3 METHODOLOGY

3 METHODOLOGY

3.1 Setting Out and Utility Survey

SVE test was conducted at the four locations (VT1, VT2, VT3 and VT4) within the Hot Spot B; and AS, helium and SVE/AS combined tests were conducted at VT3 and VT4 only. At each location, one SVE well and three to six pairs of nested soil vapour probes were installed for monitoring soil vacuum/ pressure. At VT3 and VT4, one AS well and eight groundwater monitoring wells were installed for monitoring water table level (see Figures 3.1 to 3.4).

For all proposed drilling locations, prior to any drilling works, the Contractor surveyed, set out, and identified each of the proposed locations to within 0.1m of the provisional co-ordinates. The Contractor then undertook a utility survey for each location prior to any drilling.

3.2 Boring Log and Soil Particle Size Analyses

Drilling at each locations for installation of SVE, AS and groundwater monitoring wells or soil vapour probes was carried out by means of a rotary method. The appearance of soil cuttings from different depth at each location was recorded on-site. Selected soil samples were then sent to an HOKLAS accredited laboratory for analysis of particle size.

The grain size distribution analyses are useful for comparison of the different well locations to each other. However, giver that the soil samples were collected from cuttings for an air rotary drill rig, this data should not be used to determined gas permeability in place of the results from in situ SVE testing.

The drilling and soil sampling exercises were undertaken with proper occupational health protection. The health, safety and environmental plan is given in Appendix D.

3.3 Installation of Testing Wells and Monitoring Wells

3.3.1 Soil Vapour Extraction Wells

At each of VT1 to VT4, one SVE well was installed to the depth immediately above the prevailing groundwater table. The wells were constructed in accordance with the specifications of Figure 3.5.

3.3.2 Soil Vapour Monitoring Wells

At VT1 and VT2, three pairs of soil vapour monitoring wells (Figure 3.6), each comprising one shallow and one deep soil vapour probe, were installed at distances of 5m, 10m and 20m respectively from the SVE well.

At VT3 and VT4, four pairs of such wells were installed at distances of 1m, 5m, 10m and 20m respectively from the SVE well. At 5m from the SVE well two additional pairs of vapour monitoring wells were installed at 120° from one another around the SVE well.

For each pair of soil vapour monitoring wells:

1) wells were installed within the same drill hole
2) one well was constructed such that the screen is located 0.5 m *above* the prevailing water level
3) one well was constructed such that the screen is located 0.3 m *below* the lowest extent of the apron concrete

One calibrated air pressure gauge was attached (with an airtight connection) to each soil vapour probe.

All probes have been installed as per the specifications in the pilot test proposal. However, it should be noted that prior to the commencement of the re-runs of long-term SVE tests at VT2 and VT3, the three deep probes at VT2 and two deep probes at VT3 were gently pulled 80 mm up above the water table. It was because due to tidal variation and groundwater mounding during the previous or AS test, these probes had ever been suspected by the Contractor to be plugged by groundwater.

An 80mm pull-up of deep probes should not have caused significant disturbance to the well packing because the probes were made of stainless steel and were sturdy. We confirm the limited pulling would not form air leakage because of the property of the bentonite plugs. The surface seals were repaired by the Contractor by re-applying cement grout, short-circuiting of air flow was not possible. The modified well construction (with deep probe pulled up) is also shown in Figure 3.6.

3.3.3 Air Sparging Wells

At VT3 and VT4, one AS well was installed such that the top of the screen is located at a depth 3 m below the prevailing water table. The wells were installed in accordance with the specifications of Figure 3.7. The internal diameter of the well and the well screen are 50mm.

3.3.4 Groundwater Monitoring Wells

At VT3 and VT4, two pairs of groundwater monitoring wells were installed at distances of 2.5m and 5m respectively from the AS well. One additional pair of groundwater monitoring wells was installed at 2.5m from the SVE well along *two* other radial directions (at 120° from one another) around the AS well.

A schematic diagram of the groundwater monitoring wells is shown on Figure 3.8. For *each* pair:

1) wells were installed 0.5m apart from each other

2) one monitoring well was constructed such that the top of the well screen is located 0.5m below the prevailing water table
3) one monitoring well was constructed such that the top of the screen is located 2.5m below the prevailing water table

The installation of all test wells and monitoring wells was also logged.

3.3.5 Comparison to Actual Design Well Layout

The well layout followed the recommendation of the American Petroleum Institute (API)'s document[7] (i.e. SVE well and AS well) and took account of the previous field permeability data. However, due to the scale of the pilot test, the well layout of the pilot test differed from that of the full-scale design in the following aspects:

1) no air intake wells in the pilot test
2) the full-scale system has SVE and AS wells with little separation
3) no cluster of wells in the pilot test

3.4 Assembly of SVE and AS System

3.4.1 Soil Vapour Extraction System

The SVE system was purpose-designed for soil venting of hydrocarbon contaminated sites. The system consisted of a blower capable of generating at least 65 inches water column (1.619×10^4 Pa) vacuum. Other components of the system included a moisture separator, vacuum relief valve, activated carbon adsorption unit and other gauges. Figure 3.9 depicts the schematic configuration of the above ground components of the SVE system.

