved CAP and the content of the Contamination Assessment Report (CAR) and the Remediation Action Plan (RAP) are presented in this chapter.

4.7 On the issue of land contamination, URS Corporation (URS) in association with BMT Asia Pacific (BMT), collectively referred as the Independent Environmental Consultant (IEC), have conducted separate environmental assessment and remediation assessment at the CLS site. Their inputs to the land contamination process include designing the Remedial Investigation Work Plan (RIWP), providing oversight for the site investigation works, independent assessment on the nature and extent of contamination, evaluation of the risks and recommendation on-site clean up measures. The IEC's report summarising their independent findings is annexed in Appendix 4I.

Environmental Legislation, Policies, Plans, Standards and Criteria

4.8 The SI has been conducted following HKSAR Environmental Protection Department's (EPD's) *Practice Note for Professional Persons, Contaminated Land Assessment and Remediation* (ProPECC Note PN 3/94) and EPD's *Guidance Notes for Investigation and Remediation of Contaminated Sites of Petrol Filling Stations, Boatyards, and Car Repairing/*

Dismantling Workshops and the U.S. Environmental Protection Agency's (USEPA's) *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA*.

4.9 Hong Kong environmental guidelines make reference to criteria (Dutch List) developed in the Netherlands, which are comprehensive and widely used for contaminated site assessment. However, numerous chemicals analysed are not included in the Dutch List. As such, in the present assessment, a hierarchy of action levels and/or cleanup standards was adopted. In order of priority, these include the following 3 types of standards:

i) Dutch "B" standards;

ii) If there is no Dutch "B" standard for a certain chemical, U.S. Environmental Protection Agency (USEPA) federal standard was adopted (e.g. Soil Screening Levels (SSL) published under *Soil Screening Guidance : Technical Background Document*);

iii) If there is no USEPA federal standard, USEPA Region IX Preliminary Remediation Goal (PRG) was used. The USEPA Region IX PRGs are adopted because they are more comprehensive compared with other USEPA regional standards.

Dutch Guidelines

4.10 The Dutch criteria consist of three levels of standards for a range of soil and groundwater contaminants, representing the following three scenarios:

- A – level implies unpolluted;
- B – level implies potential pollution present and requires further investigation or remediation; and
- C – level implies pollution, which requires remediation.

4.11 The Dutch guidelines are very stringent as they are developed based on a 'good for all uses' philosophy. The EPD generally requires remediation for soil contamination above the Dutch 'B' Standards. In other words, the Dutch 'B' standards are the clean-up target for remediation of soil.

USEPA Federal Standard

4.12 The USEPA federal standard contains generic Soil Screening Levels (SSLs) for 110 chemicals. The generic SSL are derived using default values in standardised equations. The default values are conservative and are likely to be protective for the majority of site conditions across the nation. It should be noted that for some chemicals, there are four SSL representing four pathways, namely direct ingestion, inhalation, migration to groundwater (with dilution-attenuation factor of 20) and migration to groundwater (no dilution-attenuation). For each chemical, the SSL for ingestion or for inhalation, whichever is lower, was used for screening.

USEPA Region IX PRGs

4.13 PRGs, risk-based concentrations taking into account of exposure pathway and toxicity data, are tools for evaluating and cleaning up contaminated sites in U.S. Environmental Protection

Agency (USEPA) Region IX Superfund sites. Two PRGs are applicable for soil medium, namely residential soil and industrial soil. In this SI, for conservative approach, the PRGs for residential soil are adopted as the action levels for chemicals not included in Dutch guidelines. Please refer Appendix 4A for the action levels for soil remediation.

Risk-based Criteria for Groundwater

4.14 The Dutch standards for groundwater and the USEPA Region IX PRGs for tap water are not directly applicable in assessing the groundwater contamination in Hong Kong, where groundwater is not a source of potable water. (The USEPA federal standard does not contain groundwater screening levels). As such, the Dutch 'B' standards and the USEPA Region IX PRGs for tap water are only for screening out the chemicals of concern for risk assessment and are not for assessing groundwater contamination in Hong Kong. A risk-based assessment would be carried out for chemicals with concentration exceeding the Dutch 'B' standards or the USEPA Region IX PRGs for tap water if there is no Dutch 'B' standard for a certain chemical to evaluate the risks posed to the sensitive receptors. The risk-based assessment that has been adopted in USEPA takes into account concentrations of individual contaminants in groundwater, the anticipated most sensitive human receptor and the potential exposure pathways. For a worst-case scenario, the largest contaminant concentrations in the groundwater samples would be taken as the source concentration for the risk calculation.

4.15 Exceedance of the risk-based criteria would be qualified in two tiers. For noncarcinogens, the first is the Total Pathway Hazard Index (TPHI) that is the sum of contaminant hazard quotients exceeds one. The second is the largest contaminant concentration exceeds the corresponding Risk-based Screening Level (RBSL) that is derived from the recognised oral reference dose. For carcinogens, the first is the Total Carcinogenic Risk that is the sum of contaminant carcinogenic risk exceeds 1×10^{-6}. The second is the largest carcinogenic contaminant concentration exceeds the corresponding RBSL that is derived from the recognised carcinogenic slope factor.

Action Level / Cleanup Target for Dioxins

4.16 The USEPA's OSWER Directive 9200.4-26 ("Approach for Addressing Dioxin in Soil at Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and Resource Conservation and Recovery Act (RCRA) Sites" signed 13 April 1998) states that 1 ppb Toxicological Equivalence Quotient (TEQ) is generally recommended as a cleanup target for dioxins for residential soils at CERCLA and RCRA sites (5 to 20 ppb TEQ has been selected for industrial use scenarios). As such, 1 ppb TEQ is used as both the action level and cleanup target for dioxins in the present study.

Universal Treatment Standards

4.17 For metal contaminants to be remediated by solidification, the Universal Treatment Standards (UTS) of U.S. Resource Conservation and Recovery Act (RCRA) wastes that contain metals (in 40 CFR 268) should be referred. These standards were derived from the performance of the Best Demonstrated Available Technologies for treating these types of wastes.

4.18 Treating dioxin-contaminated soil to 1 ppb TEQ would meet the Universal Treatment Standards (UTS) and would be consistent with USEPA's OSWER Directive 9200.4-26. In Hong Kong, the UTS standards have been applied to the acceptance criteria of metal contaminated soil treatment

Site Setting and Physical Characteristics of Study Area

Overview

4.19 The most detailed information available regarding site land use and former operations at the CLS site at Penny's Bay is contained in the *Final Environmental Impact Assessment Report for Lantau Port Development—Stage 1, Reclamation for Shipyard at To Kau Wan, North Lantau, EIA for Operational Phase* prepared by Binnie Consultants Limited (BCL, October 1995).

4.20 According to BCL, Cheoy Lee Shipyards Limited established their Penny's Bay shipyard in 1963 on reclaimed land leased from the Government. Over the years of operation, the CLS site was expanded, with additional land reclamation to the southeast of the original site. CLS' shipbuilding business consisted of three main activities: fiberglass or glass-reinforced plastic (GRP) boat manufacture, metal (usually steel or aluminium) boat manufacture, and boat repair and maintenance. Historically, CLS manufactured wooden-hulled boats, and the sawmill operations and building were present until plant operations ceased. CLS's boat-building operations included complete fabrication from raw materials to the finished product, which minimised purchase of components from other suppliers.

4.21 Ships and boats fabricated at the CLS site ranged from small launches to ocean-going yachts, passenger ferries, tugs and luxury pleasure craft. Vessels up to 80 meters (260 feet) in length were constructed at the site.

4.22 The boat repair and maintenance aspect of Cheoy Lee's business included general repair of boat hulls and superstructures, shot blasting of boat hulls, re-painting, and the repair, or removal for renovation, of marine engines.

4.23 The Penny's Bay Shipyard layout evolved over time and was modified to suit changing demand. CLS increased the size of the shipyard land area with further reclamation by quarrying the hillside to provide the materials for reclamation. According to the Final EIA Report by BCL (1995), the reclaimed area used by CLS at the time the EIA was prepared totaled approximately 14 hectares (34.6 acres); of which about 4.2 hectares (10.4 acres) was occupied by buildings, 2.1 hectares (5.2 acres) for the storage of fiberglass boat molds and 7.5 hectares (18.5 acres) of open areas and roads for access, cranes, storage, maneuvering, slipways and open-air boat fabrication.

Site Details

4.24 The CLS site was divided into three areas: Area 1 consists of the northern part of the site that was the original CLS facility; Area 2 includes the central part of the site that was formed by land reclamation following initiation of shipbuilding operations by CLS within Area 1; and Area 3 includes the southeastern portion of the site, which is located on the most recent part of reclaimed land.

Area 1

Building A—Company Store

4.25 This building is approximately 9 by 46 metres (30 by 150 feet) in size and appears to have been used for dry goods storage, including various boat/ship fittings and components.

Building B—Plating, Anodising and Laboratory

4.26 The building was used by CLS for metals electroplating and anodising. It also has a small quality control testing laboratory. An office was also present in the southwestern corner of the building. The building is approximately 19 by 67 metres (62 by 220 feet) in size.

4.27 Chemicals that are used in the plating and anodising process are included:

- Copper cyanide;
- Sodium hydroxide;
- Sodium carbonate;
- Nickel chloride;
- Boric acid;
- Chromic acid;
- Sulphuric acid;
- Phosphoric acid; and
- Nitric acid.

4.28 Various other chemicals may have been used, such as trisodium phosphate of sodium carbonate during the alkali wash, or ammonia to neutralise the wastewater.

4.29 From the chemicals listed above, cyanide and hexavalent chromium are probably of greatest concern due to their known acute toxicity. Other chemicals used were either very corrosive, such as acids and alkalis, or toxic, such as nickel or copper solutions. The plating and anodising operations were carried out as a batch process and that all of the plating and acid baths did not discharge waste into the drainage system but were either continually topped up with fresh chemicals or, when potency of the solution fell below that required, poured into a container for disposal.

4.30 The waste discharge from each of the washing processes were reportedly collected in a large underfloor "diffuser" before being discharged to the drainage system. The drainage discharge reportedly was monitored for pH, nickel, copper, iron, cyanide and phosphorus by the in-house laboratory so as to comply with the discharge regulations specified in CLS' Water Pollution Control Ordinance License.

4.31 The laboratory present in this building was used to measure the quality of metals formed in the foundry and to monitor the quality of solutions and effluent from the electroplating and anodising operations.

Building C—Warehouse

4.32 The warehouse was reported by BCL to have been used for dry goods storage. The building is approximately by 9 by 46 metres (30 by 150 feet) in size and contains a mezzanine level of steel construction over approximately one-half of the building. The building appeared to have a fairly new roof and floor, suggesting it had been remodelled.

Building D—Hull Moulding and Pressing Workshop, Aluminium Smelter

4.33 Building D is a large multi-use building that has been compartmentalised with interior walls separating different use areas. The building was originally two separate buildings with an intervening open-air passageway. The passageway was subsequently roofed over and a concrete floor placed to create one building. Overall, the building is approximately 43 by 46 metres (140 by 150 feet) in size.

4.34 Storage and an office area were located on the eastern part of the building. An aluminium smelter, document storage area and an office was located on the second bay from eastern of the building. The smelter area at the rear contain a crucible furnace with a hood and venting system. The furnace was apparently fuelled with diesel fuel and is supplied by an aboveground diesel tank mounted on the wall adjacent to the furnace. A die-casting and metal stamping area was situated at central part of the building. A small-scale fiberglassing and pipe storage was located in the western part of this building.

Building E and F—Security Guards Quarters and Staff Canteen

4.35 Building E and F are approximately 6 by 32 metres (20 by 105 feet). These buildings are served as site security guards quarters and a staff canteen for resident CLS staff.

Building G—Worker's Canteen

4.36 This building served as the kitchen and dining area for the CLS workers. The main environmental concern may be associated with food waste and oil and grease.

Building H—Dangerous Goods Stores

4.37 Building H consists of two parts. This is a row of six 3-metre square (10 feet by 10 feet) concrete-constructed dangerous goods lockers along one side and a partially depressed larger storage area that measures approximately 9 by 10 meters (30 by 35 feet) to the rear.

4.38 The dangerous goods lockers were constructed with walls on the order of 30 cm (1 foot) thick and a 0.5 m (1.5 feet) high door sill that provided secondary containment. The lockers were contained as labelled, from east to west, MEKP, paints, oxygen (O_2), paints, sulphuric and acetylene.

4.39 The building to the rear has an elevated loading dock approximately 1 meter (3.3 feet) above ground level with stairs leading down approximately 2.5 metres (8 feet) to a concrete floor. This area is used to store fiberglass resins.

Building I—Machine Shop

4.40 The machine shop is an approximately 18 by 32 meters (60 by 105 feet) in size and consists of two bays. Two diesel fuel-fired crucible furnaces were located in the northern bay. A tool and parts storage room and another open area of unknown past use is located at the southern bay. Stamping steel, fabrication and assembly of various components may be processed in this area.

Building J—Lost Wax Store

4.41 Lost wax store is a small, approximately 9 by 18 metres (30 by 60 feet) two-storey building located adjacent to the machine shop and foundry. A small crucible furnace, a mould curing area, and three apparent dip tanks and a number of propeller molds were located in the in the first floor. Storage of welding electrode is the main purpose for second floor.

Building K—Fiberglass Hull Construction Workshop

4.42 This large building is approximately 43 by 46 metres (140 by 150 feet) in size and was formerly used for laying up of fiberglass boat hulls. It has an open-plan construction with interior columns supporting the roof and a concrete floor.

Building L—Foundry

4.43 The foundry building is approximately 18 by 46 metres (60 by 150 feet) in size and is a large, open bay building. A large induction furnace for stainless steel production, three smaller diesel-fuelled crucible furnaces, three large annealing furnaces and a burn pit were located in the building.

4.44 An aboveground tank mounted on the exterior building supplied diesel to the three crucible furnaces. The annealing furnaces were fuelled with diesel fed from aboveground tanks adjacent to the furnaces. A burn pit with burned wood and ashes with approximately 2 meters (6.5 feet) was located in the building.

Building M—Former Rolling Mill

4.45 Building M was formerly used for rolling of metal sheets for fabrication of steel-hulled vessels. This building was dismantled sometime prior to 1991. The area has been used as a scrap yard.

Building N—Metal Stamping Building (a.k.a. Hammer Room)

4.46 The building N is approximately 9 by 14 metres (30 by 45 feet) building that contained a remnant foundation from heavy machinery.

Building O—Sawmill and Moulding Shed

4.47 The building is approximately 24 by 73 metres (80 by 240 feet). It consists of two parts, sawmill and moulding shed, separated by a wall down its long axis. It was equipped with wood milling equipment.

Building P—Leather Dressing, Stores, and Vehicle Maintenance Shed

4.48 This building is approximately 15 by 37 metres (50 by 120 feet). The building served for two activities, vehicle maintenance and leather dressing and stores. The vehicle maintenance shed occupied an area roughly 6 by 15 metres (20 by 50 feet). The leather dressing and stores part is a two-storey building.

Fuelling and Loading Area along Seawall

4.49 There was an area adjacent to the seawall at the southeast end of Buildings A, B, P and O being used for salvage and for loading of these materials onto barges for offsite shipment.

Area 2

Building R—Fiberglass Boat Finishing (Yacht Building)

4.50 This open-plan building is approximately 47 by 47 metres (154 by 154 feet) in size. It has a very high roof and a roof drain system connected to the perimeter drain system. The building was used for fiberglass boat finishing.

Building S—Boat Finishing (Yacht Building)

4.51 The building is approximately 43 by 70 metres (140 by 230 feet) in size and has a high-roof. A row of office, tool crib, and speciality rooms was located in the building.

Building T—Boat Finishing and Painting Building

4.52 The building is compartmentalised and is approximately 33 by 70 meters in size. This building was used for painting and drying of shipbuilding components and yachts, yacht finishing and plumbing and joinery. Besides, some areas are used as offices, storage of fitting, piping and other materials and solvent still area.

Building U—Fire Suppression Pump House

4.53 The building is small and is located adjacent to the seawall near the slipway in the central part of the site. A diesel powered engine and pump for firefighting were located in the building.

Building V—Mould Lofting Room, Paint Booth, and Mould Mock-up Building

4.54 The building is approximately 41 to 44 metres by 70 metres (135 to 145 by 230 feet). The building contained a mould lofting room, paint spray booth and wood mould mock-ups.

Building W-Welding/Metal Workshop

4.55 Building W is an approximately 25 by 25 metres (82 by 82 feet) open building. It was used for welding and metal works, like grinding and steel fabrication. It contained a transfer room.

Building X—Shot-blasting Building

4.56 Building X is approximately 11 metres wide by 26 metres long (35 by 85 feet). It is located adjacent to the welding/metal workshop. Shot-blasting was processed in the building to make a clean surface for finishing.

Building Y—Metal Workshop/Hull Finishing Building

4.57 The building is approximately 19 by 58 metres (63 by 190 feet). It was used for welding and fabrication of steel-hulled vessels.

Building Z—Metal Boat/Metal Sheet Fabrication Building

4.58 Building Z is approximately 19 by 43 metres (62 by 140 feet) and open at both ends. The building had an office-like enclosure or tool crib.

Slipway and Boat Launch

4.59 A boat slipway (launch ramp) was located adjacent to the pump house (Building U). It has an elevated ramp north of the slipway near the northern end of Building Y.

Area 3

Building Q—Boat Repair Building and Area

4.60 This building is located at the southeastern area of the site adjacent of two parallel slips for docking of vessels. Maintenance and repair of vessels was performed in this area. Several sheds and a long rectangular building were used to store various paints and solvents used in boat maintenance and refinishing. Paint chipping as preparation for painting was also performed in this area. Some engine or other mechanical equipment maintenance and repair was located in the building.

Hull Mould Storage Area

4.61 The area extending from the base of the hills behind Building S southeastward to the fence line was used by CLS to store fiberglass hull molds. Based on review of aerial photographs taken in 1991, more than 125 molds of various sizes and configurations were stored in this area of the site.

Identification of Sensitive Receivers

4.62 Typical land uses to be considered as sensitive receivers include residential gardens and grassed public areas, such as parks and playgrounds. No such sensitive receivers are represented in our assessment area. There are no agricultural or groundwater wells in the subject shipyard to create two potential contaminant exposure pathways, namely produce and potable water. This situation affords little exposure of aboveground population to underlying soil. Consequently the identification of sensitive receivers will be dependent both upon the locations of the redevelopment of existing sites and when this will take place, and upon the proposed end use of the land.

4.63 Any contaminated soil and groundwater found within the site will be remediated and any such remediation system will be effectively mitigated so as to prevent any potential negative impact. No contaminated soil and groundwater is likely to remain after remediation to the agreed cleanup targets and satisfaction of EPD. As such, land contamination at CLS will not adversely affect the Theme Park development and will not pose significant heath threat to the future users of the site.

4.64 Compared to the future land users, construction workers will be more exposed to the contaminated material during excavation and remediation works. Therefore, mitigation measures for workers' health and safety should be addressed. The principal exposure routes for workers include:

- Direct ingestion of contaminated soils through eating or drinking on site; and
- Dermal contact with contaminated spoil during earth moving operations and excavation.
- Inhalation of dust (from soil).

Assessment Methodology

4.65 The objectives of the SI are to:

i) Identify sources of contamination beneath the CLS site;

ii) Define the presence, nature, and concentrations of contaminants in soil and groundwater beneath the CLS site and establish their vertical and lateral extents;

iii) Evaluate the potential risk to humans and the environment posed by the identified soil and groundwater contamination; and

iv) Establish cleanup levels for contaminants identified to be present at concentrations that exceed appropriate risk-based criteria.

4.66 The following tasks have been undertaken:

- Review of the current and historical land uses of the shipyard to evaluate the likelihood of contamination.
- Description of the nature and extent of contamination based on the available analytical data.
- Recommendations of appropriate and cost-effective remediation strategy to cleanup the site.

Soil Boring and Sampling

4.67 For buildings with limited use of chemicals and no apparent signs of contamination, limited soil borings were planned to provide site coverage. However, extensive sampling and testing were conducted in areas where significant use of chemical was expected and visual signs of contamination were noted. For areas with access limits of drilling equipment or where shallow impacts are of concern, soil samples were collected at depths of 0.15m, 0.75m and 1.5m below ground surface (bgs). In areas where liquid chemical or fuel hydrocarbon releases are of concern, samplings were proceeded at 3m and 4.5m bgs.

Exploratory Trenching

4.68 The southeastern area of the site formerly used for hull mould storage, and where burn pits are suspected and disposal to open trench was observed, a phased approach consisting of geophysical surveys and trenching were carried out. Geophysical survey (i.e. employing electromagnetic ground conductivity mapping, magnetic mapping, and ground penetrating radar profiling) exploring subsurface anomalies indicative of past disposal activities was conducted by a Geophysical Surveying Contractor. Areas identified with geophysical anomalies were explored by excavation, visual inspection, logging, and sampling in a series of trenches by backhoe.

Groundwater Investigation

4.69 Impacts to groundwater were assessed by installing, developing and sampling at groundwater monitoring wells.

Soil Analytical Programme

4.70 Metals, Total Petroleum Hydrocarbons (TPH), Volatile Organic Compounds (VOCs), Semi-volatile Organic Compounds (SVOCs), pH and cyanide were tested for in all samples. Hexavalent chromium was tested at selected locations. Polychlorinated Biphenyls (PCBs) were tested soil samples taken at locations where electrical equipment or oil heating bath which might use PCB-containing oil. Dioxins were tested in apparent burning areas. Tributyltin (TBT) was tested in areas where metal-hulled boats were constructed or repaired.

Testing of pesticides and herbicides were done in areas where such chemicals might have been used to control vermin and weed.

4.71 In addition to the above chemical testing, physical parameters such as moisture content, bulk and grain density, effective and air filled porosity, total organic carbon (TOC), and permeability and hydraulic conductivity were tested at the locations of groundwater monitoring wells for evaluating the fate and mobility of contaminants.

Groundwater Analytical Programme

4.72 Similar to the above soil analytical programme, cations/ anions and natural attenuation parameters were added to selected groundwater samples.

4.73 For the details of the SI methodology, please refer to the approved CAP, which has been approved by EPD.

Identification of Environmental Impacts

4.74 Land contamination can cause polluted groundwater and contaminated soil. The decontamination/ remediation process(es) can also cause air quality impacts, waste arising, and health and safety to construction workers. The environmental impacts due to land contamination and decontamination have been addressed in air quality, water quality, waste management, and ecological impact sections.

Evaluation of Environmental Impacts

Fieldwork and On-site Measurements

4.75 The field work (soil and groundwater sampling) of the site investigation was undertaken in accordance with the sampling schedule detailed in the approved CAP by the drilling contractor. A total number of 316 boreholes and 33 groundwater wells, and 3.1-km of trial trenches have been completed. Furthermore, 127 additional boreholes and 23 additional groundwater wells were completed. For the total 57 trenches excavated, groundwater sampling was undertaken at 15 of them. The as-built locations of the sampling boreholes and trenches at Areas 1, 2 and 3 are shown in Figure 4.1.

4.76 On-site measurement including Photo-ionisation Detector (PID) measurement, free product and groundwater level measurement were undertaken in accordance with the approved CAP. The elevated PID readings for soil samples are given in Appendix 4B. In general, the VOC levels of the soil samples are low (i.e. below 10 ppm), which will not pose harmful effects to site workers during decontamination. The maximum PID reading of the soil samples is about 297.0 ppm (at additional borehole AB-39 (at 3.1-3.2m below ground)), which is considered localised. Nevertheless, it is recommended that personal protective equipment (e.g. mask) be used the site workers for the decontamination works of that building.

4.77 Based on the results of the groundwater levels measurements, the groundwater level contours have been plotted in Figure 4.2. It can be seen from Figure 4.2 that the predominant groundwater flow direction of the subject site is from hillside to the shore side. The results of the groundwater level measurements are given in Appendix 4C.

Action Levels for Soil Remediation

4.78 The action levels for soil remediation are used to determine if remediation of soil is necessary. In principle, the Dutch 'ABC' criteria are considered by the EPD as the remediation standards. The Dutch 'ABC' criteria consist of 3 levels of standards, namely A, B, C, which generally indicate the followings:

- 'A' level implies unpolluted;
- 'B' level implies potential pollution present and requires further investigation or remediation; and
- 'C' level implies pollution which requires remediation.

4.79 The action levels for soil remediation were used to determine if remediation of soil is necessary. According to EPD's requirements, these action levels are the Dutch 'B' Standards for the concerned chemicals. For chemicals that are not included in the Dutch 'B' Standards, the USEPA federal standard's Soil Screening Levels (SSLs) (published under *Soil Screening Guidance : Technical Background Document*) were used. In this case, the SSLs for ingestion or inhalation, whichever is lower, were used. If the chemicals are not included in the USEPA federal standard's SSLs, then the USEPA Region IX PRGs were used to determine if soil remediation is necessary.

Action Level / Cleanup Target for Dioxins

4.80 The USEPA's OSWER Directive 9200.4-26 ("Approach for Addressing Dioxin in Soil at Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and Resource Conservation and Recovery Act (RCRA) Sites" signed 13 April 1998) states that 1 ppb TEQ is generally recommended as a cleanup target for dioxins for residential soils at CERCLA and RCRA sites (5 to 20 ppb TEQ has been selected for industrial use scenarios). As such, 1 ppb TEQ is used as both the action level and cleanup target for dioxins in the present study.

Action Level for Tributyl-Tin (TBT) in Soil and Groundwater

4.81 Tributyl-Tin (TBT) is a chemical commonly used as anti-fouling agent in paint coated on ships and therefore is a potential contaminant at shipyard sites. TBT is a toxic to human beings and marine animals.

4.82 The Dutch List does not include TBT in soil and groundwater. However, the USEPA Region IX PRGs for TBT-oxide are 18 mg/kg and 260 mg/kg for residential soil and industrial soil respectively, and 11 μg/L for tap water. Although the future land use of the study site is not residential and groundwater is not used for drinking purpose at the study site, for conservative approach, 18 mg/kg for residential soil and 11 μg/L for tap water are adopted as the cleanup criteria for soil and groundwater respectively.

4.83 There are some reasons supporting the use of TBT-oxide standard for TBT. Firstly, according to the Extension Toxicity Network maintained by University of California at Davis, Michigan State University, Cornell University, and Oregon State University, TBT by itself is unstable and will break down in the environment unless it is combined with an element such as oxygen. One of the most common TBT compounds is *bis* (Tributyltin) Oxide (TBTO). Therefore, it is considered that the TBT found at shipyards exist predominantly in the oxide form.

4.84 For the analysis of TBT in laboratory, the analysis method usually gives a result of total TBT, which includes the predominant TBTO and other possible forms of TBT. As the TBT in soil is expected to be in the predominant form of TBTO. Therefore, the use of TBT-oxide standard for TBT is justified.

4.85 As the analytical results for TBT in soil and groundwater are reported in μg Sn/ kg and μg Sn/L respectively, the RBC for TBT oxides are converted to equivalent concentration of tin for comparison with the analytical results.

4.86 Given the chemical formula of TBT-oxide as $C_{24}H_{54}OSn_2$, 18 mg of TBT-oxide (the PRG for TBT-oxide) in 1 kg soil is equivalent to 7 mg/kg of Tin in soil. Similarly, 11 μg of TBT oxide (the PRG for TBT-oxide) in 1 L groundwater is equivalent to 4.3 μg/L of Tin in groundwater. Therefore, the action levels for TBT, in terms of Sn in soil and groundwater are 7 mg/kg of Sn (or 7,000 μg Sn/kg) in soil and 4.3 μg/L of Sn (4,300 ηg Sn/L) in groundwater, respectively.

4.87 The action levels for soil remediation (including dioxins and TBT) are provided in Appendix 4A.

Screening Criteria for Groundwater

4.88 The Dutch 'ABC' criteria were established based on the assumption that groundwater is used as potable water. However, as groundwater is not a source of potable water in Hong Kong, it is not practical to adopt the Dutch 'B' standards or the USEPA Region IX PRGs for tap water as the action levels for groundwater remediation in Hong Kong. As such, a human risk assessment is used to derive the action level for groundwater contaminants that exceed the Dutch 'B' standards or the USEPA Region IX PRGs for tap water (if there is no Dutch 'B' standard for a certain chemical). Therefore, the Dutch 'B' Standards or the USEPA Region IX PRGs for tap water are used for screening out the chemicals of concerns for risk assessment only. All groundwater results with detectable concentrations were screened for risk assessment. The Dutch 'B' standards were used as the first priority. If there is no Dutch 'B' standards for a certain chemical, the USEPA Region IX PRGs were used. The screening criteria for chemicals with detectable concentrations in groundwater samples are given in Appendix 4D.

Nature of Contamination of Groundwater

4.89 The laboratory results of groundwater samples reveal some exceedances in the screening criteria, which are tabulated in Table 4.1. The concerned test parameters include Antimony, Arsenic, Barium, Cadmium, Chromium, Cobalt, Copper, Lead, Molybdenum, Nickel, Zinc, Chloroform, Naphthalene, Bi(2-ethylhexyl)phathalate (DEHP) and Dioxins.

4.90 The laboratory results of TBT reveal that there are no exceedances in the screening criterion for TBT for all groundwater samples. For all the 12 groundwater samples analysed for dioxins, only the groundwater sample collected from groundwater well AW-11 has non-zero dioxin TEQ of 2.76 x 10^{-7} mg/L (please refer Table 4.1). The source of the dioxins in that groundwater sample is considered to be the historical burning activities took place in the burn pit locating adjacent to and up-gradient of the groundwater well. As dioxins are very insoluble in water and dioxins have a strong tendency to sorb to fine soil particles, the likelihood of wide spread solubilisation of dioxins is considered very low. It is likely that the dioxins detected in that sample were related to colloidal or finely suspended particles within the groundwater sample because the groundwater samples were not filtered in the field.

Furthermore, as there were no other organic contaminants detected in that sample and no other wells adjacent to or up-gradient of that well exhibit non-zero dioxin TEQ, the source of the dioxins is considered localised and the groundwater impacts are insignificant. Nevertheless, this dioxin laboratory result will be assessed in the risk assessment.

Table 4.1 Groundwater Results with Exceedances in Screening Criteria

Groundwater Sample	Contaminant	Unit (μg/L or otherwise specified)	Concentration
MW-B24	Chromium	μg/L	67
MW-B24	Copper	μg/L	58
MW-B24	Nickel	μg/L	7200
MW-B24	TPH	μg/L	231
MW-B24	Zinc	μg/L	250
MW-B34	Barium	μg/L	261
MW-B34	Naphthalene	μg/L	25
MW-C2	Barium	μg/L	108
MW-D6	Barium	μg/L	130
MW-D6	TPH	μg/L	433
MW-J7	Barium	μg/L	106
MW-L34	Cadmium	μg/L	4.3
MW-L34	TPH	μg/L	304
MW-L37	Cadmium	μg/L	5.5
MW-OB5	Barium	μg/L	240
MW-OB11	Bis(2-ethylhexyl)phthalate	μg/L	27
MW-OB11	TPH	μg/L	449
MW-P8	Cadmium	μg/L	7.7
MW-P8	TPH	μg/L	459
MW-Q1	Zinc	μg/L	742
MW-Q5	Zinc	μg/L	620
MW-S4	Zinc	μg/L	788
MW-S8	Molybdenum	μg/L	29
GW-T19(5-6)	Arsenic	μg/L	38
GW-T19(5-6)	Barium	μg/L	134
GW-T20(7-8)	Barium	μg/L	354
GW-T22(1-2)	Barium	μg/L	181
GW-T22(1-2)	Molybdenum	μg/L	42
GW-T22(3-4)	Antimony	μg/L	44
GW-T22(3-4)	Barium	μg/L	669
GW-T22(3-4)	Cadmium	μg/L	3.1
GW-T22(3-4)	Copper	μg/L	1187
GW-T22(3-4)	Lead	μg/L	725
GW-T22(3-4)	Molybdenum	μg/L	50
GW-T22(3-4)	Nickel	μg/L	77
GW-T22(3-4)	Zinc	μg/L	1200
GW-T26(1-2)	Arsenic	μg/L	37
GW-T26(1-2)	Barium	μg/L	747
GW-T26(1-2)	Cadmium	μg/L	17.8
GW-T26(1-2)	Cobalt	μg/L	166
GW-T26(1-2)	Copper	μg/L	259

Groundwater Sample	Contaminant	Unit (μg/L or otherwise specified)	Concentration
GW-T26(1-2)	Lead	μg/L	2254
GW-T26(1-2)	Zinc	μg/L	519
GW-T29(3-4)	Barium	μg/L	120
AW-1C	Chloroform	μg/L	0.7
AW-2	Barium	μg/L	146
AW-2	Zinc	μg/L	237
AW-5	Zinc	μg/L	206
AW-10	TPH	μg/L	213
AW-12	Barium	μg/L	233
AW-13	Molybdenum	μg/L	28
AW-14	Barium	μg/L	220
AW-15	Molybdenum	μg/L	23
AW-16a	Barium	μg/L	101
AW-11	Dioxins	mg/L	2.76×10^{-7} (TEQ)

Remark:

Groundwater samples with suffix "MW" are groundwater samples collected from originally proposed groundwater wells; groundwater samples with suffix "GW" are groundwater samples collected from trenches; groundwater samples with suffix "AW" are groundwater samples collected from additional groundwater wells.

4.91 The evaluation of significance of risk due to groundwater contamination is shown in Table 4.2. It can be seen from Table 4.2 that the risk due to ingestion of groundwater by site workers is warranted. It should be noted that the risk due to dermal contact with groundwater by site workers is uncertain. It is because risk assessment regarding to dermal contact cannot be undertaken as the toxicity and/or chemical specific data for the chemicals of concern (COCs) do not exist. As such, it is recommended that personal protective equipment be used by site works as a mitigation measure.

Table 4.2 Evaluation of Significance of Risk Due to Groundwater Contamination

Nature of Receptor	Specific Receptor	Significance of Risk due to Groundwater Contamination	Rationale
Terrestrial Ecology	Trees	Insignificant	As the existing groundwater level is about 2m below ground and the site will be covered by filling materials of about 3m thick, roots of trees will not reach the groundwater which is at 5m below ground.
Marine Ecology	Marine species in off-site surface watercourse	Insignificant	The level of any contaminant in surface watercourse will be very low due to the dilution effect when groundwater seeps into surface watercourse.
	Artificial lake of planned Water Recreation Centre	Insignificant	Please to Chapter 7 "Water Quality" for the assessment of potential impact of the groundwater quality on the artificial lake of the planned Water Recreation Centre.
Humans	Construction workers (by ingestion)	Significant	Existence of potential risk.

Nature of Receptor	Specific Receptor	Significance of Risk due to Groundwater Contamination	Rationale
	Construction workers (by inhalation)	Insignificant	The levels of volatile contaminants in groundwater are very low because the levels of VOCs in groundwater are below the screening criteria.
	Construction workers (by dermal contact)	Uncertain	Toxicity and/or chemical specific data do not exist for the chemicals of concern (COCs) for risk assessment to be undertaken. As such, it is recommended that personal protective equipment be used by site works as a mitigation measure.
	Future land users	Insignificant	Groundwater at the site will not be used as potable water or used for recreation/irrigation purposes.
	Personnel for maintenance in future	Insignificant	Existing groundwater level is about 3m below ground and the site will be covered by filling materials of about 7-8m thick. Level of utility will be limited to 1-2 m below ground.

4.92 The risk assessment was based on the scenario of exposure of human receptors to contaminated groundwater in future. The analysed concentrations of various parameters in groundwater, the anticipated most sensitive human receptor and the potential exposure pathways were taken into account in the risk assessment.

4.93 For each parameter, the source concentration is the maximum concentration of that parameter found in the groundwater samples irrespective of their locations. Chromium was assumed to be Cr(VI) for conservative assessment. The maximum source concentration (of groundwater samples) of the chemicals of concern (i.e. with concentration above the screening criteria or with detectable concentration for dioxins) and their corresponding noncarcinogenic oral reference doses or carcinogenic slope factor are tabulated in Table 4.3. It should be noted that for lead, World Health Organisation's (WHO) oral reference dose (3.6×10^{-3} mg/kg-day) was adopted for the risk assessment.

Table 4.3 Maximum Source Concentrations and Noncarcinogenic Oral Reference Doses/Carcinogenic Oral Slope Factors of Chemicals of Concern

Parameter	Max. Source Concentration (of groundwater samples) (mg/L)	Sample I.D.	Noncarcinogenic Oral Reference Dose[b] (RfDo) (mg/kg-day)	Min. Noncarcinogenic Oral Reference Dose[b] (RfDo) (mg/kg-day)	Carcinogenic Oral Slope Factor[c] (CSFo) 1/(mg/kg-day)
Antimony	4.40E-02	GW-T22(3-4)	4.00E-04	Not applicable	Not applicable
Arsenic	3.80E-02	GW-T19(5-6)	3.00E-04	Not applicable	1.50E+00
Barium	7.47E-01	GW-T26(1-2)	7.00E-02	Not applicable	Not applicable
Bis(2-ethylhexyl)phthalate (DEHP)	2.70E-02	MW-OB11	2.00E-02	Not applicable	1.40E-02
Cadmium	1.78E-02	GW-T26(1-2)	5.00E-04	Not applicable	Not applicable
Chloroform	7.00E-04	AW-1C	1.00E-02	Not applicable	6.10E-03
Chromium (VI)[a]	6.70E-02	MW-B24	3.00E-03	Not applicable	7.30E-03
Cobalt	1.66E-01	GW-T26(1-2)	6.00E-02	Not applicable	Not applicable
Copper	1.19E+00	GW-T22(3-4)	3.70E-02	Not applicable	Not applicable
Lead	2.25E+00	GW-T26(1-2)	3.60E-03	Not applicable	Not applicable

Parameter	Max. Source Concentration (of groundwater samples) (mg/L)	Sample I.D.	Noncarcinogenic Oral Reference Dose[b] (RfDo) (mg/kg-day)	Min. Noncarcinogenic Oral Reference Dose[b] (RfDo) (mg/kg-day)	Carcinogenic Oral Slope Factor[c] (CSFo) 1/(mg/kg-day)
Molybdenum	5.00E-02	GW-T22(3-4)	5.00E-03	Not applicable	Not applicable
Naphthalene	2.50E-02	MW-B34	2.00E-02	Not applicable	Not applicable
Nickel	7.20E+00	MW-B24	2.00E-02	Not applicable	Not applicable
TPHs	4.59E-01	MW-P8	3.00E-02 to 5.00E+00	3.00E-02	Not applicable
Zinc	1.20E+00	GW-T22(3-4)	3.00E-01	Not applicable	Not applicable
Dioxins	2.76E-07	AW-11	Not applicable	Not applicable	1.50E+05

[a] Chromium is assumed to be Cr (VI) for conservative assessment.

[b] Source for TPHs : Total Petroleum Hydrocarbons Criteria Working Group (1999). *Total Petroleum Hydrocarbons Criteria Working Group Series Volume 5 – Human Health Risk-Based Evaluation of Petroleum Release Sites: Implementing the Working Group Approach.* Massachusetts, U.S.A., Amherst Scientific Publishers.

Source for Antimony (Sb), Arsenic (As), Ba, DEHP, Cd, Chloroform, Cr(VI), Co, Cu, Pb, Mo, Naphthalene, Ni and Zn : *USEPA Region IX Risk-based Concentration Table (revised on 1 Nov 2000)*, USEPA Region IX.

Source for Lead : World Health Organisation.

[c] Source for Arsenic (As), DEHP, Chloroform and Dioxins : *USEPA Region IX Risk-based Concentration Table* (revised on 1 Nov 2000), USEPA Region IX.

Source for Cr(VI): *USEPA Region III Risk-based Concentration Table*, USEPA Region III, March 7, 1995.

4.94 The details of the risk assessment for groundwater are given in Appendix 4E. According to the results of the risk assessment, the concentrations of all chemicals of concern do not exceed the calculated 'allowable' concentrations. As the "allowable" concentration for TPH derived from the risk assessment (2.13E+02 mg/L) is above the solubility limit of TPH in water, the remediation criterion for TPH is considered as "no free product" present in groundwater. As the clay content of backfilled clean soil would be very low, the distribution coefficients for the metals in groundwater adsorbing onto the backfilled clean soil would also be very low. As such, it is unlikely that the metals in groundwater will re-contaminate backfilled clean soil. The derived 'allowable' concentrations for the chemicals of concern for groundwater are tabulated in Table 4.4.

Table 4.4 Derived 'Allowable' Concentrations for Chemicals of Concern for Groundwater

Parameter	Calculated 'Allowable' Concentrations (mg/L)
Antimony	2.84E+00
Arsenic	3.31E-01
Barium	4.97E+02
Bis(2-ethylhexyl)phthalate (DEHP)	3.55E+01
Cadmium (Cd)	3.55E+00
Chloroform	7.10E+01
Chromium (VI)	2.13E+01
Cobalt	4.26E+02
Copper	2.63E+02
Lead	2.56E+01
Molybdenum	3.55E+01
Naphthalene	1.42E+02

Parameter	**Calculated 'Allowable' Concentrations (mg/L)**
Nickel	1.42E+02
TPH	No free product[a]
Zinc	2.13E+03
Dioxins	3.31E-06

[a] Indicates that the derived remediation target is above the solubility limit of the contaminant, i.e. the concentration of the contaminant in water will not exceed the derived remediation target.

4.95 The results of the risk assessment indicate that the concentrations of the chemicals of concern of the groundwater samples do not exceed the 'allowable' concentrations. Therefore, remediation of groundwater is considered not necessary. This consideration is supported by the followings:

i) there will be no beneficial use of groundwater at the CLS site during both construction and operation stages (please also refer Section 4.88);

ii) during construction, any groundwater pumped out at the CLS site will be recharged back to the ground at the same site (please also refer Section 4.97 and Section 7.48);

iii) the water level in the artificial lake will be at a higher level than the contaminated groundwater and will be lined with a impermeable liner, hence the artificial lake will not be affected (please also refer Section 7.50);

iv) the contaminated soil at the CLS site will be excavated for on-site or off-site treatment during the project construction stage (please also refer Sections 4.158 and 4.159).