As the system has built-in carbon adsorption facilities, any volatile organic carbons could be removed from air stream prior to venting to the atmosphere.

3.4.2 Air Sparging System

The AS system consisted of a low-pressure air compressor, accumulation tank, pressure regulator, flow meter, check valves, gauges and a sub-system for helium supply. The pressure applied to the subsurface was maintained below 12 psi (8.274×10^4 Pa) to prevent fracturing of the formation. All piping connections were airtight. The schematic configuration of the above ground components of the AS system is shown on Figure 3.10.

[7] Marley, M. C. and Bruell, C. J. (1995) *In Situ Air Sparging: Evaluation of Petroleum Industry Sites and Considerations for Applicability, Design and Operation.* American Petroleum Institute, Washington.

3.5 Pilot Testing

3.5.1 Short-term Soil Vapour Extraction Tests

Tests were undertaken (at VT1 to VT4) at different levels of flow rate/vacuum. The flow rate was varied according to the level of vacuum applied to each well, the air permeability of the soil in the vicinity of each testing location, and the capacity of the test apparatus. The measuring parameters, locations and frequency are tabulated in Table 3.1.

Total VOCs were measured with a calibrated photo-ionisation detector (MultiRAE™ PGM-50-5PD Gas Monitor). CO_2, O_2 and CH_4 were measured with a calibrated landfill gas meter (LFG-20™ Landfill Gas Monitor). Water table elevation at the SVE well was measured with a water level meter (SISGEO™ Water Level Meter C113). Water table at groundwater monitoring wells was measured with an ultrasonic water level meter (HONDA™ Ultrasonic Airborne Level Meter HD700-A) installed on each well. Free product was measured with an interface probe. All test parameters were measured prior to commencement of the pilot test to obtain baseline reference.

Each test was undertaken until the vacuum at all vapour monitoring wells had become steady for three consecutive measurements.

It should be noted that due to actual site conditions, the flow rate of some tests were different from that proposed in the scope (refer to Appendix B).

3.5.2 Long-term Soil Vapour Extraction Tests

Tests were undertaken (at VT1 to VT4) continuously for 72 hours at a predetermined flow rate/vacuum level based on the results of the short term SVE tests. The measuring parameters, locations and frequency are tabulated in Table 3.1. The measurement methods were identical to those of short-term tests. All test parameters were measured prior to commencement of the pilot test to obtain baseline reference.

It should be noted that as some doubtful measurements of the tests conducted at VT1-4 had been identified during the data review stage. This is because the gas concentrations in the blower inlet were considerably different from the vapour probes. It was considered that some atmospheric air might have diffused into the probes during the gas sampling exercise. This was corrected by using an airtight apparatus. The contractor was instructed to conduct re-tests of long term SVE at the four locations.

3.5.3 Short-term Air Sparging Tests

As recorded in the data sheets, about two weeks and one month had elapsed after the completion of SVE testing and before the commencement of AS testing conducted at VT3 and VT4 respectively. Furthermore, several consecutive readings were taken prior to the start of the AS tests to ensure that sufficient lapse time was provided for the wells to recover and attain steady state between the SVE testing and AS testing.

Tests were undertaken at VT3 and VT4 at different levels of flow rates, namely 10 cfm (16.8 m^3h^{-1}), 4 cfm (6.72 m^3h^{-1}), and 2 cfm (3.36 m^3h^{-1}). The flow rate was varied according to the maximum achievable flow of the SVE system, which, in turn was dependent on the air permeability of the soil in the vicinity of the testing location. The injecting pressure at the AS well was kept below 12 psi (8.274×10^4 Pa) to avoid soil fracturing.

The measuring locations, parameters and frequency are tabulated in Table 3.1. Dissolved oxygen (DO) was measured with a calibrated DO meter (YSI52 Dissolved Oxygen Meter). The other measurement methods were identical to those of short-term SVE tests. All test parameters were measured prior to commencement of the pilot test to obtain a baseline reference.

Each test was undertaken until the static pressure at all monitoring wells had become steady for three consecutive measurements.

It should be noted that due to the actual site conditions, the duration of the tests were different from the originally predicted duration and ranged from 30 minutes to 3.5 hours.

3.5.4 Tracer (Helium) Tests

Tracer (helium) tests were conducted at VT3 and VT4 to provide additional evidence on the ROI of the AS wells, and to provide a tracer to help evaluate the radius of influence of the AS wells and the potential presence of preferential air migration pathways. The tests were conducted at two different air flow rates. Air with approximately 10 to 20 % helium (v/v) was injected into the AS well. The tests were initiated after an AS test had been operated and stabilised at an operating flow rate. Helium gas was injected as a "slug" for 15 to 30 minutes and its concentration at each soil vapour monitoring wells was measured.

The measuring parameter, locations and frequency are tabulated in Table 3.1. Helium was measured with a calibrated helium detector (Mark™ 9821 Helium Detector). Helium was measured prior to commencement of the pilot test to obtain baseline reference.

It should be noted that due to actual site conditions, both the injected helium concentration and the duration of injection had been modified.

3.5.5 Long-term Combined Soil Vapour Extraction/ Air Sparging Tests

Long-term combined SVE/AS tests were undertaken at VT3 and VT4 at a flow rate/ vacuum level based on results of the SVE and short term AS tests for 120 hours. The flow rate at the SVE system was about twice that of the AS system so as to control contaminant migration induced by the air sparging.

At VT4, it was attempted to start the long-term SVE test with a flow rate close to the design flow rate. Because of the high permeability at VT4, the lowest achievable steady flow rate was 80 cfm (134.4 m^3h^{-1}) at the start of the test. As the test progressed, the flow rate was

modified in an attempt to best evaluate the effectiveness of SVE at the site. At VT4, the soils are very permeable and thus the flow rate was adjusted as necessary to aerate the subsurface without extracting an excessive amount of air. Excessive air would create burden on the activated carbon unit. It is important during pilot testing to adjust the flows as necessary to attain a good evaluation to the technology.

It should be noted that the mass of total VOC extracted is calculated by integration of the product of concentration and flow rate at different intervals, so the adjustment of flow rate would not impact the overall conclusion.

The measuring locations, parameters and frequency are tabulated in Table 3.1. The measurement methods were identical to those of long-term SVE and short-term AS tests. All test parameters were measured prior to commencement of the pilot test to obtain baseline reference.

Although not included in the scope of the pilot test, cross-checking of measurements was undertaken by MEMCL staff. The purpose was to assess the variability of the VOC measurements taken by the Contractor.

All site works were undertaken in accordance with the health, safety and environmental plan provided in Appendix D.

Table 3.1 Measuring Parameters, Locations and Frequency for Pilot Tests

		SVE Test Short-term	SVE Test Long-term	AS Test Short-term	Combined SVE/AS Test Long-term
Test Location		VT1, VT2, VT3, VT4	VT1, *VT2, VT3,* VT4	VT3 & VT4	VT3 & VT4
Test Hours		< 3 hr	72 hr	*< 4 hr*	120 hr
Flow Rate (cfm ; m^3h^{-1})		This varied substantially from well to well	Based on results of short-term tests	10, 4 & 2 cfm (16.8, 6.72 & 3.36 m^3h^{-1}) (system pressure < 12 psi (8.274×10^4 Pa))	Based on results of short-term tests
Measuring Parameters & Locations	Vac./Pres.	SVE well, all shallow and deep probes	SVE system, all shallow and deep probes	SVE system, all shallow and deep probes	SVE and AS system, all shallow and deep probes
	Flow Rate	SVE system	SVE system	AS system	SVE and AS system
	VOC	Inlet and outlet of carbon filter, all shallow and deep probes	Inlet and outlet of carbon filter, all shallow and deep probes	All shallow and deep probes	Inlet and outlet of carbon filter, all shallow and deep probes
	$CO_2 + O_2$	Inlet and outlet of carbon filter, all shallow and deep probes	All shallow and deep probes	All shallow and deep probes	All shallow and deep probes
	CH_4	Inlet and outlet of carbon filter, all shallow and deep probes	Inlet and outlet of carbon filter, all shallow and deep probes	All shallow and deep probes	Inlet and outlet of carbon filter, all shallow and deep probes
	Depth to Water Table	SVE well and GW wells (for VT3 only)	SVE well and GW wells (for VT3 and VT4)	GW Wells	SVE Well and GW Wells
	Free Product	SVE well	SVE well	GW Wells	SVE Well and GW Wells
	DO	---	---	GW Wells	GW Wells
Measuring Frequency	Vac./Pres.	Every 30 sec for the first 5 min, every minute for minutes 5 to 10, every 2 min for minutes 10 to 20	Every 1 hr for the first 4 hr, and every 4 hr for the rest	Every 5 min for the first hr, and every 15 min for the rest	Every 1 hr for the first 4 hr, every 4 hr for the next 12 hr, and every 8 hr for the rest
	Flow Rate	Every 15 min	Every 1 hr for the first 4 hr, and every 4 hr for the rest	Every 15 min	Every 1 hr for the first 4 hr, every 4 hr for the next 12 hr, and every 8 hr for the rest
	VOC	Before and after the test	Before, then every 1 hr for the first 4 hr, every 4 hr for the rest, and after the test	Before, then every 30 min, and after the test	Before, then every 1 hr for the first 4 hr, every 4 hr for the next 12 hr, every 8 hr for the rest; and after the test