Nevertheless, as the risk due to dermal contact by site workers is uncertain, it is recommended that personal protective equipment be used by site works as a mitigation measure.

4.96 Floating oil/free product (of TPH) has only been found in Building D, with maximum thickness being several inches. As the free product is very localised, it appears that the quantity of the free product would be small (i.e. less than 100 litres). As such, it is proposed that where free product is detected at the groundwater surface at excavated areas within Building D, only the free product shall be skimmed off manually. The skimmed free product shall be then be drummed properly and collected by a licensed chemical waste collector for disposal. Skimming of free product shall continue until no free product can be measured by an interface probe (with usual detection limit of about 1.5mm). At that time, a confirmation sample of groundwater shall be collected at the surface of the excavated area and analysed for TPH by a laboratory accredited by the Hong Kong Laboratory Accreditation Scheme (HOKLAS). If the TPH concentration of the groundwater sample is below the "allowable" TPH concentration derived from the risk assessment (2.13E+02 mg/L, please refer to Section 4.95 above), the removal of all TPH free product is considered completed. Failing this, skimming of free product shall continue and additional confirmation sample shall be collected there is no exceedance in the "allowable" until there is no exceedance in the "allowable" TPH concentration.

4.97 Discharge to surface watercourse will not be carried out. Where dewatering is necessary during excavation, the groundwater at the excavated area water at excavation will be recharged on-site within the 10m-zone around from the boundary of the excavated area. The water shall be recharged in continuous mode. The physical test results for the soil samples taken at the groundwater well locations across the CLS site (Appendix 4F) indicate that the soil beneath the site is predominately sand with relatively high hydraulic conductivity. Owing to the short distance between the excavation area and the recharge point, and the high hydraulic conductivity of sandy soil, the groundwater at the recharge location will be driven to flow away from the recharge point and towards the excavated area.

4.98 In order to detect if there is any likelihood of migration of contaminants in soil due to locally risen groundwater level during recharge, it is recommended to install 5 groundwater monitoring wells: one at the recharge point and four 5m apart from the recharge point in four directions. Figure 4.3 depicts a typical extraction point, recharge point and the groundwater monitoring locations. The baseline groundwater level at the 5 monitoring wells shall be measured before any recharge. During the recharge period, the groundwater level at the 5 monitoring wells shall be monitored regularly (every 5 minutes in the first hour, hourly check afterwards) to check that the groundwater at the recharge point flows toward the excavated area and there is no likelihood of migration of contaminants in soil due to locally risen groundwater level during recharge. The details of the monitoring requirements are provided in Chapter 5 of "Environmental Monitoring and Audit Manual".

Nature of Contamination of Soil Samples

4.99 Generally, the laboratory results reveal that the major contaminants in soils are metals (mainly barium, copper, lead and zinc) and total petroleum hydrocarbons (TPH). Semivolatile organic compounds (SVOCs) and dioxins are also found in some soil samples.

Area 1

4.100 The major sources of the contamination in Area 1 are associated with the historical operations undertaken within and outside the buildings. Chemicals with exceedance in the relevant standards were found in some buildings including Buildings B, D, I, J, L, M, N, O and P. The most significant soil contamination occurs in Building B (metals and TPHs), Building D (TPHs, metals and SVOCs), and Building L (metals and TPHs). Soils contaminated with metals (i.e. with levels higher than the relevant standards) are also found in boreholes advanced amongst the buildings.

4.101 Some additional boreholes were drilled in the roads and between buildings to further assess the soil contamination.

Building A

4.102 A total of 15 soil samples were collected from 3 boreholes inside the building to access the overall contamination in the vicinity of the building. No exceedance in the relevant standards was found.

Building B

4.103 A total of 141 soil samples from 34 boreholes and 2 ground water samples were collected at this building to assess the overall contamination in the vicinity of the building. The exceedances in the relevant standards are summarised in Table 4.5.

Table 4.5 Analytical Results for Soil Samples of Building B

Borehole Number	Depth (m)	Contaminant	Concentration (mg/kg or otherwise specified)
B-B2	0.15-0.30	Copper	103
B-B4	0.12-0.27	Nickel	275
B-B4	0.68-0.83	Nickel	289
B-B8	0.15-0.30	Chromium	508
B-B8	0.15-0.30	Nickel	152
B-B14	0.68-0.77	Nickel	161
B-B18	0.11-0.16	Chromium	906
B-B20	0.11-0.26	Copper	130
B-B20	0.11-0.26	Nickel	153
B-B21	0.12-0.29	Nickel	404
B-B21	0.65-0.81	Nickel	148
B-B21	1.45-1.61	Nickel	215
B-B22	0.14-0.29	Copper	234
B-B22	0.14-0.29	Nickel	444
B-B22	0.68-0.83	Copper	541
B-B22	0.68-0.83	Nickel	196
B-B22	1.38-1.68	Copper	167
B-B22	1.38-1.68	Nickel	148
B-B23	0.13-0.29	Chromium	2670
B-B23	0.13-0.29	Copper	331
B-B23	0.13-0.29	Lead	153
B-B23	0.65-0.81	Copper	775
B-B23	0.65-0.81	Nickel	380
B-B23	1.40-1.56	Copper	354
B-B23	1.40-1.56	Nickel	397
B-B23a	2.85-3.10	Copper	109
B-B23a	2.85-3.10	Nickel	297
B-B24	0.14-0.29	Copper	122
B-B24	0.14-0.29	Nickel	195
B-B24	0.68-0.83	Chromium	575
B-B24	0.68-0.83	Copper	1790
B-B24	0.68-0.83	Cyanide	123
B-B24	0.68-0.83	Nickel	1780
B-B24	2.88-3.13	Nickel	212
B-B25	0.15-3.0	Chromium	291
B-B25	0.15-3.0	Nickel	298
B-B25	0.68-0.83	Chromium	417
B-B25	1.38-1.63	Nickel	119
B-B25	2.88-3.13	Chromium	700
B-B25	2.88-3.13	Nickel	174
B-B26	0.13-0.29	Nickel	210
B-B26	0.65-0.81	Nickel	206
B-B27	0.13-0.28	Nickel	110
B-B27	0.45-0.69	Nickel	195
B-B33	0.08-0.23	TPH	1343
B-B33	0.08-0.23	Copper	274
B-B34	0.07-0.22	TPH	1868

Building C

4.104 A total of 22 soil samples and 1 groundwater sample were collected at 4 boreholes to assess the overall contamination in the vicinity of the building. No exceedance in the relevant standards was found.

Building D

4.105 Twenty-four (24) boreholes were drilled and 1 monitoring well was installed in the vicinity area of the building. A total of 109 soil samples and 1 groundwater sample were collected to assess the overall contamination in the vicinity of the building. The exceedances in the relevant standards are highlighted in Table 4.6.

Table 4.6 Analytical Results for Soil Samples of Building D

Borehole Number	Depth (m)	Contaminant	Concentration (mg/kg or otherwise specified)
B-D1	2.24-2.51	TPH	1495
B-D4	0.63-0.79	TPH	1947
B-D4	1.45-1.61	TPH	25891
B-D4	1.45-1.61	Naphthalene	20
B-D5	1.47-1.63	TPH	16563
B-D5	1.47-1.63	Naphthalene	10.9
B-D6	0.63-0.88	TPH	15989
B-D6	0.63-0.88	Naphthalene	11.4
B-D6	1.37-1.62	TPH	8417
B-D6	1.37-1.62	Naphthalene	14.1
B-D7	1.47-1.63	TPH	3204
B-D8	0.15-0.31	TPH	12283
B-D8	0.64-0.80	TPH	14973
B-D8	0.64-0.80	Zinc	550
B-D8	1.46-1.62	TPH	13030
B-D15	1.38-1.63	Copper	191
B-D18	0.05-0.20	Copper	783
B-D18	0.05-0.20	Lead	205
B-D18	0.05-0.20	Zinc	574
B-D19	0.02-0.17	Copper	1100
B-D19	0.02-0.17	Zinc	968
B-D21	0.14-0.29	Chromium	300
B-D23	0.07-0.22	Copper	1400
B-D23	0.07-0.22	Zinc	800
B-D25	1.40-1.65	TPH	25218
B-D25	1.40-1.65	Naphthalene	20.8
B-D26	1.40-1.65	TPH	9548
B-D26	1.40-1.65	Naphthalene	8

Building H

4.106 Ten (10) boreholes were drilled within the building and the vicinity area. A total of 15 soil samples was collected. No exceedance was found.

Building I

4.107 A total of 40 soil samples and 1 groundwater sample were collected from 12 boreholes to assess the overall contamination in the building. Exceedances were found at the samples collected. The exceedances are highlighted in Table 4.7.

Table 4.7 Analytical Results for Soil Samples of Building I

Borehole Number	Depth (m)	Contaminant	Concentration (mg/kg or otherwise specified)
B-I1	1.40-1.55	Copper	507
B-I2	0.10-0.26	TPH	1214
B-I5	0.12-0.28	Copper	578
B-I7	0.1-0.25	Lead	181

Building J

4.108 A total of 30 soil samples and 1 groundwater sample were collected from 7 borehole locations to assess the overall contamination in the building and the vicinity area. The exceedances are tabulated in Table 4.8.

Table 4.8 Analytical Results for Soil Samples of Building J

Borehole Number	Depth (m)	Contaminant	Concentration (mg/kg or otherwise specified)
B-J4	1.02-1.27	Lead	494
B-J6	0.0-0.16	Copper	899
B-J6	0.0-0.16	Lead	777
B-J6	0.0-0.16	Nickel	140
B-J6	0.0-0.16	Zinc	974

Building K

4.109 A total of 25 soil samples were collected from 5 borehole locations to assess the overall contamination in the building. No exceedance in the relevant standards was found.

Building L

4.110 Thirty-eight (38) boreholes were drilled and 3 of them were installed as monitoring wells in the vicinity area of the building. The exceedances are highlighted in Table 4.9.

Table 4.9 Analytical Results for Soil Samples of Building L

Borehole Number	Depth (m)	Contaminant	Concentration (mg/kg or otherwise specified)
B-L1	0.68-0.83	Lead	165
B-L2	0.20-0.35	TPH	6325
B-L2	0.20-0.35	Copper	210
B-L2	0.35-1.00	TPH	5819
B-L2	1.40-1.65	TPH	21814
B-L3	0.15-0.30	TPH	3092
B-L7	0.08-0.23	TPH	12220
B-L7	0.83-0.98	TPH	1056

Borehole Number	Depth (m)	Contaminant	Concentration (mg/kg or otherwise specified)
B-L13	0.0-0.16	Copper	1850
B-L13	0.0-0.16	Nickel	110
B-L13	0.0-0.16	Zinc	545
B-L15	0.0-0.16	Copper	430
B-L15	0.0-0.16	Zinc	636
B-L16	0.0-0.16	Copper	283
B-L16	0.0-0.16	Copper	102
B-L16	0.0-0.16	Lead	170
B-L17	0.0-0.16	Copper	485
B-L17	0.63-0.79	Copper	111
B-L19	0.10-0.26	Copper	350
B-L20	0.0-0.16	Copper	845
B-L20	0.0-0.16	Lead	535
B-L20	0.0-0.16	Zinc	1590
B-L22	0.10-0.26	TPH	4201
B-L23	0.0-0.16	Copper	564
B-L23	0.0-0.16	Lead	267
B-L23	0.0-0.16	Nickel	138
B-L23	0.0-0.16	Zinc	562
B-L24	0.0-.016	Cadmium	18.1
B-L24	0.0-.016	Cobalt	52.4
B-L24	0.0-.016	Copper	2680
B-L24	0.0-.016	Lead	1740
B-L24	0.0-.016	Nickel	1140
B-L24	0.0-.016	Zinc	4180
B-L25	0.0-0.13	Cadmium	10.7
B-L25	0.0-0.13	Cobalt	70.3
B-L25	0.0-0.13	Copper	876
B-L25	0.0-0.13	Lead	447
B-L25	0.0-0.13	Nickel	1260
B-L25	0.0-0.13	Zinc	2940
B-L26	0.0-0.16	Antimony	66.59
B-L26	0.0-0.16	Cadmium	6.92
B-L26	0.0-0.16	Copper	235
B-L26	0.0-0.16	Lead	26300
B-L26	0.68-0.84	Copper	237
B-L26	0.68-0.84	Lead	521
B-L26a	1.40-1.65	Lead	368
B-L28	0.10-0.26	Arsenic	31.6
B-L28	0.10-0.26	Copper	377
B-L28	0.10-0.26	Lead	420
B-L28	0.10-0.26	Nickel	143
B-L28	0.64-0.80	Chromium	624
B-L29	0.15-0.31	TPH	1267
B-L29	0.15-0.31	Chromium	429
B-L30	0.0-0.16	Copper	281
B-L30	0.0-0.16	Lead	880
B-L30	0.0-0.16	Nickel	349
B-L31	0.0-0.16	Barium	494

Borehole Number	Depth (m)	Contaminant	Concentration (mg/kg or otherwise specified)
B-L31	0.0-0.16	Copper	1380
B-L31	0.0-0.16	Lead	1060
B-L31	0.0-0.16	Nickel	125
B-L31	0.0-0.16	Zinc	1510
B-L32	0.0-0.16	Copper	499
B-L33	0.0-0.16	TPH	2376
B-L33	0.0-0.16	Copper	1180
B-L33	0.0-0.16	Lead	488
B-L33	0.0-0.16	Zinc	812

Building M

4.111 Eight (8) boreholes were drilled and 1 monitoring well was installed within the building. A total of 28 soil samples and 1 groundwater sample were collected. The exceedances are shown in Table 4.10.

Table 4.10 Analytical Results for Soil Samples of Building M

Borehole Number	Depth (m)	Contaminant	Concentration (mg/kg or otherwise specified)
B-M1	0.10-0.25	Arsenic	30.5
B-M1	0.10-0.25	Chromium	303
B-M1	0.10-0.25	Copper	127
B-M1	0.10-0.25	Nickel	867
B-M1	0.68-0.87	Chromium	331
B-M1	0.68-0.87	Nickel	322
B-M5	0.07-0.22	Nickel	302
B-M6	0.0-0.16	Copper	4490
B-M6	0.0-0.16	Lead	1390
B-M6	0.0-0.16	Dioxins	6.070 ppb (TEQ)
B-M6	0.65-0.81	Copper	579
B-M6	0.65-0.81	Lead	448
B-M6	0.65-0.81	Nickel	327

Building N

4.112 A total of 26 soil samples and 1 groundwater sample were collected to assess overall contamination of the building. The exceedance in the relevant standards are summarised in Table 4.11.

Table 4.11 Analytical Results for Soil Samples of Building N

Borehole Number	Depth (m)	Contaminant	Concentration (mg/kg or otherwise specified)
B-N1	0.02-0.18	TPH	2696
B-N1	1.43-1.59	TPH	1917
B-N2	0.07-0.22	Cadmium	5.28
B-N2	0.07-0.22	TPH	8615
B-N2	0.07-0.22	Copper	504
B-N2	0.07-0.22	Lead	245

Borehole Number	Depth (m)	Contaminant	Concentration (mg/kg or otherwise specified)
B-N2	0.07-0.22	Nickel	178
B-N2	0.07-0.22	Tin	139
B-N5	0.68-0.83	Copper	255
B-N6	0.05-0.20	Lead	249
B-N6	1.40-1.65	TPH	1644

Building O

4.113 A total of 51 soil samples and 1 groundwater sample were collected from 10 borehole locations to assess the overall contamination. The exceedances are tabulated in Table 4.12.

Table 4.12 Analytical Results for Soil Samples of Building O

Borehole Number	Depth (m)	Contaminant	Concentration (mg/kg or otherwise specified)
B-O2	0.78-1.03	Lead	191
B-O6	1.63-1.73	Copper	290
B-O7	0.15-0.30	Copper	1260

Building P

4.114 Ten (10) boreholes were drilled and 1 monitoring well were installed in the building. A total of 38 soil samples and 1 groundwater sample were collected. The exceedances are summarised in Table 4.13.

Table 4.13 Analytical Results for Soil Samples of Building P

Borehole Number	Depth (m)	Contaminant	Concentration (mg/kg or otherwise specified)
B-P1	0.10-0.26	Lead	475
B-P6	0.40-0.56	TPH	13645
B-P10	0.08-0.23	TPH	19239
B-P10	0.68-0.83	TPH	5881

Outside Boring Boreholes in Area 1 (OB)

4.115 Ten (10) boreholes were drilled and 4 monitoring wells were installed in Area 1. A total of 48 soil samples and 4 groundwater samples were collected to assess the area of outside building in Area 1. The exceedances are summarised in Table 4.14.

Table 4.14 Analytical Results for Soil Samples for Outside Borings in Area 1

Borehole Number	Depth (m)	Contaminant	Concentration (mg/kg or otherwise specified)
OB-5	0.15-0.25	Barium	1100
OB-5	0.15-0.25	Chromium	274
OB-5	0.15-0.25	Copper	2780
OB-5	0.15-0.25	Lead	2730
OB-5	0.15-0.25	Nickel	221
OB-5	0.15-0.25	Zinc	1740
OB-5	1.40-1.65	Copper	713

Borehole Number	Depth (m)	Contaminant	Concentration (mg/kg or otherwise specified)
OB-5	1.40-1.65	Lead	1830
OB-5	2.87-3.12	Copper	150
OB-5	2.87-3.12	Lead	502

Surface Drainage Boreholes in Area 1 (SD)

4.116 Twelve (12) boreholes were drilled to verify the overall contamination around surface drainage. The exceedances in the relevant standards are highlighted in Table 4.15.

Table 4.15 Analytical Results for Soil Samples of Surface Drainage Borings in Area 1

Borehole Number	Depth (m)	Contaminant	Concentration (mg/kg or otherwise specified)
SD-1	0.08-0.23	TPH	1198
SD-3	0.15-0.30	Copper	380
SD-4	0.08-0.23	Copper	291
SD-6	0.07-0.22	Copper	117
SD-7	0.08-0.23	Copper	1280
SD-8	0.0-0.18	Copper	130
SD-9	0.0-0.18	Lead	230

Trenches for Debris Pile

4.117 Eleven (11) trenches with total length of approximately 215m for debris pile were excavated, with total number of soil samples being 45. It should be noted that only one of these trenches was excavated in Area 1. The exceedances are tabulated in Table 4.16.

Table 4.16 Analytical Results for Soil Samples of Debris Pile in Area 1

Trench Number	Depth (m)	Sample ID	Contaminant	Concentration (mg/kg or otherwise specified)
T1	0.74	T1/0.74m/2	Copper	105
T1	0.74	T1/0.74m/2	Lead	311

Additional Boreholes in Area 1

4.118 Thirty-nine (39) additional boreholes have been drilled in Area 1 to delineate the soil contamination extent in Area 1 more exactly. The exceedances in the relevant standards are tabulated in Table 4.17.

Table 4.17 Analytical Results for Soil Samples of Additional Boreholes in Area 1

Borehole Number	Depth (m)	Contaminant	Concentration (mg/kg or otherwise specified)
AB-1	0.08-0.23	TPH	5942
AB-3	0.08-0.23	TPH	1206
AB-14	0.05-0.30	Chromium	682
AB-14	0.05-0.30	Hexavalent Chromium	392
AB-14	0.68-0.83	Chromium	788
AB-14	0.68-0.83	Hexavalent Chromium	288

Borehole Number	Depth (m)	Contaminant	Concentration (mg/kg or otherwise specified)
AB-15	0.78-0.93	Arsenic	54.4
AB-15	0.78-0.93	Barium	848
AB-15	0.78-0.93	Chromium	841
AB-15	0.78-0.93	Copper	4960
AB-15	0.78-0.93	Lead	1260
AB-15	0.78-0.93	Nickel	228
AB-15	0.78-0.93	Zinc	2380
AB-21	0.45-0.56	TPH	2802
AB-22	0.70-0.85	Lead	157
AB-25	0.08-0.23	Copper	7680
AB-25	0.08-0.23	Zinc	9090
AB-34	0.08-023	Chromium	280
AB-38	1.35-1.60	TPH	13965

4.119 The maximum and average concentrations of contaminants in Area 1 with exceedance in the relevant standards are given in Table 4.18.

Table 4.18 Maximum and Average Concentrations of Contaminants in Area 1 with Exceedance

	Unit	No. of Exceedance	No. of Samples Analysed	Maximum	Average (exceedance only)	Overall Average
Antimony	Mg/kg	1	780	67	67	0.203
Arsenic	Mg/kg	3	778	54	39	1.222
Barium	Mg/kg	3	779	1100	814	29.474
Cadmium	Mg/kg	4	779	18	10	0.142
TPH	Mg/kg	36	862	25891	8053	364.577
Chromium	Mg/kg	17	778	2670	642	23.135
Cobalt	Mg/kg	2	779	70	61	2.411
Copper	Mg/kg	56	778	7680	883	71.677
Cyanide	Mg/kg	1	701	123	123	0.211
Hexavalent Chromium	Mg/kg	2	687	392	340	1.579
Lead	Mg/kg	32	775	26300	1417	81.677
Naphthalene	Mg/kg	6	747	20.80	14.20	0.128
Nickel	Mg/kg	39	777	1780	334	21.350
Tin	Mg/kg	1	778	139	139	0.628
Zinc	Mg/kg	16	778	9090	1866	76.376
Dioxins	Ppb (TEQ)	1	11	6.070	6.070	0.581

Area 2

4.120 The soil contamination found in Area 2 appears to be associated with the historical operations in the buildings within this area, areas adjacent to several buildings, and in the waste disposal mounds and pits located east to Buildings of S and T. Major soil contamination occurs in Building S (metals, TPHs and SVOCs) and Building T (metals, SVOCs and TPHs), debris pile area (metals, TPHs and SVOCs) and burn pit area (metals and dioxins).

Building R

4.121 Four boreholes were drilled and one of them was installed as monitoring well. A total of 22 soil samples and 1 groundwater sample were collected to assess the overall contamination of the building. The only exceedance in the relevant standards is shown in Table 4.19.

Table 4.19 Analytical Results for Soil Samples of Building R

Borehole Number	Depth (m)	Contaminant	Concentration (mg/kg or otherwise specified)
B-R3	0.71-0.86	Lead	155

Building S

4.122 A total of 50 soil samples and 2 groundwater samples were collected. They come from 12 borehole locations and 2 of them were then installed with groundwater monitoring wells. The exceedances are tabulated in Table 4.20.

Table 4.20 Analytical Results for Soil Samples of Building S

Borehole Number	Depth (m)	Contaminant	Concentration (mg/kg or otherwise specified)
B-S6	0.18-0.34	Copper	159
B-S8	0.08-0.23	TPH	11219
B-S9	0.30-0.45	Benzo(a)anthracene	1.18
B-S9	0.30-0.45	Benzo(b)fluoranthene	1.26
B-S9	0.30-0.45	TPH	1362
B-S9	0.30-0.45	Dibenz(a,h)anthracene	0.16
B-S10	0.17-0.32	Lead	431
B-S11	0.68-0.82	Copper	126

Building T

4.123 Twelve (12) boreholes were drilled and two (2) of them were installed as monitoring wells in the area vicinity to the building. A total of 58 soil samples and two groundwater samples were collected. The exceedances are highlighted in Table 4.21.

Table 4.21 Analytical Results for Soil Samples of Building T

Borehole Number	Depth (m)	Contaminant	Concentration (mg/kg or otherwise specified)
B-T3	0.12-0.30	Barium	789
B-T5	0.35-0.53	Barium	437
B-T5	0.35-0.53	Benzo(a)anthracene	1.22
B-T5	0.35-0.53	Benzo(b)fluoranthene	1.15
B-T5	0.35-0.53	Copper	2950
B-T5	0.35-0.53	Dibenz(a,h)anthracene	0.159
B-T5	0.35-0.53	Lead	1760
B-T5	0.35-0.53	Zinc	1300
B-T5	1.28-1.72	Copper	156
B-T6	0.25-0.40	TPH	7635
B-T6	0.68-0.83	TPH	1289

Additional Boreholes in vicinity of Building T

4.124 Twenty-two (22) additional boreholes have been drilled inside or in the vicinity of Building T to delineate the soil contamination extent near this building more exactly. The exceedances in the relevant standards are tabulated in Table 4.22.

Table 4.22 Analytical Results for Soil Samples of Additional Boreholes near Building T

Borehole Number	Depth (m)	Contaminant	Concentration (mg/kg or otherwise specified)
AB-T3	0.08-0.23	Benzo(a)anthracene	1.6
AB-T3	0.08-0.23	Benzo(a)pyrene	1.43
AB-T3	0.08-0.23	Benzo(b)fluoranthene	1.4
AB-T3	0.08-0.23	Dibenz(a,h)anthracene	0.212
AB-T3	0.08-0.23	Indeno(1,2,3-cd)pyrene	1.09
AB-T6	0.10-0.25	Copper	245
AB-T6	0.65-0.80	Copper	208
AB-T7	0.30-0.45	Bis(2-ethylhexyl)phthalate	46
AB-T8	0.25-0.40	Copper	179
AB-T12	0.40-0.56	TPH	2558
AB-T15	0.65-0.80	Lead	155
AB-T18	0.35-0.50	Copper	362
AB-T21a	0.08-0.23	Copper	398
AB-T22	0.20-0.35	Copper	110
AB-T22	0.20-0.35	Copper	110

Building U

4.125 A total of 11 soil samples and 1 groundwater sample were collected to assess the overall contamination of the building and the vicinity. No exceedance in the relevant standards was found.

Building V

4.126 A total of 47 soil samples and 1 groundwater sample were collected to assess the overall contamination of the building. The exceedances are summarised in Table 4.23.

Table 4.23 Analytical Results for Soil Samples of Building V

Borehole Number	Depth (m)	Contaminant	Concentration (mg/kg or otherwise specified)
B-V2	0.68-0.83	TPH	3120
B-V2	0.68-0.83	Copper	166

Building W

4.127 A total of 24 soil samples were collected from 6 boring locations. The exceedances are tabulated in Table 4.24.

Table 4.24 Analytical Results for Soil Samples of Building W

Borehole Number	Depth (m)	Contaminant	Concentration (mg/kg or otherwise specified)
B-W2	0.20-0.35	TPH	7648
B-W2	0.20-0.35	Lead	414

Building X

4.128 Five boreholes were drilled and one of them was installed as a monitoring well. A total of 19 soil samples and 1 groundwater sample were collected. The only exceedance is shown in Table 4.25.

Table 4.25 Analytical Results for Soil Samples of Building X

Borehole Number	Depth (m)	Contaminant	Concentration (mg/kg or otherwise specified)
B-X4	0.11-0.26	Dibenz(a,h)anthracene	0.093

Building Y

4.129 A total of 25 soil samples were collected to assess the overall contamination of the building. The exceedances are summarised in Table 4.26.

Table 4.26 Analytical Results for Soil Samples of Building Y

Borehole Number	Depth (m)	Contaminant	Concentration (mg/kg or otherwise specified)
B-Y4	0.08-0.23	Benzo(a)anthracene	1.67
B-Y4	0.08-0.23	Benzo(a)pyrene	1.6
B-Y4	0.08-0.23	Benzo(b)fluoranthene	1.5
B-Y4	0.08-0.23	Dibenz(a,h)anthracene	0.18
B-Y4	0.08-0.23	Indeno(1,2,3-cd)pyrene	0.92

Building Z

4.130 A total of 29 soil samples were collected from 6 boring locations. One of them was installed as monitoring well and a groundwater sample was taken. The exceedances are tabulated in Table 4.27.

Table 4.27 Analytical Results for Soil Samples of Building Z

Borehole Number	Depth (m)	Contaminant	Concentration (mg/kg or otherwise specified)
B-Z2	0.25-0.40	TPH	7032

Outside Borings in Area 2 (OB)

4.131 Twenty-one (21) boreholes were drilled and six (6) of them were installed as groundwater monitoring wells. A total of 102 soil samples and 6 groundwater samples were collected. The exceedances are highlighted in Table 4.28.

Table 4.28 Analytical Result for Soil Samples of Outside Borings in Area 2

Borehole Number	Depth (m)	Contaminant	Concentration (mg/kg or otherwise specified)
OB-16	0.18-0.38	Copper	637
OB-16	0.18-0.38	Nickel	469
OB-18	1.41-1.66	Copper	171
OB-18	1.41-1.66	Lead	300
OB-19	0.72-0.87	Copper	244
OB-20	0.07-0.22	Copper	276
OB-26	0.14-0.29	Benzo(a)pyrene	1.01
OB-26	0.14-0.29	Benzo(b)fluoranthene	0.98
OB-26	0.14-0.29	Copper	206
OB-26	0.14-0.29	Dibenz(a,h)anthracene	0.177
OB-27	0.08-0.23	Zinc	1340
OB-31	0.06-0.21	Copper	181

Surface Drainage Borings in Area 2 (SD)

4.132 A total of 38 soil samples were collected at 12 boring locations in Area 2. The exceedances are tabulated in Table 4.29.

Table 4.29 Analytical Results for Soil Samples of Surface Drainage Borings in Area 2

Borehole Number	Depth (m)	Contaminant	Concentration (mg/kg or otherwise specified)
SD-16	1.23-1.48	Zinc	545
SD-19a	2.0-2.25	Copper	111
SD-21	0.80-0.94	Benzo(a)anthracene	1.34
SD-21	0.80-0.94	Benzo(a)pyrene	1.9
SD-21	0.80-0.94	Benzo(b)fluoranthene	2.38
SD-21	0.80-0.94	Copper	115
SD-21	0.80-0.94	Dibenz(a,h)anthracene	0.657
SD-21	0.80-0.94	Indeno(1,2,3-cd)pyrene	1.51
SD-21	1.46-1.71	Lead	169
S-D22	0.30-0.45	Barium	858

Trenches for Debris Pile

4.133 Ten of the eleven trenches for debris pile were excavated in Area 2. The exceedances are tabulated in Table 4.30.

Table 4.30 Analytical Results for Soil Samples of Debris Pile in Area 2

Trench Number	Depth (m)	Sample ID	Contaminant	Concentration (mg/kg or otherwise specified)
T5	0.96	T5/0.96m/3	TPH	14290
T6	0.96	T6/0.96m/5	Copper	393
T7	1.08	T7/1.08m/1	Copper	111
T7	1.47	T7/1.47m/3	Copper	162
T8	0.25	T8/0.25m/1	Cadmium	5
T8	0.25	T8/0.25m/1	Chromium	672
T8	0.25	T8/0.25m/1	Cobalt	67.8

Trench Number	Depth (m)	Sample ID	Contaminant	Concentration (mg/kg or otherwise specified)
T8	0.25	T8/0.25m/1	Copper	7080
T8	0.25	T8/0.25m/1	Lead	1310
T8	0.25	T8/0.25m/1	Nickel	726
T8	0.25	T8/0.25m/1	Tin	66.4
T8	0.25	T8/0.25m/1	Zinc	4350
T9	1.17	T9/1.17m/1	Barium	3290
T9	1.17	T9/1.17m/1	Chromium	477
T9	1.17	T9/1.17m/1	Copper	11400
T9	1.17	T9/1.17m/1	Lead	1300
T9	1.17	T9/1.17m/1	Nickel	497
T9	1.17	T9/1.17m/1	Tin	64.09
T9	0.92	T9/0.92m/5	Barium	1800
T9	0.92	T9/0.92m/5	Chromium	432
T9	0.92	T9/0.92m/5	Copper	4270
T9	0.92	T9/0.92m/5	Lead	881
T9	0.92	T9/0.92m/5	Nickel	487
T10	1.11	T10/1.11m/3	Copper	103
T10	0.79	T10/0.79m/5	Copper	222
T10	0.26	T10/0.26m/7	TPH	1297
T11	0.31	T11/0.31m/1	Styrene	6.3

Trenches for Burn Pit

4.134 A total of thirty-seven (37) main trenches for burn pit have been excavated and six of them were excavated in Area 2. The exceedances are tabulated in Table 4.31.

Table 4.31 Analytical Results for Soil Samples of Burn Pit in Area 2

Trench No.	Transect	Sample ID	Contaminant	Conc. (mg/kg or otherwise specified)
IEC-T1	1-10	IEC-T1(1-10)/2.46m/1	Copper	408
IEC-T1	1-10	IEC-T1(1-10)/2.46m/1	Lead	1580
IEC-T1	1-10	IEC-T1(1-10)/1.3m/5	PCB	33.4
IEC-T1	1-10	IEC-T1(1-10)/1.3m/5	Copper	3850
IEC-T1	1-10	IEC-T1(1-10)/1.3m/5	Lead	509
IEC-T1	1-10	IEC-T1(1-10)/1.3m/5	Zinc	2150
IEC-T1	1-10	IEC-T1 (1-10)/1.9/7	Dioxins	1.400 ppb (TEQ)
IEC-T1	2-3	IEC-T1(2-3)/0.9m/21	PCB	5.7
IEC-T1	2-3	IEC-T1(2-3)/0.9m/21	TPH	1436
IEC-T1	2-3	IEC-T1(2-3)/0.9m/21	Copper	10300
IEC-T1	2-3	IEC-T1(2-3)/0.9m/21	Lead	359
IEC-T1	2-3	IEC-T1(2-3)/0.9m/21	Tin	64.09
IEC-T1	2-3	IEC-T1(2-3)/0.9m/21	Zinc	3650
IEC-T1	2-3	IEC-T1(2-3)/1.35m/23	Copper	140
IEC-T2	1-8	IEC-T2(1-8)/2.4m/1	Barium	1360
IEC-T2	1-8	IEC-T2(1-8)/2.4m/1	Copper	2400
IEC-T2	1-8	IEC-T2(1-8)/2.4m/1	Lead	1770
IEC-T2	1-8	IEC-T2(1-8)/2.4m/1	Nickel	159
IEC-T2	1-8	IEC-T2(1-8)/2.4m/1	Zinc	1190

Trench No.	Transect	Sample ID	Contaminant	Conc. (mg/kg or otherwise specified)
IEC-T2	1-8	IEC-T2 (1-8)/2.4/1&2	Dioxins	1.020 ppb (TEQ)
IEC-T2	1-8	IEC-T2(1-8)/2.5m/7	Barium	524
IEC-T2	1-8	IEC-T2(1-8)/2.5m/7	Cadmium	12.9
IEC-T2	1-8	IEC-T2(1-8)/2.5m/7	Copper	27900
IEC-T2	1-8	IEC-T2(1-8)/2.5m/7	Lead	675
IEC-T2	1-8	IEC-T2(1-8)/2.5m/7	Nickel	239
IEC-T2	1-8	IEC-T2(1-8)/2.5m/7	Tin	232
IEC-T2	1-8	IEC-T2(1-8)/2.5m/7	Zinc	6840
IEC-T2	1-8	IEC-T2 (1-8)/2.5/7&8	Dioxins	3.990 ppb (TEQ)
IEC-T2	2-3	IEC-T2(2-3)/0.1m/13	Barium	2190
IEC-T2	2-3	IEC-T2(2-3)/0.1m/13	Cadmium	5.24
IEC-T2	2-3	IEC-T2(2-3)/0.1m/13	Chromium	350
IEC-T2	2-3	IEC-T2(2-3)/0.1m/13	Copper	5010
IEC-T2	2-3	IEC-T2(2-3)/0.1m/13	Lead	2010
IEC-T2	2-3	IEC-T2(2-3)/0.1m/13	Nickel	327
IEC-T2	2-3	IEC-T2(2-3)/0.1m/13	Zinc	3240
IEC-T2	2-3	IEC-T2 (2-3)/0.1/13	Dioxins	1.580 ppb (TEQ)
IEC-T2	4-5	IEC-T2(4-5)/1.5m/19	Barium	885
IEC-T2	4-5	IEC-T2(4-5)/1.5m/19	Copper	1470
IEC-T2	4-5	IEC-T2(4-5)/1.5m/19	Lead	1180
IEC-T2	4-5	IEC-T2(4-5)/1.5m/19	Zinc	1190
IEC-T2	4-5	IEC-T2 (4-5)/1.5/19&20	Dioxins	2.440 ppb (TEQ)
IEC-T2	4-5	IEC-T2(4-5)/1.0m/21	Barium	1880
IEC-T2	4-5	IEC-T2(4-5)/1.0m/21	Cadmium	6.11
IEC-T2	4-5	IEC-T2(4-5)/1.0m/21	Cobalt	50.8
IEC-T2	4-5	IEC-T2(4-5)/1.0m/21	Copper	5690
IEC-T2	4-5	IEC-T2(4-5)/1.0m/21	Lead	4630
IEC-T2	4-5	IEC-T2(4-5)/1.0m/21	Nickel	393
IEC-T2	4-5	IEC-T2(4-5)/1.0m/21	Tin	73.2
IEC-T2	4-5	IEC-T2(4-5)/1.0m/21	Zinc	5710
IEC-T2	4-5	IEC-T2 (4-5)/1.0/21&22	Dioxins	2.160 ppb (TEQ)
IEC-T2	6-7	IEC-T2(6-7)/0.8m/27	Barium	1340
IEC-T2	6-7	IEC-T2(6-7)/0.8m/27	Cadmium	5.36
IEC-T2	6-7	IEC-T2(6-7)/0.8m/27	Chromium	313
IEC-T2	6-7	IEC-T2(6-7)/0.8m/27	Copper	3840
IEC-T2	6-7	IEC-T2(6-7)/0.8m/27	Lead	1390
IEC-T2	6-7	IEC-T2(6-7)/0.8m/27	Nickel	234
IEC-T2	6-7	IEC-T2(6-7)/0.8m/27	Zinc	2340
IEC-T2	6-7	IEC-T2(6-7)/0.3m/31	Barium	1050
IEC-T2	6-7	IEC-T2(6-7)/0.3m/31	Cadmium	7.87
IEC-T2	6-7	IEC-T2(6-7)/0.3m/31	Chromium	655
IEC-T2	6-7	IEC-T2(6-7)/0.3m/31	Cobalt	56.5
IEC-T2	6-7	IEC-T2(6-7)/0.3m/31	Copper	9360
IEC-T2	6-7	IEC-T2(6-7)/0.3m/31	Lead	2000
IEC-T2	6-7	IEC-T2(6-7)/0.3m/31	Nickel	728
IEC-T2	6-7	IEC-T2(6-7)/0.3m/31	Tin	61
IEC-T2	6-7	IEC-T2(6-7)/0.3m/31	Zinc	5860

Trench No.	Transect	Sample ID	Contaminant	Conc. (mg/kg or otherwise specified)
IEC-T2	6-7	IEC-T2 (6-7)/0.3/31&32	Dioxins	3.000 ppb (TEQ)
IEC-T3	1-8	IEC-T3(1-8)/0.3-0.45m/3	Barium	1470
IEC-T3	1-8	IEC-T3(1-8)/0.3-0.45m/3	Chromium	524
IEC-T3	1-8	IEC-T3(1-8)/0.3-0.45m/3	Copper	5570
IEC-T3	1-8	IEC-T3(1-8)/0.3-0.45m/3	Lead	1980
IEC-T3	1-8	IEC-T3(1-8)/0.3-0.45m/3	Nickel	357
IEC-T3	1-8	IEC-T3(1-8)/0.3-0.45m/3	Zinc	5570
IEC-T3	1-8	IEC-T3(1-8)0.65-0.8m/5	Barium	1060
IEC-T3	1-8	IEC-T3(1-8)0.65-0.8m/5	Chromium	307
IEC-T3	1-8	IEC-T3(1-8)0.65-0.8m/5	Copper	8070
IEC-T3	1-8	IEC-T3(1-8)0.65-0.8m/5	Lead	1140
IEC-T3	1-8	IEC-T3(1-8)0.65-0.8m/5	Nickel	411
IEC-T3	1-8	IEC-T3(1-8)0.65-0.8m/5	Tin	56.6
IEC-T3	1-8	IEC-T3(1-8)0.65-0.8m/5	Zinc	4830
IEC-T3	1-8	IEC-T3(1-8)/0.45m/9	Barium	771
IEC-T3	1-8	IEC-T3(1-8)/0.45m/9	Chromium	388
IEC-T3	1-8	IEC-T3(1-8)/0.45m/9	Copper	3590
IEC-T3	1-8	IEC-T3(1-8)/0.45m/9	Lead	1600
IEC-T3	1-8	IEC-T3(1-8)/0.45m/9	Nickel	343
IEC-T3	1-8	IEC-T3(1-8)/0.45m/9	Zinc	1960
IEC-T3	1-8	IEC-T3(1-8)/0.6m/13	Copper	134
IEC-T3	2-3	IEC-T3(2-3)/0.65m/1	Barium	2220
IEC-T3	2-3	IEC-T3(2-3)/0.65m/1	Cadmium	5.5
IEC-T3	2-3	IEC-T3(2-3)/0.65m/1	Chromium	1670
IEC-T3	2-3	IEC-T3(2-3)/0.65m/1	Cobalt	134
IEC-T3	2-3	IEC-T3(2-3)/0.65m/1	Copper	10100
IEC-T3	2-3	IEC-T3(2-3)/0.65m/1	Lead	2420
IEC-T3	2-3	IEC-T3(2-3)/0.65m/1	Molybdenum	46
IEC-T3	2-3	IEC-T3(2-3)/0.65m/1	Nickel	1380
IEC-T3	2-3	IEC-T3(2-3)/0.65m/1	Tin	92.7
IEC-T3	2-3	IEC-T3(2-3)/0.65m/1	Zinc	8800
IEC-T4	1-8	IEC-T4(1-8)/3.0m/1	Lead	189
IEC-T4	4-5	IEC-T4(4-5)/3.4m/1	Lead	158
IEC-T6	1-6	IEC-T6(1-6)0.4m/5	Copper	1410
IEC-T6	1-6	IEC-T6(1-6)0.4m/5	Nickel	172
IEC-T6	1-6	IEC-T6(1-6)0.4m/5	Zinc	1210

Additional Boreholes in Area 2

4.135 Forty-three (43) additional boreholes have been drilled in Area 2 to delineate the soil contamination extent in this area more exactly. The exceedances in the relevant standards are tabulated in Table 4.32.