Table 3.1 Measuring Parameters, Locations, and Frequency for Pilot Tests (cont'd)

		SVE Test Short-term	SVE Test Long-term	AS Test Short-term	Combined SVE/AS Test Long-term
Measuring Frequency	$CO_2 + O_2$	Before and after the test, and during lapse time as frequent as possible	Before, then every 1 hr for the first 4 hr, every 4 hr for the rest, and after the test; and during the lapse time as frequent as possible	Before, then every 30 min and after the test; and during the lapse time as frequent as possible	Before, then every 1 hr for the first 4 hr, every 4 hr for the next 12 hr, every 8 hr for the rest, and after the test; and during the lapse time as frequent as possible
	CH_4	Before and after the test	Before, then every 1 hr for the first 4 hr, every 4 hr for the rest, and after the test	Before, then every 30 min, and after the test	Before, then every 1 hr for the first 4 hr, every 4 hr for the next 12 hr, every 8 hr for the rest, and after the test
	Depth to Water Table	Every 5 min	Before, then every 4 hr, and after the test	Before, then every 30 min, and after the test	Every 1 hr for the first 4- hr, every 4 hr for the next 12 hour, and every 8 hr for the rest
	Free Product	Before and after the test	Before and after the test	Before and after the test	Before and after the test
	DO	---	---	Before, then every 30 min and after the test	Before, then every 4 hr, and after the test
Tracer (Helium) Test	Conditions	---	---	*8-25% He injection for 15 to 45 min at AS well*	---
	Measuring Point	---	---	AS system and all shallow and deep probes	---
	Measuring Frequency	---	---	Before test, then every 10 to 15 min after He injection	---
Observation of Bubbling		---	---	Observe bubbling at GW wells	Observe bubbling at GW wells

Remarks

a Parameters that were adjusted according to specific site conditions are different from that proposed in the scope are italicised

b All parameters were measured prior to commencement of test

c VOC was measured with a calibrated photo-ionisation detector (PID)

d CO_2, O_2 and CH_4 were measured with a calibrated landfill gas meter

e Water table at SVE wells and groundwater monitoring wells were measured with a calibrated water level meter and an ultrasonic airborne level respectively
f Free product was measured with a calibrated interface probe
g DO was measured with a calibrated DO meter

3.5.6 Equipment Employed

Lists of equipment employed and their specifications are provided in Appendix E. Moreover, the records of calibration of measuring equipment are provided in Appendix F.

3.6 Computer Modelling for Soil Permeability

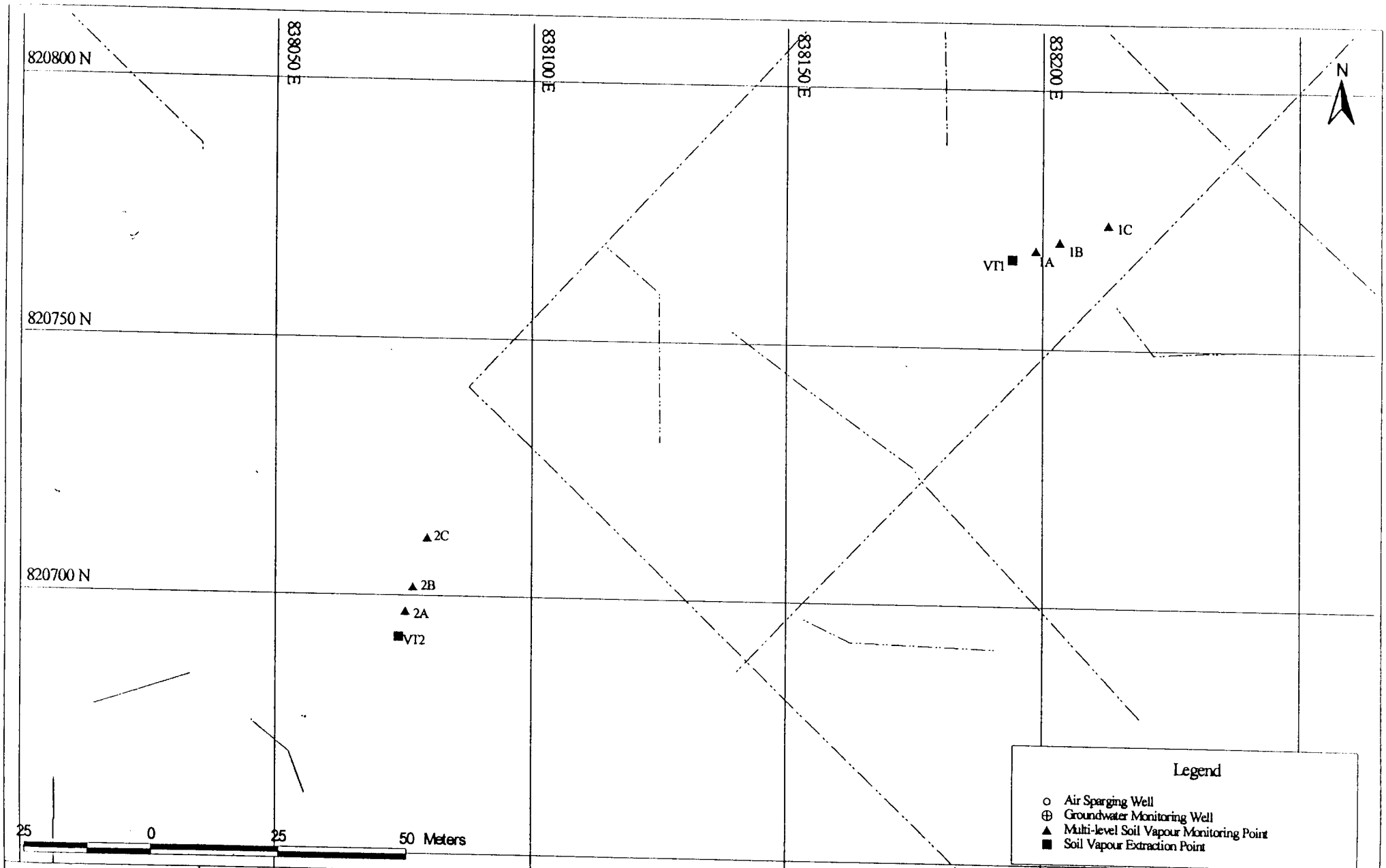
A screening computer model called HyperVentilate[8] was used to obtain additional information about the permeability of soil. HyperVentilate software is associated with a Federal Technology Transfer Act Co-operative Research and Development Agreement between U.S. Environmental Protection Agency and Shell Oil Company. *HyperVentilate is designed for SVE system design and is recommended in the U.S. EPA Manual entitled "Bioventing Principles and Practice, Volume II: Bioventing Design" (1995) (See Appendix G).* HyperVentilate guides the user through a structured decision-making process with illustrations and discussions of the various stages of the program. *It has been widely applied in assessing permeability in international airport sites.*

The permeability of soil in the vicinity of the four testing locations was calculated using the permeability test of the model. The input parameters for this test include:

1) radial distances of monitoring points from SVE well
2) measured times and gauge vacuums
3) SVE system flow rate
4) screened interval thickness

For (a) to (c), the field data of the short-term SVE tests conducted at the four testing locations were utilised as the input data. The screen thickness of the SVE wells was input as 6.6ft (3m). The output of the test was (intrinsic) permeability of soil in the unit of darcy (refer to Figure 1.6).

[8] U.S. Environmental Protection Agency (1993) *Decision Support Software for Soil Vapour Extraction Technology Applications: HyperVentilate.* EPA/600/R-93/028. Office of Research and Development.