Table 4.32 Analytical Results for Soil Samples of Additional Boreholes in Area 2

Borehole Number	Depth (m)	Contaminant	Concentration (mg/kg or otherwise specified)
AB-43	0.80-0.95	Copper	191

Borehole Number	Depth (m)	Contaminant	Concentration (mg/kg or otherwise specified)
AB-44	0.72-0.87	Copper	258
AB-46	0.07-0.22	Copper	225
AB-48	0.65-0.80	Copper	107
AB-50	0.08-0.23	Copper	7780
AB-50	0.08-0.23	Lead	2690
AB-50	0.08-0.23	Tin	167
AB-50	0.08-0.23	Zinc	1950
AB-50	0.80-0.95	Copper	3050
AB-50	0.80-0.95	Lead	3020
AB-50	0.80-0.95	Tin	156
AB-50	0.80-0.95	Zinc	790
AB-65	0.08-0.23	Copper	315
AB-65	0.65-0.80	Copper	223
AB-68	0.68-0.83	Lead	150
AB-68	0.68-0.83	Zinc	564
AB-70	0.65-0.80	Zinc	1270
AB-71	0.08-0.23	Lead	151
AB-71	0.08-0.23	Zinc	2070
AB-73	0.08-0.23	Copper	199
AB-80	0.65-0.80	Lead	162
AB-82	0.08-0.23	Copper	124

Additional Groundwater Monitoring Wells at Area 2

4.136 Seven (7) additional boreholes have been drilled in Area 2. Groundwater monitoring wells were then installed at these locations. The soil samples (taken from these boreholes) with exceedance in the relevant standards are summarised in Table 4.33.

Table 4.33 Analytical Results for Soil Samples of Additional Groundwater Wells in Area 2

Borehole Location	Depth (m)	Contaminant	Concentration (mg/kg or otherwise specified)
AW-6	0.10-0.25	Copper	175
AW-6	0.10-0.25	Zinc	2500

4.137 The maximum and average concentrations of contaminants in Area 2 with exceedance in the relevant standards are given in Table 4.34.

Table 4.34 Maximum and Average Concentrations of Contaminants in Area 2 with Exceedance

	Unit	No. of Exceedances	No. of Samples Analysed	Maximum	Average (exceedance only)	Overall Average
PCB	mg/kg	2	65	33.40	19.55	0.602
Barium	mg/kg	16	650	3290	1370	63.684
Benzo(a)anthracene	mg/kg	5	622	1.67	1.40	0.017
Benzo(a)pyrene	mg/kg	4	623	1.90	1.49	0.017
Benzo(b)fluoranthene	mg/kg	6	615	2.38	1.45	0.020
Bis(2-	mg/kg	1	623	46.00	46.00	0.109

	Unit	No. of Exceedances	No. of Samples Analysed	Maximum	Average (exceedance only)	Overall Average
ethylhexyl)phthalate						
Cadmium	mg/kg	7	654	13	7	0.160
TPH	mg/kg	11	654	14290	5353	118.800
Chromium	mg/kg	10	653	1670	579	14.412
Cobalt	mg/kg	4	650	134	77	4.274
Copper	mg/kg	56	654	27900	2549	227.167
Dibenz(a,h)anthracene	mg/kg	7	624	0.66	0.23	0.003
Indeno(1,2,3-cd)pyrene	mg/kg	3	623	1.51	1.17	0.014
Lead	mg/kg	31	657	4630	1182	105.991
Molybdenum	mg/kg	1	653	46	46	1.066
Nickel	mg/kg	15	654	1380	461	13.209
Styrene	mg/kg	1	616	6.30	6.30	0.010
Tin	mg/kg	10	657	232	103	2.092
Zinc	mg/kg	24	656	8800	2967	144.210
Dioxins	ppb (TEQ)	7	21	3.990	2.227	0.775

Area 3

4.138 Although the majority of Area 3 was not used for shipbuilding operations, it appears that it was used for disposal of wastes generated at the shipyard facility because many burn pits and buried wastes were encountered in exploratory trenches excavated in this area. Many samples collected from the burn pits and monitoring well borings in this area were found to contain dioxins.

Building Q

4.139 Fifty-one (51) soil samples were collected from 13 boreholes to assess contamination at Building Q. The exceedances are summarised in Table 4.35.

Table 4.35 Analytical Results for Soil Samples of Building Q

Borehole Number	Depth (m)	Contaminant	Concentration (mg/kg or otherwise specified)
B-Q2	0.20-0.35	Copper	275
B-Q4	0.10-0.25	TPH	9122
B-Q7	0.08-0.23	Copper	142
B-Q7	0.68-0.83	Copper	438
B-Q7	1.38-1.63	Copper	566
B-Q7	1.38-1.63	Lead	278
B-Q14	0.22-0.38	TPH	2614
B-Q15	0.24-0.39	TPH	3031

Trenches for Burn Pit

4.140 Thirty-one (31) main trenches for burn pit were excavated in Area 3. The exceedances are tabulated in Table 4.36.

Table 4.36 Analytical Results for Soil Samples of Burn Pit in Area 3

Trench No.	Transect	Sample ID	Contaminant	Conc. (mg/kg or otherwise specified)
IEC-T7	2-3	IEC-T7(2-3)/1.2m/9	Lead	183
IEC-T7	2-3	IEC-T7(2-3)0.6m/13	Lead	184
IEC-T9	1-10	IEC-T9(1-10)/1.27m/5	Barium	643
IEC-T9	1-10	IEC-T9(1-10)/1.27m/5	Cadmium	10.2
IEC-T9	1-10	IEC-T9(1-10)/1.27m/5	Copper	1510
IEC-T9	1-10	IEC-T9(1-10)/1.27m/5	Lead	296
IEC-T9	1-10	IEC-T9(1-10)/1.27m/5	Zinc	2000
IEC-T9	1-10	IEC-T9 (1-10)/1.27/5	Dioxins	14.900 ppb (TEQ)
IEC-T9	1-10	IEC-T9(1-10)/0.84m/9	Barium	538
IEC-T9	1-10	IEC-T9(1-10)/0.84m/9	Cadmium	6.42
IEC-T9	1-10	IEC-T9(1-10)/0.84m/9	Copper	819
IEC-T9	1-10	IEC-T9(1-10)/0.84m/9	Lead	412
IEC-T9	1-10	IEC-T9(1-10)/0.84m/9	Nickel	103
IEC-T9	1-10	IEC-T9(1-10)/0.84m/9	Zinc	5860
IEC-T9	1-10	IEC-T9 (1-10)/0.84/9	Dioxins	1.550 ppb (TEQ)
IEC-T9	8-9	IEC-T9(8-9)/0.4m/13	Copper	837
IEC-T9	8-9	IEC-T9(8-9)/0.4m/13	Lead	179
IEC-T9	8-9	IEC-T9(8-9)/0.4m/13	Nickel	214
IEC-T9	8-9	IEC-T9(8-9)/0.4m/13	Zinc	1110
IEC-T9	8-9	IEC-T9(8-9)/1.91m/17	Cadmium	7.38
IEC-T9	8-9	IEC-T9(8-9)/1.91m/17	Chromium	984
IEC-T9	8-9	IEC-T9(8-9)/1.91m/17	Cobalt	328
IEC-T9	8-9	IEC-T9(8-9)/1.91m/17	Copper	28100
IEC-T9	8-9	IEC-T9(8-9)/1.91m/17	Lead	2000
IEC-T9	8-9	IEC-T9(8-9)/1.91m/17	Molybdenum	599
IEC-T9	8-9	IEC-T9(8-9)/1.91m/17	Nickel	1790
IEC-T9	8-9	IEC-T9(8-9)/1.91m/17	Tin	107
IEC-T9	8-9	IEC-T9(8-9)/1.91m/17	Zinc	23400
IEC-T9	8-9	IEC-T9 (8-9)/1.91/17	Dioxins	1.500 ppb (TEQ)
IEC-T11	1-2	IEC-T11(1-2)/1.1m/7	Copper	534
IEC-T11	1-2	IEC-T11(1-2)/1.1m/7	Lead	401
IEC-T11	1-2	IEC-T11(1-2)/1.1m/7	Zinc	885
IEC-T11	1-2	IEC-T11(1-2)/0.9m/11	Copper	294
IEC-T11	1-2	IEC-T11(1-2)/0.9m/11	Lead	1060
IEC-T11	1-2	IEC-T11(1-2)/0.9m/11	Nickel	108
IEC-T11	1-2	IEC-T11(1-2)/0.9m/11	Zinc	682
IEC-T11	1-2	IEC-T11(1-2)/3.3m/13	Lead	254
IEC-T11	1-2	IEC-T11(1-2)/1.0m/15	Copper	408
IEC-T11	3-4	IEC-T11(3-4)/1.8m/3	Arsenic	42
IEC-T11	3-4	IEC-T11(3-4)/1.8m/3	Cadmium	6.21
IEC-T11	3-4	IEC-T11(3-4)/1.8m/3	TPH	1617
IEC-T11	3-4	IEC-T11(3-4)/1.8m/3	Chromium	890
IEC-T11	3-4	IEC-T11(3-4)/1.8m/3	Copper	5300
IEC-T11	3-4	IEC-T11(3-4)/1.8m/3	Lead	590

Trench No.	Transect	Sample ID	Contaminant	Conc. (mg/kg or otherwise specified)
IEC-T11	3-4	IEC-T11(3-4)/1.8m/3	Nickel	280
IEC-T11	3-4	IEC-T11(3-4)/1.8m/3	Zinc	2870
IEC-T12	1-2	IEC-T12(1-2)/1.6m/1	Barium	442
IEC-T12	1-2	IEC-T12(1-2)/1.6m/1	Copper	3220
IEC-T12	1-2	IEC-T12(1-2)/1.6m/1	Lead	181
IEC-T12	1-2	IEC-T12(1-2)/1.6m/1	Nickel	123
IEC-T12	1-2	IEC-T12 (1-2)/1.6m/1	Dioxins	4.545 ppb (TEQ)
IEC-T12	1-2	IEC-T12(1-2)/1.4m/3	Copper	485
IEC-T12	1-2	IEC-T12(1-2)/1.4m/3	Lead	168
IEC-T12	1-2	IEC-T12(1-2)/1.8m/7	Copper	5770
IEC-T12	1-2	IEC-T12(1-2)/1.8m/7	Dibenz(a,h)anthracene	0.169
IEC-T12	1-2	IEC-T12(1-2)/1.8m/7	Lead	307
IEC-T12	1-2	IEC-T12(1-2)/1.8m/7	Nickel	222
IEC-T12	1-2	IEC-T12(1-2)/1.8m/7	Zinc	997
IEC-T12	1-2	IEC-T12 (1-2)/1.8m/7	Dioxins	1.218 ppb (TEQ)
IEC-T12	3-4	IEC-T12 (3-4)/4.1/1&2	Dioxins	5.060 ppb (TEQ)
IEC-T12	3-4	IEC-T12(3-4)/2.0m/4	Lead	188
IEC-T12	3-4	IEC-T12 (3-4)/1.8/5&6	Dioxins	1.570 ppb (TEQ)
IEC-T12	5-6	IEC-T12(5-6)/2.5m/1	Copper	158
IEC-T12	9-10	IEC-T12(9-10)/1.80m/5	Copper	1900
IEC-T12	9-10	IEC-T12(9-10)/1.80m/5	Nickel	159
IEC-T12	9-10	IEC-T12(9-10)/1.80m/5	Zinc	954
IEC-T12	9-10	IEC-T12 (9-10)/1.8m/5	Dioxins	3.548 ppb (TEQ)
IEC-T13	1-2	IEC-T13(1-2)/1.5m/1	Zinc	543
IEC-T13	1-2	IEC-T13(1-2)/0.6m/7	Lead	335
IEC-T13	7-8	IEC-T13(7-8)/2.4m/5	Arsenic	114
IEC-T13	7-8	IEC-T13(7-8)/2.4m/5	Barium	619
IEC-T13	7-8	IEC-T13(7-8)/2.4m/5	Chromium	524
IEC-T13	7-8	IEC-T13(7-8)/2.4m/5	Copper	619
IEC-T13	7-8	IEC-T13(7-8)/2.4m/5	Lead	2410
IEC-T13	7-8	IEC-T13(7-8)/2.4m/5	Nickel	907
IEC-T13	7-8	IEC-T13(7-8)/2.4m/5	Tin	50.1
IEC-T13	7-8	IEC-T13(7-8)/2.4m/5	Zinc	2940
IEC-T13	7-8	IEC-T13(7-8)/2.1m/9	Antimony	101
IEC-T13	7-8	IEC-T13(7-8)/2.1m/9	Zinc	28900
IEC-T18	3-4	IEC-T18(3-4)/1.4m/5	Copper	2100
IEC-T18	3-4	IEC-T18(3-4)/1.4m/5	Lead	278
IEC-T19	1-2	IEC-T19(1-2)/1.03m/1	Copper	7490
IEC-T19	1-2	IEC-T19(1-2)/1.03m/1	Lead	624
IEC-T19	1-2	IEC-T19(1-2)/1.03m/1	Nickel	114
IEC-T19	1-2	IEC-T19(1-2)/1.03m/1	Zinc	2150
IEC-T19	1-2	IEC-T19(1-2)/3.5m/5	Chromium	1110
IEC-T19	1-2	IEC-T19(1-2)/3.5m/5	Copper	643
IEC-T19	1-2	IEC-T19(1-2)/3.5m/5	Lead	215
IEC-T19	1-2	IEC-T19(1-2)/3.5m/5	Zinc	602
IEC-T19	3-4	IEC-T19(3-4)/1.0m/1	Barium	1780
IEC-T19	3-4	IEC-T19(3-4)/1.0m/1	Copper	202

Trench No.	Transect	Sample ID	Contaminant	Conc. (mg/kg or otherwise specified)
IEC-T19	3-4	IEC-T19(3-4)/1.0m/1	Lead	825
IEC-T19	5-6	IEC-T19(5-6)/1.1m/1	Copper	1150
IEC-T19	5-6	IEC-T19(5-6)/1.1m/1	Lead	685
IEC-T19	5-6	IEC-T19(5-6)/1.1m/1	Zinc	706
IEC-T19	5-6	IEC-T19 (5-6)/1.1m/1	Dioxins	1.040 ppb (TEQ)
IEC-T19	5-6	IEC-T19(5-6)/1.9m/5	Arsenic	36
IEC-T19	5-6	IEC-T19(5-6)/1.9m/5	Cadmium	8.17
IEC-T19	5-6	IEC-T19(5-6)/1.9m/5	Chromium	266
IEC-T19	5-6	IEC-T19(5-6)/1.9m/5	Copper	4050
IEC-T19	5-6	IEC-T19(5-6)/1.9m/5	Lead	3110
IEC-T19	5-6	IEC-T19(5-6)/1.9m/5	Nickel	331
IEC-T19	5-6	IEC-T19(5-6)/1.9m/5	Tin	67.5
IEC-T19	5-6	IEC-T19(5-6)/1.9m/5	Zinc	3910
IEC-T19	5-6	IEC-T19(5-6)/1.3m/9	Copper	388
IEC-T19	7-8	IEC-T19(7-8)/2.4m/7	Chromium	516
IEC-T19	7-8	IEC-T19(7-8)/2.4m/7	Copper	6300
IEC-T19	7-8	IEC-T19(7-8)/2.4m/7	Lead	424
IEC-T19	7-8	IEC-T19(7-8)/2.4m/7	Nickel	285
IEC-T19	7-8	IEC-T19(7-8)/2.4m/7	Zinc	2230
IEC-T20	1-2	IEC-T20 (1-2)/1.6m/2	Dioxins	1.148 ppb (TEQ)
IEC-T20	1-2	IEC-T20(1-2)/2.8m/3	Copper	117
IEC-T20	1-2	IEC-T20(1-2)/1.6m/5	Copper	137
IEC-T20	1-2	IEC-T20(1-2)/1.3m/7	Copper	142
IEC-T20	1-2	IEC-T20(1-2)/1.3m/9	Barium	3100
IEC-T20	1-2	IEC-T20(1-2)/1.3m/9	Cobalt	51.4
IEC-T20	1-2	IEC-T20(1-2)/1.3m/9	Copper	3310
IEC-T20	1-2	IEC-T20(1-2)/1.3m/9	Lead	860
IEC-T20	1-2	IEC-T20(1-2)/1.3m/9	Nickel	234
IEC-T20	1-2	IEC-T20(1-2)/1.3m/9	Zinc	3610
IEC-T20	1-2	IEC-T20 (1-2)/1.3m/9	Dioxins	1.067 ppb (TEQ)
IEC-T20	1-2	IEC-T20(1-2)/2.2m/11	Barium	1820
IEC-T20	1-2	IEC-T20(1-2)/2.2m/11	Copper	3450
IEC-T20	1-2	IEC-T20(1-2)/2.2m/11	Lead	1380
IEC-T20	1-2	IEC-T20(1-2)/2.2m/11	Nickel	170
IEC-T20	1-2	IEC-T20(1-2)/2.2m/11	Zinc	1810
IEC-T20	1-2	IEC-T20(1-2)/2.2m/11	Dioxins	1.473 ppb (TEQ)
IEC-T20	1-2	IEC-T20(1-2)/2.2m/13	Dioxins	5.393 ppb (TEQ)
IEC-T20	3-4	IEC-T20(3-4)/3.9m/5	Barium	4660
IEC-T20	3-4	IEC-T20(3-4)/3.9m/5	Copper	5470
IEC-T20	3-4	IEC-T20(3-4)/3.9m/5	Lead	1500
IEC-T20	3-4	IEC-T20(3-4)/3.9m/5	Nickel	352
IEC-T20	3-4	IEC-T20(3-4)/3.9m/5	Tin	64.6
IEC-T20	3-4	IEC-T20(3-4)/3.9m/5	Zinc	3020
IEC-T20	3-4	IEC-T20 (3-4)/3.9m/6	Dioxins	1.882 ppb (TEQ)
IEC-T20	3-4	IEC-T20(3-4)/3.8m/9	Barium	3520
IEC-T20	3-4	IEC-T20(3-4)/3.8m/9	Copper	4590
IEC-T20	3-4	IEC-T20(3-4)/3.8m/9	Lead	1670

Trench No.	Transect	Sample ID	Contaminant	Conc. (mg/kg or otherwise specified)
IEC-T20	3-4	IEC-T20(3-4)/3.8m/9	Nickel	262
IEC-T20	3-4	IEC-T20(3-4)/3.8m/9	Tin	81.1
IEC-T20	3-4	IEC-T20(3-4)/3.8m/9	Zinc	2910
IEC-T20	3-4	IEC-T20 (3-4)/3.8m/10	Dioxins	1.776 ppb (TEQ)
IEC-T20	3-4	IEC-T20(3-4)/2.0m/19	Copper	790
IEC-T20	3-4	IEC-T20(3-4)/2.0m/19	Lead	689
IEC-T20	3-4	IEC-T20(3-4)/2.0m/19	Zinc	559
IEC-T20	5-6	IEC-T20(5-6)/3.5m/1	TPH	15094
IEC-T20	5-6	IEC-T20(5-6)/3.5m/1	Copper	233
IEC-T20	5-6	IEC-T20(5-6)/3.5m/1	Lead	237
IEC-T20	5-6	IEC-T20 (5-6)/3.5m/1	Dioxins	1.461 ppb (TEQ)
IEC-T20	5-6	IEC-T20(5-6)/1.4m/9	Barium	2050
IEC-T20	5-6	IEC-T20(5-6)/1.4m/9	Copper	4470
IEC-T20	5-6	IEC-T20(5-6)/1.4m/9	Lead	1300
IEC-T20	5-6	IEC-T20(5-6)/1.4m/9	Nickel	471
IEC-T20	5-6	IEC-T20(5-6)/1.4m/9	Zinc	2370
IEC-T20	5-6	IEC-T20 (5-6)/1.4m/10	Dioxins	3.457 ppb (TEQ)
IEC-T20	5-6	IEC-T20(5-6)/2.0m/11	Lead	227
IEC-T20	5-6	IEC-T20(5-6)/2.0m/13	Antimony	340
IEC-T20	5-6	IEC-T20(5-6)/2.0m/13	Bis(2-ethylhexyl)phthalate	563
IEC-T20	5-6	IEC-T20(5-6)/2.0m/13	Cadmium	118
IEC-T20	5-6	IEC-T20(5-6)/2.0m/13	TPH	88482
IEC-T20	5-6	IEC-T20(5-6)/2.0m/13	Chromium	412
IEC-T20	5-6	IEC-T20(5-6)/2.0m/13	Cobalt	69
IEC-T20	5-6	IEC-T20(5-6)/2.0m/13	Copper	14100
IEC-T20	5-6	IEC-T20(5-6)/2.0m/13	Lead	21100
IEC-T20	5-6	IEC-T20(5-6)/2.0m/13	Nickel	664
IEC-T20	5-6	IEC-T20(5-6)/2.0m/13	Tin	3650
IEC-T20	5-6	IEC-T20(5-6)/2.0m/13	Zinc	35700
IEC-T20	7-8	IEC-T20(7-8)/4.5m/1	Chromium	5390
IEC-T20	7-8	IEC-T20(7-8)/4.5m/1	Copper	4080
IEC-T20	7-8	IEC-T20(7-8)/4.5m/1	Lead	867
IEC-T20	7-8	IEC-T20(7-8)/4.5m/1	Nickel	108
IEC-T20	7-8	IEC-T20(7-8)/4.5m/1	Zinc	1690
IEC-T20	7-8	IEC-T20 (7-8)/4.5m/1	Dioxins	1.333 ppb (TEQ)
IEC-T20	7-8	IEC-T20(7-8)/2.0m/5	Chromium	798
IEC-T20	7-8	IEC-T20(7-8)/2.0m/5	Copper	780
IEC-T20	7-8	IEC-T20(7-8)/2.0m/5	Lead	418
IEC-T20	7-8	IEC-T20(7-8)/2.0m/5	Nickel	706
IEC-T20	7-8	IEC-T20(7-8)/2.0m/5	Zinc	509
IEC-T20	7-8	IEC-T20(7-8)/2.0m/5	Dioxins	1.767 ppb (TEQ)
IEC-T20	9-10	IEC-T20(9-10)/1.5m/3	Lead	170
IEC-T20	9-10	IEC-T20(9-10)/1.0m/5	Antimony	35.5
IEC-T20	9-10	IEC-T20(9-10)/1.0m/5	Barium	1180
IEC-T20	9-10	IEC-T20(9-10)/1.0m/5	Chromium	703
IEC-T20	9-10	IEC-T20(9-10)/1.0m/5	Cobalt	59

Trench No.	Transect	Sample ID	Contaminant	Conc. (mg/kg or otherwise specified)
IEC-T20	9-10	IEC-T20(9-10)/1.0m/5	Copper	3960
IEC-T20	9-10	IEC-T20(9-10)/1.0m/5	Lead	1140
IEC-T20	9-10	IEC-T20(9-10)/1.0m/5	Molybdenum	56.6
IEC-T20	9-10	IEC-T20(9-10)/1.0m/5	Nickel	906
IEC-T20	9-10	IEC-T20(9-10)/1.0m/5	Tin	50.6
IEC-T20	9-10	IEC-T20(9-10)/1.0m/5	Zinc	3590
IEC-T20	9-10	IEC-T20 (9-10)/1.0m/5	Dioxins	7.572 ppb (TEQ)
IEC-T20	9-10	IEC-T20(9-10)/2.6m/7	Copper	259
IEC-T21	1-2	IEC-T21(1-2)/1.4m/1	Copper	789
IEC-T21	1-2	IEC-T21(1-2)/1.4m/1	Lead	160
IEC-T21	1-2	IEC-T21(1-2)/2.9m/3	Barium	617
IEC-T21	1-2	IEC-T21(1-2)/2.9m/3	Copper	490
IEC-T21	1-2	IEC-T21(1-2)/2.9m/3	Lead	193
IEC-T21	1-2	IEC-T21(1-2)/2.9m/3	Nickel	215
IEC-T21	1-2	IEC-T21(1-2)/2.9m/3	Tin	169
IEC-T21	1-2	IEC-T21(1-2)/1.0m/5	Copper	110
IEC-T21	1-2	IEC-T21(1-2)/1.4m/13	Copper	10300
IEC-T21	1-2	IEC-T21(1-2)/1.4m/13	Hexachlorobenzene	1
IEC-T21	1-2	IEC-T21(1-2)/1.4m/13	Lead	182
IEC-T21	1-2	IEC-T21(1-2)/1.4m/13	Nickel	767
IEC-T21	1-2	IEC-T21(1-2)/1.4m/13	Zinc	2190
IEC-T21	1-2	IEC-T21 (1-2)/1.4m/14	Dioxins	14.084 ppb (TEQ)
IEC-T21	1-2	IEC-T21(1-2)/2.6m/15	Barium	1690
IEC-T21	1-2	IEC-T21(1-2)/2.6m/15	Chromium	266
IEC-T21	1-2	IEC-T21(1-2)/2.6m/15	Cobalt	65.1
IEC-T21	1-2	IEC-T21(1-2)/2.6m/15	Copper	3420
IEC-T21	1-2	IEC-T21(1-2)/2.6m/15	Lead	256
IEC-T21	1-2	IEC-T21(1-2)/2.6m/15	Nickel	337
IEC-T21	1-2	IEC-T21(1-2)/2.6m/15	Tin	55
IEC-T21	1-2	IEC-T21(1-2)/2.6m/15	Zinc	1700
IEC-T21	1-2	IEC-T21 (1-2)/2.6m/16	Dioxins	1.212 ppb (TEQ)
IEC-T21	3-4	IEC-T21(3-4)/1.5m/1	Arsenic	36
IEC-T21	3-4	IEC-T21(3-4)/1.5m/1	Barium	431
IEC-T21	3-4	IEC-T21(3-4)/1.5m/1	Chromium	252
IEC-T21	3-4	IEC-T21(3-4)/1.5m/1	Copper	3590
IEC-T21	3-4	IEC-T21(3-4)/1.5m/1	Lead	751
IEC-T21	3-4	IEC-T21(3-4)/1.5m/1	Nickel	411
IEC-T21	3-4	IEC-T21(3-4)/1.5m/1	Zinc	919
IEC-T21	3-4	IEC-T21 (3-4)/1.5m/(1,2)	Dioxins	1.467 ppb (TEQ)
IEC-T21	3-4	IEC-T21(3-4)/2.6m/3	Copper	5230
IEC-T21	3-4	IEC-T21(3-4)/2.6m/3	Lead	241
IEC-T21	3-4	IEC-T21(3-4)/2.6m/3	Nickel	269
IEC-T21	3-4	IEC-T21(3-4)/2.6m/3	Zinc	782
IEC-T21	3-4	IEC-T21 (3-4)/2.6m/3	Dioxins	2.948 ppb (TEQ)
IEC-T21	3-4	IEC-T21(3-4)/1.6m/5	Lead	183
IEC-T21	3-4	IEC-T21(3-4)/1.4m/7	Copper	3430
IEC-T21	3-4	IEC-T21(3-4)/1.4m/7	Lead	583

Trench No.	Transect	Sample ID	Contaminant	Conc. (mg/kg or otherwise specified)
IEC-T21	3-4	IEC-T21(3-4)/1.4m/7	Nickel	286
IEC-T21	3-4	IEC-T21(3-4)/1.4m/7	Zinc	2140
IEC-T21	3-4	IEC-T21 (3-4)/1.4m/(7,8)	Dioxins	23.596 (TEQ)
IEC-T21	9-10	IEC-T21(9-10)/3.0m/5	Copper	315
IEC-T21	9-10	IEC-T21(9-10)/3.0m/5	Dibenz(a,h)anthracene	0.092
IEC-T21	9-10	IEC-T21(9-10)/3.0m/5	Nickel	155
IEC-T21	9-10	IEC-T21(9-10)/3.0m/5	Zinc	3180
IEC-T22	1-2	IEC-T22(1-2)/2.3m/1	Copper	274
IEC-T22	1-2	IEC-T22(1-2)/2.3m/1	Lead	3340
IEC-T22	1-2	IEC-T22(1-2)/1.4m/5	Copper	863
IEC-T22	1-2	IEC-T22(1-2)/1.4m/5	Lead	162
IEC-T22	1-2	IEC-T22(1-2)/1.4m/5	Zinc	730
IEC-T22	1-2	IEC-T22(1-2)/2.9m/7	Copper	361
IEC-T22	1-2	IEC-T22(1-2)/1.1m/13	Barium	4330
IEC-T22	1-2	IEC-T22(1-2)/1.1m/13	Cobalt	63.3
IEC-T22	1-2	IEC-T22(1-2)/1.1m/13	Copper	4830
IEC-T22	1-2	IEC-T22(1-2)/1.1m/13	Lead	6580
IEC-T22	1-2	IEC-T22(1-2)/1.1m/13	Nickel	295
IEC-T22	1-2	IEC-T22(1-2)/1.1m/13	Tin	51.7
IEC-T22	1-2	IEC-T22(1-2)/1.1m/13	Zinc	3350
IEC-T22	1-2	IEC-T22(1-2)/1.5m/15	Copper	137
IEC-T22	1-2	IEC-T22(1-2)/1.5m/15	Tin	51
IEC-T22	4-3	IEC-T22(4-3)/1.5m/1	Arsenic	37.9
IEC-T22	4-3	IEC-T22(4-3)/1.5m/1	Barium	401
IEC-T22	4-3	IEC-T22(4-3)/1.5m/1	Cadmium	6.7
IEC-T22	4-3	IEC-T22(4-3)/1.5m/1	Chromium	299
IEC-T22	4-3	IEC-T22(4-3)/1.5m/1	Copper	4950
IEC-T22	4-3	IEC-T22(4-3)/1.5m/1	Lead	5060
IEC-T22	4-3	IEC-T22(4-3)/1.5m/1	Nickel	299
IEC-T22	4-3	IEC-T22(4-3)/1.5m/1	Tin	90.2
IEC-T22	4-3	IEC-T22(4-3)/1.5m/1	Zinc	4230
IEC-T22	4-3	IEC-T22(4-3)/3.8m/3	TPH	1695
IEC-T22	4-3	IEC-T22(4-3)/1.1m/5	Copper	1210
IEC-T22	4-3	IEC-T22(4-3)/1.1m/5	Lead	174
IEC-T22	4-3	IEC-T22(4-3)/1.1m/5	Zinc	803
IEC-T22	4-3	IEC-T22 (4-3)/1.1m/5	Dioxins	1.018 ppb (TEQ)
IEC-T22	6-5	IEC-T22(6-5)/1.4m/5	Antimony	35.2
IEC-T22	6-5	IEC-T22(6-5)/1.4m/5	Chromium	284
IEC-T22	6-5	IEC-T22(6-5)/1.4m/5	Copper	876
IEC-T22	6-5	IEC-T22(6-5)/1.4m/5	Lead	168
IEC-T22	6-5	IEC-T22(6-5)/1.4m/5	Molybdenum	353
IEC-T22	6-5	IEC-T22(6-5)/1.4m/5	Nickel	726
IEC-T22	6-5	IEC-T22(6-5)/1.4m/5	Zinc	2900
IEC-T22	6-5	IEC-T22(6-5)/2.9m/7	Barium	554
IEC-T22	6-5	IEC-T22(6-5)/2.9m/7	Chromium	1520
IEC-T22	6-5	IEC-T22(6-5)/2.9m/7	Cobalt	62.1
IEC-T22	6-5	IEC-T22(6-5)/2.9m/7	Copper	5670

Trench No.	Transect	Sample ID	Contaminant	Conc. (mg/kg or otherwise specified)
IEC-T22	6-5	IEC-T22(6-5)/2.9m/7	Lead	8460
IEC-T22	6-5	IEC-T22(6-5)/2.9m/7	Molybdenum	84.2
IEC-T22	6-5	IEC-T22(6-5)/2.9m/7	Nickel	1450
IEC-T22	6-5	IEC-T22(6-5)/2.9m/7	Zinc	4470
IEC-T22	6-5	IEC-T22(6-5)/1.2m/11	TPH	1377
IEC-T22	6-5	IEC-T22(6-5)/1.2m/11	Copper	908
IEC-T22	6-5	IEC-T22(6-5)/1.2m/11	Lead	170
IEC-T22	6-5	IEC-T22(6-5)/1.2m/11	Zinc	640
IEC-T22	7-8	IEC-T22(7-8)/1.4m/1	Barium	862
IEC-T22	7-8	IEC-T22(7-8)/1.4m/1	TPH	1022
IEC-T22	7-8	IEC-T22(7-8)/1.4m/1	Copper	14900
IEC-T22	7-8	IEC-T22(7-8)/1.4m/1	Lead	1450
IEC-T22	7-8	IEC-T22(7-8)/1.4m/1	Nickel	162
IEC-T22	7-8	IEC-T22(7-8)/1.4m/1	Zinc	3170
IEC-T22	7-8	IEC-T22 (7-8)/1.4m/1	Dioxins	6.268 ppb (TEQ)
IEC-T22	7-8	IEC-T22(7-8)/2.8m/3	Barium	452
IEC-T22	7-8	IEC-T22(7-8)/2.8m/3	Copper	3670
IEC-T22	7-8	IEC-T22(7-8)/2.8m/3	Lead	402
IEC-T22	7-8	IEC-T22(7-8)/2.8m/3	Tin	56.5
IEC-T22	7-8	IEC-T22(7-8)/1.4m/5	Cobalt	108
IEC-T22	7-8	IEC-T22(7-8)/1.4m/5	Copper	4230
IEC-T22	7-8	IEC-T22(7-8)/1.4m/5	Lead	856
IEC-T22	7-8	IEC-T22(7-8)/1.4m/5	Nickel	197
IEC-T22	7-8	IEC-T22(7-8)/1.4m/5	Tin	55.5
IEC-T22	7-8	IEC-T22(7-8)/1.4m/5	Zinc	4930
IEC-T25	1-2	IEC-T25(1-2)/1.4m/3	Barium	486
IEC-T25	1-2	IEC-T25(1-2)/1.4m/3	Lead	155
IEC-T26	1-2	IEC-T26(1-2)/0.7m/9	Lead	182
IEC-T26	3-4	IEC-T26(3-4)/0.9m/3	Copper	173
IEC-T26	3-4	IEC-T26(3-4)/0.9m/3	Lead	178
IEC-T26	3-4	IEC-T26(3-4)/0.55m/7	Copper	207
IEC-T29	3-4	IEC-T29(3-4)/1.4m/1	Chromium	2740
IEC-T29	3-4	IEC-T29(3-4)/1.4m/1	Cobalt	57.6
IEC-T29	3-4	IEC-T29(3-4)/1.4m/1	Copper	3310
IEC-T29	3-4	IEC-T29(3-4)/1.4m/1	Lead	174
IEC-T29	3-4	IEC-T29(3-4)/1.4m/1	Nickel	1210
IEC-T29	3-4	IEC-T29(3-4)/1.4m/1	Zinc	1050
IEC-T30	2-1	IEC-T30(2-1)/1.2m/9	PCB	0.7
IEC-T30	2-1	IEC-T30(2-1)/1.2m/9	Chromium	343
IEC-T30	2-1	IEC-T30(2-1)/1.2m/9	Copper	3190
IEC-T30	2-1	IEC-T30(2-1)/1.2m/9	Lead	2760
IEC-T30	2-1	IEC-T30(2-1)/1.2m/9	Nickel	368
IEC-T30	2-1	IEC-T30(2-1)/1.2m/9	Zinc	3390
IEC-T30	2-1	IEC-T30(2-1)/2.3m/11	Copper	2300
IEC-T30	3-4	IEC-T30(3-4)/0.6m/7	TPH	3816
IEC-T31	1-2	IEC-T31(1-2)/0.2m/1	TPH	2031
IEC-T33	3-4	IEC-T33(3-4)/4.6m/1	TPH	4474

Trench No.	Transect	Sample ID	Contaminant	Conc. (mg/kg or otherwise specified)
IEC-T33	3-4	IEC-T33(3-4)/1.8m/5	Copper	2300
IEC-T33	3-4	IEC-T33(3-4)/1.8m/5	Zinc	1210
IEC-T35	2-1	IEC-T35(2-1)/1.2m/5	Cadmium	12
IEC-T35	2-1	IEC-T35(2-1)/1.2m/5	Cobalt	132
IEC-T35	2-1	IEC-T35(2-1)/1.2m/5	Copper	3020
IEC-T35	2-1	IEC-T35(2-1)/1.2m/5	Lead	834
IEC-T35	2-1	IEC-T35(2-1)/1.2m/5	Nickel	107
IEC-T35	2-1	IEC-T35(2-1)/1.2m/5	Zinc	3170
IEC-T35	2-1	IEC-T35 (2-1)/1.2m/6	Dioxins	7.946 ppb (TEQ)
IEC-T35	2-1	IEC-T35(2-1)/2.5m/9	Chromium	269
IEC-T35	2-1	IEC-T35(2-1)/2.5m/9	Copper	4700
IEC-T35	2-1	IEC-T35(2-1)/2.5m/9	Lead	491
IEC-T35	2-1	IEC-T35(2-1)/2.5m/9	Nickel	245
IEC-T35	2-1	IEC-T35(2-1)/2.5m/9	Zinc	4300
IEC-T35	5-6	IEC-T35(5-6)/1.1m/1	Copper	903
IEC-T35	5-6	IEC-T35(5-6)/1.1m/1	Lead	269
IEC-T35	5-6	IEC-T35(5-6)/1.1m/1	Nickel	177
IEC-T35	5-6	IEC-T35(5-6)/1.1m/1	Zinc	1560
IEC-T36	1-2	IEC-T36(1-2)/0.6m/5	Lead	151
IEC-T36	1-2	IEC-T36(1-2)/2.0m/11	Cadmium	5.89
IEC-T36	1-2	IEC-T36(1-2)/2.0m/11	Chromium	793
IEC-T36	1-2	IEC-T36(1-2)/2.0m/11	Copper	2660
IEC-T36	1-2	IEC-T36(1-2)/2.0m/11	Lead	6090
IEC-T36	1-2	IEC-T36(1-2)/2.0m/11	Nickel	1590
IEC-T36	1-2	IEC-T36(1-2)/2.0m/11	Tin	175
IEC-T36	1-2	IEC-T36(1-2)/2.0m/11	Zinc	6290
IEC-T36	7-8	IEC-T36(7-8)/0.9m/1	Copper	2970
IEC-T36	7-8	IEC-T36(7-8)/0.9m/1	Lead	274
IEC-T36	7-8	IEC-T36(7-8)/0.9m/1	Zinc	3070
IEC-T36	9-10	IEC-T36(9-10)/1.8m/5	Cobalt	88.8
IEC-T36	9-10	IEC-T36(9-10)/1.8m/5	Copper	3250
IEC-T36	9-10	IEC-T36(9-10)/1.8m/5	Lead	1320
IEC-T36	9-10	IEC-T36(9-10)/1.8m/5	Nickel	405
IEC-T36	9-10	IEC-T36(9-10)/1.8m/5	Zinc	1790
IEC-T36	11-12	IEC-T36(11-12)/3.1m/1	Chromium	615
IEC-T36	11-12	IEC-T36(11-12)/3.1m/1	Cobalt	103
IEC-T36	11-12	IEC-T36(11-12)/3.1m/1	Copper	5410
IEC-T36	11-12	IEC-T36(11-12)/3.1m/1	Lead	898
IEC-T36	11-12	IEC-T36(11-12)/3.1m/1	Nickel	803
IEC-T36	11-12	IEC-T36(11-12)/3.1m/1	Tin	113
IEC-T36	11-12	IEC-T36(11-12)/3.1m/1	Zinc	3440
IEC-T36	11-12	IEC-T36(11-12)/4.0m/3	Copper	257
IEC-T36	11-12	IEC-T36(11-12)/4.0m/3	Lead	255
IEC-T37	1-2	IEC-T37(1-2)/1.5m/7	Barium	1480
IEC-T37	1-2	IEC-T37(1-2)/1.5m/7	Copper	2650
IEC-T37	1-2	IEC-T37(1-2)/1.5m/7	Lead	4080
IEC-T37	1-2	IEC-T37(1-2)/1.5m/7	Nickel	188

Trench No.	Transect	Sample ID	Contaminant	Conc. (mg/kg or otherwise specified)
IEC-T37	1-2	IEC-T37(1-2)/1.5m/7	Zinc	7840
IEC-T37	1-2	IEC-T37(1-2)/1.0m/9	Copper	116
IEC-T37	1-2	IEC-T37(1-2)/2.9m/11	Barium	986
IEC-T37	1-2	IEC-T37(1-2)/2.9m/11	Copper	2970
IEC-T37	1-2	IEC-T37(1-2)/2.9m/11	Lead	921
IEC-T37	1-2	IEC-T37(1-2)/2.9m/11	Nickel	171
IEC-T37	1-2	IEC-T37(1-2)/2.9m/11	Tin	71.3
IEC-T37	1-2	IEC-T37(1-2)/2.9m/11	Zinc	2060
IEC-T37	1-2	IEC-T37(1-2)/0.6m/13	Copper	887
IEC-T37	1-2	IEC-T37(1-2)/3.3m/15	Copper	117
IEC-T37	3-4	IEC-T37(3-4)/0.6m/1	Lead	213
IEC-T37	3-4	IEC-T37(3-4)/2.4m/3	Copper	337
IEC-T37	6-5	IEC-T37(6-5)/0.8m/5	Barium	2220
IEC-T37	6-5	IEC-T37(6-5)/0.8m/5	TPH	8668
IEC-T37	6-5	IEC-T37(6-5)/0.8m/5	Copper	6050
IEC-T37	6-5	IEC-T37(6-5)/0.8m/5	Lead	599
IEC-T37	6-5	IEC-T37(6-5)/0.8m/5	Nickel	191
IEC-T37	6-5	IEC-T37(6-5)/0.8m/5	Zinc	1330
IEC-T37	6-5	IEC-T37 (6-5)/0.8m/6	Dioxins	109.383 ppb (TEQ)
IEC-T37	8-7	IEC-T37 (8-7)/0.7m/2	Dioxins	3.552 ppb (TEQ)
IEC-T37	8-7	IEC-T37(8-7)/1.3m/5	Chromium	305
IEC-T37	8-7	IEC-T37(8-7)/1.3m/5	Copper	5360
IEC-T37	8-7	IEC-T37(8-7)/1.3m/5	Lead	658
IEC-T37	8-7	IEC-T37(8-7)/1.3m/5	Nickel	519
IEC-T37	8-7	IEC-T37(8-7)/1.3m/5	Zinc	1750
IEC-T37	8-7	IEC-T37(8-7)/2.8m/7	Copper	245
IEC-T37	12-11	IEC-T37(12-11)/3.4m/3	Lead	158

Additional Groundwater Monitoring Wells at Area 3

4.141 Sixteen (16) additional boreholes have been drilled in Area 3. Groundwater monitoring wells were then installed at these locations. The soil samples (taken from these boreholes) with exceedance in the relevant standards are summarised in Table 4.37.