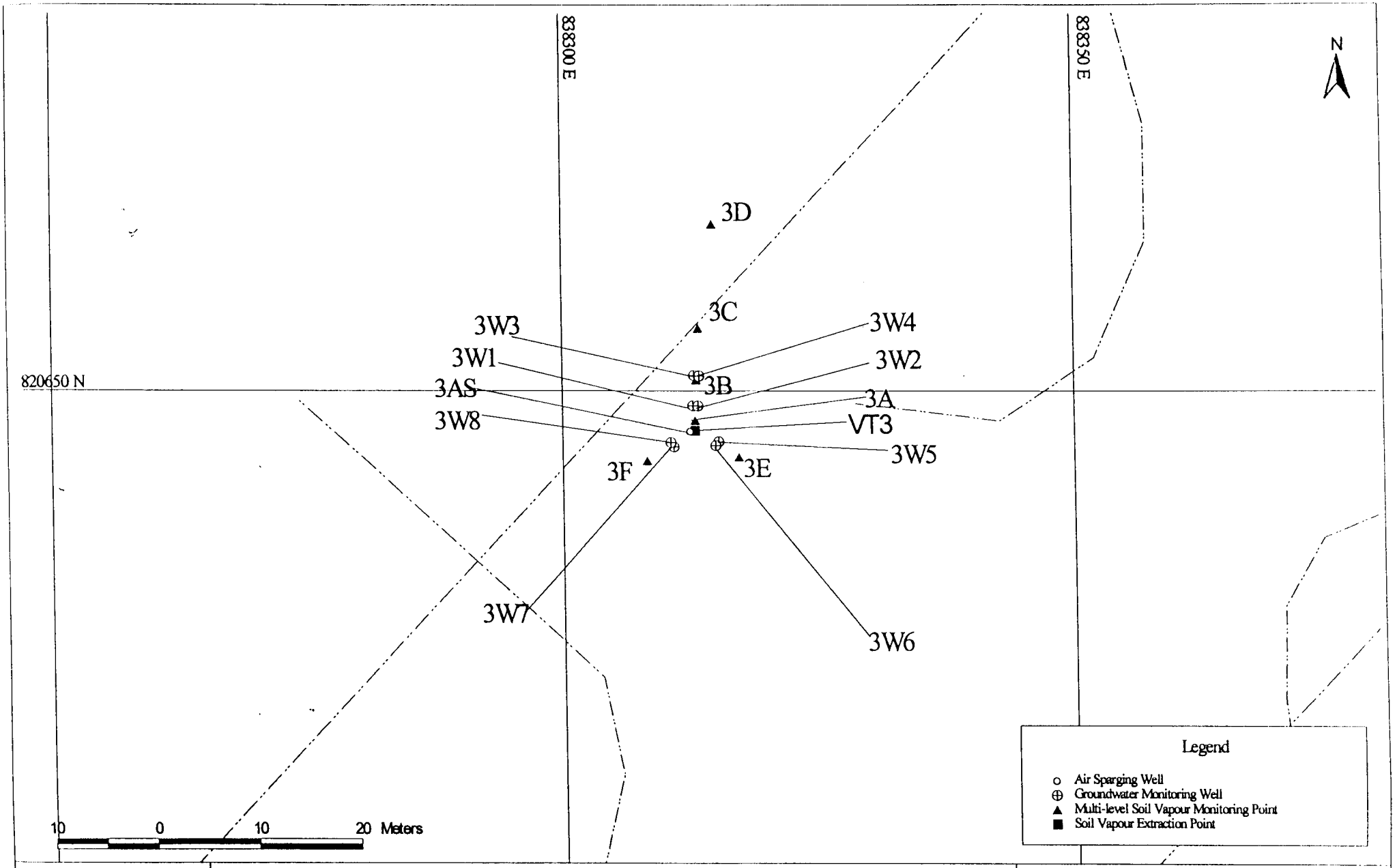
Maunsell

TITLE

Layout of SVE Wells and Monitoring Points at VT1 and VT2

MAUNSELL ENVIRONMENTAL MANAGEMENT CONSULTANTS LTD

PROJECT NO.	C418	DATE	Dec. 1998
DESIGNED/ CHECKED	Eric Lai	DRAWING NO.	Figure 3.1