Table 4.37 Analytical Results for Soil Samples of Additional Groundwater Wells in Area 3

Borehole Location	Depth (m)	Contaminant	Concentration (mg/kg or otherwise specified)
AW-7	2.90-3.15	Lead	201
AW-9	1.60-1.85	Lead	200
AW-10	0.68-0.83	Antimony	59.5
AW-10	0.68-0.83	Barium	1420
AW-10	0.68-0.83	Copper	5890
AW-10	0.68-0.83	Lead	582
AW-10	0.68-0.83	Nickel	189
AW-10	0.68-0.83	Zinc	3390
AW-10	0.68-0.83	Dioxins	67.25 ppb (TEQ)
AW-10	1.41-1.66	Copper	778

Borehole Location	Depth (m)	Contaminant	Concentration (mg/kg or otherwise specified)
AW-10	1.41-1.66	Zinc	2170
AW-10	2.88-3.13	Lead	185
AW-11	0.08-0.23	Lead	212
AW-11	0.65-0.80	Copper	1970
AW-11	0.65-0.80	Lead	357
AW-11	0.65-0.80	Nickel	124
AW-11	0.65-0.80	Zinc	868
AW-11	1.40-1.65	Copper	764
AW-11	1.40-1.65	Nickel	156
AW-11	1.40-1.65	Zinc	763
AW-14	2.85-3.10	Copper	455
AW-14	2.85-3.10	Phenol	1.3
AW-15	1.40-1.65	Lead	305
AW-16	0.05-0.23	Copper	322
AW-16	0.05-0.23	Lead	179
AW-18	0.20-0.35	TPH	10681
AW-21	0.68-0.83	Lead	189

4.142 The maximum and average concentrations of contaminants in Area 3 with exceedance are given in Table 4.38.

Table 4.38 Maximum and Average Concentrations of Contaminants in Area 3 with Exceedance

	Unit	No. of Exceedances	No. of Samples Analysed	Maximum	Average (exceedances only)	Overall Average
Antimony	mg/kg	5	479	340	114	2.205
PCB	mg/kg	1	44	0.70	0.70	0.043
Arsenic	mg/kg	5	477	114	53	1.836
Barium	mg/kg	24	477	4660	1512	121.246
Bis(2-ethylhexyl)phthalate	mg/kg	1	474	563.00	563.00	1.211
Cadmium	mg/kg	9	478	118	20	0.643
TPH	mg/kg	14	390	88482	10980	428.456
Chromium	mg/kg	21	478	5390	918	54.671
Cobalt	mg/kg	12	485	328	99	7.649
Copper	mg/kg	92	478	28100	2758	537.664
Dibenz(a,h)anthracene	mg/kg	2	474	0.17	0.13	0.001
Hexachlorobenzene	mg/kg	1	474	1.00	1.00	0.002
Lead	Mg/kg	85	477	21100	1172	259.790
Molybdenum	Mg/kg	4	477	599	273	4.271
Nickel	Mg/kg	49	479	1790	419	46.734
Phenol		1	474	1.30	1.30	0.004
Tin	Mg/kg	17	479	3650	292	12.315
Zinc	Mg/kg	60	478	35700	3701	502.405
Dioxins	ppb (TEQ)	31	170	109.383	9.741	1.837

Overall Maximum and Average Concentrations of Contaminants

4.143 The overall maximum and average concentrations of 3 different types of contaminated soils are given in Tables 4.39 to 4.41. The maximum and average levels of all 3 types contaminated soils are provided in Table 4.42.

Table 4.39 Maximum and Average Concentrations of Contaminants (with Exceedance) in Soil Contaminated with Organic Compounds Only

	Unit	No. of Exceedances	Maximum	Average (exceedances only)
Benzo(a)anthracene	mg/kg	3	1.67	1.48
Benzo(a)pyrene	mg/kg	2	1.60	1.52
Benzo(b)fluoranthene	mg/kg	3	1.50	1.39
Bis(2-ethylhexyl)phthalate	mg/kg	1	46.00	46.00
TPH	mg/kg	42	25891.00	6814.38
Dibenz(a,h)anthracene	mg/kg	4	0.21	0.16
Indeno(1,2,3-cd)pyrene	mg/kg	2	1.09	1.01
Naphthalene	mg/kg	6	20.80	14.20
Styrene	mg/kg	1	6.30	6.30

Table 4.40 Maximum and Average Concentrations of Contaminants (with Exceedance) in Soil Contaminated with Metals Only

	Unit	No. of Exceedance	Maximum	Average (exceedances only)
Antimony	mg/kg	5	101.00	59.56
Arsenic	mg/kg	7	114.00	48.63
Barium	mg/kg	40	4660.00	1428.20
Cadmium	mg/kg	17	18.10	8.26
Chromium	mg/kg	44	5390.00	770.73
Cobalt	mg/kg	17	328.00	91.18
Copper	mg/kg	183	28100.00	1992.45
Cyanide	mg/kg	1	123.00	123.00
Hexavalent Chromium	mg/kg	2	392.00	340.00
Lead	mg/kg	133	26300.00	1130.89
Molybdenum	mg/kg	5	599.00	227.76
Nickel	mg/kg	94	1790.00	398.55
Tin	mg/kg	25	232.00	91.12
Zinc	mg/kg	86	28900.00	3037.48

Table 4.41 Maximum and Average Concentrations of Contaminants (with Exceedance) in Soil Contaminated with Metals & Organic Compounds

	Unit	No. of Exceedance	Maximum	Average (exceedances only)
Antimony	mg/kg	1	340.00	340.00
PCB	mg/kg	3	33.40	13.27
Arsenic	mg/kg	1	42.00	42.00
Barium	mg/kg	3	2220.00	1173.00
Benzo(a)anthracene	mg/kg	2	1.34	1.28
Benzo(a)pyrene	mg/kg	2	1.90	1.46
Benzo(b)fluoranthene	mg/kg	3	2.38	1.50
Bis(2-ethylhexyl)phthalate	mg/kg	1	563.00	563.00
Cadmium	mg/kg	3	118.00	43.16
TPH	mg/kg	19	88482.00	11384.68
Chromium	mg/kg	4	890.00	518.50
Cobalt	mg/kg	1	69.00	69.00
Copper	mg/kg	21	14900.00	3870.29
Dibenz(a,h)anthracene	mg/kg	5	0.66	0.25
Hexachlorobenzene	mg/kg	1	1.00	1.00
Indeno(1,2,3-cd)pyrene	mg/kg	1	1.51	1.51
Lead	mg/kg	15	21100.00	2078.00
Nickel	mg/kg	9	767.00	331.89
Phenol	mg/kg	1	1.30	1.30
Tin	mg/kg	3	3650.00	1284.36
Zinc	mg/kg	14	35700.00	4423.50

Table 4.42 Maximum and Average Concentrations of All Contaminants with Exceedance

	Unit	No. of Exceedances	No. of Samples Analysed	Max.	Average (exceedances only)	Overall Average
Antimony	mg/kg	6	1910	340.00	106.30	0.709
PCB	mg/kg	3	333	33.40	13.27	0.124
Arsenic	mg/kg	8	1905	114.00	47.80	1.185
Barium	mg/kg	43	1903	4660.00	1410.40	64.174
Benzo(a)anthracene	mg/kg	5	1844	1.67	1.40	0.008
Benzo(a)pyrene	mg/kg	4	1847	1.90	1.49	0.009
Benzo(b)fluoranthene	mg/kg	6	1849	2.38	1.45	0.010
Bis(2-ethylhexyl)phthalate	mg/kg	2	1847	563.00	304.50	0.361
Cadmium	mg/kg	20	1910	118.00	13.50	0.274
TPH	mg/kg	61	1906	88482.00	8237.92	293.315
Chromium	mg/kg	48	1910	5390.00	749.71	28.034
Cobalt	mg/kg	18	1914	328.00	89.95	4.371
Copper	mg/kg	204	1910	28100.00	2185.75	241.537
Cyanide	mg/kg	1	1634	123.00	123.00	0.095
Dibenz(a,h)anthracene	mg/kg	9	1849	0.66	0.21	0.002
Hexachlorobenzene	mg/kg	1	1849	1.00	1.00	0.001
Hexavalent Chromium	mg/kg	2	1585	392.00	340.00	0.769

	Unit	No. of Exceedances	No. of Samples Analysed	Max.	Average (exceedances only)	Overall Average
Indeno(1,2,3-cd)pyrene	mg/kg	3	1848	1.51	1.17	0.007
Lead	mg/kg	148	1907	26300.00	1226.88	134.691
Molybdenum	mg/kg	5	1907	599.00	227.76	1.783
Naphthalene	mg/kg	6	1848	20.80	14.20	0.053
Nickel	mg/kg	103	1910	1790.00	392.73	24.928
Phenol		1	1849	1.30	1.30	0.001
Styrene	mg/kg	1	1836	6.30	6.30	0.005
Tin	mg/kg	28	1906	3650.00	218.97	4.072
Zinc	mg/kg	100	1912	35700.00	3231.52	206.157
Dioxins	ppb (TEQ)	39	202	109.383	8.299	1.658

4.144 The laboratory results of TBT for soil samples indicate that there is no exceedance in the action level of TBT for soil remediation.

Extent of Soil Contamination

4.145 Plan views of the soil-contaminated areas at Area 1, Area 2 and Area 3 are shown in Figure 4.4, Figure 4.5 and Figure 4.6, respectively.

4.146 Contaminated areas, depths, and conservative estimated volume of soil that may exceed the cleanup targets are summarised in Table 4.43. As the distribution of sampling locations and soil sample volumes tested are very small compared with the estimated contaminated areas and volumes of contaminated soil, the volumes shown in Table 4.43 are 'best conservative estimates'.

Table 4.43 Contaminated Areas, Depth & Estimated Volumes of Soil Exceeding Action Levels

Area	Buildings	Contaminants	Average Depth	Maximum Depth	Soil Volume
1	B, D, I, J, L, M, N, O, and P	Metals, Petroleum Hydrocarbons (TPH), Semi-volatile Organic Compounds (SVOCs), and Dioxins	0.9m	3.1m	10,150 m^3
2	R, S, T, V, W, X, Y, Z, and trenches	Metals, Petroleum Hydrocarbons (TPH), Semi-volatile Organic Compounds (SVOCs), and Dioxins	1.4m	3.4m	15,250 m^3
3	Q and trenches	Metals, Petroleum Hydrocarbons (TPH), Semi-volatile Organic Compounds (SVOCs), and Dioxins	2.9m	4.5m	61,600 m^3
				Total =	**87,000 m^3**

Volumes of Contaminated Soil

4.147 On the other hand, the volumes of different types of contaminated soil at Area 1, Area 2 and Area 3 have been estimated based on the available laboratory results and are tabulated in Table 4.44. It should be noted that although 1 ppb TEQ is used as the action level for dioxins in soil, in order to have a safety factor for treatment of dioxin-contaminated soil, 0.1 ppb TEQ is used for estimating the volume of dioxin-containing soil that needs to be excavated for treatment.

Table 4.44 Estimated Volume of Different Types of Contaminated Soil in Areas 1, 2 and 3

Area	Metals Only	TPH/ SVOCs	Metals and TPH/ SVOCs	Dioxins and Metals/TPH/ SVOCs
1	6,000 m^3	300 m^3	3,800 m^3	50 m^3
2	7,000 m^3	400 m^3	4,000 m^3	3,850 m^3
3	35,000 m^3	0 m^3	500 m^3	26,100 m^3
Total	**48,000 m^3**	**700 m^3**	**8,300 m^3**	**30,000 m^3**

4.148 Note that the locations of the proposed exploratory trenches of buried waste were determined by the results of the geophysical survey. Normally, one soil sample was collected from the apparently impacted soil and another from beneath the impacted soil per every 15 linear meters of the trench. If presence of pollutants is confirmed in the impacted sample by laboratory results, the whole portion of the trench (15m), where the impacted soil were collected, is then classified as contaminated, and vice versa. The depth of contamination was then determined by the laboratory results of the apparently "clean" sample. The estimation of impacted soil shown in Table 4.44 is based on this approach.

4.149 The percentages of different types of contaminated soil in Area 1, Area 2 and Area 3 have been calculated based on the estimated volumes of different types of contaminated soil, and are tabulated in Table 4.45. Furthermore, the percentages of different types of contaminated soil in the whole CLS site are shown in Table 4.46.

Table 4.45 Estimated Percentages of Different Types of Contaminated Soil in Areas 1, 2 and 3

Contaminant(s)	Area 1	Area 2	Area 3
Metals only	59.1 %	45.9 %	56.8 %
TPH/SVOCs	3.0 %	2.6 %	0 %
Metals and TPH/SVOCs	37.4 %	26.2 %	0.8 %
Dioxins and Metals/TPH/ SVOCs	0.5 %	25.2 %	42.4 %
(Total =)	(100 %)	(100 %)	(100 %)

Table 4.46 Estimated Percentages of Different Types of Contaminated Soil in Whole CLS Site

Contaminant(s)	Whole CLS Site
Metals only	55.2 %
TPH/SVOCs	0.8 %
Metals and TPH/SVOCs	9.5 %
Dioxins and Metals/TPH/SVOCs	34.5 %
(Total =)	(100 %)

Mitigation for Land Contamination

Objectives of Remediation

4.150 The objectives of the remediation are as follows:

i) To clean up the site to the remediation targets and within the overall development programme with cost effective and well established method;

ii) To minimise the environmental impacts during the excavation, construction and operation of the remedial systems; and

iii) To protect construction workers adequately from site hazards.

Cleanup Targets for Soil

4.151 In general, the cleanup targets for soil are also the Dutch 'B' Standards of the concerned contaminants. For chemicals (except dioxins which is discussed in the following paragraphs) that are not included in the Dutch 'B' Standards, the USEPA federal standard's Soil Screening Levels (SSLs) (published under *Soil Screening Guidance : Technical Background Document*) were used. The SSLs for ingestion or inhalation, whichever is lower, were used. If the chemicals are not included in the USEPA federal standard's SSLs, then the USEPA Region IX PRGs were used as the cleanup targets.

Cleanup Target for Dioxins in Soil

4.152 The USEPA's OSWER Directive 9200.4-26 ("Approach for Addressing Dioxin in Soil at Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and Resource Conservation and Recovery Act (RCRA) Sites" signed 13 April 1998) states that 1 ppb TEQ is generally recommended as a cleanup standard for dioxins for residential soils at CERCLA and RCRA sites (5 to 20 ppb TEQ has been selected for industrial use scenarios).

4.153 Treating soils to this standard would meet the Universal Treatment Standards (UTS) and would be consistent with USEPA's OSWER Directive 9200.4-26. In Hong Kong, the UTS standard has been applied to the acceptance criteria of metal contaminated soil treatment. The level is also adopted as the cleanup level for dioxins in the EIA Report for Decommissioning of Kwai Chung Incinerator.

Cleanup Targets for Metals in Soil

4.154 For metal contaminants to be remediated by solidification, the Universal Treatment Standards (UTS) of U.S. Resource Conservation and Recovery Act (RCRA) wastes that contain metals (in 40 CFR 268) should be referred. These standards were derived from the performance of the Best Demonstrated Available Technologies for treating these types of wastes. The UTS for metals are given in Table 4.47.

Table 4.47 Universal Treatment Standards for Metals

Parameter	Universal Treatment Standard (mg/L as TCLP)
Antimony	1.15
Arsenic	5
Barium	21

Parameter	Universal Treatment Standard (mg/L as TCLP)
Beryllium	1.22
Cadmium	0.11
Chromium (Total)	0.6
Hexavalent Chromium	Not available
Cobalt	Not available
Copper	7.8[a]
Lead	0.75
Mercury	0.025
Molybdenum	Not available
Nickel	11
Selenium	5.7
Silver	0.14
Thallium	0.2
Tin	Not available
Vanadium	1.6
Zinc	4.3
Cyanide (Total)	590

a Please refer Section 4.155 for the derivation of this value.

4.155 It should be noted that the UTS standard for copper is unavailable. To determine the UTS for copper, a comparison has been made between Drinking Water Standards for the USEPA and the USEPA Federal Register. It was found that the 2 sets of standards differ by a factor of ~6 (for Chromium) to ~2950 (for Cyanide). Using a more conservative approach, the factor of 6 is taken. Therefore, the UTS for copper is taken to be the Drinking Water Standard value of 1.3 mg/L times a factor of 6, giving a value of 7.8 mg/L.

4.156 It should be noted that there is no UTS or USEPA Drinking Water Standard for hexavalent chromium, cobalt, molybdenum, and tin. Therefore, cleanup targets are not established for these four metals. Nevertheless, it is expected that the solidification process will likely isolate these metals in the same manner as the other metals present.

4.157 The cleanup targets for soil remediation for chemicals with exceedance in the relevant standards are provided in Appendix 4G. Furthermore, the unconfined compressive strength of the solidified material shall be not less than 150 pound-force per square inch (psi).

On-site Excavation

4.158 Owing to the tight programme of the decommissioning of the subject shipyard for the development of theme park, it is anticipated that any contaminated soil found will be excavated for on-site or off-site treatment. Delineation of soil contaminated areas (taking account of the site observations) has been carried out. The conservative estimated soil-contaminated areas at Area 1, Area 2 and Area 3 that require to be excavated are depicted in Figure 4.7, Figure 4.8 and Figure 4.9, respectively. After excavation, confirmation sampling and testing shall be carried out at limits of excavation to confirm that all contaminated soil has been excavated. Soil samples shall be collected at the limits of excavation for laboratory analysis of contaminants with exceedance in action levels for soil remediation. If laboratory results exceed the relevant standards, more soil shall be excavated (either laterally or vertically) and additional confirmation samples shall be collected and analysed until all confirmation samples are below the action levels. A sampling plan showing the sampling locations, methodology, analysis parameters and QA/QC procedures shall be prepared by the Engineer for DEP's approval before excavation begins. More details about the excavation plan are provided in Sections 4.216 to 4.224.

4.159 The recommended remediation methods require excavation of contaminated soil from the ground for ex-situ treatment or disposal. Excavated soils will be placed in stockpiles. Appropriate measures will be taken for the control of release of contaminants from the soil stockpiles.

Off-site Treatment

4.160 Metal-contaminated soil will be treated on site. To Kau Wan is the site identified for off-site treatment. The justifications for selecting To Kau Wan include its location being in the same district (Lantau Island), being comparatively far from sensitive receivers, and its availability for the next two/three years for treatment use. It is anticipated that all other contaminated soil (including dioxin-contaminated soil) will be transported from CLS to To Kau Wan for off-site treatment.

Evaluation of Remedial Treatment Methods

Potential Remediation Methods for Non-dioxin Contaminated Soil

4.161 Soil remediation options applicable to the subject site were addressed (the remedial options for dioxin-contaminated soil will be discussed later in this chapter), based on the following criteria:

- Technical and cost effectiveness;
- Technology development status;
- Commercial availability;
- Experience; and
- Expertise requirement.

4.162 Common in-situ and ex-situ treatment technologies that were screened for the targeted soil contaminants (other than dioxins) are presented in Table 4.48. The technologies are classified into biological treatment, physical/chemical treatment and removal, under in-situ and ex-situ methods.

Table 4.48 Treatment Technologies for Contaminated Soil with Metals/TPH/SVOCs

Technology	In-situ Treatment	Ex-situ Treatment
Biological Treatment	Bioventing Natural Attenuation	Biopile Slurry Phase Bioreactors
Physical/Chemical Treatment	Soil Flushing Solidification/stabilisation	Physical Separation Soil washing Solidification/stabilisation Incineration
Removal	N/A	Landfill disposal / disposal of to off-site treatment facility

4.163 A number of treatment technologies for the soil remediation are selected for detailed examination. The applicability and limitations of the candidate treatment technologies are detailed in Table 4.49.

Table 4.49 Summary Listing of Selected Soil Remediation Technologies for Non-dioxin Contaminated Soil

Remediation Option	Status [a]	Applicability	Limitations	O & M Duration [b]
Biopile	Conventional	• Applicable to soils contaminated with biodegradable organic compounds, e.g. TPH. • Most cost-effective for large volumes of contaminated material. • All materials and equipment are commercially available.	• Substantial space required for static pile. • Excavation may cause release of VOCs. • Heavy metals are not treated. • Labour-intensive; require considerable maintenance.	Short to Medium
Solidification/ Stabilisation (ex-situ)	Conventional	• Applicable to inorganics, including heavy metals.	• Environmental conditions may affect the long-term immobilisation of contaminants. • Some processes result in volume increase.	Short
Solidification/ Stabilisation (in-situ)	Innovative	• Applicable to inorganics, including heavy metals.	• Depth of contaminants may limit some types of application processes. • Some processes result in volume increase. • Reagent delivery and effective mixing are more difficult and costly than for ex-situ applications. • Difficult for confirmatory sampling.	Short to medium
Landfill Disposal	Conventional	• Applicable to all wastes that meet land disposal restriction treatment standards. • Best for removal and disposal of limited volumes of 'hotspot' materials from a vast area that may otherwise be 'clean'. • Common practice for shallow, highly-contaminated soils.	• Pretreatment is required for contaminated soil to meet landfill disposal criteria. • Least desirable management option. • Potential for long-term liabilities. • Long-term monitoring required.	Short
Incineration	Conventional	• Applicable to halogenated and nonhalogenated organics, explosives, PCBs, and dioxins. • Economy of scale for large volumes.	• Generally high costs. • Potential disposal problems for residual materials; residual ash may require further treatment. • Heavy metals can produce a bottom ash that requires stabilisation.	Short
Bioventing	Conventional	• Applicable to TPH, non-chlorinated solvents, some pesticides, wood preservatives, & other organic chemicals.	• The presence of the water table within several feet of the surface, saturated soil lenses, or low permeability soils reduce bioventing performance. • Vapours can build up in basements within the radius of influence of air injection wells. • Low soil moisture content may limit the effectiveness of bioventing. • Monitoring of off-gases at the soil surface may be required. • Low temperatures slow remediation.	Medium to long
Natural	Innovative	• Applicable to non-halogenated VOCs/SVOCs, and fuel	• Data must be collected to determine model input	Long

Remediation Option	Status [a]	Applicability	Limitations	O & M Duration [b]
Attenuation		hydrocarbons.	parameters. • Highly skilled modellers are required. • Intermediate degradation products may be more mobile and more toxic than the original contaminant. • Contaminants may migrate before they are degraded. • The site may have to be fenced and may not be available for re-use until contaminant levels are reduced.	
Slurry-phase bioreactors	Innovative	• Applicable to nonhalogenated SVOCs and VOCs. • Slurry-phase bioreactors are favoured over in-situ biological techniques for heterogeneous soils, low permeability soils, areas where underlying groundwater would be difficult to capture, or when faster treatment time is required. • Slurry-phase bioreactors containing cometabolites and specially adapted micro-organisms may be used to treat halogenated VOCs and SVOCs, pesticides, and PCBs in excavated soils and dredged sediments.	• Excavation is required. • Sizing of materials prior to putting them into the reactor can be difficult and expensive; highly heterogeneous soils can create serious materials-handling problems. • Dewatering soil fines after treatment can be expensive. • An acceptable method for disposing of nonrecycled wastewater is required.	Short to medium
Soil Flushing	Innovative	• Applicable to remove halogenated SVOCs, nonhalogenated SVOCs, PCBs, and explosives from in situ materials. • Water soluble inorganic contaminants may also be removed using soil flushing. • Most applicable when contamination extends to groundwater table.	• Leachate collection required. • Low permeability soils are difficult to treat. • Surfactants can adhere to soil and reduce effective soil porosity. • Reactions of flushing fluids with soil can reduce contaminant mobility. • The potential of washing the contaminant beyond the capture zone and the introduction of surfactants to the subsurface concern regulators. • Flushing solution must be recovered and treated. • Long-term monitoring required.	Short to medium
Physical Separation	Conventional	• Applicable to recovery of metals from soils, sediments, or slags in either of two situations.	• Physical separation requires that the desired component be present in higher concentrations in a phase having different physical properties than the bulk material. • Separation methods applied to dry the material (e.g., screening) generate dust.	Short to medium
Soil Washing	Innovative	• Applicable to SVOCs, fuels, and inorganics. • The technology offers the potential for recovery of metals and can clean a wide range of organic and inorganic	• Fine soil particles (e.g., silt, and clay) may require the addition of a polymer to remove them from the washing fluid.	Medium

Remediation Option	Status [a]	Applicability	Limitations	O & M Duration [b]
		contaminants from coarse-grained soils.	• Complex waste mixtures (e.g., metals with organics) make formulating washing fluid difficult • High humic content in soil may require pretreatment. • The aqueous stream will require treatment.	

[a] Conventional – technologies are in common use, and design and cost information is available.
Innovative – technologies are proven but may not be in common use; however, design and cost information is available.

[b] Short – range from weeks to a few months.
Medium – range from several months to a year.
Long – take over a year.

Selection of Remediation Methods for Non-dioxin Contaminated Soil

4.164 In assisting the formulation of appropriate remedial measures, the *Guidance Notes for Investigation and Remediation of Contaminated Sites of Petrol Filling Stations, Boatyards, and Car Repair/Dismantling Workshops* published by the EPD suggest the following factors to be taken into consideration when evaluating the different available remediation methods:

i) degree and extent of the contamination;
ii) anticipated future use of the site;
iii) nature of the contaminants;
iv) soil characteristics; and
v) time available for remediation.

4.165 Soil contaminated with metals can be remediated by either cement solidification or chemical stabilisation (e.g. with "Triple Super Phosphate" (TSP) as the stabilising agent).

Solidification with Cement

4.166 Cement solidification is an immobilisation technique applicable to the treatment of soil contaminated with heavy metals. By mixing the contaminated soil with cement and sand, the metal contaminants in soil become physically bound within a stable mass. The solid monolithic block is extremely resistant to the leaching of metal contaminants.

4.167 Cement-based solidification involves mixing contaminated materials with an appropriate ratio of cement, and possibly water and other additives. The fundamental materials used to perform this technology are Portland-type cements.

4.168 Ex situ cement solidification has the advantages that it can provide better control of reagent addition and mixing, and quality control sampling is easier.

Stabilising with Triple Super Phosphate (TSP)

4.169 Stabilisation is an immobilisation technique applicable to the treatment of soils contaminated with heavy metals. By reacting with a stabilising agent, the metal contaminants in soil will be reduced substantially in mobility and become fully or partially bound within the stabilised mass which is extremely resistant to the leaching of contaminants.

4.170 One option is to use "Triple Super Phosphate" (TSP) as stabilising agent (2-4%), the TSP stabilises metals by chemically binding them into new stable phosphate phases and other relatively insoluble phases in the soil. The stabilising agent is typically mixed with contaminated soils using a pugmill (soil mixing equipment) or excavation equipment if the quantities are small (<2000 tons). Metals most effectively stabilised by this treatment include lead, zinc, copper, cadmium and nickel.

4.171 Depending on chemical feed and water requirements, the volume expansion of the treated soil may range from 3 to 16 %. The total metal concentrations in and the physical characteristics of the soil are not significantly changed by the treatment, however the stabilised insoluble metals compounds are much less likely to leach and migrate from the site.

4.172 In the US, remediated soils are often removed from the site, which could make the cement solidification procedure more costly because of the larger amount of solids (up to 30%) added to the contaminated materials. This results in a substantial increase in the total mass of material that must be transported and disposed off-site. Therefore, stabilisation with TSP or a similar material is commonly used in the US.

Selection between TSP Stabilisation and Cement Solidification

4.173 In general, stabilised soil (whether stabilised by TSP or other stabilising agents) are not backfilled on-site unless they are placed in a cell lined with an impermeable membrane. There is little or no data on the very long-term stability of stabilised soil. Thus, although test results indicate only minimal (substantially less than TCLP standards) leaching of metals from stabilised soils, there is no data for duration greater than approximately 25 years.

4.174 Owing to the concern about long-term stability of soil stabilised by TSP, it is recommended to use cement solidification rather than stabilisation with TSP for remediation of metal-contaminated soil.

Remediation for Soil Contaminated with Metals Only

4.175 Soil that is contaminated by metals only will be excavated and then solidified by cement.

Remediation for Soil Contaminated with TPH/SVOCs

4.176 It is proposed to adopt biopiling for the treatment of soils contaminated with TPH/SVOCs because the contaminant levels of SVOCs are below their respective Dutch 'C' Standards. Furthermore, the soils contaminated with TPH and SVOCs shall co-biodegrade in a biopile without interference with each other.

4.177 The contaminated soil will be excavated, then treated by means of biopiling.

Remediation for Soil Contaminated with Metals and TPH/SVOCs

4.178 Soil contaminated with metals and TPH/SVOCs will first be biopiled and then solidified by cement. It is because organic compounds may interfere with the process of solidification[1]. Interference with Portland cement or other cementitious materials can occur in several ways. Oils and grease can coat the cement, preventing the reaction between water and cement. Some organic compounds can be adsorbed on cement surfaces and severely retard cement hydration.

4.179 Contaminated soil of this category shall be biopiled separately from those contaminated with TPH/SVOCs, which will be backfilled into the site after biopiling without solidification.

4.180 For soil contaminated with heavy metals and TPH/SVOCs, during the biopiling, the TPH/SVOCs in soils shall be treated to below the relevant cleanup targets prior to cement solidification.

Proposed Remediation Methods for Non-dioxin Contaminated Soil

4.181 The proposed remediation methods for "conventional contaminants' at the subject shipyard are summarised in Table 4.50 whereas the proposed remediation strategy for the non-dioxin contaminated soil is presented in Figure 4.10.

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[1] Suthersan, S. S. (1997). *Remediation Engineering Design Concepts*. Lewis Publishers, New York. p.305

Table 4.50 Proposed Remediation Methods for Different Types of Contaminated Soils^{+}

Soil Contaminant(s)	Remediation Method	Justification
Metals	Cement solidification	• Well developed technology • More cost effective that chemical stabilisation • Higher certainty of success • Simplicity in process (for limited quantity) • Solidified soil is acceptable to be reused as backfill
TPH/SVOCs	Biopiling	• Much faster that in situ treatment • Higher certainty of success • Simple operation • With operation experience in Hong Kong • Can address TPH and SVOCs • Cost effective
Metals and TPH/SVOCs	Biopiling followed by cement solidification	Same as above for biopiling and cement solidification

$^{+}$ Except dioxins which will be discussed later in this chapter.

Justifications for Recommended Remedial Methods

4.182 There is presence of cyanide at one location (B-B24 at Building B) at which metal contamination also occurs. As solidification/stabilisation treatment is also suitable for cyanide-contaminated soil, the contaminated soil at this location shall be treated by solidification/stabilisation with other metal-contaminated soil.

4.183 The average pH of the soil ranges from 6.5 to 8, which is amenable to treatment by solidification/stabilisation or biopiles. According to the physical test results for the soil samples taken at the groundwater well locations proposed in the CAP across the CLS site (please refer Appendix 4F), the soil beneath the site is predominately sand. Furthermore, it has been estimated based on the soil test results of a site investigation undertaken at CLS (please refer Appendix 4H) that the average clay content of the soil is only about 6-10%, which will not reduce the biological availability of the contaminants.

Treatability Tests for Biopile and Solidification/Stabilisation

4.184 It is recommended to carry out treatability tests to investigate the requirements and set design/operational parameters for the biopile and solidification/stabilisation methods. These tests might have to be carried out as a follow-up work during the detailed design.

4.185 The objectives of the biopile treatability test are to: (i) determine if the presence of a wide variety of heavy metals at high concentrations in the soil will inhibit biodegradation process in biopile; and (ii) determine the appropriate design parameters, including necessary amendments, operating conditions, and treatment duration to optimise the full-scale biopile treatment.

4.186 The objective of the cement solidification/stabilisation treatability test is to determine the appropriate design parameters for the full-scale S/S treatment.

Potential Remedial Methods for Dioxin-contaminated Soil

4.187 This subsection describes the results of a comparative analysis of several process options for treatment of dioxin-contaminated soil that is found in Area 3 of CLS. The options were compared based on effectiveness, implementability, and relative cost. The purpose of this screening and evaluation process is to eliminate technologies that are not feasible or have severe limitations that might prevent achievement of the overall project objectives. Based on the results of the comparative analysis, a recommendation has been made for each technology (or process option) to be retained or eliminated from further consideration.

4.188 General response actions have been pre-screened, so that the remedial action will consist of either on-site/in situ storage/containment or excavation followed by off-site treatment. General response actions such as No Action and Institutional Controls have not been considered in this evaluation as the program objective is to remove the dioxin-contaminated soils from CLS and subsequently either contained and treated off-site. This section will therefore focus on identifying and screening applicable removal and treatment technologies (both short-term and long-term) for soils containing dioxins. The criteria used in the evaluation are the following:

- Effectiveness; and
- Implementability.

Effectiveness

4.189 The effectiveness of each technology/process option was assessed, taking into account the following:

- Effectiveness of the process option in meeting project objectives.
- Potential impacts to human health and the environment during the construction and implementation phases.
- How proven and reliable the process is with respect to the contaminants and conditions at the site.

Implementability

4.190 Process options were evaluated against the following implementability factors:

- Ability to obtain necessary permits and/or public acceptance.
- Commercial availability of equipment and related support services necessary to implement the process option.
- Ability to implement the technology in a time frame that meets the overall program requirements.

4.191 Table 4.51 presents the comparative analysis of process options for soils containing dioxins at Area 3 of the Cheoy Lee Shipyard. The results of the screening and evaluation process for the general response actions, remedial technologies, and process options are graphically represented in Figure 4.11.

Table 4.51 Comparative Analysis of Process Options for Dioxin-contaminated Soil

Remediation Option	Effectiveness	Implementability	Relative Cost	Env. Benefits/Disbenefits
Incineration (Rotary Kiln): High-temperature incineration option that would be capable of treating both solid and liquid feed materials. After passing through a screen to reduce the maximum particle size to two inches, the feed materials would be passed through a cylindrical, refractory-lined shell mounted on a slight incline (rotary kiln). The kiln rotates to promote mixing and transfer of the material through the kiln. Temperatures in the kiln would reach 1,800° F. A secondary combustion chamber (called an afterburner) is designed to destroy organics in the flue gases and would operate at temperatures as high as 2,200° F. Treatment residuals requiring additional treatment or disposal include ash and possibly a liquid waste stream if a wet scrubber is used for treatment of emissions.	Rotary kiln incinerators have been used successfully in remediation of soils contaminated with a wide range of organic compounds. It is expected that this technology could meet the cleanup objectives for all organic contaminants, including dioxins. Provides complete destruction of dioxins to required PRGs. High metals concentrations in the soil may result in substantial accumulation of metals in the fly ash. Based on the metals concentrations in the fly ash, a secondary treatment, such as stabilisation, may be required to immobilise metals before placing treated soil in the ground.	Both mobile (transported intact) and transportable (delivered in pieces and assembled on-site) rotary kiln incinerators are available for on-site use. In addition, soils can be transported off-site for treatment at a stationary commercial incinerator. It is likely that a trial burn and performance test would need to be conducted to verify the effectiveness of the kiln, if conducted on-site.	The costs for high-temperature incineration would be high when compared to other treatment technologies.	Incineration is potentially applicable to destroy dioxins concentrated in treatment residuals generated from other treatment processes such as thermal desorption or solvent extraction. Incineration would produce significant amount of slag-like residue which is difficult to treat. The residue thus requires final disposal to landfill. Incineration consumes more energy than thermal desorption, thus will produce more greenhouse gases than thermal desorption.
Thermal Desorption: Thermal desorption is a technology in which wastes are heated to temperatures between 300° F and 600° F (low temperature thermal desorption) or 600° F and 1,000° F (high temperature thermal desorption) to volatilise organic compounds. Bed temperatures and residence times cause selected contaminants to volatilise without oxidising. A carrier gas or vacuum system transports volatilised water and organic compounds to a vapour treatment system.	Thermal desorption systems have proven to be effective for many organic contaminants, including VOCs, PAHs, PCBs, pesticides, and dioxins. Thermal desorption alone does not reduce the toxicity or volume of contamination, but the associated vapour treatment system would, either directly (through treatment) or indirectly (through collection and off-site destruction of contamination).	Thermal desorption is a well-established technology; however, advance scheduling may be required to reserve a thermal desorption unit at the site. A treatability test may be required to verify the design parameters for the thermal desorption system.	The costs for thermal desorption are moderate to high. Residuals, including concentrated oily waste stream, water, off-gases, and treated soil, would all likely require further treatment and disposal.	Thermal desorption is potentially applicable and will be retained for further consideration. Treatment residuals will require further treatment, such as solidification of treated soils and incineration of concentrated oily waste containing dioxins.

Remediation Option	Effectiveness	Implementability	Relative Cost	Env. Benefits/Disbenefits
	Additional treatment of waste streams would be required.			
Ex Situ Vitrification: In this process, excavated soil is passed through a high-temperature reactor where the materials are heated to their melting point and converted to a glass-like matrix, which can be used as non-structural fill material on-site or disposed of off-site. During the process, inorganic compounds become entrapped within the matrix and organic compounds are destroyed by oxidation.	Almost all organic compounds are destroyed during the process due to extremely high temperatures. Metals are immobilised into a compatible glass-like product. The resulting vitrified mass effectively immobilises the entrapped compounds, including any residual contaminants not destroyed by the vitrification process.	Ex situ vitrification is a relatively complex, high-energy technology requiring a high degree of specialised skill and training. It has not been used extensively to date. Moisture content and soil classification can affect the applicability of the technology. Limestone or soda ash is sometimes added to the feed soils.	The costs of ex situ vitrification would be high because of the high capital costs, high-energy requirements to melt the solids, and the specialised skill and training required to operate the system.	Because of the expected high cost of this option and the lack of proven experience in its implementation, it will not be retained for further consideration.
Soil Washing: Soil washing is a physical/chemical process that reduces the volume of soil material undergoing further treatment by removing organic contaminants that adhere to organic matter and fine particles within a soil matrix. The affected soils are subjected to a multistage washing system where surfactants are used to separate the contaminants and the finer particles from the coarser soil materials. The exiting wash stream then undergoes additional treatment.	In soil washing the contaminated wash stream requiring treatment is only a small fraction of the original soil volume. Soil washing has been proven effective for VOCs, SVOCs, and a wide range of metals. Soil washing is less effective for PCBs and limited data is available for dioxins. The effectiveness will depend on factors such as: particle size distribution, moisture content, pH, and cation exchange capacity, among others. The site soils in areas targeted for excavation may not contain a sufficient coarse fraction to make the application of soil washing effective. Soil washing alone does not	Treatability studies would need to be conducted to identify the optimal washing reagents, estimate the amount of residual waste volumes to be created, and to quantify the effectiveness of the process for site contaminants. Treatment residuals require additional treatment or disposal.	The costs associated with soil washing would be moderate to high; however, these costs may increase significantly if multiple treatments are required.	Soil washing will not be retained for further consideration due to its questionable effectiveness on dioxins.

Remediation Option	Effectiveness	Implementability	Relative Cost	Env. Benefits/Disbenefits
	reduce the toxicity or volume of contamination, but the associated treatment system would, either directly (through treatment) or indirectly (through collection and off-site destruction of contamination).			
Solvent Extraction: Solvent extraction is a process by which contaminants are extracted from the soil using chemical solvents. The process involves contacting the solvent with the contaminated soil or sediment long enough to extract the contaminants. The solvent is then removed from the soil or sediment and the contaminants are separated from the solvent as a concentrated wastestream that typically requires further treatment and/or disposal.	The contaminated waste stream requiring further treatment is only a small fraction of the original soil volume. Solvent extraction has been successfully used for PCBs and pesticides; however, little or no data are available for dioxins. Several applications may be required to achieve cleanup goals. Achievable removal efficiencies are not high enough to meet cleanup standards. Effectiveness is dependent upon characteristics of the soil matrix to be treated. Particle size is an important factor (fines are difficult to treat); therefore, a treatability study is required. Solvent extraction alone does not reduce the toxicity or volume of contamination. Incineration of treatment residuals would be required to permanently destroy dioxins. Solvents used in the process can have undesirable characteristics such as strong odour and high flammability.	Treatability studies would need to be conducted to identify the optimal process configuration, to estimate the amount of residual waste volumes to be created, and to quantify the effectiveness of the process for site contaminants. Full-scale solvent extraction process systems are not widely commercially available. Fabrication of a properly sized system (3-400 tons/day) unit would take 1 year to complete. Treatment residuals require additional treatment or disposal. On-site treatment of soil may not be practical due to the length of time required for implementation, including treatability studies, and unit fabrication.	Due to the limited commercial use of this technology, the Penny's Bay project would have to absorb the full capital cost of constructing a new system. The costs associated with fabricating a full-scale unit are high. Operational costs are expected to be moderate to high; however, these costs may increase significantly if multiple treatments or expensive solvents are required.	Solvent washing is potentially applicable for treatment of dioxins; however, due to its limited commercial availability, potential difficulty achieving cleanup goals, and concerns related to the safety of the solvents used, it will be eliminated from further consideration.

Remediation Option	Effectiveness	Implementability	Relative Cost	Env. Benefits/Disbenefits
Stabilisation/Solidification: Soil stabilisation is a technology that would immobilise contaminants in a soil matrix using chemical treatment. Several types of stabilisation processes are available including: cement-based, pozzolanic, thermoplastic, sulphide, and organic polymerisation.	Effectiveness with site-specific organic contaminants would need to be demonstrated. Effectiveness is proven for a wide range of inorganic constituents. The mobility of the contaminants would be decreased, but not toxicity or volume. However, dioxins are already relatively immobile in soil, therefore, stabilisation/solidification would accomplish very little reduction in mobility. The likelihood of contact with residual contaminants in the stabilised soil would be minimised because the treated materials would be contained in a solidified matrix. Off-site use of stabilised soil would result in elimination of contaminated soil exceeding cleanup goals from the site, however, additional costs would be incurred due to backfill required.	Ex situ stabilisation is a commonly used technology that could be readily implemented at the site. Treatability testing would be required to determine the types and amounts of admixtures and the effectiveness of the technology with site-specific organic and inorganic contaminants.	The costs for this option would be moderate compared to other treatment options.	Due to its failure to remove dioxins from soil, this process option will not be retained as a primary option to treat soil; however, it will be retained for use as a secondary treatment process for the residuals from the primary treatment process.
Chemical Dechlorination: Chemical dechlorination is a technology in which a reagent is used to remove the chlorine atoms of chlorinated organic contaminants, transforming the contaminants into less toxic compounds. There are three types of dechlorination processes: solvated electron technology, base-catalysed decomposition (BCD), and glycolate dehalogenation. This process	Dechlorination has been proven effective for detoxification of pesticides, PCBs, and pentachlorophenol. Dechlorination is one of the few processes other than incineration that has been successfully field tested for treating PCBs. The BCD process has been shown to reduce dioxin concentrations to	Dechlorination is available commercially and could be implemented on-site; however, it has been used to treat small volumes of soil or concentrated oily residuals only. Treatability studies would be required to confirm the effectiveness of the process.	The unit cost for this technology is moderate to high.	Addition of substantial volume of a special blended oil (5:1) is needed for this process, increasing final volume of chemical waste disposal. As such, this option is not recommended.

Remediation Option	Effectiveness	Implementability	Relative Cost	Env. Benefits/Disbenefits
can be used to treat soil directly or to treat the concentrated oil residuals generated by other processes such as thermal desorption and solvent extraction.	to reduce dioxin concentrations to parts per trillion level.	Would produce treatment residuals that would require additional treatment or disposal. On-site treatment of soil may not be practical due the current use of the property and the length of time required for implementation.		
In Situ Thermal Treatment: In situ thermal treatment involves the injection of heat into thermal wells to volatilise organic compounds. Soil vapour is extracted and treated.	In situ thermal treatment systems have not been used widely for contaminants with very low volatility. Effectiveness depends on the conductive properties of the soil and the volatility of the contaminants. Collected vapours would require additional treatment to reduce toxicity, mobility and volume. Time to achieve project objectives likely to be much longer than off-site treatment options. Effectiveness is marginal for removal of low-volatility contaminants from below the water table.	There are a limited number of vendors actively promoting in situ thermal desorption technology. Requires a large number of wells per acre. Technology may be more easily implemented at smaller sites. The high water table at the site makes this technology difficult to implement. Pumping to lower the water table would be required. A pilot test or treatability study would be required to determine the applicability in site soils.	The costs for in situ thermal desorption are moderate to high. Treatment of saturated zone soils increases costs.	In situ thermal treatment will not be retained for further consideration due to the high water table at the site, the length of time required to achieve objectives, and the large number of wells that would be required for treatment.
In Situ Soil Vitrification: In this process, electrodes would be placed in the ground and an electrical current would be passed through the soil. This current would heat the soil to temperatures in excess of 2,400°F. At these temperatures, the soils would begin to melt and would convert to a glass-like material upon cooling. During the	Tests have shown that the vitrified soils are very durable and leach-resistant. Very effective for immobilising metals in soil. Organics would be destroyed by pyrolysis at high temperatures; however metals remain.	The technology requires an unsaturated subsurface to make heat transfer to the soil matrix most effective. The high water table at the site makes this technology difficult to implement. The residual hardened material left	The costs of in situ vitrification would be high due to the significant electrical costs, especially in a high water table environment.	This process option will not be retained for further consideration because of the high water table at the site, the presence of metals remaining in the soils, and the geotechnical properties of the material left in place.

Remediation Option	Effectiveness	Implementability	Relative Cost	Env. Benefits/Disbenefits
material upon cooling. During the process, inorganic target compounds would be effectively encapsulated and rendered immobile within this glass-like matrix, while some organic compounds would be destroyed by pyrolysis.	however metals remain.	in-place may not be acceptable for future construction activities planned at the site.		
In-situ Capping: A cap would be constructed of multiple layers of different materials. The multi-layered in-situ cap is used to limit or eliminate infiltration of rainwater into the waste. The first step in constructing a multi-layered cap is typically relocation of waste and grading of the landfill surface. Construction of a gas vent layer may be required. The gas vent layer allows landfill gases to be conveyed to vents that extend through the impermeable cap. Above the gas vent layer, a cushion layer would be constructed. A low permeability soil cover or a geomembrane is then constructed over the cushion layer. Above the geomembrane or soil cover, an optional drainage layer is constructed to help convey water that has infiltrated through the top soil layer away from the impermeable liner or soil cover. Above the drainage layer a vegetative and protective layer would be constructed. The top layer of the multilayer cap would be a top soil layer capable of supporting grassy vegetation. The vegetation prevents erosion of the cap. Additional elements of this alternative include construction of a slurry wall, installation of extraction wells, and a leachate	In-situ capping is an effective technology for preventing further migration of contaminants and direct human exposure to contamination. Because wastes would remain on-site without treatment, no reduction in toxicity, mobility, or volume of the contaminants would be achieved.	In situ capping technology is readily available and has been implemented at hundreds of contaminated sites in U.S.	The costs for in-situ capping are moderate including construction costs of a multi-layered cap, a slurry wall, extraction wells and a treatment plant. Long term O&M costs include maintenance and treatment plan O&M.	The option is not recommended as this technology will limit the future landuse of the site, pose long-term liability and leaving the problem t future generation.

Remediation Option	Effectiveness	Implementability	Relative Cost	Env. Benefits/Disbenefits
treatment plant.				
Excavation and Long-term Off-site Storage in a Secured Landfill: This alternative would include the excavation of contaminated soils at CLS and barging of the soils to a location (assumed to be TKW site) where they would be disposed of in a secure landfill. For long-term storage of the CLS soils, construction of a double lined landfill cell. The lower liner includes a leak detection system and the upper liner includes a leachate collection system. Each liner system would be composed of a geomembrane and/or a low permeability soil liner. The final surface of the upper liner would be constructed (sloped) so that leachate is conveyed to the leachate collection system.	Excavation and Disposal of Soils in an On-Site Secure Landfill, is an effective technology for isolating the contaminated materials. No reduction in toxicity, mobility, or volume would be achieved.	Landfill construction technology are readily available and have been implemented at hundreds of contaminated sites in U.S. There is potential for some degree of public opposition based on the fact that contaminants are not removed and treated, rather they are relocated leaving the land permanently unusable	The costs for this option would be high including capital costs for excavation of site soils, backfill of the CLS site, barging of the soils to the landfill site, and construction of a double-lined landfill cell, a multilayered cap, and a treatment plant. Long-term O&M costs include cap maintenance and treatment plant O&M.	This option is not recommended due to the difficulty in finding a new landfill site and leaving the problem for future generation.
Excavation and Temporary On-site Storage of Soils: This alternative would include the excavation of contaminated soils at CLS and barging of the soils to TKW where they would be temporarily stored in sealable containers. Material excavated at the CLS site would be loaded into large 'roll-off' type containers. These containers can be placed on a truck for transport to the barge or can be placed directly by crane onto the barge. Similarly, the containers at the off-loading site can be placed by crane onto trucks for transport to the	Excavation and Temporary On-Site Storage of Soils could potentially effectively temporarily store soils. Continued monitoring of the containers would be required to verify that leaks do not develop.	A large amount of customized roll-off containers would require fabrication. This type of container could be easily fabricated. This alternative would rely on obtaining a very large area of land to store the containers.	The largest component of these costs is purchase of the roll-off storage containers. The cost for the containers is expected to be high due to the customized nature of the containers.	This option is not recommended due to the potential secondary environmental impact arising from the storage of dioxin-contaminated soil. In addition, this option is not acceptable because it is a temporary solution, leaving the problem for future generation.

Remediation Option	Effectiveness	Implementability	Relative Cost	Env. Benefits/Disbenefits
storage area. For purposes of the FS report, it has been assumed that each container would be capable of holding a maximum of 23 tonnes and would have the following dimensions: 6.7m long, 2.5 m wide, and 1.5 m high. Each container would be lined with a durable industrial coating capable of preventing leakage and reducing damage to the metal roll-off box. In addition, the containers would require a sealable cover that would need to placed on top of the container to prevent material from escaping and water from entering. This type of design for a container of this size would require some amount of customization.				
Strategic Landfill Disposal: This is the excavation of contaminated soil and direct disposal to landfill.	This is the most simple and quickest way to dispose of large volume of contaminated soil.	Similar to excavation. To minimize the health risk and environmental impact during transportation, the excavated soil should be placed in sealable containers.	The excavation cost will be moderate to high depending on the depth of excavation below the water table. However, the disposal cost to landfill will be high.	This option is not recommended as this option will deplete the landfill space and long-term liability still exists.

Selection of Remedial Method for Dioxin-contaminated Soil

4.192 The following subsections provide a comparison of the effectiveness and implementability for the identified thermal treatment options (Incineration and Thermal Desorption) including recommendations for treatment of dioxin-contaminated soil. Non-thermal treatment technologies have not been considered further in the following subsections as they are identified as "not recommended" in Table 4.51.

Effectiveness of Thermal Treatment Technologies

4.193 With respect to the ability to excavate the site to the cleanup objectives, both alternatives would meet the site cleanup criteria by performing confirmation sampling followed by additional excavation, as necessary.

4.194 Regarding the two thermal treatment technologies evaluated, both incineration and thermal desorption are well-developed technologies that can meet a cleanup criterion of 1 ppb TEQ dioxins. For incineration, treatability studies would not be necessary to verify the technology's effectiveness. Treatability studies would be required for thermal desorption to verify design criteria necessary to meet cleanup levels. In addition, these studies would provide detailed information regarding the optimal combination of operating parameters necessary to achieve the cleanup standards, including operating temperature, residence time, and feed preparation. The treatability study would provide estimates of volumes of the concentrated oily waste generated in the process and estimates of carbon usage.

4.195 For both options, feed preparation would be required to remove debris, to improve handling characteristics, to decrease soil moisture content, to break up clay clumps, and to provide a consistent feed. Feed preparation includes such activities as screening, crushing, debris removal, addition of lime, tilling, and blending. High moisture contents are likely to be encountered at the site due to the proximity of the water table to the excavation limits.

4.196 Because thermal desorption does not directly destroy contaminants in the treatment process, a concentrated oily waste is generated that requires further handling, treatment, and disposal. Incineration does not produce this process residual because contaminants are permanently destroyed (oxidised) in the combustion chamber and the afterburner. Both systems would employ a Continuous Environmental Monitoring (CEM) to verify that the system is operated within acceptable ranges, ensuring that emissions requirements are met.

4.197 For incineration, used Personal Protective Equipment (PPE) generated by personnel performing excavation, materials handling, treatment system operation, and sampling activities and spent activated carbon can be treated in the rotary kiln. For thermal desorption, these wastes would require classification and off-site transportation (by roll-off trucks) for appropriate disposal.

4.198 Both technologies would not effectively treat leachable metals and stabilisation would be required regardless of which thermal technology is selected. Stabilisation is a well-developed technology that has been proven to reduce the concentrations of leachable metals in soils. The required mix design would be determined through bench- and pilot-scale treatability testing for stabilisation.

Implementability of Thermal Treatment Technologies

4.199 The thermal desorption option would require off-site incineration of the oily residue at the Chemical Waste Treatment Centre (CWTC). Currently, CWTC is treating about 45 tonnes of chemical waste per day and it can treat an additional 10 to 15 tonnes per day provided that the waste is of compatible composition. Based on our estimation of the quantity of oily waste generated in the process (Section 6 of this Report) and CWTC's acceptance to the proposal, the oily residue arising from thermal desorption can be disposed of at CWTC for incineration.

4.200 Both incineration and thermal desorption could be implemented in a similar timeframe. Thermal desorption would require treatability studies whereas incineration would not. This would add 12 weeks to the overall thermal desorption schedule. Shipping time, mobilisation, and set-up and shakedown would all require about the same length of time to complete (5 months). Both technologies are commercially available and require permitting and licensing; however, the process is likely to be more time consuming and intensive for incineration than thermal desorption.

4.201 Both alternatives would provide similar levels of protection to workers, the public, and the environment. The major implementability benefit of thermal desorption relative to incineration, is that it typically would reduce the quantity/ amount of material needs to be incinerated significantly (only around $600m^3$ non-aqueous dioxin condensate would require incineration as compared against $30,000m^3$ dioxin-contaminated soil), thus lowering the overall treatment cost and minimising the secondary environmental impacts.

4.202 The two options also would require a very similarly sized area for staging of equipment and treated soil stockpiles. Both would require erection of a structure to cover contaminated soils as part of feed preparation. Both options would require the same size area for the stabilisation equipment. In total, an area of approximately 5.2 hectares would be required for the treatment equipment in addition to the stockpile area.

Selection of Secondary Remedial Method for Residue Arising from Primary Treatment

4.203 According to Table 4.51, incineration and chemical dechlorination (CD) is retained as an option for treatment of dioxin-containing residue generated from the primary treatment. Incineration is recommended over chemical dechlorination for the following reasons:

- The presence of soil debris reduces the effectiveness of BCD reagents which require a longer reaction time at higher temperatures.

- The relatively small amount of residue generated from primary treatment can be readily accepted by CWTC, which is designed to handle hazardous organic pollutants including PCBs and dioxins, for destruction.

- A separate process train is required for CD which will drastically increase the capital cost and land requirements of the decontamination system.

- Oily residue, which again entails additional treatment, will be produced from CD. Such residue cannot be recovered by local recycler as it contains hazardous components and is classified as chemical waste. Overseas experience reveals that the quantity of final residue generated after BCD treatment will be 5 times higher than the original amount. Additional treatment of such residue is required (i.e. disposed of at CWTC).

Proposed Remedial Method for Dioxin-contaminated Soil

4.204 Based on our analysis, thermal desorption is recommended for implementation over incineration. Thermal desorption technology would provide a level of overall performance similar to incineration, but at a lower cost based on a cleanup level of 1 ppb TEQ dioxin. However, thermal desorption would require treatability studies to verify design parameters before implementation and would generate a concentrated oily waste requiring disposal at CWTC. A performance test of the residue is required to ensure CWTC's operation and performance will not be compromised (as proposed in Section 6). If necessary, additional stack monitoring and ambient monitoring will be carried out by operator of CWTC.

4.205 According to *"Innovative Site Remediation Technology: Thermal Desorption"*, effective removal of a number of contaminants have been demonstrated by thermal desorption, including petroleum-contaminated and PCB-contaminated soil, VOCs, SVOCs, and pesticides but not effective in separating inorganics from the contaminated media (except very volatile metals such as mercury). Therefore, further treatment of metal-contaminated soil (i.e. solidification) is required after thermal desorption.

4.206 Thermal desorption is an innovative technology for site remediation and has been widely adopted in US sites (examples are shown in Table 4.52). Recently, thermal desorption is being carried out in Australia and US for dioxin removal (dioxin project cases are also exemplified in Table 4.52).

Table 4.52 Project Cases of Thermal Desorption for Dioxins and Other Contaminants

Project Site	Major Contaminants	Remediation Methods	Project Status
Re-solve, MA, US	VOCs, PCBs	Thermal desorption	Completed
Metaltec/Aerosystems, NJ, US	VOCs	Thermal desorption	Completed
Reich Farms, NJ, US	VOCs, SVOCs	Thermal desorption	Completed
American Thermostat, NJ, US	VOCs	Thermal desorption	Completed
USA Letterkenney SE Area, PA, US	VOCs	Thermal desorption	Completed
Wamchem, SC, US	BTEX, VOCs, SVOCs	Thermal desorption	Completed
Jacksonville NAS, FL, US	PAHs	Thermal desorption	Completed
Outboard Marine/Waukegan Harbour, IL, US	PCBs	Thermal desorption	Completed
Pristine, OH, US	BTEX, pesticides, herbicides, VOCs	The treatment consisted of thermal desorption of soil and base catalyzed dechlorination of the condensate.	Completed
Sand Creek Industrial, CO, US	Pesticides, herbicides	Thermal desorption	Completed
Homebush Bay – Australia	Dioxins	The remediation process is a two-stage operation – Indirect Thermal Desorption followed by Base Catalysed Dechlorination of oily condensate.	Phase 1 completed and Phase 2 is on-going.
Coleman-Evans Wood Preserving Site, Whitehouse, Florida, US	Pentachlorophenol, Dioxins	Thermal desorption followed by off-site incineration of oily condensate.	On-going

4.207 It is worth noting that thermal desorption is capable of treating organic contaminants other than dioxins, however, such technology is not recommended for the treatment of organic contaminants (i.e. TPH and SVOCs) found in Areas 1 and 2 due to the following reasons:

- The operating and processing cost of thermal desorption is substantially higher than biopiling.
- The treatment capacity of thermal desorption is limited, <10 ton/hr (due to high moisture content), the handling of additional contaminated soil from Areas 1 and 2 will lengthen the whole decontamination process.
- The amount of oily residue generated will be significantly increased, resulting in additional transportation and treatment costs.

4.208 As such, thermal desorption is recommended be used solely for the treatment of dioxin-contaminated soil and a combination of biopile and solidification/stabilisation for other organic contaminants in Areas 1 and 2.

Summary of Comparison of Different Decontamination Options

4.209 Comparisons of the following five different decontamination options are summarised in Table 4.53. Detailed comparisons between incineration and thermal desorption are presented in Table 4.54. Based on the results of the comparison, the Option 3 is considered the best option for decontamination.

i) Option 1 – Excavating all contaminated soil and taking them to Tsing Yi for incineration

ii) Option 2 – Excavating all contaminated soil and treating all soil at TKW (with thermal desorption for dioxin-contaminated soil, biopile and/or solidification of non-dioxin contaminated soil)

iii) Option 3 – Excavating all contaminated soil and on-site treatment for some (metal-contaminated soil) and treatment at TKW for others (thermal desorption for dioxin-contaminated soil, and biopile/solidification for non-dioxin contaminated soil)

iv) Option 4 – Excavating all contaminated soil and on-site treatment for some (metal-contaminated soil) and treatment at TKW for others (incineration for dioxin-contaminated soil and biopile/solidification for non-dioxin contaminated soil)

v) Option 5 – Excavating all contaminated soil and treating all soil at CLS site (with thermal desorption for dioxin-contaminated soil, biopile and/or solidification of non-dioxin contaminated soil)

Table 4.53 Summary of Comparison of Different Decontamination Options

	Option 1	Option 2	Option 3	Option 4	Option 5
On-site *vs* off-site treatment	All off-site treatment - less environmentally acceptable	All off-site treatment - less environmentally acceptable	Majority will be treated on-site treatment – more environmentally acceptable	Majority will be treated on-site treatment – more environmentally acceptable	All on-site treatment – more environmentally acceptable
Treatment method	CWTC is not designed for incineration of large quantity of contaminated soil. May have air quality impact on nearby community.	Release of toxic components would not be a major concern as no direct incineration of soil would take place in thermal desorption process. Also, the quantity of oily residue required disposal at CWTC would be insignificant.	Release of toxic components would not be a major concern as no direct incineration of soil would take place in thermal desorption process. Also, the quantity of oily residue required disposal at CWTC would be insignificant.	May have air quality impact on nearby community.	Release of toxic components would not be a major concern as no direct incineration of soil would take place in thermal desorption process. Also, the quantity of oily residue required disposal at CWTC would be insignificant.
Transportation Route (Land transport)	Require higher number of laden trips compared to on-site treatment.	Require higher number of laden trips compared to on-site treatment.	Require less laden trips compared to off-site treatment.	Require less laden trips compared to off-site treatment.	Does not require laden trips.
Soil storage method	Require special storage/ handling facility due to limited capacity of CWTC. Additional land would be required in the vicinity of CWTC.	Land provision of storage facility would not be a constraint.	Land provision of storage facility would not be a constraint.	Land provision of storage facility would not be a constraint.	Land provision of storage facility would not be a constraint.
Final Disposal of decontaminated soil	Final disposal of ash residue generated is required.	Treated soil would be suitable for future reuse (i.e. public filling).	Treated soil would be suitable for future reuse (i.e. public filling).	Final disposal of ash residue generated is required.	Treated soil would be suitable for future reuse (i.e. public filling).
Programme compliance	Comply with Penny's Bay development	Comply with Penny's Bay development	Comply with Penny's Bay development	Comply with Penny's Bay development	Does not comply Penny's Bay development

Table 4.54 Detailed Comparison between Incineration and Thermal Desorption

	Incineration	Thermal Desorption
1. Overall Protection of Human Health and Environment	Incineration provides a permanent remedial solution by destroying all organic contaminants. However, exhausts from the incinerator would be an environmental concern major concern if not controlled properly.	Thermal desorption provides a permanent remedial solution by volatilising and removing all organic contaminants from soils without direct heating the soil. After desorption, the volatilised air emission from the desorption process would be an environmental concern if not controlled properly.
2. Reduction of Mobility, Toxicity and Volume	Incineration would greatly reduce the toxicity and the volume of contaminated soil. However, the resultant material would be slag-like and difficult to reuse.	Thermal desorption would greatly reduce the toxicity, and the soil after treatment is suitable for public filling.
3. Short-term Effectiveness	Short-term health risk exists during excavation and incinerator exhausts. Air monitoring programme is required during site activities to monitor workers' safety and health.	Short-term health risk exists during excavation and emissions from the desorption process. Air monitoring programme is required during site activities to monitor workers' safety and health.
4. Long-term Effectiveness	Incineration is a proven technology to destroy dioxin from the contaminated soil, and the source of contamination would be completely removed from CLS.	Thermal desorption is an innovative technology to remove dioxin from the contaminated soil, and has recently been adopted in US and Australia to cleanup PCB- and dioxin-contaminated sites. Similar to incineration, the source of contamination would be completely removed from CLS.
5. Implementability	This remedial option would involve the construction of an incinerator off-site at TKW. Further treatment (i.e. landfilling) is required for the disposal of the residual ash.	This remedial option would involve the construction of a desorption plant off-site at TKW. Further treatment (i.e. incineration at CWTC) is required for the treatment residue..

4.210 Both incineration and thermal desorption would completely destroy or remove source of contamination from CLS. As compared in the above table, these 2 options perform similarly by providing a similar level of performance, except (1) final disposal of the treatment residue, and (2) cost for implementation. Incineration would produce significant amount of slag-like residue requiring final disposal to strategic landfills, whereas the treated soil from thermal desorption would be suitable for public filling and residue of only 2% of the original quantity would require further treatment. Overseas experience reveals that the remedial costs (including capital cost, treatment cost, operating and maintenance cost) for incineration is around 30% higher than thermal desorption while achieving similar performance. Based on the comparison and discussion above, thermal desorption has a higher implementability in terms of finals waste handling and disposal, and is likely to be more less expensive. As a result, direct incineration of all contaminated in the existing CWTC and setting up a new incineration plant at TKW is not recommended for the following reasons:

- Existing CWTC has inadequate capacity for treating the dioxin-contaminated soil found in CLS.
- Direct incineration of such huge quantity of contaminated soil at either sites may have air quality impact on nearby community.
- With the existence of CWTC which is designed to treat hazardous wastes, constructing a new incineration plant at TKW for handling dioxin-contaminated soil is not cost-effective.

Outline Process and Operation of Remediation

On-site Excavation

Excavation Plan

4.211 The excavation plans for contaminated areas at Area 1, Area 2 and Area 3 of the CLS site are shown in Figure 4.7, Figure 4.8 and Figure 4.9, respectively. Detailed design drawings for planned excavations in the indicated areas shall be prepared by the Contractor. Factors such as excavation areas and depths, engineering properties and stability of the soils shall be considered for safe working conditions. The excavations shall be designed in accordance with the geotechnical properties of the soils and appropriate safety factors as determined by the Engineer.

4.212 The excavations shall also be designed considering the buried utilities lines. A proper utility survey shall be conducted and any live utility lines shall be de-energised properly prior to excavation.

4.213 All excavation areas shall be set out by an appropriate qualified and licensed land surveyor based upon the excavation plans shown in Figures 4.7 to 4.9.

4.214 The excavation sequence would be as follows:

i) Excavate the contaminated soil and properly packed (the package and storage requirements are dependent on the contaminants found, i.e. dioxin-contaminated soil will be placed in roll-off trucks) until no contaminants are found (confirmed by field and laboratory tests);
ii) Soils contaminated with different types of contaminants shall not be mixed to avoid the increase the volume of soil that would require treatment by different remediation methods.
iii) Transport dioxin-contaminated soil by roll-off trucks for off-site treatment.
iv) Any free product encountered during excavation will be skimmed off and drummed for off-site disposal to licensed Chemical Waste Treatment Centre (CWTC).
v) Finally, backfill the excavation with suitable materials.

4.215 It should be noted that for the areas to be excavated in Area 3, the upper 1m of soil within the whole areas shall be excavated first and managed as metal-contaminated soil. Care shall be exercised to avoid mixing apparent burn/waste pit materials with soil from this upper 1m layer.

4.216 After excavation, confirmation sampling and testing shall be carried out at limits of excavation to confirm that all contaminated soil has been excavated. Soil samples shall be collected at the limits of excavation for laboratory analysis of contaminants with exceedance in action levels for soil remediation. Samples shall be analysed and if the analytical results are below the relevant action levels, removal of contaminated soil shall be considered complete. If the analytical results exceed the relevant action levels, more soil shall be excavated (either laterally or vertically depending on whether the exceeding confirmation sample is collected from a sidewall or excavation base), and additional confirmation samples shall be collected and analysed until all confirmation samples are below the relevant action levels.

4.217 For small excavation areas (i.e. measure approximately 10m by 10m in size), one confirmation sample shall be collected from the base and one from each sidewall of the excavation. The depth of sampling shall be based on the depth of the original SI sample result that triggered excavation in that area. If SI samples from multiple depths exceeded action levels and triggered excavation, confirmation samples shall be collected for each depth where a sample exceeded these values. Furthermore, if there are any visible indications of impact, samples shall be collected from the apparent impact zone(s).

4.218 For larger excavation areas, confirmation samples shall be collected from sidewalls of the excavation with a lateral spacing of not more than 15m. At least one confirmation sample shall be collected from each sidewall. Depth of sidewall samples shall be based on the depth of the original SI sample result that triggered excavation in that area. If SI samples from multiple depths exceeded action levels and triggered excavation, confirmation samples shall be collected for each depth where a sample exceeded these values. Confirmation samples from the base of larger excavation areas shall be collected on a grid spacing not larger than 15m by 15m (i.e. one sample per approximately every 225m^2). In all cases, if there are any visible indications of impact, samples shall be collected from the apparent impact zone(s).

4.219 A sampling plan showing the sampling locations, methodology, analysis parameters and QA/QC procedures shall be prepared by the Engineer for DEP's approval before excavation begins.

Precautionary Measures to Avoid Environmental Nuisance during Excavation

4.220 Spoils generated during excavation shall be placed on heavy-duty and impermeable sheeting adjacent to the excavation. For dioxin-contaminated soils, they shall be temporarily stockpiled at such sheeting and then be placed in roll-off trucks for ex-situ treatment. The temporary stockpiles shall be properly covered by impermeable sheeting to avoid leaching out of contaminants during wet season.

Health and Safety Plan for Excavation

4.221 As contamination with TPH has been identified at the subject site, during excavation, particular emphasis is placed on contaminated soil excavation and working in areas that may contain potentially explosive and/or toxic vapours. The presence of explosive gas in the excavation pits shall be checked by using a Combustible Gas Indicator (CGI).

4.222 All construction activities shall be carried out by persons appropriately trained in health and safety and appropriated personal protective equipment shall be used by the persons engaged in decontamination activities. The following guidelines of Health and Safety shall be strictly followed by all site personnel working on the site at all times:

i) Temporary fencing or warning ribbons will be provided to the boundary of excavation, slope crest and temporarily stockpiled areas. Where necessary, the exposed areas will be temporarily covered with impermeable sheeting during heavy rainstorm.

ii) Workers are required to wear appropriate protective clothing and safety equipment.

iii) Smoking, eating and drinking are strictly prohibited.

iv) Monitoring for Lower Explosive Limit in the work zone, and total VOCs (with a Photo-ionisation Detector (PID)) in the breathing zone shall be undertaken. If the PID reading in the breathing zone is greater than 100 ppm, monitoring for benzene in the breathing zone shall also be undertaken.

v) Relevant occupational health and safety regulations and guidelines during excavation shall be observed.

Off-site Biopiling

4.223 Biopiling is a commonly accepted bioremediation method for the restoration of site contaminated with TPH and SVOCs. By using micro-organisms to degrade contaminants in soil, biopiles transform hazardous/toxic materials into harmless elements such as water, carbon dioxide, and other innocuous products. This technology offers the very important advantage of permanently removing contaminants by biodegradation, and therefore reduces potential long-term liabilities.

4.224 The biopile operates on the principle of volatilisation and biodegradation, where air is extracted from the biopile to enhance volatilisation of the hydrocarbon. The induced airflow provides oxygen for the biodegradation processes.

Biopile Formation

4.225 The schematic of a typical single biopile is shown in Figure 4.12. The main components in the treatment process for contaminated soil in the biopile system are:

i) Soil
ii) Air inlet piping
iii) Vapour extraction pipes installed inside the biopile
iv) Lateral offset, lateral and header pipes
v) Biopile knockout tank and blower
vi) Carbon adsorption system
vii) Irrigation pipes for adding moisture and nutrients
viii) Soil monitoring probes for in-situ measurement of soil moisture, temperature, oxygen, and carbon dioxide

4.226 The formation of a biopile will be started from one end and along the longitudinal direction. Uniform starting concentrations will facilitate the control of the bioremediation and ensure a short cleanup time (as decontamination will not be controlled by patches of soil with high initial concentrations). Compaction of the biopiles by excavation machinery shall be avoided in order have uniform density of the biopiles. Bulking agents are not usually added as they are hard to be compacted during backfilling. All biopiles shall be covered by impermeable sheeting (such that not longer than 5m of a biopile shall be exposed to open air) to avoid fugitive emissions of dust or any air pollutants from the biopiles affecting the surrounding environment. Adequate turning will be undertaken during biopile formation (and installation of piping) to maximise sufficient air circulation. Turning of soil may also be used during operation to enhance air circulation. Nevertheless, this will be confirmed by the cleanup progress monitoring.

4.227 The carbon filter system shall be designed, constructed, operated and maintained to ensure adequate adsorption efficiency to prevent air pollution impact to the surrounding air sensitive receivers (ASRs). The location of the exhaust of the carbon filter shall be sited as far away as possible from the nearby ASRs. The carbon adsorption system shall also be monitored regularly to check the performance of the carbon filter.

4.228 The first soil samples shall be taken once the construction of a biopile is completed to serve as the baseline samples. The baseline conditions shall be used as the reference conditions for assessing the cleanup progress of the subsequent biopile operation.

Biopile Operation

4.229 The biopile operation involves the induction of air into each biopile resulting from the establishment of a negative pressure field within each biopile. The negative pressure encourages the "evaporation" or volatilisation of part of the hydrocarbon contamination that is adsorbed to the soil particles. The inducted air collects the vapour and transports it via the extraction pipes out of the biopile. The inducted air also maintains aerobic conditions in the soil pores which encourages biodegradation of the remaining non-volatile petroleum hydrocarbons.

4.230 The typical flow rate for every 1,000m^3 soil is 4 scmm at the beginning and is to be decreased to 10-20% as the process progress.

4.231 As a large part of the hydrocarbon contaminant is not expected to be volatilised, cleanup of the non-volatile contaminant will depend on the biodegradation process, which produces CO_2. Thus, the gas obtained from the biopile shall comprise a mixture of air, water vapour, CO_2, and vaporised hydrocarbons. Exhaust air shall be passed through the activated carbon filters prior to discharge to the atmosphere to remove any contaminants.

4.232 Suitable conditions in the biopile shall be maintained for the growth of microbes. Moisture will be periodically added to the soil to maintain the moisture content within 10 % to 20 %. The optimal oxygen concentration in soil gas is 15 % to 20 %. The soil pH shall be maintained between 5 and 8 for bacteria to survive. Nutrients are required for microbial activities in small amounts. Regular progress monitoring of the soil conditions will be conducted to ascertain these conditions have been maintained. In addition, TPH levels in the soil will also be tested to assess the decontamination performance of the system. Bacterial numbers in soil (CFU heterotrophs or CFU degraders/gram soil) is a good indicator of the health of the biopile. This parameter shall be measured too whenever soil samples are collected for TPH analysis during progress monitoring.

4.233 Upon achieving the relevant cleanup targets, soil from the biopile will be transported to other sites and reused as filling material or transferred to other stockpiles for the treatment by solidification if metal contamination is present.

Mitigation Measures and Monitoring for Biopile Treatment

4.234 The following mitigation measures shall also be implemented by the Contractor: (i) during formation of biopiles, the biopiles shall be covered by impermeable sheeting such that not longer than 5m of the biopiles is exposed to open air in order to prevent dust emission; (ii) during operation, the biopiles shall be fully covered to control the extraction of TOC; and (iii) spent activated carbon of the carbon adsorption system shall be replaced at appropriate intervals such that the TOC emission rate from the system is acceptable. The Contractor shall calculate and specify the "allowable" TOC emission rate of the system and propose the replacement intervals for agreement with EPD during the detailed design stage.

4.235 Gas samples at the exhaust of the carbon filter for TOC will be monitored by CEM system. The EM&A programme shall include an event and action plan to stop the biopiling in case unacceptable air emission is detected and resumption of biopiling will only be allowed after confirmation and implementation of appropriate mitigation measures. All these requirements shall be included in the contract clauses for remediation.

Biopile Cleanup Progress Monitoring

4.236 The objective of operation progress monitoring is twofold: i) to monitor the progress of contaminant cleanup, and ii) to ensure suitable conditions of the soil to support microbial growth. Progress monitoring will involve periodic soil gas monitoring, soil sampling, and physical parameter monitoring.

4.237 Soil gas monitoring points are installed within the biopiles. Sampling of oxygen, carbon dioxide, methane and VOC concentrations in the soil gas shall be conducted once every month. Soil gas samples are taken by pulling a gas sample from the monitoring points through a vacuum pump. In-situ measurement of soil moisture shall be included for monitoring. Soil gas sampling after placing the system in operation can establish the effectiveness of the aeration system.

4.238 It is proposed to undertake soil sampling (with density of 15 samples per 10,000m^3 soil) monthly for the analysis of pH, nutrients, and bacterial number. Analyses for TPH and SVOCs for soil samples shall be conducted once every 3 months. Monitoring shall continue until the cleanup targets are achieved. Once the cleanup targets for a location have been achieved, soil sampling at that particular location may discontinue. Progress soil monitoring results will also indicate when the biopile decontamination process may stop.

Biopile Closure Assessment

4.239 The objective of the biopile closure assessment is to collect soil samples for testing in order to ensure that the soil contaminant levels in the biopiles are below the cleanup targets for TPH and SVOCs. Furthermore, for soil to be treated subsequently by cement solidification, the levels of the concerned metals will also be analysed to provide the baseline conditions.

4.240 Sampling frequency of one sample per 100 yard^3 (76.5 m^3) is an American guideline provided in the book *Biopile Design, Operation, and Maintenance Handbook for Treating Hydrocarbon-Contaminated Soils* (F M von Fahnestock, G B Wickramanayake, R J Kratzke, W R Major, 1998). However, this sampling density is intended for much smaller biopiles. No available published international reference is available for biopiles of the capacity of this project. Current USA project experience (a biopile project in Rhode Island) shows that the sampling frequency can be reduced if progress monitoring shows that majority of soil attained the cleanup target. As such, it is proposed to use a sampling frequency of one sample per 100m^3 soil treated. The locations of soil sampling shall be evenly distributed across the biopiles.

4.241 Access to the sampling locations shall be through opening of heat bonded cover panels. These openings shall be closed after each access. Extracting the soil samples shall be accomplished using a hand auger or other methods approved by the Engineer.

4.242 All soil samples shall be analysed for TPH, SVOCs and the concerned metals. The laboratory results are considered satisfactory when the levels of TPH and SVOCs in 95% of the samples meet the cleanup targets. This acceptability of 95% serves to allow for laboratory error for soil analysis.

4.243 In the event that more than 5% of the samples still exceed any cleanup targets, the biopile decontamination system shall have to be restarted to fully remediate the soil. As the typical error for laboratory analysis is ±25%, the upper limits on exceedance with respect to the 5% samples should be 1.25 times the corresponding cleanup targets for the concerned contaminants.

On-site / Off-site Cement Solidification

4.244 The soil contaminated with metals only will be treated on site at CLS at a solidification plant. The layout plan for the on-site solidification at CLS is shown in Figure 4.13. For the soil contaminated with TPH/SVOCs and metals, following off-site biopiling at To Kau Wan site, it will be treated at To Kau Wan site at another solidification plant.

4.245 Prior to solidification, metal-contaminated soils shall be screened to segregate soil from debris, rock fragments, and other materials and to break soil clumps into sizes to allow effective mixing with solidifying agents.

4.246 During the cement solidification process, cement, water and other additive(s) (such as fly ash, lime, soluble silicates, and clays) are added to the contaminated soils to form solid block. Mixing of contaminated soils and cement/water/other additive(s) will be undertaken at a solidification plant to minimise the potential for leaching during the solidification process.

4.247 Pugmill can be used for mixing. It is necessary to have a uniform mixture. Thus, the materials shall be mixed until the mixture is uniform/homogeneous. The dry materials will be firstly mixed followed by addition of water.

4.248 The total volume of the concrete blocks shall increase by up to about 10% from the original soil volume. For easy handling, the solidified blocks shall be broken up into a number of smaller blocks after verification procedure.

4.249 Considerations for cement solidification shall include the followings[2]:

i) Waste characteristics (e.g. metal content, physical characteristics);
ii) Required solidified waste properties (e.g. leachability, permeability, compressive strength.);
iii) Operational and economic factors (e.g. cost of cement and availability & cost of other additives, materials handling, volume and weight increase); and
iv) Test methods (e.g. leachability).

4.250 Two useful guidelines on solidification of contaminated soils are USEPA's *Engineering Bulletin: Technology Alternatives for the Remediation of Soils Contaminated with As, Cd, Cr, Hg, and Pb* (EPA/540/S-97/500, August 1997) and USEPA's *Engineering Bulletin: Solidification/Stabilisation of Organics and Inorganics* (EPA/540/S-92/015, May 1993).

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[2] WASTECH (1997). *Innovative Site Remediation Technology: Stabilisation/Solidification.* American Academy of Environmental Engineers, U.S.

Leachability Test

4.251 The soil mixture in the concrete blocks will be solidified within about 1 week. Tests for leachability shall then be carried out for every 100 m^3 of the solidified soil (i.e. with sampling frequency of one sample per 100 m^3 of treated material). Each sample shall be a composite sample collected at 5 locations throughout the treated soil pile, and the same volume of sample shall be collected at each of the locations so that the composite sample is not biased. Once the blocks have passed the test, they will be kept on site considering their stable and inert structure. If the blocks fail the test, they will be crushed and the soils returned to the solidification process.

4.252 Toxicity Characteristics Leaching Procedure (TCLP) shall be conducted in accordance with USEPA Method 1311 for the concerned metals.

4.253 The EPD's TCLP limits as specified in EPD's *Guidance Notes for Investigation and Remediation of Contaminated Sites of Petrol Filling Stations, Boatyards, and Car Repairing/Dismantling Workshops* are standard leachability test standards. However, this set of standards is only applicable to disposal to landfill. For on-site reuse, these standards are not applicable.

4.254 The "Universal Treatment Standards" (UTS) shall be used for interpretation of the TCLP test results. The UTS for the metals have been provided in Table 4.47.

4.255 Upon completion of the leachability testing and meeting the UTS and the unconfined compressive strength requirement specified below, the solidified material shall be reused on site or off site as filling material. As the maximum grain size of filling material is 250 mm (according to general practice), the solidified soil shall be broken down to below this size before being used as filling material. Whenever the treated soil is to be reused as filling material, the metals only solidified soil shall be put below at least 1m of clean fill. For dioxins/metal solidified soil containing dioxins at 1 ppb TEQ, they shall be put below at least 3m of clean fill to protect human health and below at least 2m of clean fill for soil containing other chemicals to protect ecological receptors.

Unconfined Compressive Strength Test

4.256 In order to ensure the soil will be solidified in the solidification/stabilisation process, all the soil treated with solidification/stabilisation shall be tested for unconfined compressive strength. All the treated soil shall have unconfined compressive strength of at least 150 pound-force per square inch (psi), with reference to USEPA guideline (USEPA 1986) for hazardous waste solidification requirement.

Thermal Desorption

4.257 The treatment of dioxin-contaminated soils will be carried out at TKW site and will consist the following processes:

(i) Mobilisation and site preparation at TKW;
(ii) Excavation of contaminated soil;
(iii) Transportation of excavated dioxin-contaminated soil from CLS to TKW;
(iv) On-site thermal desorption at TKW;
(v) On-site stabilisation at TKW;
(vi) Demobilisation of treatment plant.

4.258 In the thermal desorption process, dioxin shall be removed from the contaminated matrix by heating it to approximately 1000°F (or around 540°C), causing volatilisation of contaminants. In this process the contaminant molecules are not altered. A conceptual process flow diagram is shown in Figure 4.14.

4.259 Thermal desorption treatment systems typically consist of the following components:

(i) A material heating chamber, with a vapour collection system to collect the desorbed contaminants and water vapour.

(ii) A condenser and separation system to convert the collected vapours to the liquid phase and separate the water from the concentrated contaminants.

(iii) A treated soil cooling (or quench) system.

(iv) An air treatment system to control emissions of contaminants, including particulates, from the exhaust stack.

(v) A continuous emissions monitoring (CEM) system.

(vi) A water treatment system to clean the condensed water prior to recycling.

4.260 To avoid the generation of additional dioxins, volatilisation of dioxin will be conducted by indirect heating to contaminated materials, either by heating the carrier gas stream that is passed over the contaminated soil (which desorbs contaminants into the gas), or by heating the soil using a rotary kiln or thermal screw (which desorbs contaminants from the heated soil into a carrier gas). This indirect heat removes contaminants without incinerating them. Process residuals produced include treated soil, treated water, contaminated treatment media and fines (e.g., baghouse filters, spent activated carbon) from air and water treatment, and a highly concentrated contaminated oily condensate stream.

4.261 The carrier gas, containing desorbed contaminants and vaporised moisture, is then collected and cooled, allowing the water vapour and contaminants to condense. Particulates are removed using conventional treatment (e.g., cyclone, baghouse fabric filters), and can be fed back into the soil influent during system operation to minimise the volume of treatment residuals generated.

4.262 Non-condensable organic vapours are removed by passing the carrier gas through vapour-phase activated carbon canisters. The condensed water and contaminants are gravity separated following condensation. Conventional oil/water separation techniques are used. The water would be polished using activated carbon prior to recycling. The oily concentrated waste containing dioxins and other contaminants will be transported off site by roll-off trucks for incineration at the local chemical waste incinerator.

Thermal Desorption Treatability Test

4.263 Thermal desorption does not perform efficiently at treating soil with high clay content and moisture content. Soil with high moisture content consumes more fuel as water is vaporised along with the contaminants. Tightly packed soil does not permit uniform heat contact with all contaminants. Both will lower the performance of thermal desorption but can be overcome by adjusting the retention time and etc. As revealed in the SI results which are summarised in Appendices 4F and 4H, thermal desorption is applicable to CLS soils as they were found to have relatively low clay content and moisture content. Soil composition is summarised below:

- Clay content: 6-10%
- Moisture content: 21.4%

4.264 To verify the applicability of thermal desorption for this project, a treatability test would be required on representative site material to determine the treatment efficiency and operating parameters. The quantity and quality of the treatment residuals produced in the process will also be estimated. To perform the treatability test, a representative sample (approximately 200 L) would be submitted to a laboratory for treatability testing. This process, including plan development, sample collection and analysis, treatability testing, and reporting, may take 12 weeks.

Thermal Desorption Completion Confirmation Sampling

4.265 Following thermal treatment, the treated soil would be dry and clean. Treated material would be sampled and analysed for dioxins and other contaminants of concern including metals to confirm treatment effectiveness. Initially, the sampling frequency shall be 1 sample per $50m^3$ of treated soil. Following the establishment of acceptable system performance, we propose to collect one composite sample per day to ensure the predefined cleanup objective is achieved. The composite is made up from samples collected every 4 hours so that the composite is representative of the entire day's performance. Subject to the soil feed rate, the sampling frequency shall be either one composite sample per day or 1 sample per $100m^3$, whichever is more frequent. Due to the high cost of dioxin testing and long turnaround time for testing results, a cost-effective closure and programme-wise strategy should be proposed by the Contractor. One possible option is to use on-site test equipment (i.e. bioassay) for screening the dioxin levels. The detection limits in ppt range and quick turnaround times (i.e. less than 1 week) shall be achievable. Treated soils containing high metals concentrations exceeding allowable limits shall be treated using solidification/stabilisation prior to backfilling at the site (please refer Sections 4.244 to 4.256 above). Following solidification treatment, the treated material would be subject to leachability test as detailed previously in this Section to determine the suitability for reuse as backfill material. Upon completion of treatment of all the contaminated soils, the systems would be demobilised from the site.

Engineering Design and Construction Sequence

4.266 The proposed layout of the decontamination works for dioxin treatment, biopile, solidification and area to be used for bunded storage (of dioxin-contaminated soil) at To Kau Wan site is shown in Figure 4.15 whereas sections of dioxin waste storage building are shown in Figure 4.16. It is assumed that all the existing land at To Kau Wan will be available for decontamination.

4.267 The proposed programme for the decontamination works including excavation, biopile, solidification and dioxin treatment is shown in Figure 4.17.

Environmental Mitigation Measures and Safety Measures

Environmental Mitigation Measures

General

4.268 Impermeable sheeting shall be put on dusty vehicle loads transported between site locations.

4.269 Speed controls for vehicles shall be imposed on dusty site areas.

4.270 Vehicle wheel and body washing facilities at the site's exist points shall be established and used.

Excavation

4.271 Stockpiling site(s) shall be lined with impermeable sheeting and bunded. Stockpiles shall be fully covered by impermeable sheeting to reduce dust emission. If this is not practicable due to frequent usage, regular watering shall be applied. However, watering shall be avoided on stockpiles of contaminated soil to minimise contaminated runoff.

4.272 Stockpiles shall be fully covered by impermeable sheeting to minimise contaminated runoff for the stockpiles. All leachate from the stockpiling site(s) shall be collected and treated prior to disposal.

4.273 Although it is understood that most of the contaminated soil shall be excavated during dry season as far as practicable to minimise runoff from contaminated soils, excavation and stockpiling shall be carried out during dry season as far as possible to minimise contaminated runoff from contaminated soils.

Transportation of Dioxin-contaminated Soil/Waste for Off-site Treatment (CLS to TKW)

4.274 Environmental and safety measures for transportation to minimise secondary environmental impacts and risks of transport vehicle accidents will be addressed in Chapter 6 "Waste Management Implications".

Biopile Formation

4.275 To avoid fugitive emissions of dust or any air pollutants from the biopiles and to minimise runoff from the stockpiled soils, the stockpiled soils at the biopiles shall be covered by impermeable sheeting such that not longer than 5m of the biopile is exposed to open air.

4.276 Upon formation of a biopile, the biopile shall be fully covered by impermeable sheeting to prevent dust emission and runoff.

4.277 Impermeable sheeting shall be placed at the bottom of the biopiles and leachate collection sump shall be constructed along the perimeter of the biopiles to prevent leachate from contaminating the underlying soil/groundwater. The collected leachate shall be treated at the dedicated water treatment unit (with flocculation/coagulation and activated carbon filtering) at TKW.

Biopile Operation

4.278 The vented air from the biopiles shall be connected to blower and carbon adsorption system for treatment before release to the atmosphere. Exhaust air from the blower and carbon adsorption system shall be monitored for VOCs regularly.

4.279 The biopiles shall be fully covered by impermeable sheeting to control the extraction of VOCs.

4.280 Spent activated carbon of the carbon adsorption system shall be replaced at appropriate intervals such that the VOC emission rate from the system is acceptable.

4.281 Silencers shall be installed at the biopile blowers to minimise noise impact.

4.282 Contaminated runoff from biopiles shall be prevented by constructing a concrete bund along the perimeter of the biopiles.

Thermal Desorption

4.283 To ensure no unacceptable levels of airborne contaminants are discharged, a CEM system will be installed to measure stack emission including oxygen, carbon monoxide, and total hydrocarbons.

4.284 Dioxin emissions from the stack of thermal desorption plant shall be sampled regularly in accordance with USEPA Method 23. Upon satisfactory completion of the commissioning test (including the performance and emission compliance checks) of the plant, stack sampling shall be conducted each month for the first half year and the monitoring result shall be reviewed. Any exceedance occurs in the first half year will lead to an action of suspending the plant operation and further reviewing the plant treatment process. If no exceedance is recorded for the first half year, the monitoring frequency will be stepped down to once every 3 months for the remainder of programme. For the in-stack continuous environmental monitoring, the action for any non-compliance of the pre-determined emission standards would be to suspend the plant operation and to review the plant process before the plant operation can be resumed

4.285 The transportation of dioxin-contaminated soil shall be containerised to ensure no emissions will come from the dioxin waste during transportation and storage.

4.286 An emergency contingency plan for the control and mitigation measures in the event that there is any malfunction or accident in the thermal desorption plant will be prepared by the Contractor. In addition, a hazard and operatability study (HAZOP) shall be carried out by the Contractor to identify any hazards associated with the operation of the thermal desorption process so as to incorporate appropriate safety devices during the design of the thermal desorption plant. The HAZOP Report shall be submitted to the Engineer for his approval prior to the operation of the thermal desorption plant.

4.287 A designated pit/ shed shall be provided for decontamination of trucks or equipment in contact with the dioxin waste to avoid cross-contamination.

4.288 The by-products generated from the process shall be handled in strict accordance with the *Waste Disposal Ordinance* and *Waste Disposal (Chemical Waste) (General) Regulation.*

4.289 To minimise the waste generation and requirements for off-site disposal, the condensate shall be separated into aqueous and non-aqueous phases. The aqueous condensate shall be polished on site for recycling to quench and rehydrate the treated soils which are hot and powdery, whereas the non-aqueous condensate shall be drummed properly for off-site disposal at Chemical Waste Treatment Centre (CWTC). The details of the waste management of the non-aqueous condensate are presented in Chapter 6 "Waste Management Implications".

General Health and Safety Measures

4.290 The relevant requirements under the Occupational Safety and Health Ordinance (OSHO) (Chapter 509) and their subsidiary Regulations shall be strictly followed throughout the Project. Only experienced personnel will be employed to operate the thermal desorption plant. During the course of the site remediation, the following basic health and safety measures shall be implemented:

i) Set up a list of safety measures for site workers;
ii) Provide written information and training on safety for site workers;
iii) Keep a log-book and plan showing the contaminated zones and clean zones;
iv) Maintain a hygienic working environment;
v) Prohibit eating and cooking inside the contaminated zones;
vi) Avoid dust generation;
vii) Provide face and respiratory protection gear to site workers;
viii) Provide personal protective clothing (e.g. chemical resistant jackboot, liquid tight gloves) to site workers; and
i) Provide first aid training and materials to site workers.

Personal Protective Equipment for Workers during Excavation of Dioxin-contaminated Soil

4.291 Site workers for excavation of dioxin-contaminated soil will be exposed to dioxin-contaminated dust during excavation. To determine whether a higher level of protection is required, a past American Industrial Hygiene Association study is referred. It suggests an Occupational Exposure Limit (OEL) of 0.2ng/m^3 (note that this value is based upon a 100-fold safety factor from animal data and base dupon exposure to "pure" dioxin). Using this standard, and the 99th percentile concentration of 23.5 ppb TEQ in soil, a total dust reading in air of 8.51mg/m^3 before the dioxin exposure standard of 0.2ng/m^3 is reached has been calculated. Dioxin is not volatile and would be present in the air only in the particulate form; therefore, a NIOSH-approved respirator with a HEPA filter would be adequate to protect the site workers from dioxin-contaminated dust exposure. It is suggested to implement Level C (air purifying respirator) protection at 2.5mg/m^3 for nuisance dust purposes. With such level of protection, the site personnel will be protected at levels well below 0.2ng/m^3.

4.292 The workers engaged in the excavation of dioxin-contaminated soil shall put on appropriate PPE to minimise the exposure to the carcinogens via inhalation, ingestion and dermal contact:

- An air purifying respirator;
- Latex gloves;
- Protective clothing.

4.293 Concentration of 109.383 ppb TEQ dioxins has been measured at trench T37 for burn pit in Area 3. It is proposed that additional PPE such as powered air purifying respirator should be provided for site workers, under supervision on site.

4.294 According to our above assessment, a higher level of protection, such as self-supplied respirators, space suit, is not required. However, if other contaminants are identified or the levels of contaminant are expected to be very high, a higher level of protection, such as self-supplied respirators, space suit, may be required.

Safety Measures for Handling Dioxin-containing Residue

4.295 Though the composition of the oily residue generated from thermal desorption cannot be determined at this stage, it is expected that such residue will contain mainly 1) TPH/SVOCs and 2) TPH which are dominantly found in Area 3. According to the SI results of Area 3 presented earlier in this section, among those contaminants, TPH (particularly the heavy fractions C27-C36 which accounts for 50%) has the highest concentrations (>80,000ppm). Therefore, TPH (the fractions resemble diesel) will be the major component of the oily residue. In relation to the predicted composition, the oily residue shall be classified as Dangerous Goods (Cat.5, C3 which is applicable to diesel oils, furnace oils and other fuel oils) in accordance with Dangerous Goods (Classification) Regulations. The Contractor shall observe such ordinance during storage and conveyance of the residue.

Environmental Monitoring and Audit Requirements

4.296 The environmental monitoring and audit requirements for are those mentioned in the following sections:

ii) Section 4.96 (Free product skimming);
iii) Section 4.97 (Groundwater recharge);
iv) Section 4.158 and Sections 4.221 - 4.223 (Confirmation sampling for excavation of contaminated soils);
v) Sections 4.244 – 4.248 (Confirmation sampling for biopile treatment);
vi) Sections 4.256 – 4.261 (Confirmation sampling for solidification treatment); and
vii) Section 4.270 (Confirmation sampling for thermal desorption treatment)

The details of the requirements are provided in Chapter 11 "Environmental Monitoring and Audit Requirements".

Conclusions and Recommendations

4.297 Soil contamination is found at Area 1, Area 2 and Area 3 of the CLS site. Soil contamination has been found down to 3m below the existing ground level. The contaminants at Area 1 and Area 2 include metals, total petroleum hydrocarbons (TPH), semi-volatile organic compounds (SVOCs), and dioxins. The estimated volumes of soil contaminated with metals only in Area 1 and Area 2 are 6,000m^3 and 7,000m^3 respectively. The estimated volumes of soil contaminated with metals/TPH/SVOCs in these two areas are 3,800m^3 and 4,000m^3 respectively. The estimated volumes of soil contaminated with dioxins/metals/TPH/SVOCs in these two areas are 50m^3 and 3,850m^3 respectively. The combined estimated volume of soil contaminated with TPH/SVOCs in these two areas is only about 700m^3.

4.298 The contaminants found at Area 3 include dioxins, metals, TPH and SVOCs. The estimated volumes of soil contaminated with metals only, metals/TPH/SVOCs and dioxins/metals/TPH/SVOCs are 35,000m^3, 500m^3 and 26,100m^3 respectively.

4.299 For the whole CLS site, the estimated soil volumes by the soil contaminant type(s) are as follows:

Metals only : 48,000m^3
TPH and/or SVOCs : 700m^3
Metals and TPH and/or SVOCs : 8,300m^3
Dioxins, Metals, and TPH and/or SVOCs : 30,000m^3
Total estimated volume : 87,000m^3

4.300 The environmental impacts of land contamination and land decontamination works are considered small or can be mitigated to an extent where the impacts on the receivers are acceptable. An EM&A programme will be required for land contamination and such programme is addressed in Chapter 11 "Environmental Monitoring and Audit".

4.301 For Area 1 and Area 2, cement solidification is recommended as the remedial treatment for soil contaminated with metals only. Biopile followed by cement solidification is recommended for soil contaminated with metals/TPH/SVOCs. The soil contaminated with TPH/SVOCs only shall be treated in the same biopile for the soil contaminated with metals/TPH/SVOCs. It is recommended to treat the soil contaminated with dioxins and metals/TPH/SVOCs in these two areas using thermal desorption followed by solidification if necessary.

4.302 For Area 3, it is recommended to treat the soil contaminated with dioxins/metals/TPH/SVOCs using thermal desorption followed by cement solidification. The soil contaminated with metals only in this area is recommended be treated using cement solidification.

4.303 The recommended decontamination option is on-site treatment for some (metal-contaminated soil) and off-site treatment at TKW for others (thermal desorption for dioxin-contaminated soil, and biopile/solidification for non-dioxin contaminated soil).

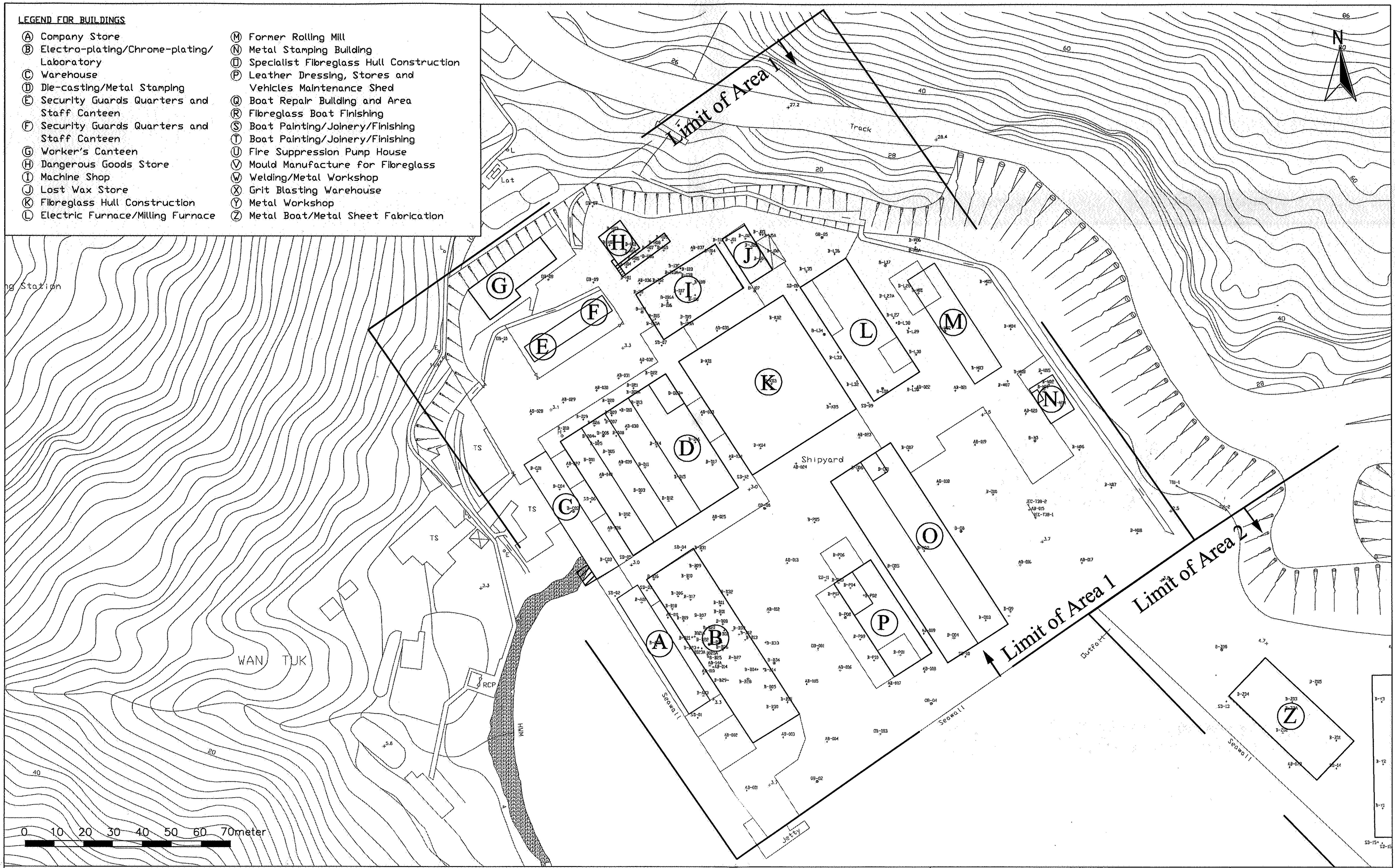
4.304 Environmental mitigation measures for the decontamination, including excavation, transportation of dioxin-contaminated soil/waste for off-site treatment, biopile formation, biopile operation, cement solidification and thermal desorption, have been recommended.

4.305 There shall be no residual impacts after implementation of the recommended mitigation measures (i.e. decontamination) for contaminated soil.

4.306 It is recommended to conduct treatability tests for biopile and cement solidification to investigate the requirements and set design/operational parameters for the biopile and cement solidification processes.

4.307 Furthermore, it is recommended to conduct a treatability test of thermal desorption for dioxin-contaminated soil to determine the treatment efficiency, operating parameters, and the quantity/quality of the treatment residuals produced in the process.

4.308 The IEC, through their own assessment, conclude that the remedial approaches recommended in this report can effectively meet the remedial action objectives and goals for the CLS site. The IEC also concur with this report's selected remedy of excavation and treatment of metals-impacted soils by cement stabilisation, TPH and SVOC-impacted soils by biopiling, and thermal treatment of dioxin-impacted soils by thermal desorption.



LEGEND FOR BUILDINGS

Ⓐ Company Store
Ⓑ Electro-plating/Chrome-plating/Laboratory
Ⓒ Warehouse
Ⓓ Die-casting/Metal Stamping
Ⓔ Security Guards Quarters and Staff Canteen
Ⓕ Security Guards Quarters and Staff Canteen
Ⓖ Worker's Canteen
Ⓗ Dangerous Goods Store
Ⓘ Machine Shop
Ⓙ Lost Wax Store
Ⓚ Fibreglass Hull Construction
Ⓛ Electric Furnace/Milling Furnace
Ⓜ Former Rolling Mill
Ⓝ Metal Stamping Building
Ⓞ Specialist Fibreglass Hull Construction
Ⓟ Leather Dressing, Stores and Vehicles Maintenance Shed
Ⓠ Boat Repair Building and Area
Ⓡ Fibreglass Boat Finishing
Ⓢ Boat Painting/Joinery/Finishing
Ⓣ Boat Painting/Joinery/Finishing
Ⓤ Fire Suppression Pump House
Ⓥ Mould Manufacture for Fibreglass
Ⓦ Welding/Metal Workshop
Ⓧ Grit Blasting Warehouse
Ⓨ Metal Workshop
Ⓩ Metal Boat/Metal Sheet Fabrication

Title

Agreement No. CE 68/99 Infrastructure for Penny's Bay Development - Engineering Design and Construction - Decomission of CLS

As - built Locations of Sampling Boreholes and Trenches (Area 1)

Scale As Shown
Project No. R06100
Date Feb 2002
Figure No. 4.1a

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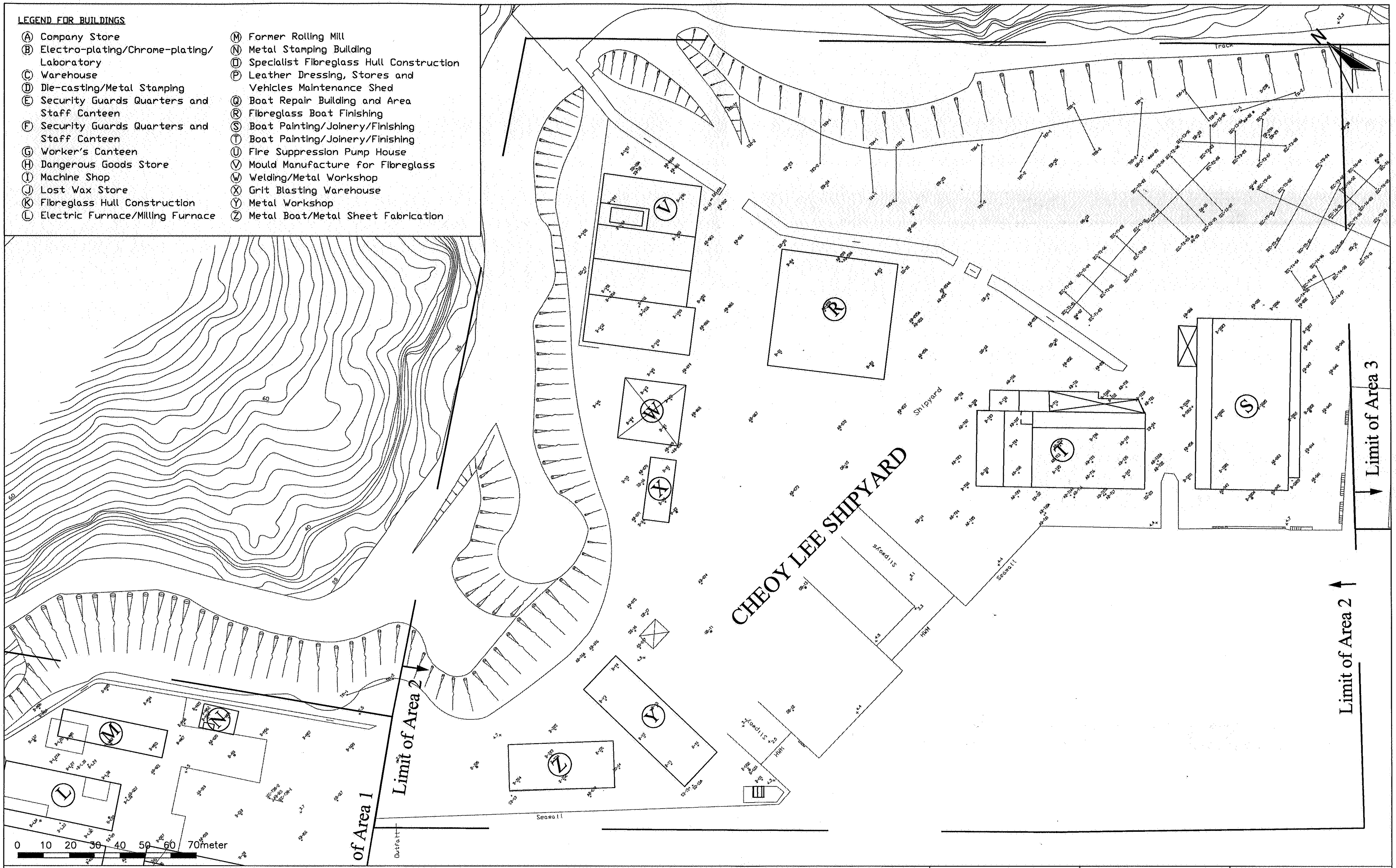

LEGEND FOR BUILDINGS

- Ⓐ Company Store
- Ⓑ Electro-plating/Chrome-plating/ Laboratory
- Ⓒ Warehouse
- Ⓓ Die-casting/Metal Stamping
- Ⓔ Security Guards Quarters and Staff Canteen
- Ⓕ Security Guards Quarters and Staff Canteen
- Ⓖ Worker's Canteen
- Ⓗ Dangerous Goods Store
- Ⓘ Machine Shop
- Ⓙ Lost Wax Store
- Ⓚ Fibreglass Hull Construction
- Ⓛ Electric Furnace/Milling Furnace
- Ⓜ Former Rolling Mill
- Ⓝ Metal Stamping Building
- Ⓞ Specialist Fibreglass Hull Construction
- Ⓟ Leather Dressing, Stores and Vehicles Maintenance Shed
- Ⓠ Boat Repair Building and Area
- Ⓡ Fibreglass Boat Finishing
- Ⓢ Boat Painting/Joinery/Finishing
- Ⓣ Boat Painting/Joinery/Finishing
- Ⓤ Fire Suppression Pump House
- Ⓥ Mould Manufacture for Fibreglass
- Ⓦ Welding/Metal Workshop
- Ⓧ Grit Blasting Warehouse
- Ⓨ Metal Workshop
- Ⓩ Metal Boat/Metal Sheet Fabrication

Title

Agreement No. CE 68/99 Infrastructure for Penny's Bay Development - Engineering Design and Construction - Decomission of CLS

As - Built Locations of Samling Boreholes and Trenches (Area 2)

Scale As Shown

Date Feb 2002

Project No. R06100

Figure No. 4.1b

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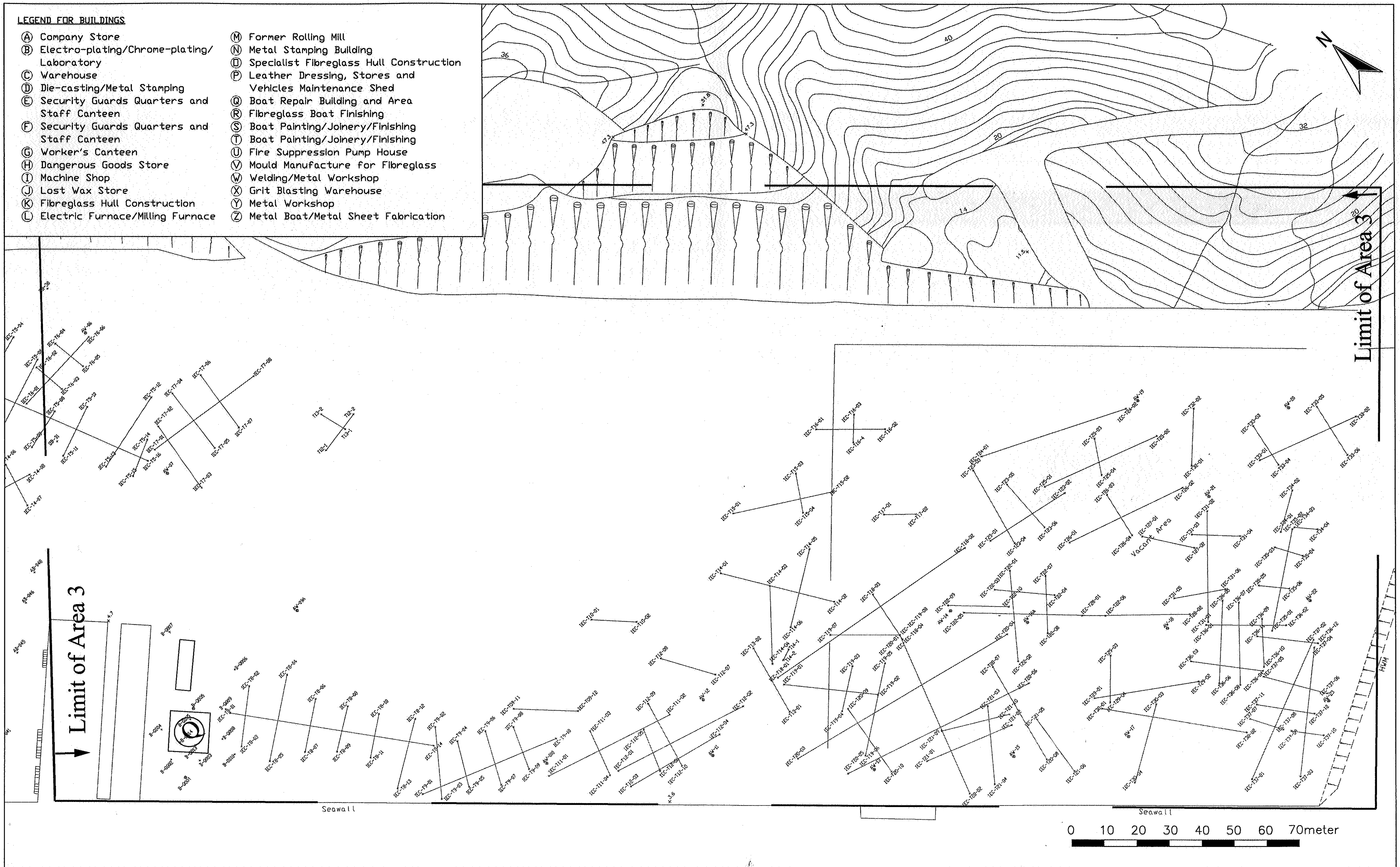

LEGEND FOR BUILDINGS

- Ⓐ Company Store
- Ⓑ Electro-plating/Chrome-plating/ Laboratory
- Ⓒ Warehouse
- Ⓓ Die-casting/Metal Stamping
- Ⓔ Security Guards Quarters and Staff Canteen
- Ⓕ Security Guards Quarters and Staff Canteen
- Ⓖ Worker's Canteen
- Ⓗ Dangerous Goods Store
- Ⓘ Machine Shop
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- Ⓜ Former Rolling Mill
- Ⓝ Metal Stamping Building
- Ⓞ Specialist Fibreglass Hull Construction
- Ⓟ Leather Dressing, Stores and Vehicles Maintenance Shed
- Ⓠ Boat Repair Building and Area
- Ⓡ Fibreglass Boat Finishing
- Ⓢ Boat Painting/Joinery/Finishing
- Ⓣ Boat Painting/Joinery/Finishing
- Ⓤ Fire Suppression Pump House
- Ⓥ Mould Manufacture for Fibreglass
- Ⓦ Welding/Metal Workshop
- Ⓧ Grit Blasting Warehouse
- Ⓨ Metal Workshop
- Ⓩ Metal Boat/Metal Sheet Fabrication

Title

Agreement No. CE 68/99 Infrastructure for Penny's Bay Development - Engineering Design and Construction - Decomission of CLS

As - Built Locations of Samling Boreholes and Trenches (Area 3)

Scale
As Shown

Date
Feb 2002

Project No. R06100

Figure No. 4.1c

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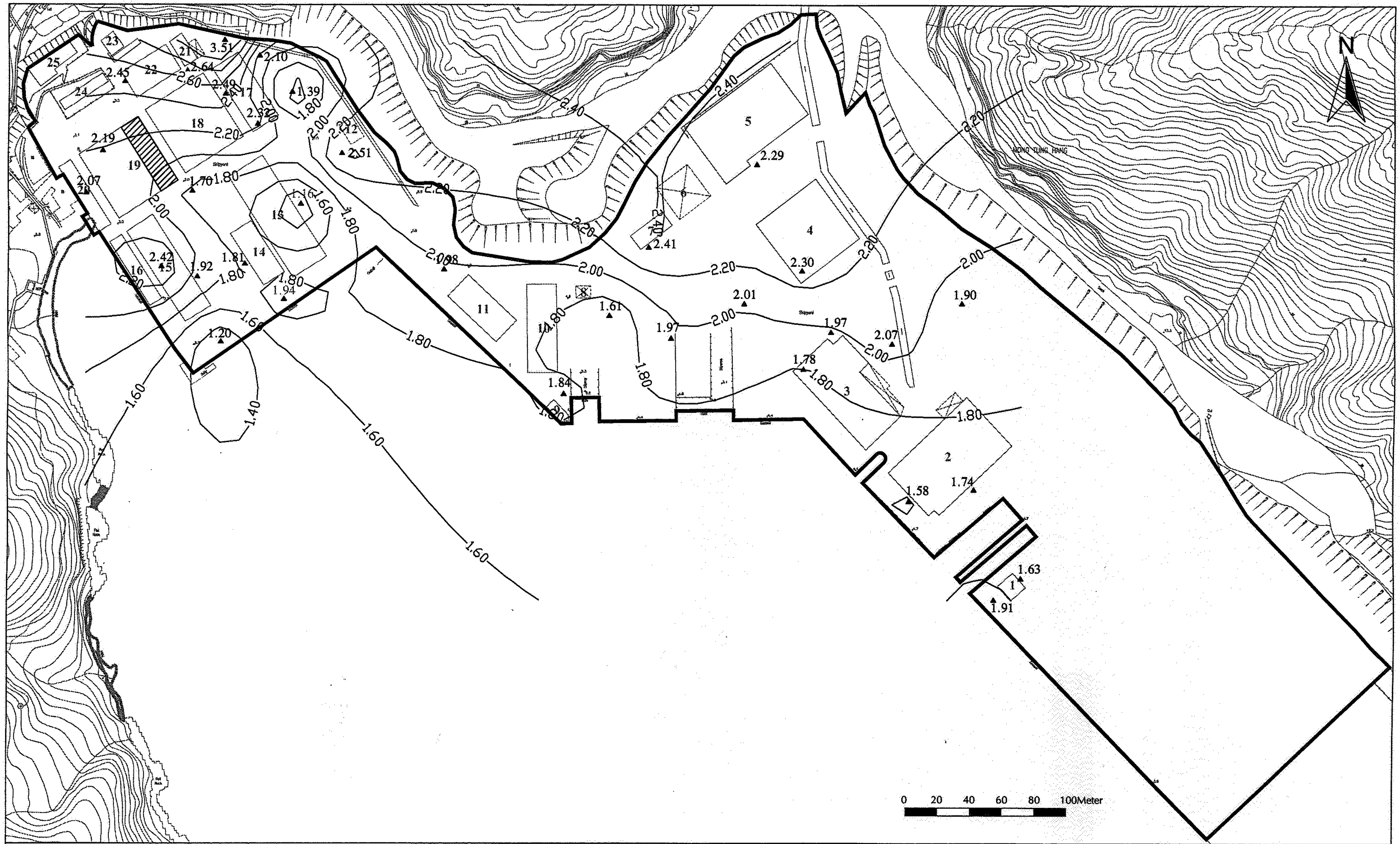

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Agreement No. CE 68/99 Infastrusture for Penny's Bay Development - Engineering Design and Construction Decommissioning of Cheoy Lee Shipyard Goundwater Level Contour Map	Scale As Shown	Project No. R06100	**Maunsell** MAUNSELL ENVIRONMENTAL MANAGEMENT CONSULTANTS LTD
	Date Feb 2002	Figure No. 4.2	

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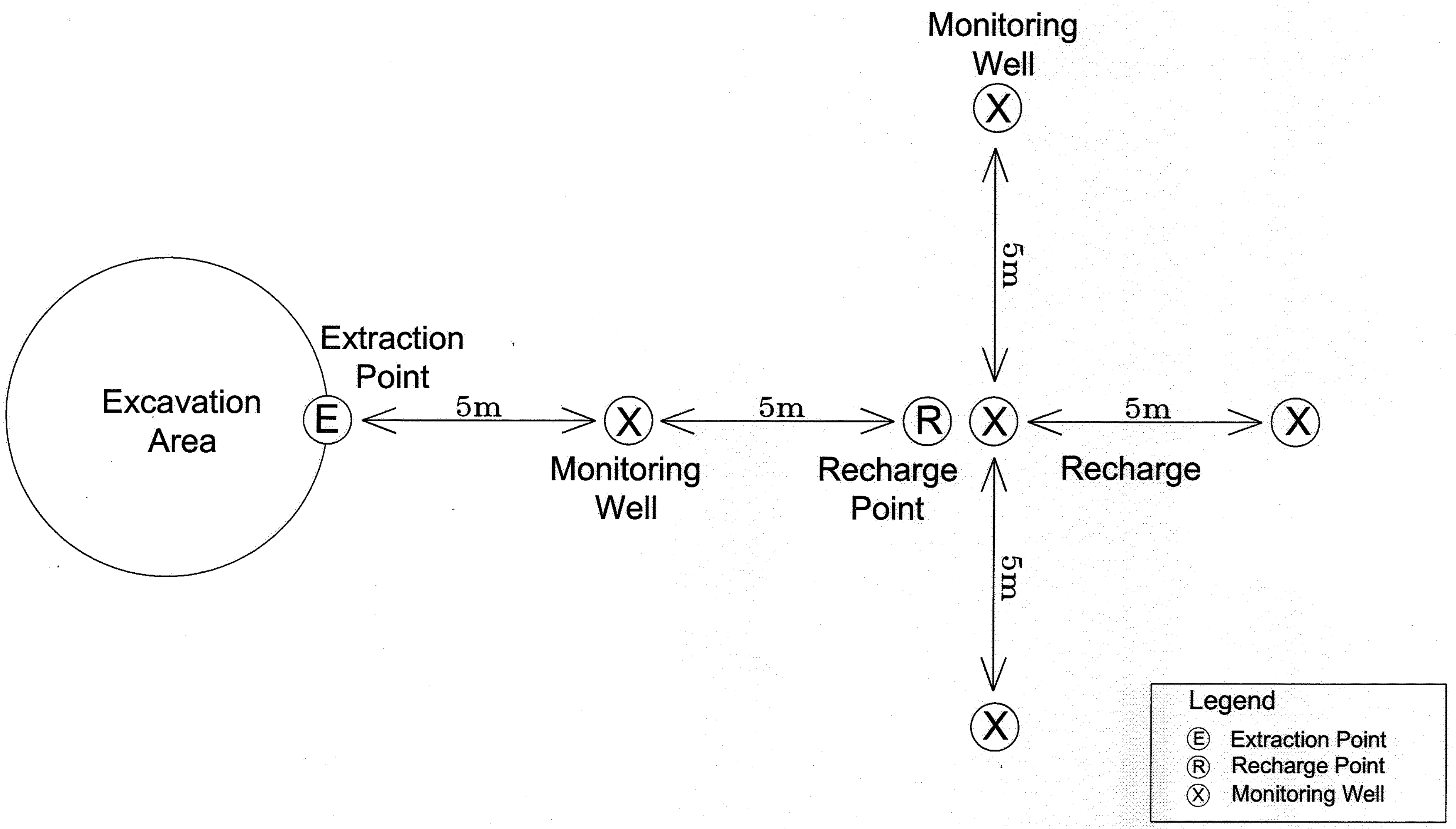

Title Agreement No. CE 68/99 Infrastructure for Penny's Bay Development - Engineering Design and Construction Decommissioning of Choey Lee Shipyard Typical Extraction Point, Recharge Point and Groundwater Level Monitoring Locations	Scale N.T.S. Date Feb 2002	Project No. R06100 Figure No. 4.3

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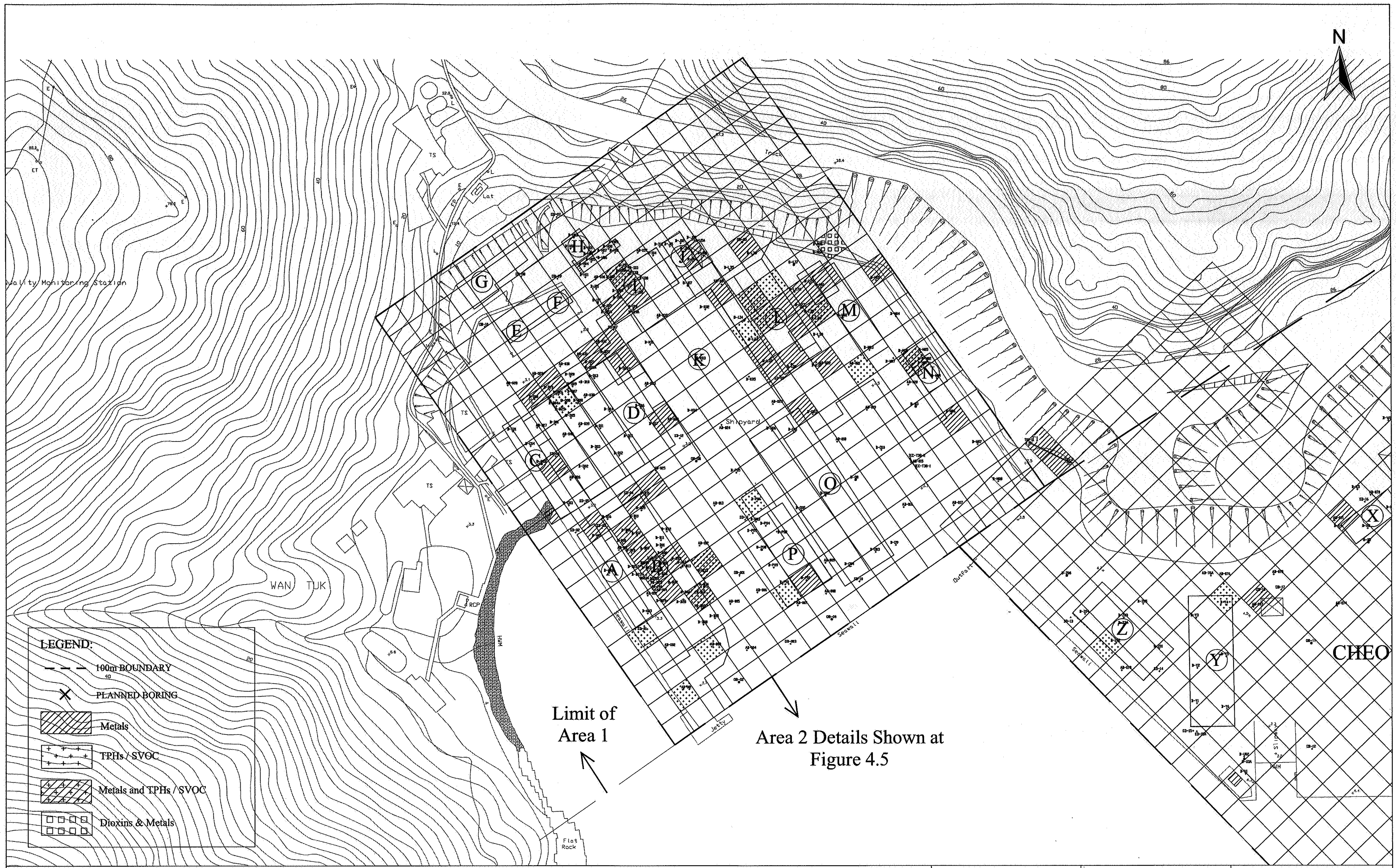

Title

Agreement No. CE 68/99 Infrastructure for Penny's Bay Development - Engineering Design and Construction
Decommissioning of Choey Lee Shipyard
Sampling Locations with Contamination Found at Area 1 (0.5m Below Ground) (Without Interpolation)

Scale 1:1500

Project No. R06100

Date Feb 2002

Figure No. 4.4a

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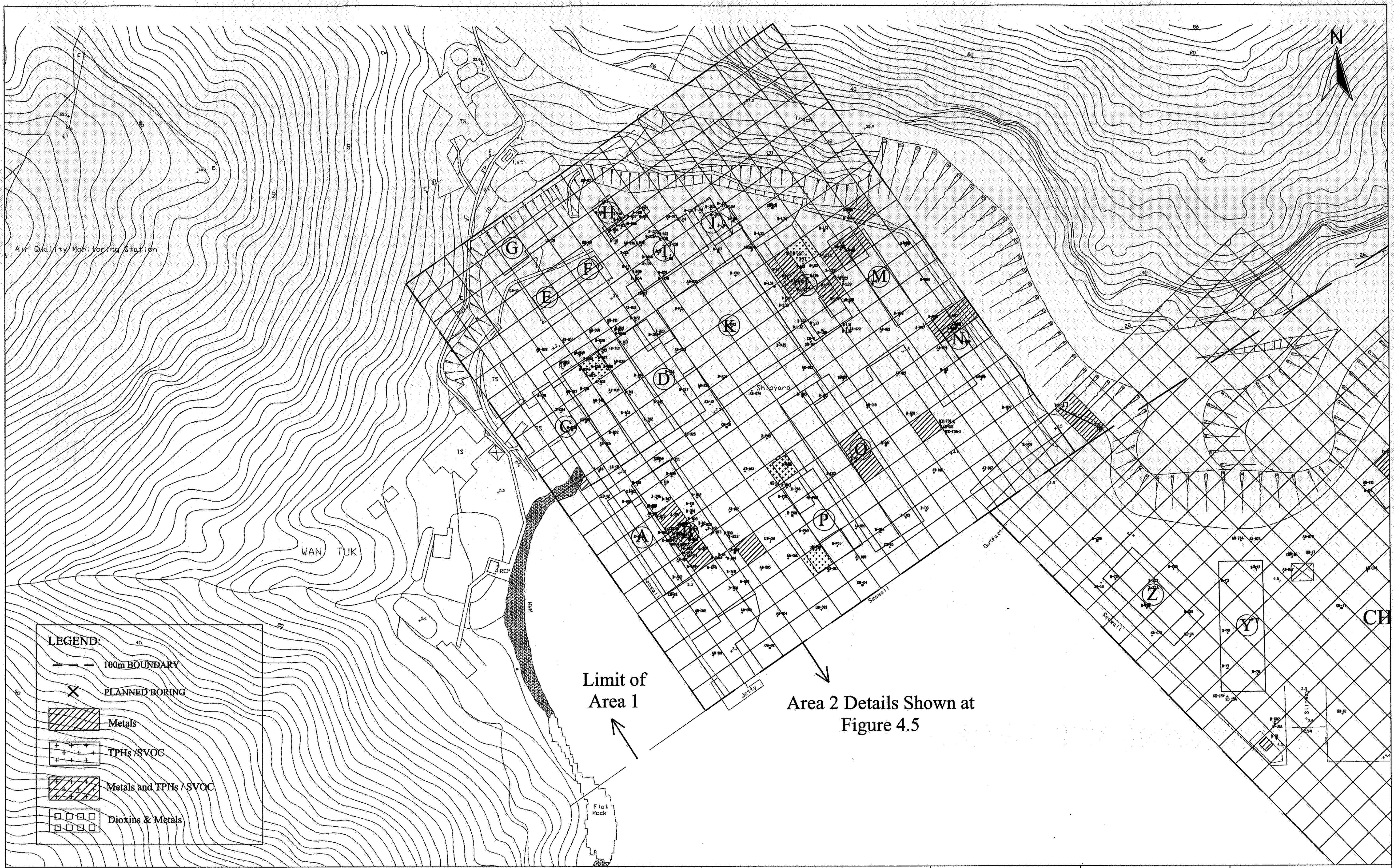

Title
Agreement No. CE 68/99 Infrastructure for Penny's Bay Development - Engineering Design and Construction
Decommissioning of Choey Lee Shipyard

Sampling Locations with Contamination Found at Area 1 (1m Below Ground) (Without Interpolation)

Scale 1:1500
Project No. R06100
Date Feb 2002
Figure No. 4.4b

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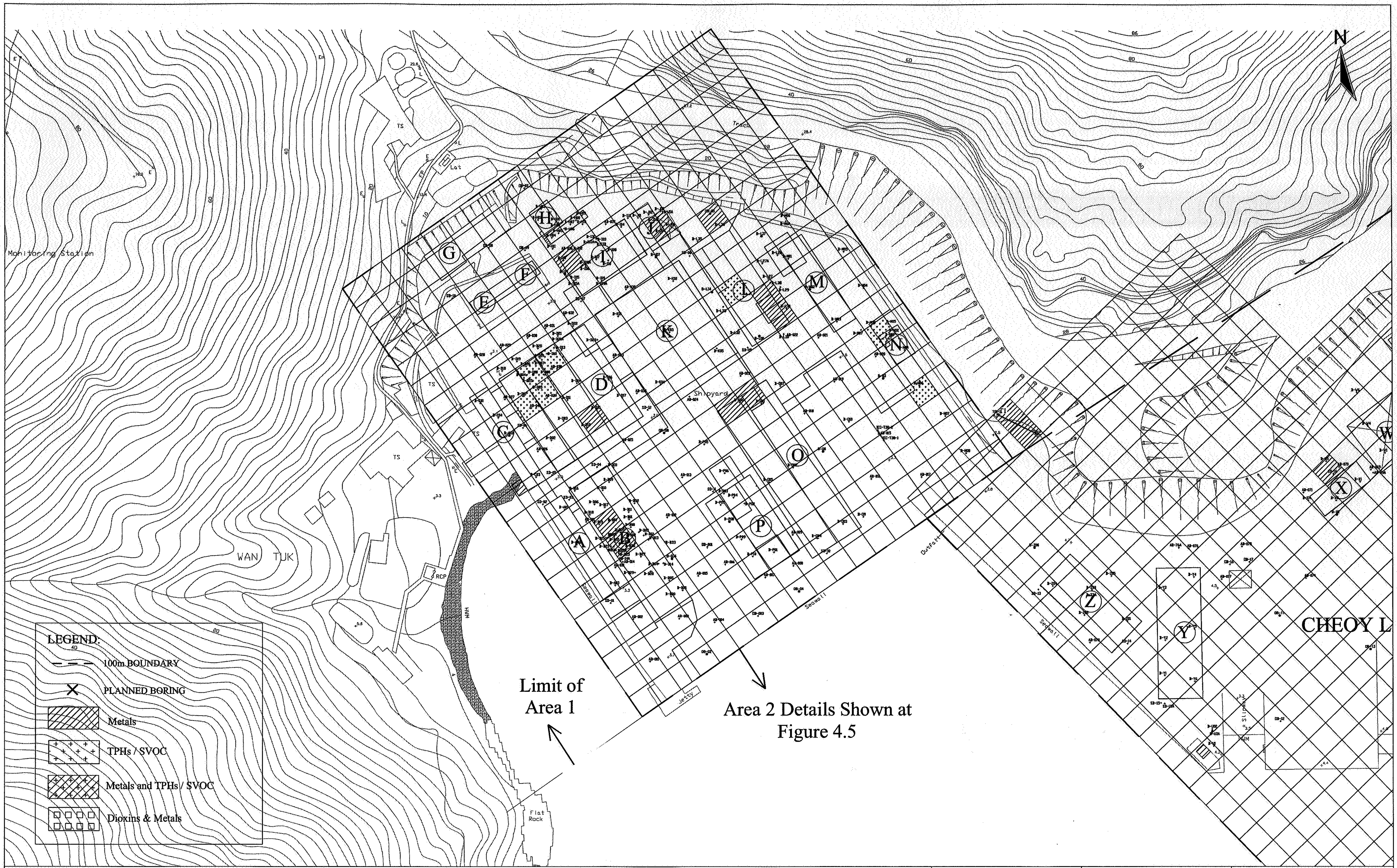

Title	Scale	Project No.
Agreement No. CE 68/99 Infrastructure for Penny's Bay Development - Engineering Design and Construction Decommissioning of Choey Lee Shipyard Sampling Locations with Contamination Found at Area 1 (1.5m Below Ground) (Without Interpolation)	1:1500	R06100
	Date	**Figure No.**
	Feb 2002	4.4c

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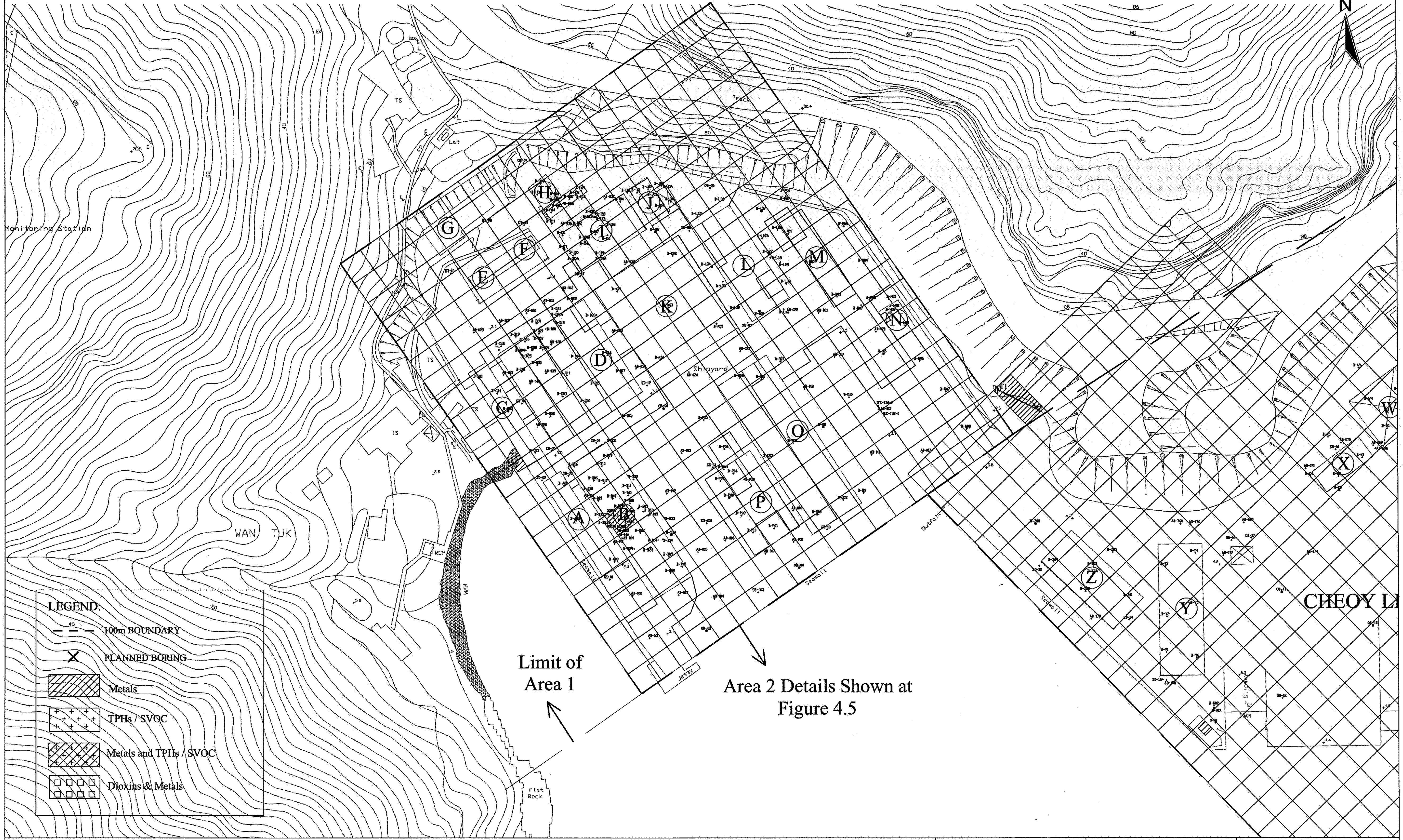

Title

Agreement No. CE 68/99 Infrastructure for Penny's Bay Development - Engineering Design and Construction
Decommissioning of Choey Lee Shipyard

Sampling Locations with Contamination Found at Area 1 (3.0m Below Ground) (Without Interpolation)

Scale 1:1500

Date Feb 2002

Project No. R06100

Figure No. 4.4d

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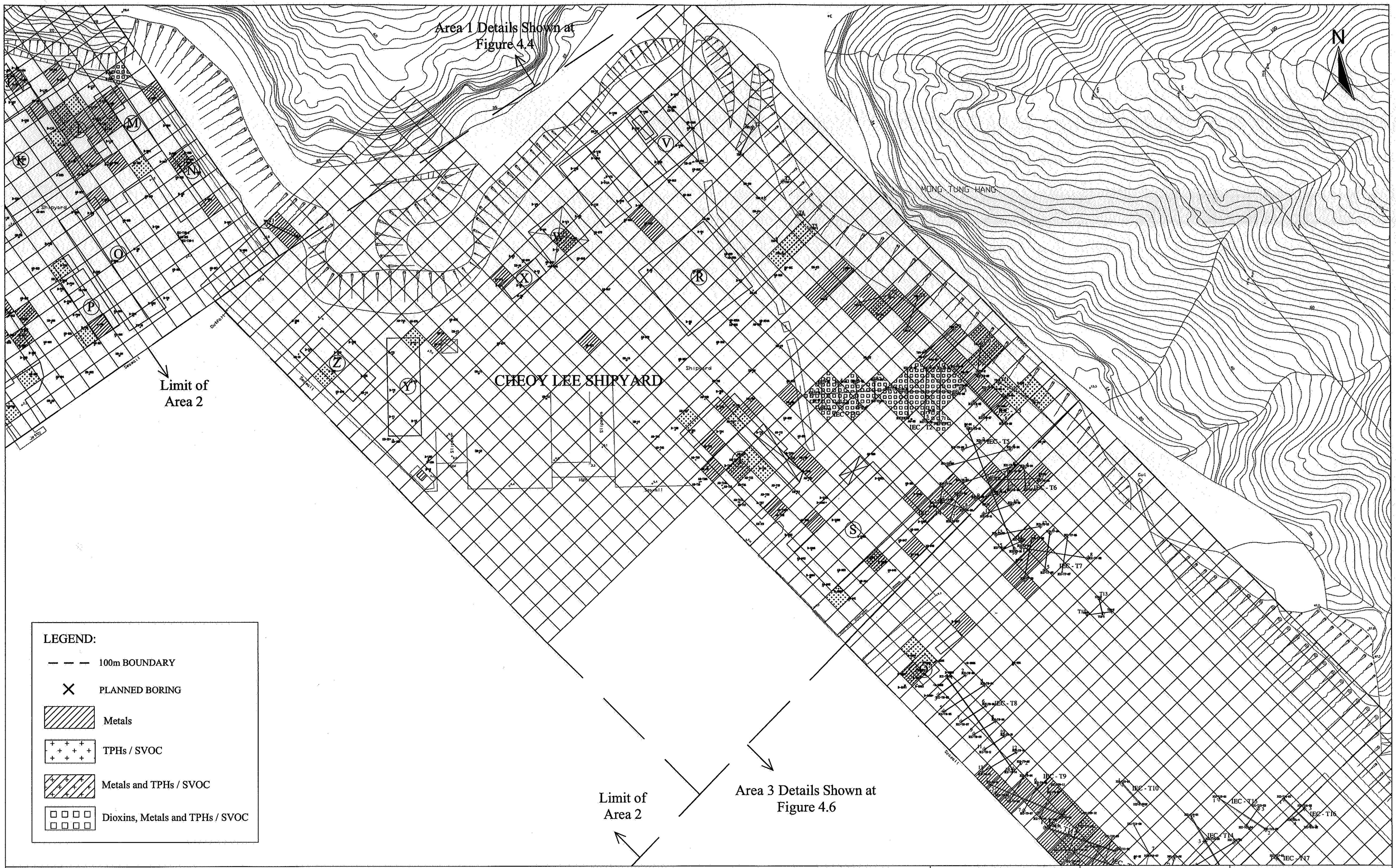

Title	Scale	Project
Agreement No. CE 68/99 Infrastructure for Penny's Bay Development - Engineering Design and Construction Decommissioning of Choey Lee Shipyard Sampling Locations with Contamination Found at Area 2 (0.5m Below Ground) (Without Interpolation)	1:2000	No. R06100
	Date Feb 2002	Figure No. 4.5a

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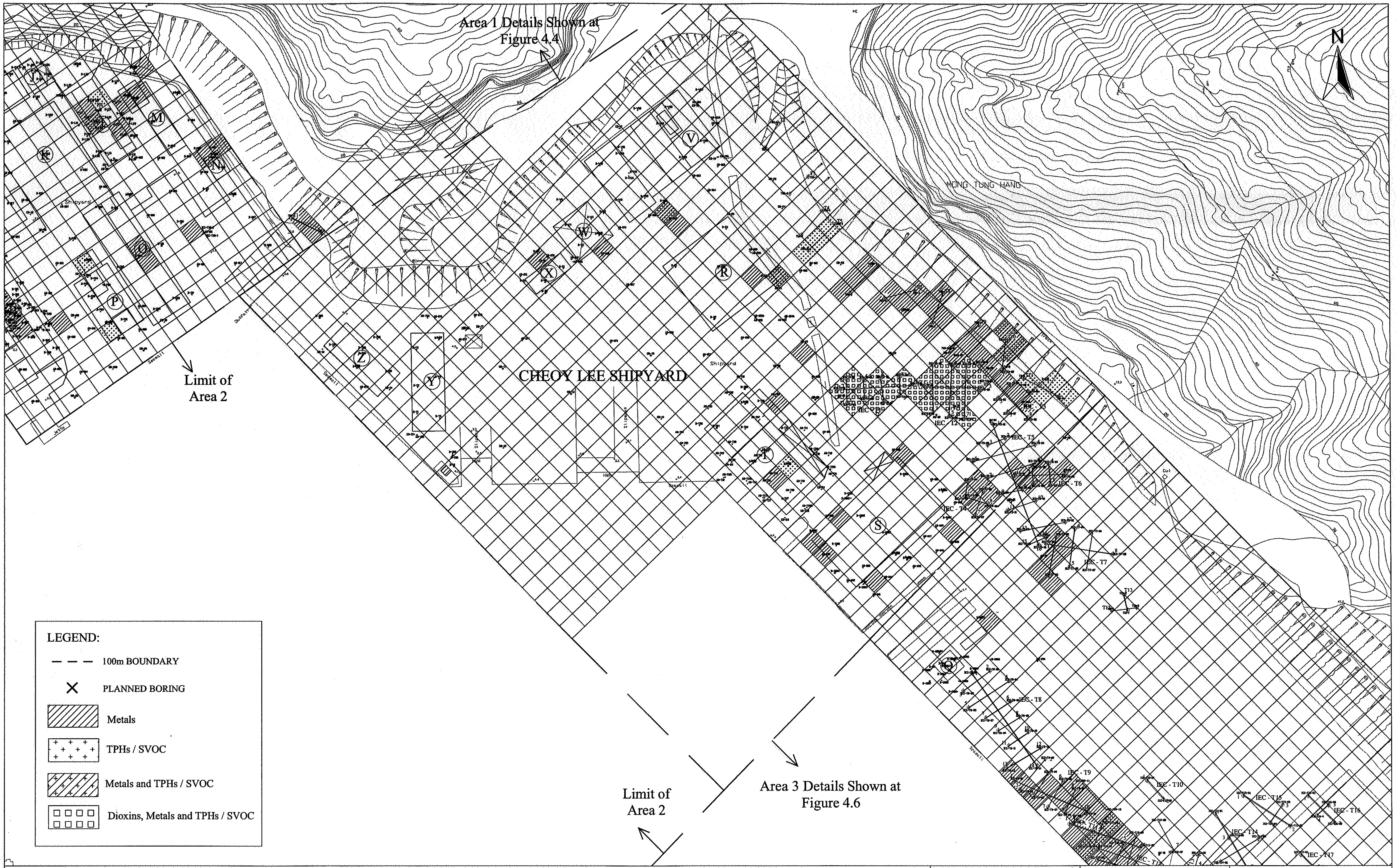

Title Agreement No. CE 68/99 Infrastructure for Penny's Bay Development - Engineering Design and Construction Decommissioning of Choey Lee Shipyard Sampling Locations with Contamination Found at Area 2 (1m Below Ground) (Without Interpolation)	Scale 1:2000 Date Feb 2002	Project No. R06100 Figure No. 4.5b

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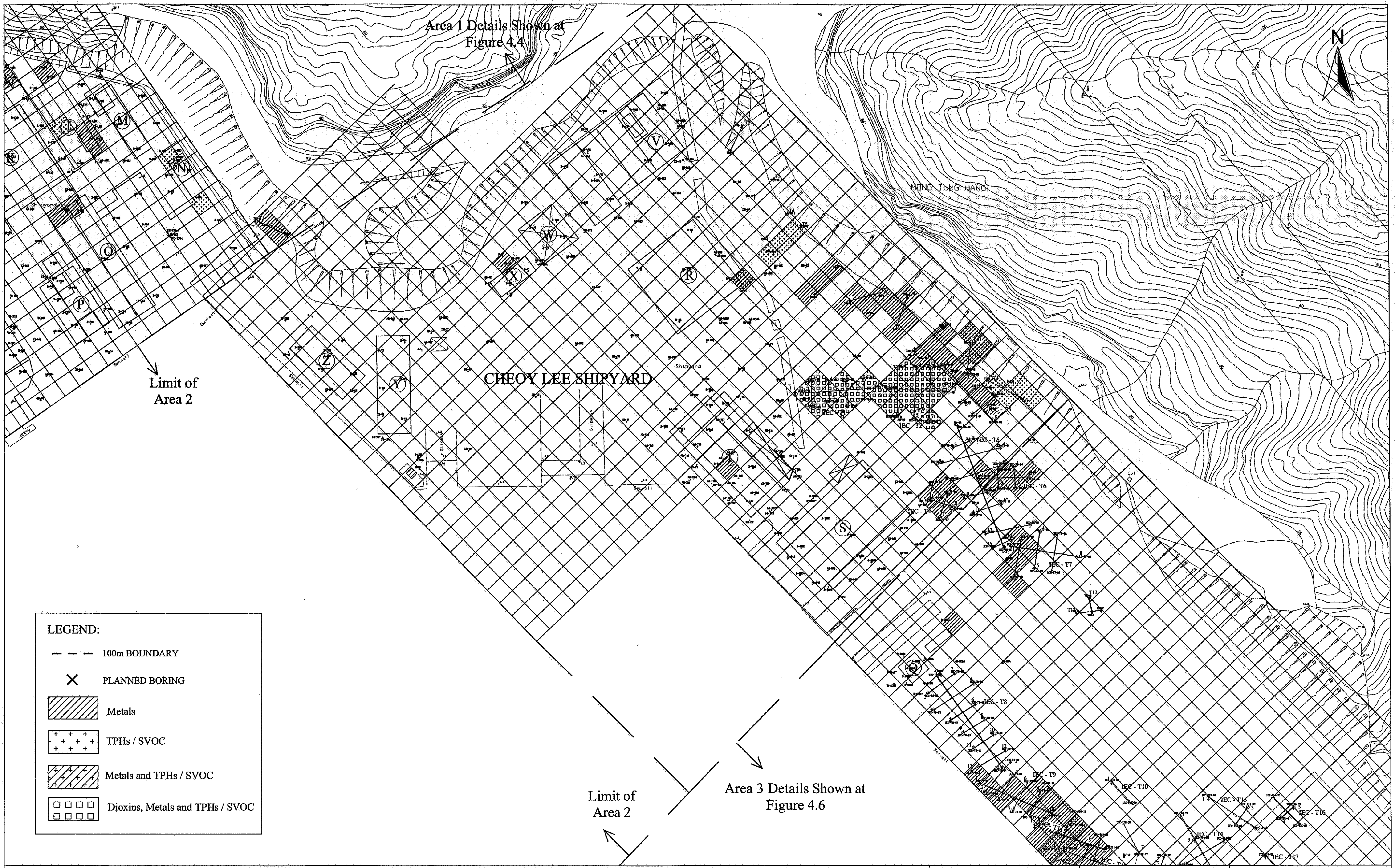

Title

Agreement No. CE 68/99 Infrastructure for Penny's Bay Development - Engineering Design and Construction
Decommissioning of Choey Lee Shipyard

Sampling Locations with Contamination Found at Area 2 (1.5m Below Ground) (Without Interpolation)

Scale 1:2000

Date Feb 2002

Project No. R06100

Figure No. 4.5c

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MAUNSELL ENVIRONMENTAL MANAGEMENT CONSULTANTS LTD

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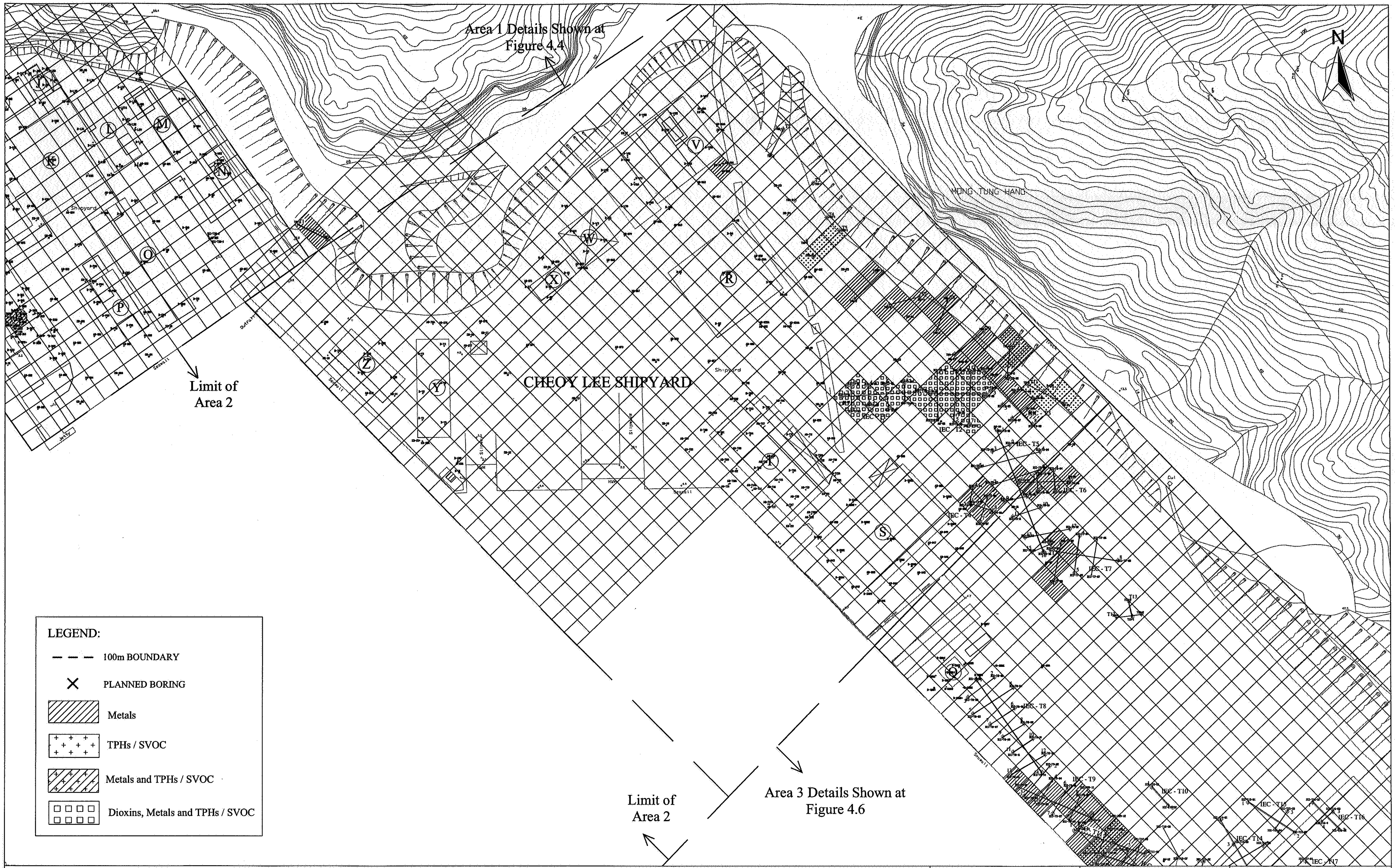

Title	Scale	Project No.
Agreement No. CE 68/99 Infrastructure for Penny's Bay Development - Engineering Design and Construction Decommissioning of Choey Lee Shipyard	1:2000	R06100
Sampling Locations with Contamination Found at Area 2 (3.0m Below Ground) (Without Interpolation)	Date Feb 2002	Figure No. 4.5d

Maunsell
MAUNSELL ENVIRONMENTAL MANAGEMENT CONSULTANTS LTD

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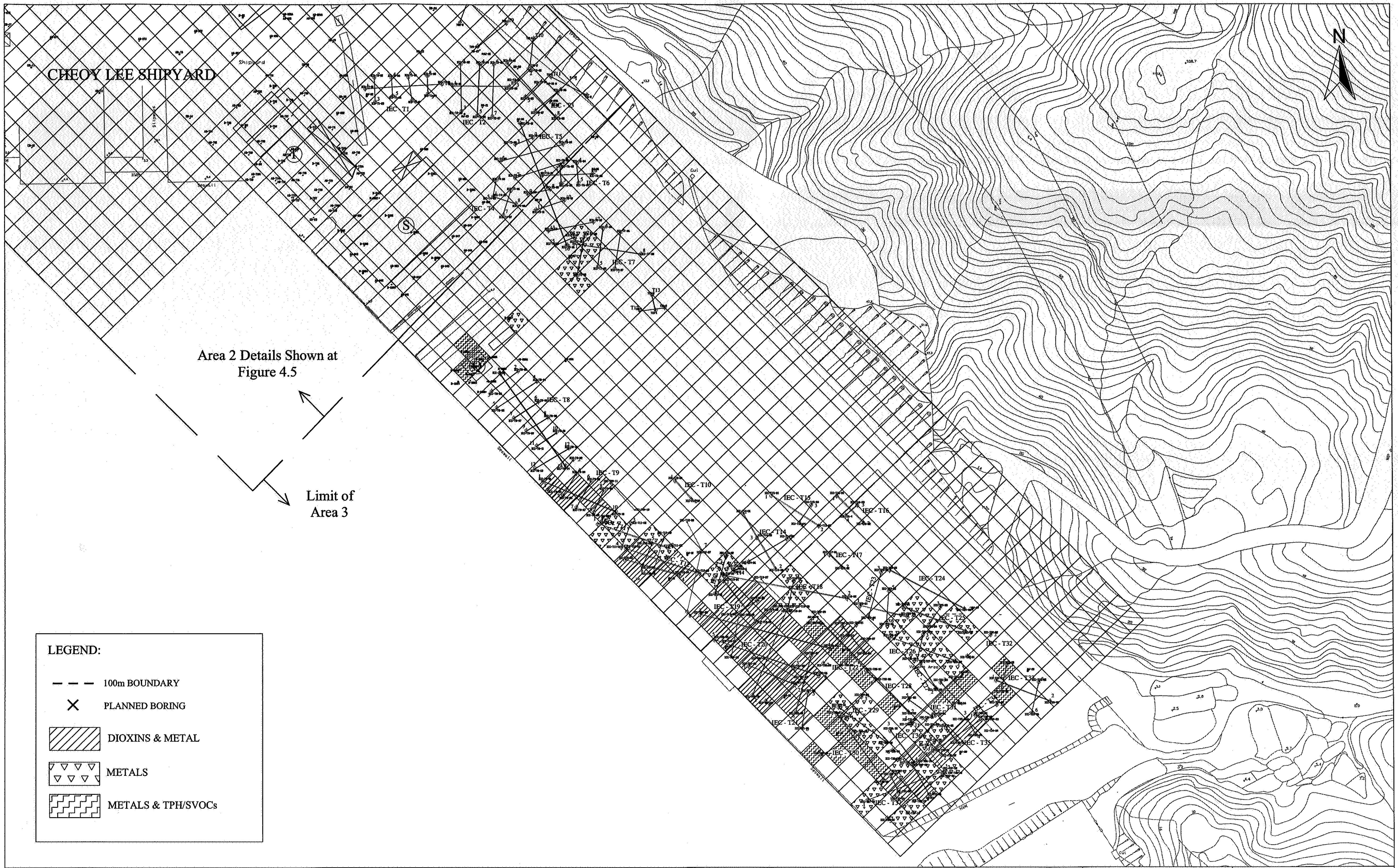

Title

Agreement No. CE 68/99 Infrastructure for Penny's Bay Development - Engineering Design and Construction
Decommissioning of Choey Lee Shipyard

Sampling Locations with Contamination Found at Area 3 (1m Below Ground) (Without Interpolation)

Scale	1:2000
Project No.	R06100
Date	Feb 2002
Figure No.	4.6a

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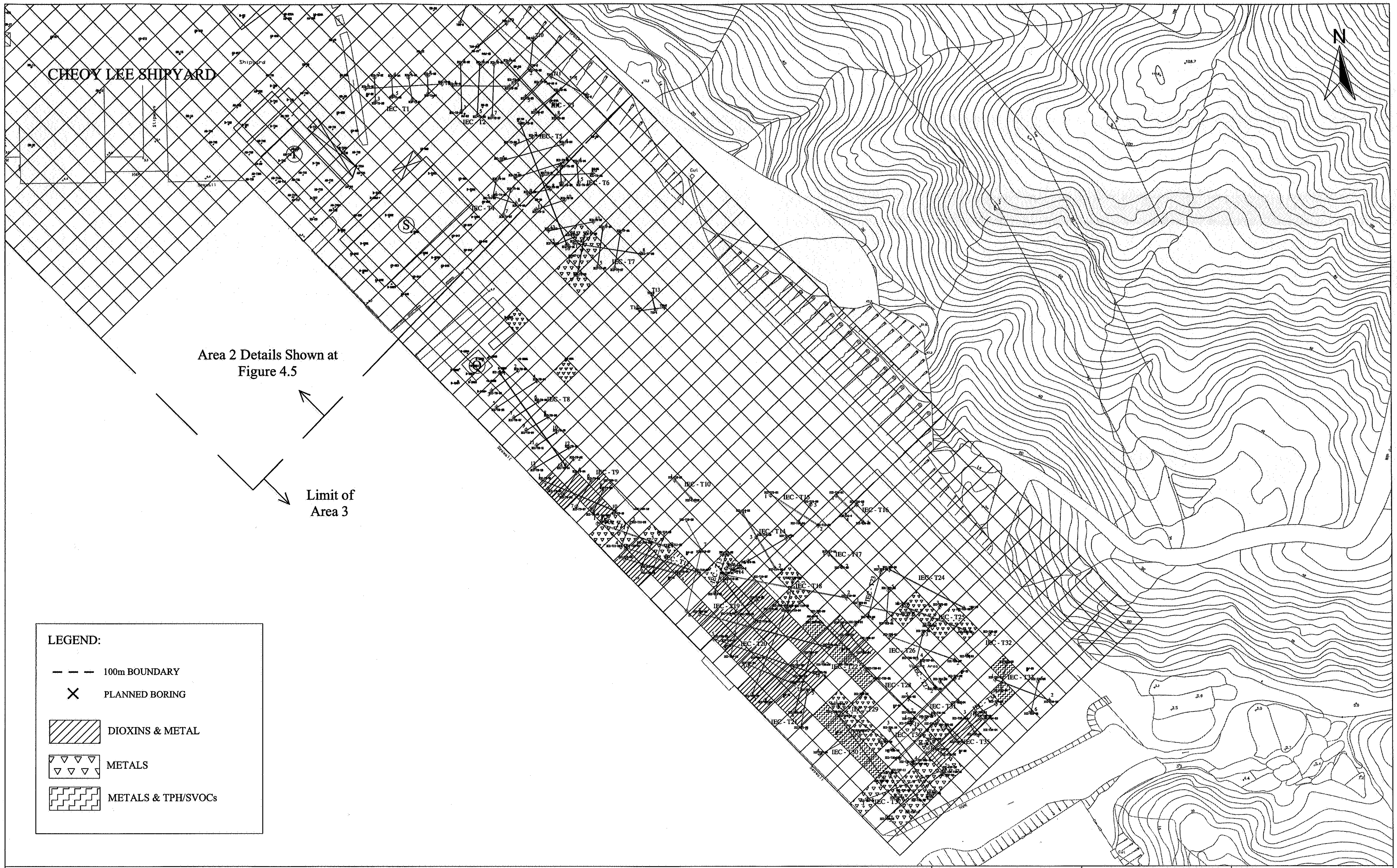

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Agreement No. CE 68/99 Infrastructure for Penny's Bay Development - Engineering Design and Construction Decommissioning of Choey Lee Shipyard Sampling Locations with Contamination Found at Area 3 (2m Below Ground) (Without Interpolation)	1:2000	R06100
	Date	Figure No.
	Feb 2002	4.6b

Maunsell
MAUNSELL ENVIRONMENTAL MANAGEMENT CONSULTANTS LTD

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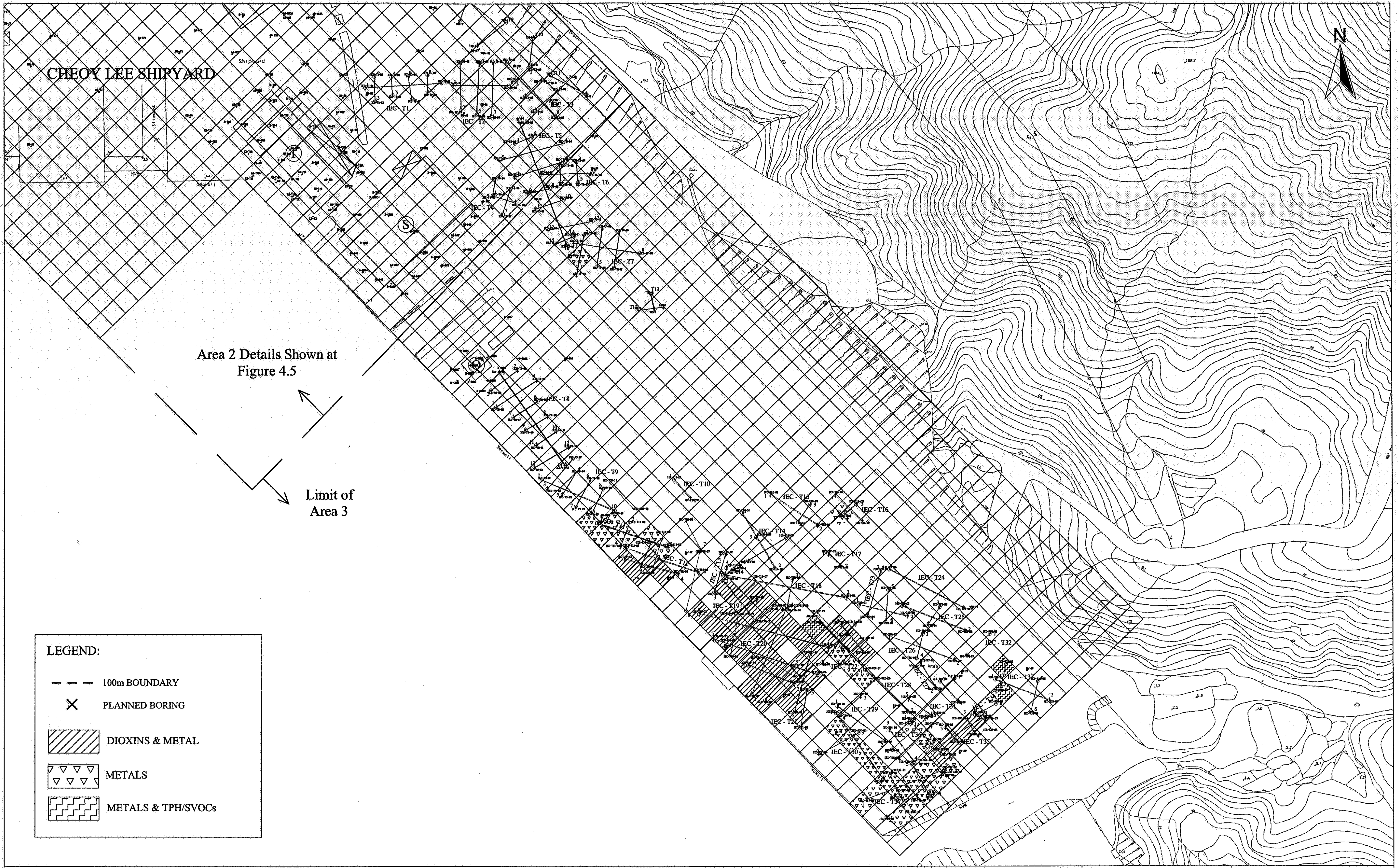

Title

Agreement No. CE 68/99 Infrastructure for Penny's Bay Development - Engineering Design and Construction
Decommissioning of Choey Lee Shipyard

Sampling Locations with Contamination Found at Area 3 (3m Below Ground) (Without Interpolation)

Scale	Project No.
1:2000	R06100
Date	**Figure No.**
Feb 2002	4.6c

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MAUNSELL ENVIRONMENTAL MANAGEMENT CONSULTANTS LTD

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Title	Scale	Project No.
Agreement No. CE 68/99 Infrastructure for Penny's Bay Development - Engineering Design and Construction Decommissioning of Choey Lee Shipyard Excavation Plan for Soil Contaminated Areas at Area 1	1 : 1000	R06100
	Date	**Figure No.**
	Feb 2002	4.7

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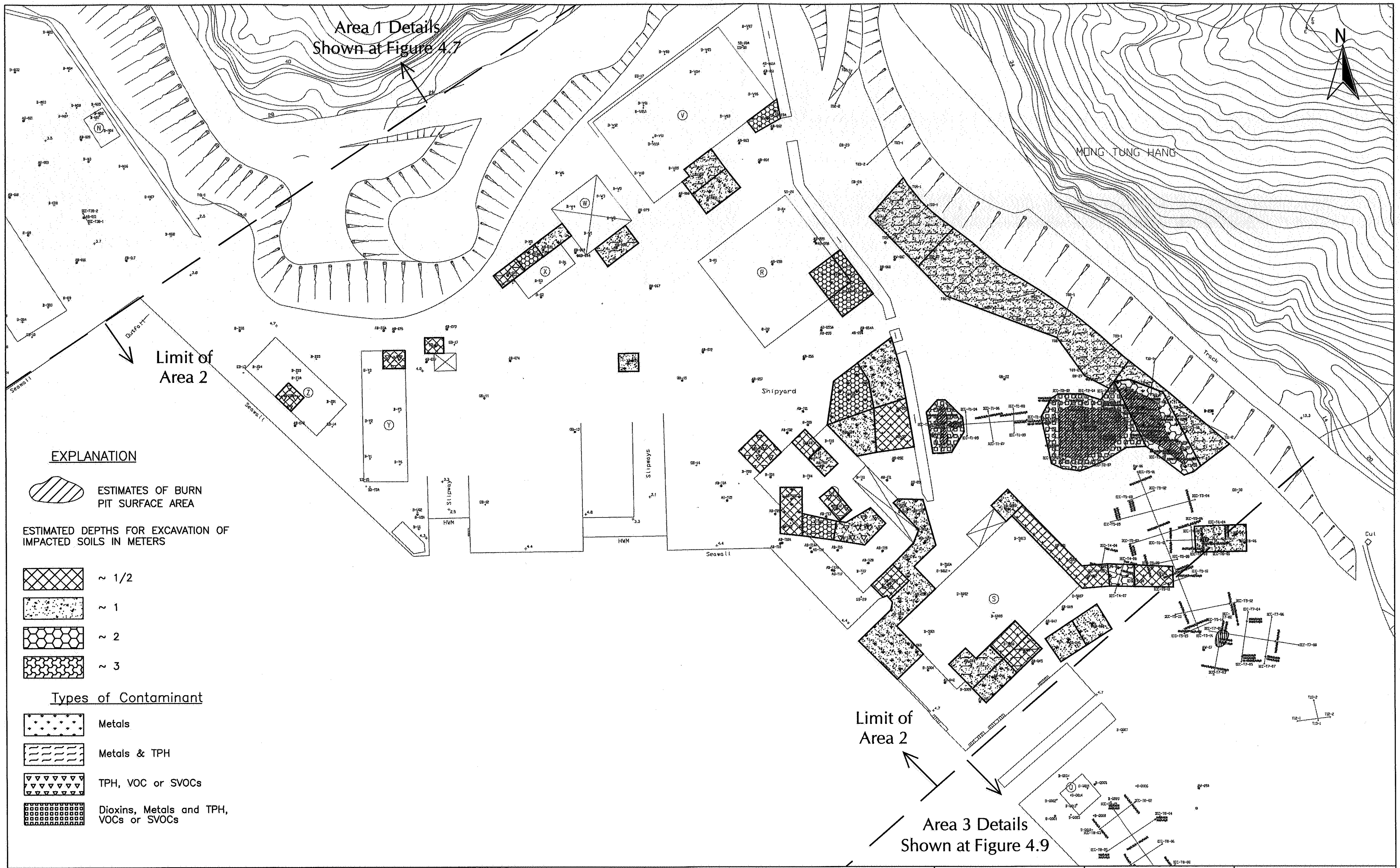

Title	Scale	Project
Agreement No. CE 68/99 Infrastructure for Penny's Bay Development - Engineering Design and Construction Decommissioning of Choey Lee Shipyard	1 : 1500	No. R06100
Excavation Plan for Soil Contaminated Areas at Area 2	Date Feb 2002	Figure No. 4.8

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Title

Agreement No. CE 68/99 Infrastructure for Penny's Bay Development - Engineering Design and Construction
Decommissioning of Choey Lee Shipyard

Excavation Plan for Soil Contaminated Areas at Area 3

Scale 1 : 1800

Project No. R06100

Date Feb 2002

Figure No. 4.9

Maunsell
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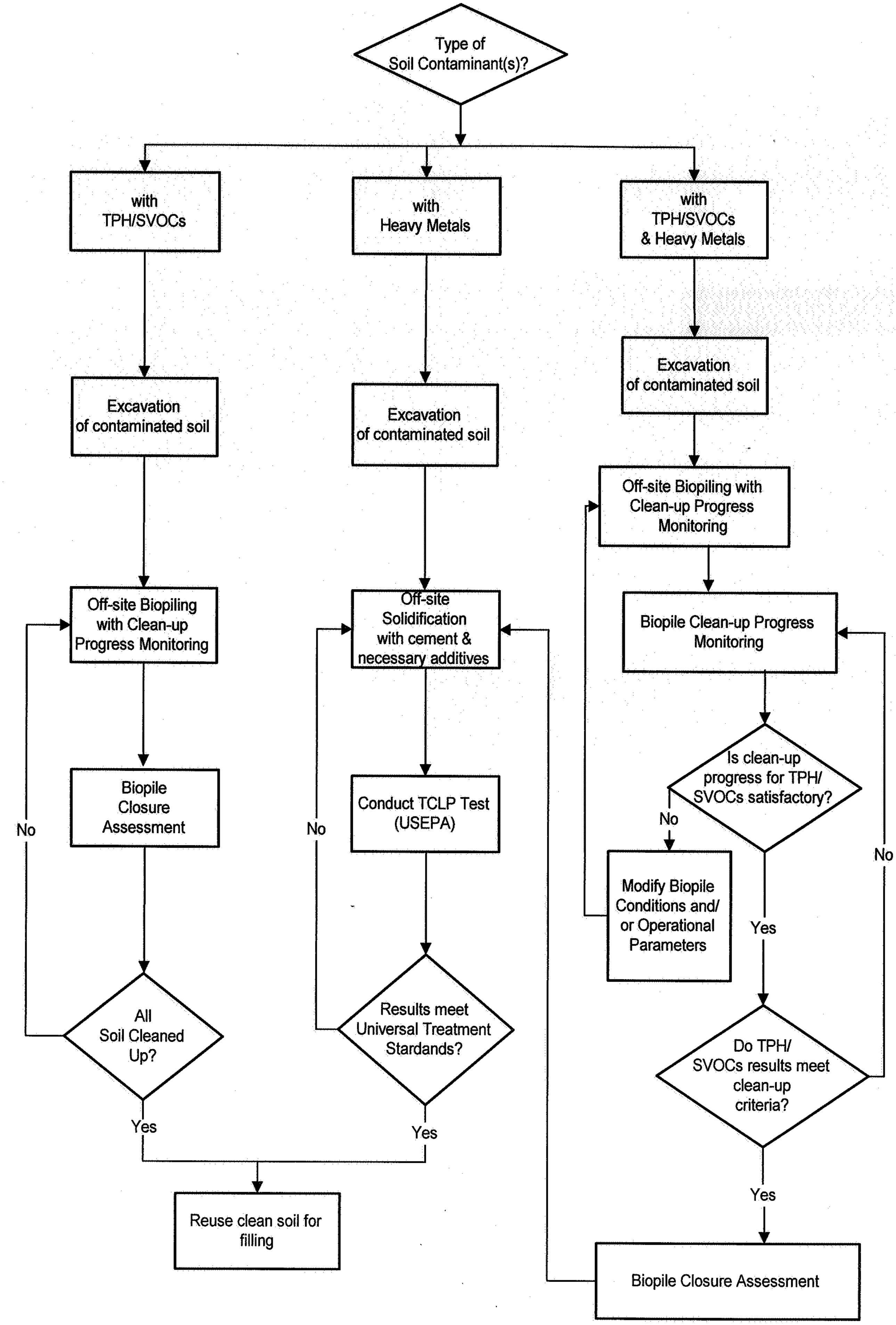

Title Agreement No. CE68/99 Infrastructure for Penny's Bay Development - Engineering Designed and Construction Decommissioning of Cheoy Lee Shipyard Proposed Remediation Strategy for Non-dioxin Contaminated Soils	Scale N.T.S.	Project No. R06100	**Maunsell** MAUNSELL ENVIRONMENTAL MANAGEMENT CONSULTANTS LTD
	Date Feb 2002	Figure No. 4.10	

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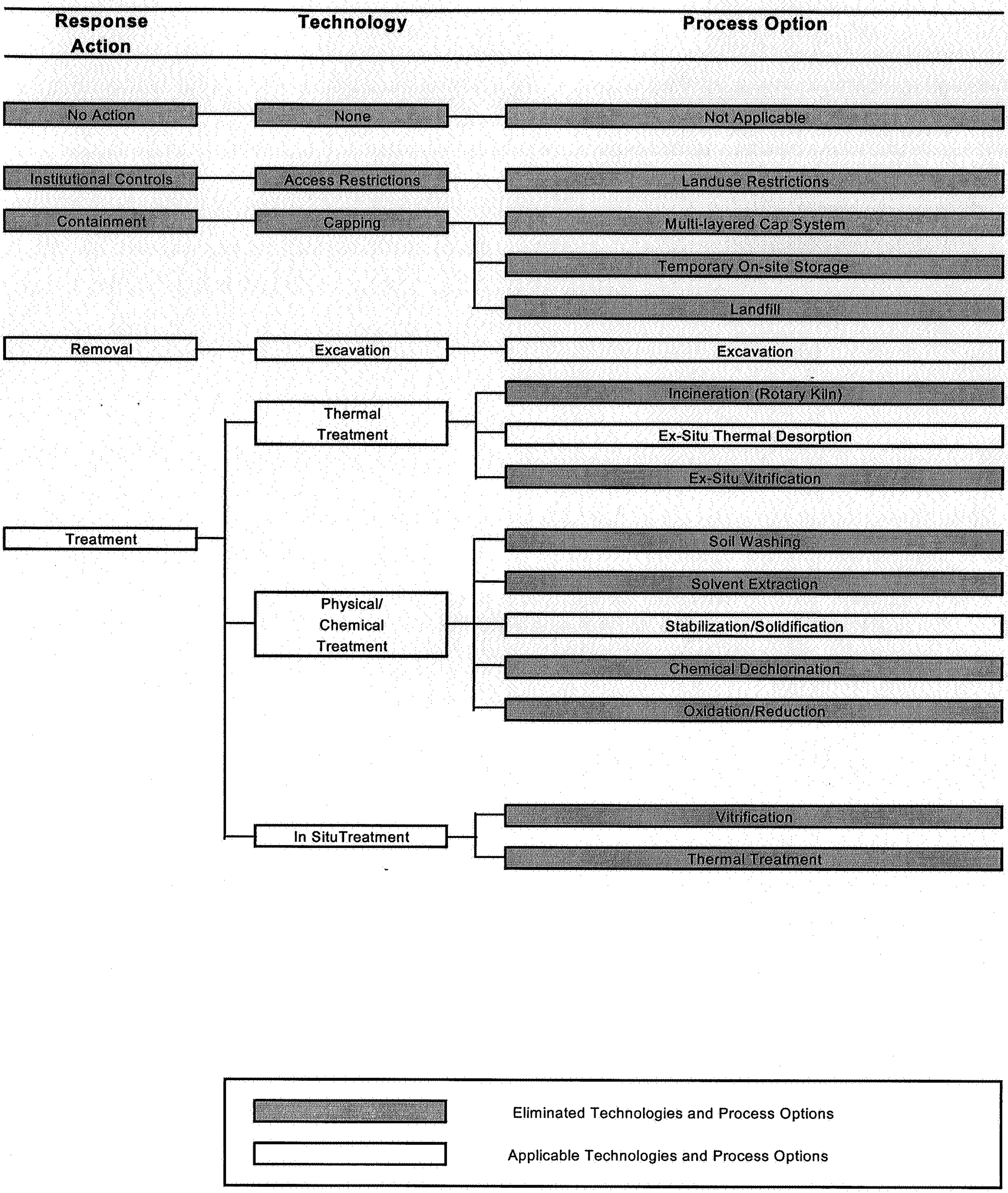

Title
Agreement No. CE 68/99 Infrastrusture for Penny's Bay Development -
Engineering Design and Construction Decommissioning of Cheoy Lee Shipyard

Screening Matrix of Process Options for Dioxin - Contaminated Soil

Scale N.T.S.

Project No. R06100

Date Feb 2002

Figure No. 4.11

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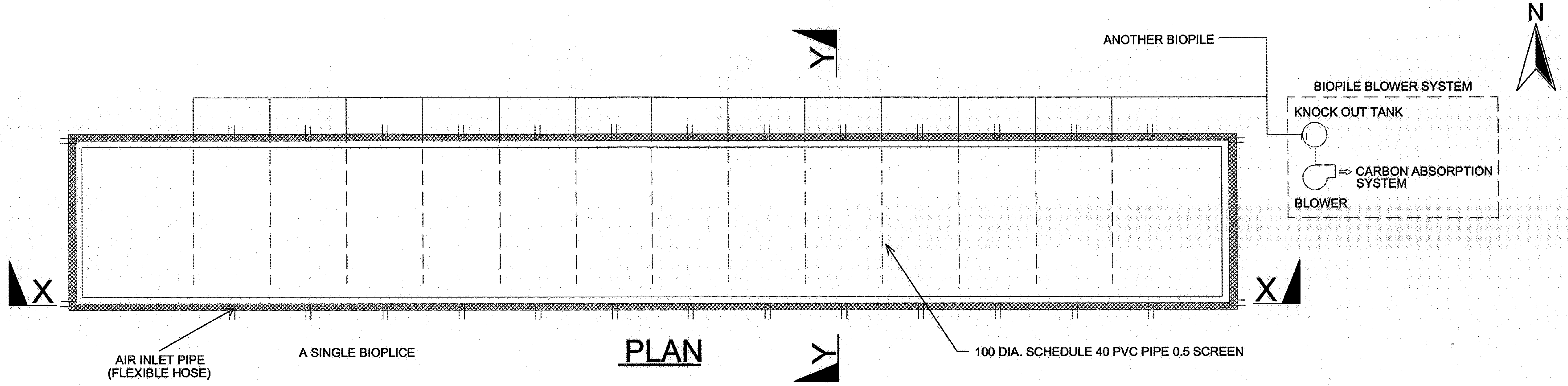

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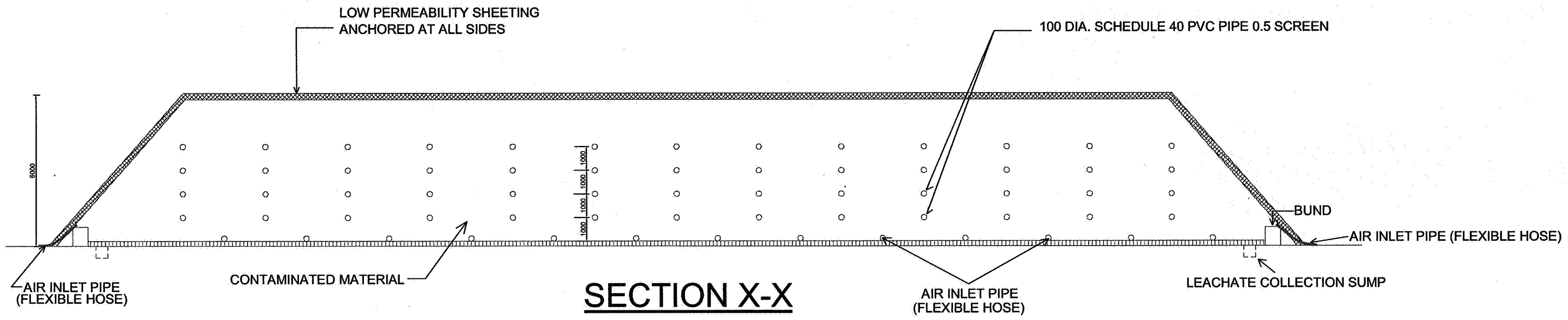
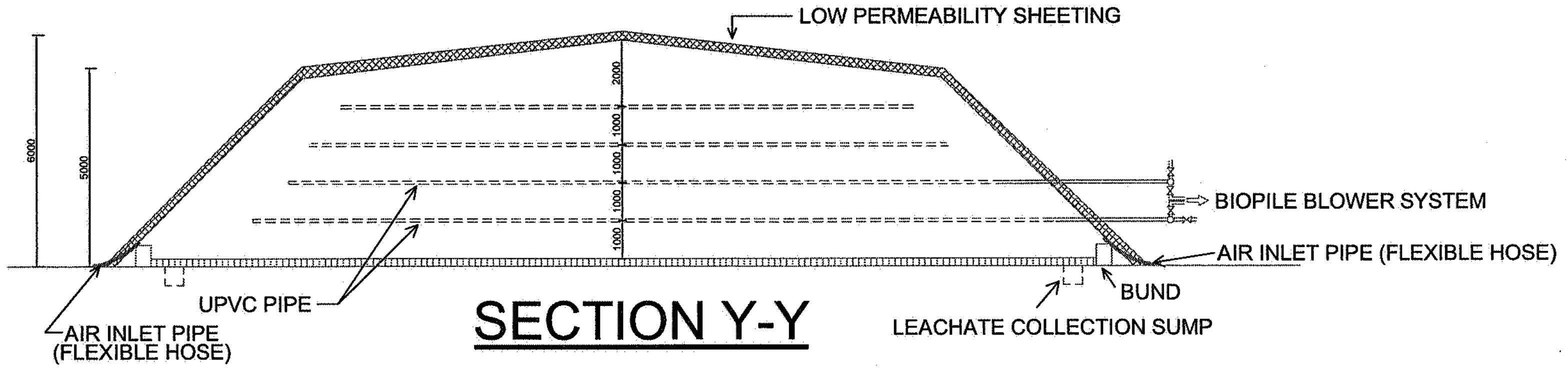


SECTION X-X



SECTION Y-Y

Title	Scale	Project
Agreement No. CE 68/99 Infrastructure for Penny's Bay Development - Engineering Design and Construction Decommissioning of Cheoy Lee Shipyard	As Shown	No. R06100
Schematic of a Typical Single Bio-pile	Date Feb 2002	Figure No. 4.12

Maunsell
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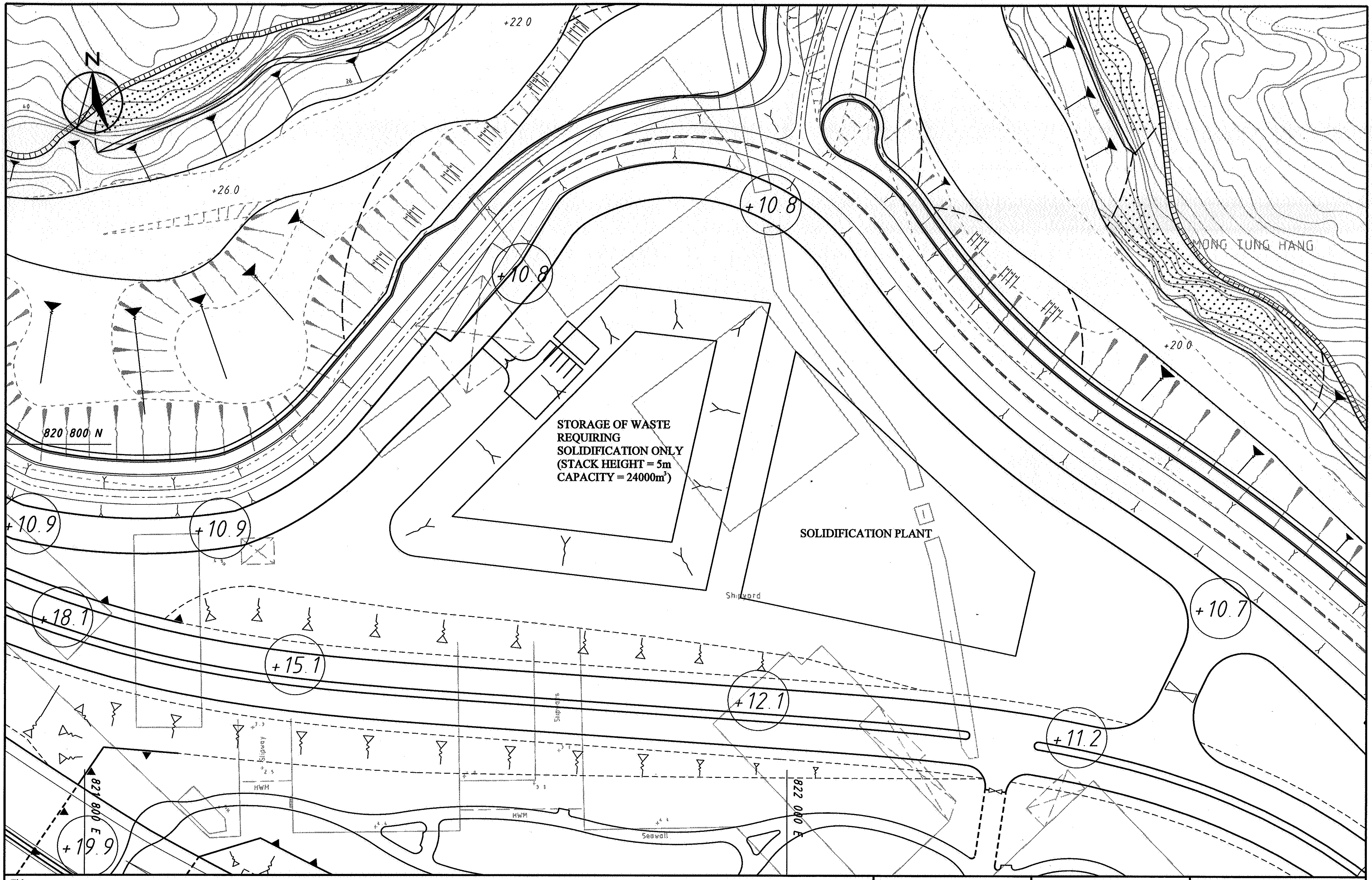

Title

Agreement No. CE 68/99 Infrastructure for Penny's Bay Development - Engineering Design and Construction
Decommissioning of Cheoy Lee Shipyard

LAYOUT PLAN FOR ON-SITE SOLIDIFICATION AT CLS

Scale 1:1000

Projects No. R06100

Date Feb. 2002

Figure No. 4.13

Maunsell
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Date = 02/06/02

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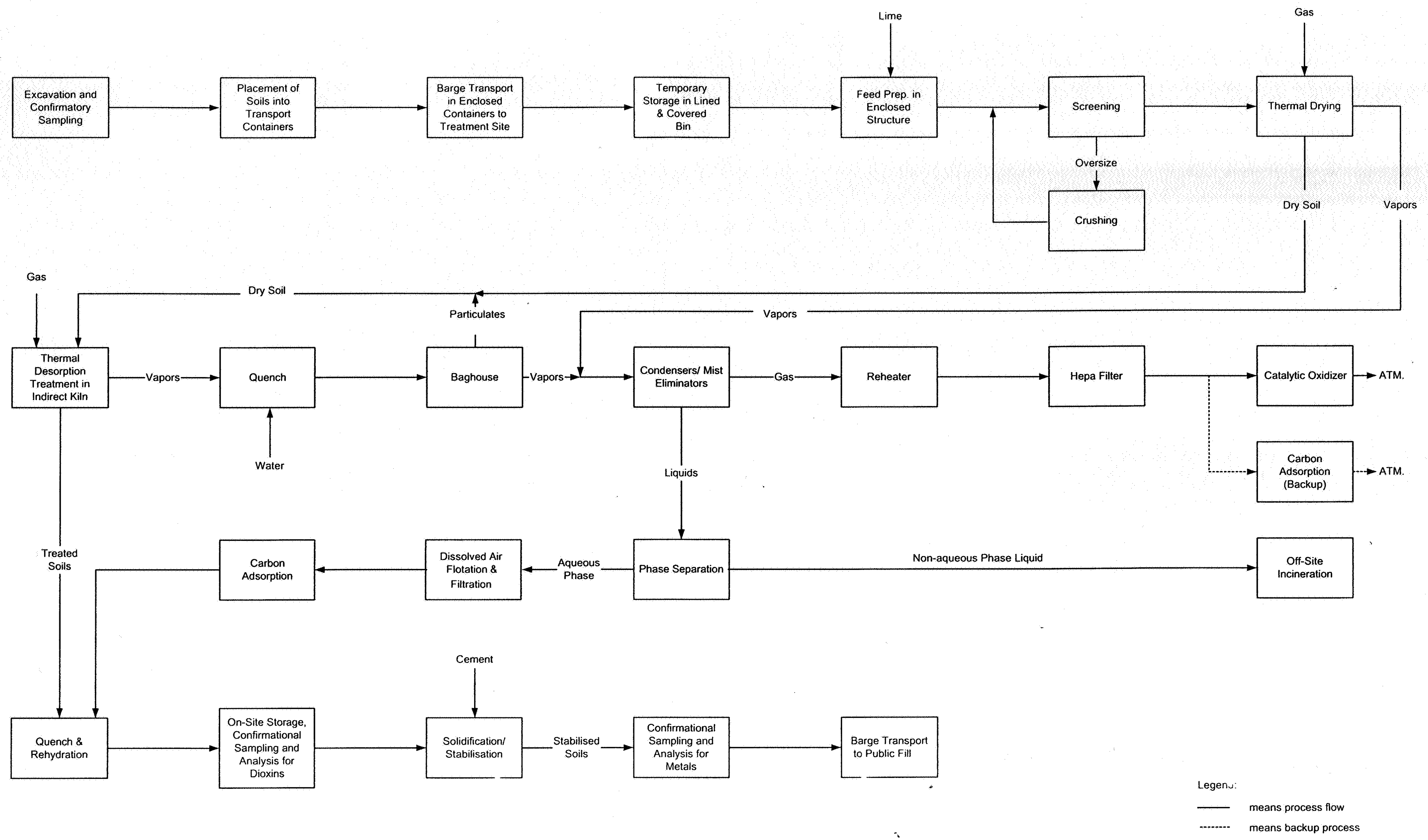

Title

Agreement No. CE 68/99 Infrastructure for Penn's Bay Development - Engineering Design and Construction
Decommissioning of Cheoy Lee Shipyard

Process Flow Diagram for Thermal Desorption Treatment

Scale
N.T.S.

Project No. R06100

Date
Feb 2002

Figure No. 4.14

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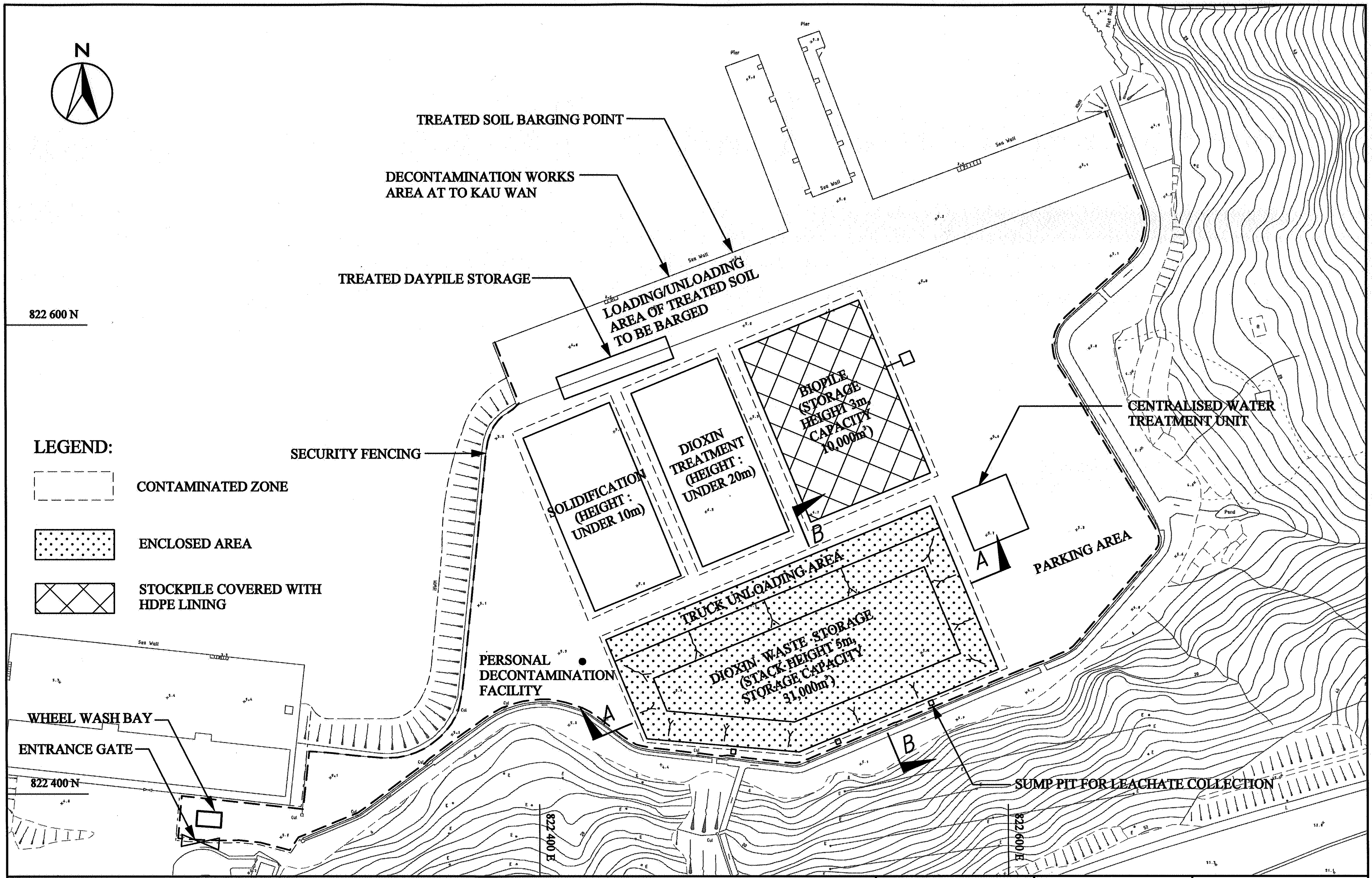

Title			
Agreement No. CE 68/99 Infrastructure for Penny's Bay Development - Engineering Design and Construction Decommissioning of Cheoy Lee Shipyard DECONTAMINATION WORKS AREA AT TO KAU WAN	Scale 1:1500	Projects No. R06100	Maunsell MAUNSELL ENVIRONMENTAL MANAGEMENT CONSULTANTS LTD
	Date Feb 2002	Figure No. 4.15	

Date = $DATE$

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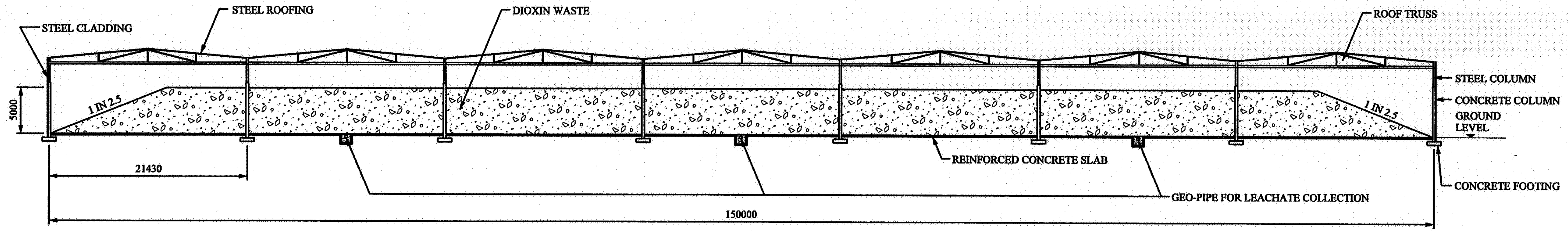
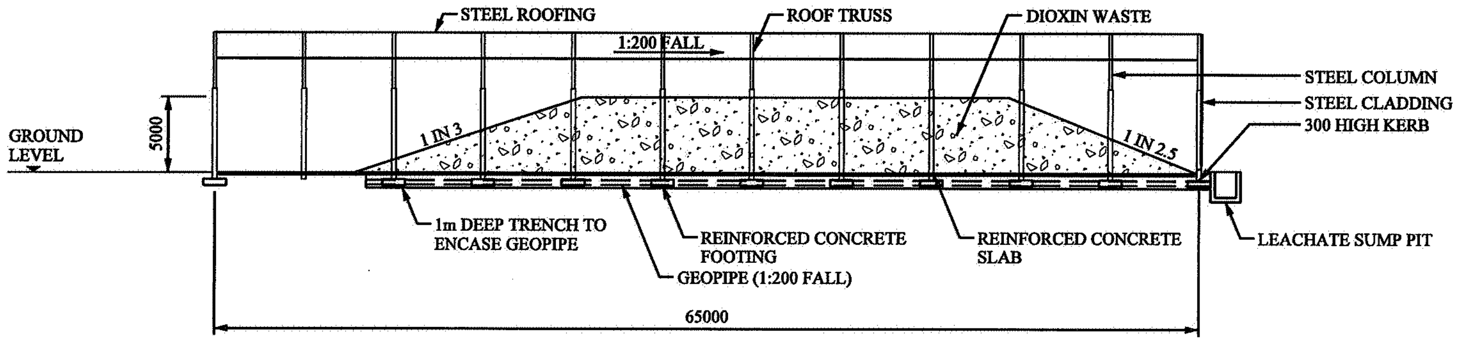


SECTION A - A



SECTION B - B

Title

Agreement No. CE 68/99 Infrastructure for Penny's Bay Development - Engineering Design and Construction
Decommissioning of Cheoy Lee Shipyard

SECTIONS OF DIOXIN WASTE STORAGE BUILDING

Scale	1:500
Date	Feb. 2002
Projects No.	R06100
Figure No.	4.16

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Date = 02/06/02

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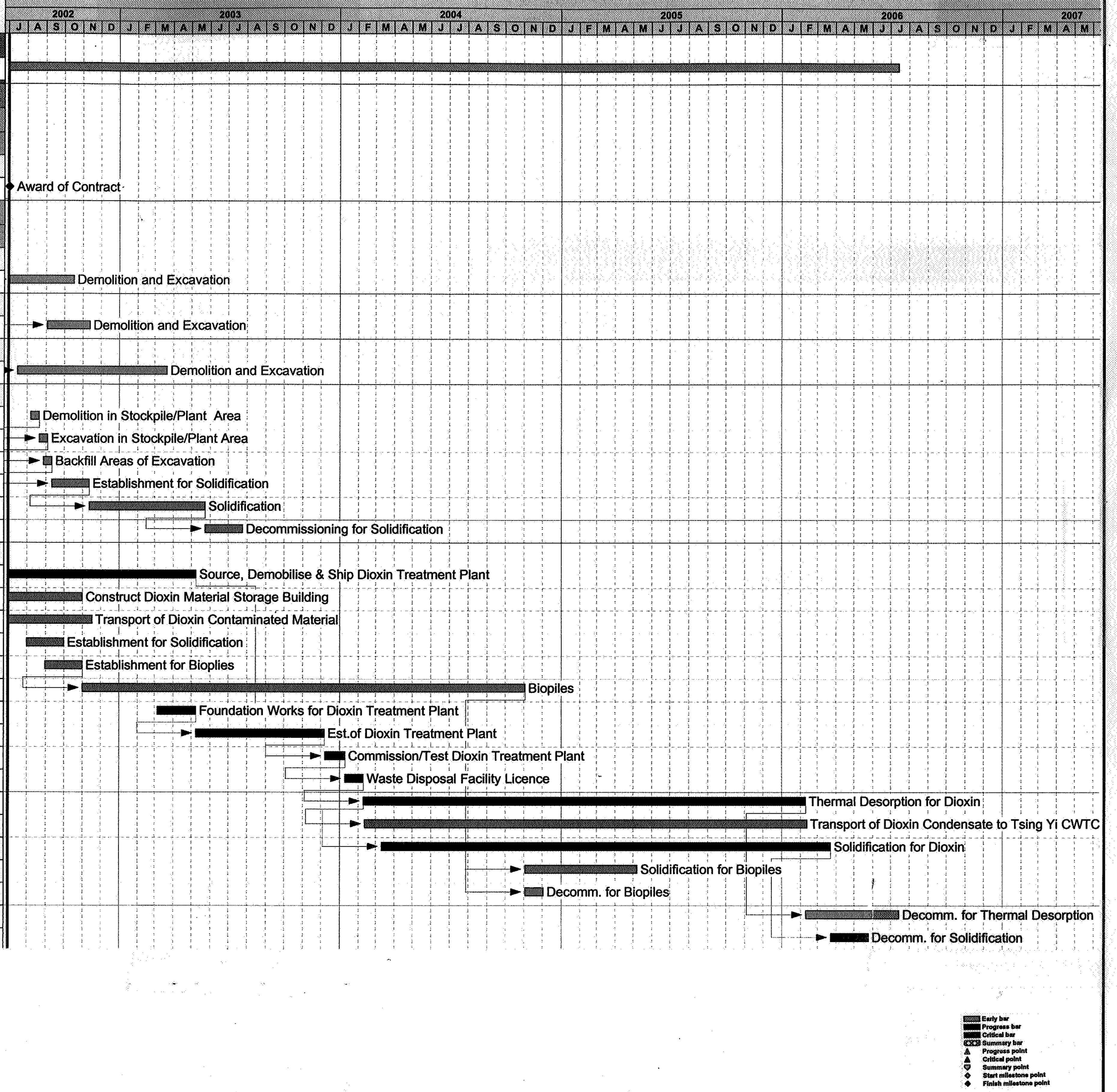
Activity ID	Description	Original Duration	Early Start	Early Finish
CED's Infrastructure for Penny's Bay Development				
		1237	02JUL02	14JUL06
Infrastructure for P.B. Dev. Contract 2				
Tender Phase				
Tender Gazette, Analysis, Award				
Area 1				
CB17T17350	Award of Contract	0	02JUL02 *	
Construction\Installation Phase				
Decontaminate & Decommission Cheoy Lee Shipyard				
Area 1				
CB17CN1160	Demolition and Excavation	90	03JUL02	16OCT02
Area 2				
CB17CN1320	Demolition and Excavation	60	03SEP02 *	12NOV02
Area 3				
CB17CN1380	Demolition and Excavation	210	16JUL02	21MAR03
On-Site Treatment				
CB17CN1681	Demolition in Stockpile/Plant Area	12	07AUG02 *	20AUG02
CB17CN1682	Excavation in Stockpile/Plant Area	12	21AUG02	03SEP02
CB17CN1695	Backfill Areas of Excavation	12	28AUG02	10SEP02
CB17CN1683	Establishment for Solidification	52	11SEP02	11NOV02
CB17CN1684	Solidification	160	12NOV02	23MAY03
CB17CN1685	Decommissioning for Solidification	52	24MAY03	24JUL03
To Kau Wan Treatment Site				
CB17CN1510	Source, Demobilise & Ship Dioxin Treatment Plant	260	02JUL02	08MAY03
CB17CN1720	Construct Dioxin Material Storage Building	104	02JUL02	31OCT02
CB17CN1760	Transport of Dioxin Contaminated Material	118	02JUL02	16NOV02
CB17CN1660	Establishment for Solidification	52	01AUG02 *	30SEP02
CB17CN1690	Establishment for Bioplies	52	31AUG02 *	31OCT02
CB17CN1700	Biopiles	612	01NOV02	02NOV04
CB17CN1550	Foundation Works for Dioxin Treatment Plant	52	06MAR03	08MAY03
CB17CN1620	Est.of Dioxin Treatment Plant	180	09MAY03	06DEC03
CB17CN1630	Commission/Test Dioxin Treatment Plant	26	08DEC03	09JAN04
CB17CN1730	Waste Disposal Facility Licence	26	10JAN04	09FEB04
CB17CN1640	Thermal Desorption for Dioxin	615	10FEB04	09FEB06
CB17CN1740	Transport of Dioxin Condensate to Tsing Yi CWTC	615	12FEB04	11FEB06
CB17CN1741	Solidification for Dioxin	624	11MAR04	22MAR06
CB17CN1670	Solidification for Biopiles	156	03NOV04	07MAY05
CB17CN1710	Decomm. for Biopiles	26	03NOV04	02DEC04
CB17CN1650	Decomm. for Thermal Desorption	130	10FEB06	14JUL06
CB17CN1680	Decomm. for Solidification	52	23MAR06	24MAY06



Title

Agreement No. CE 68/99 Infrastructure for Penny's Bay Development - Engineering Design and Construction
Decommissioning of Cheoy Lee Shipyard

PROGRAMME FOR DECONTAMINATION WORKS

Scale	N.T.S.
Projects No.	R06100
Date	Feb. 2002
Figure No.	4.17

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