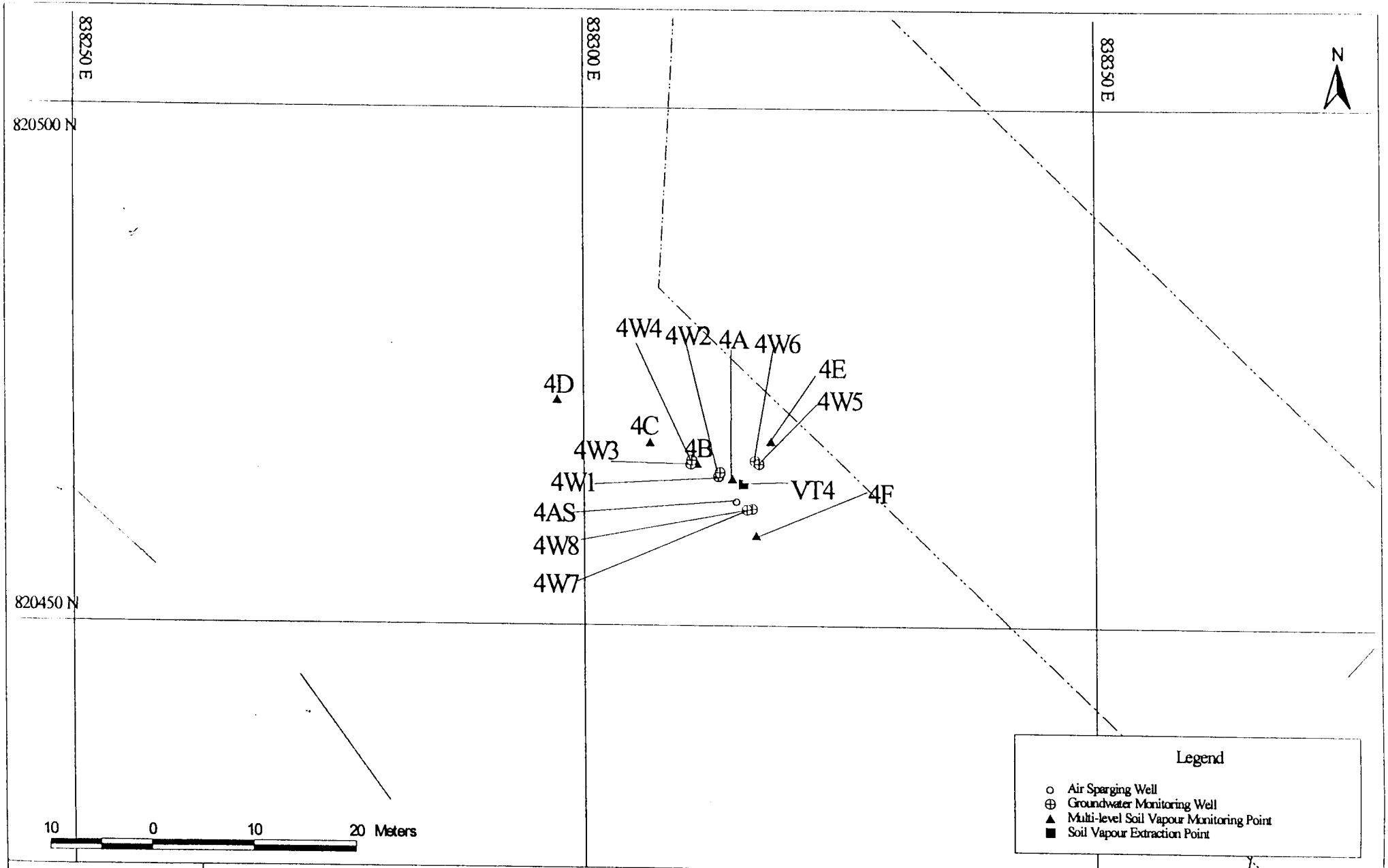
Maunsell

TITLE

Layout of SVE Wells and Monitoring Points at VT3

MAUNSELL ENVIRONMENTAL MANAGEMENT CONSULTANTS LTD

PROJECT NO.	C418	DATE	Dec. 1998
DESIGNED/ CHECKED	Eric Lai	DRAWING NO.	Figure 3.2



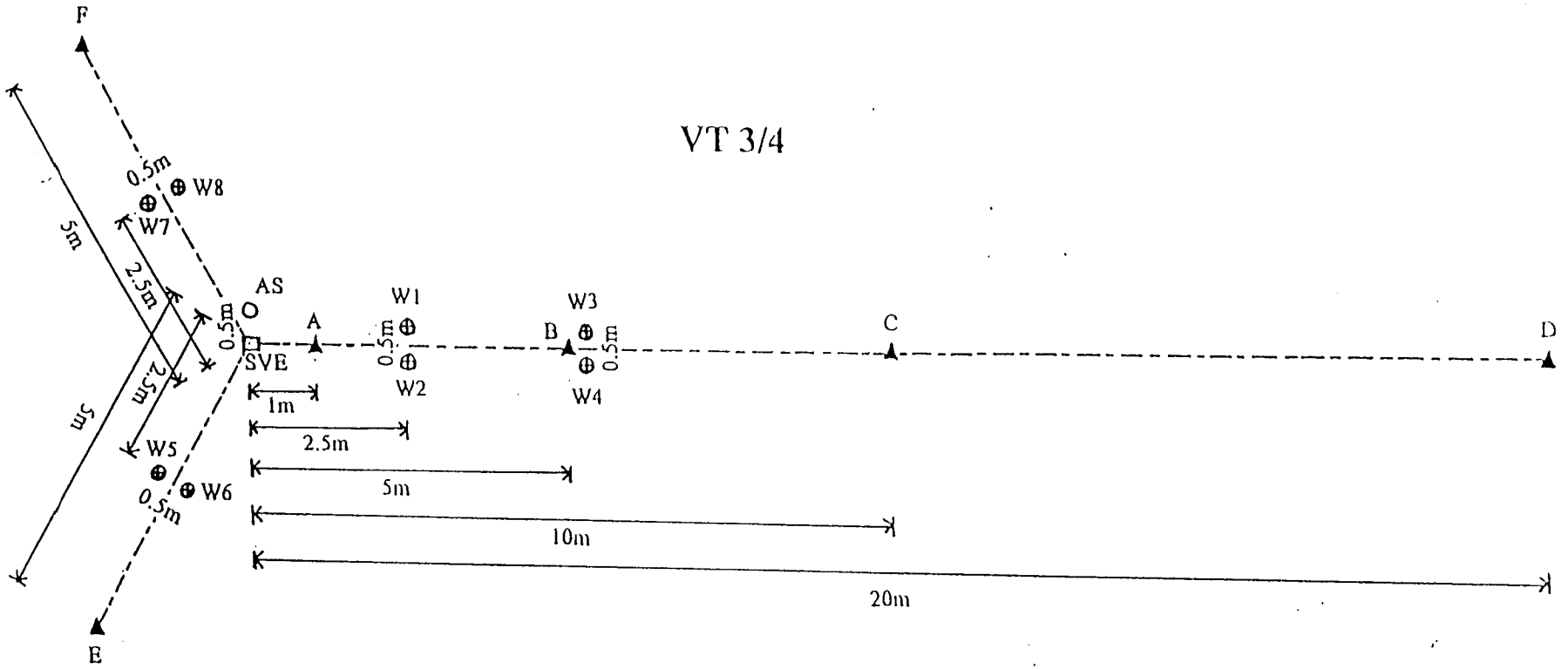
Maunsell

TITLE

Layout of SVE Wells and Monitoring Points at VT4

MAUNSELL ENVIRONMENTAL MANAGEMENT CONSULTANTS LTD

PROJECT NO.	C418	DATE	Dec. 1998
DESIGNED/CHECKED	Eric Lai	DRAWING NO.	Figure 3.3



Legend:

- Soil Venting Extraction Well
- Air Sparging Well
- Nested Soil Vapour Probes
- Groundwater Monitoring Well

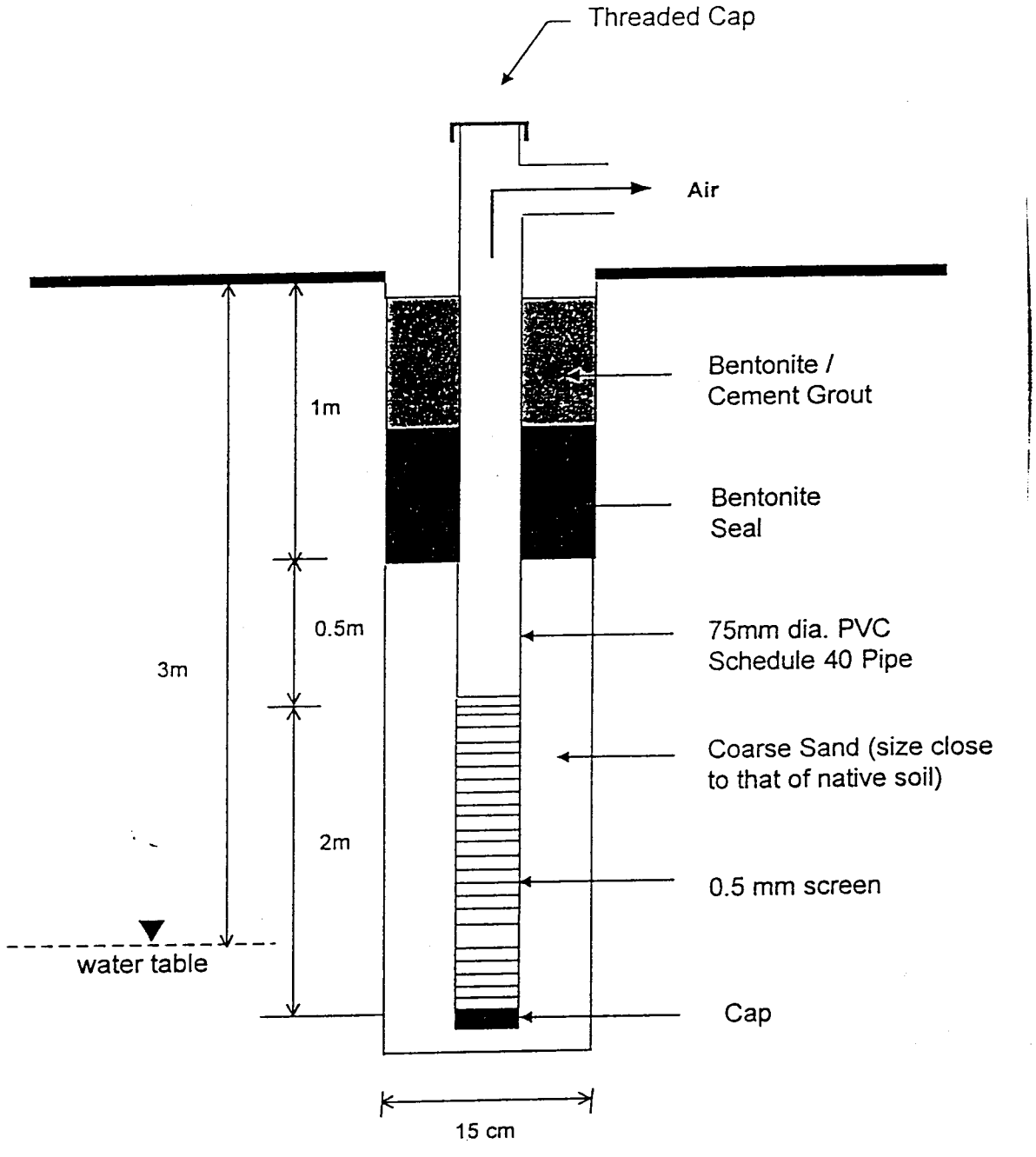
Maunsell

TITLE

Detailed Arrangement of SVE Wells, AS Wells and Monitoring Points at VT3 and VT4

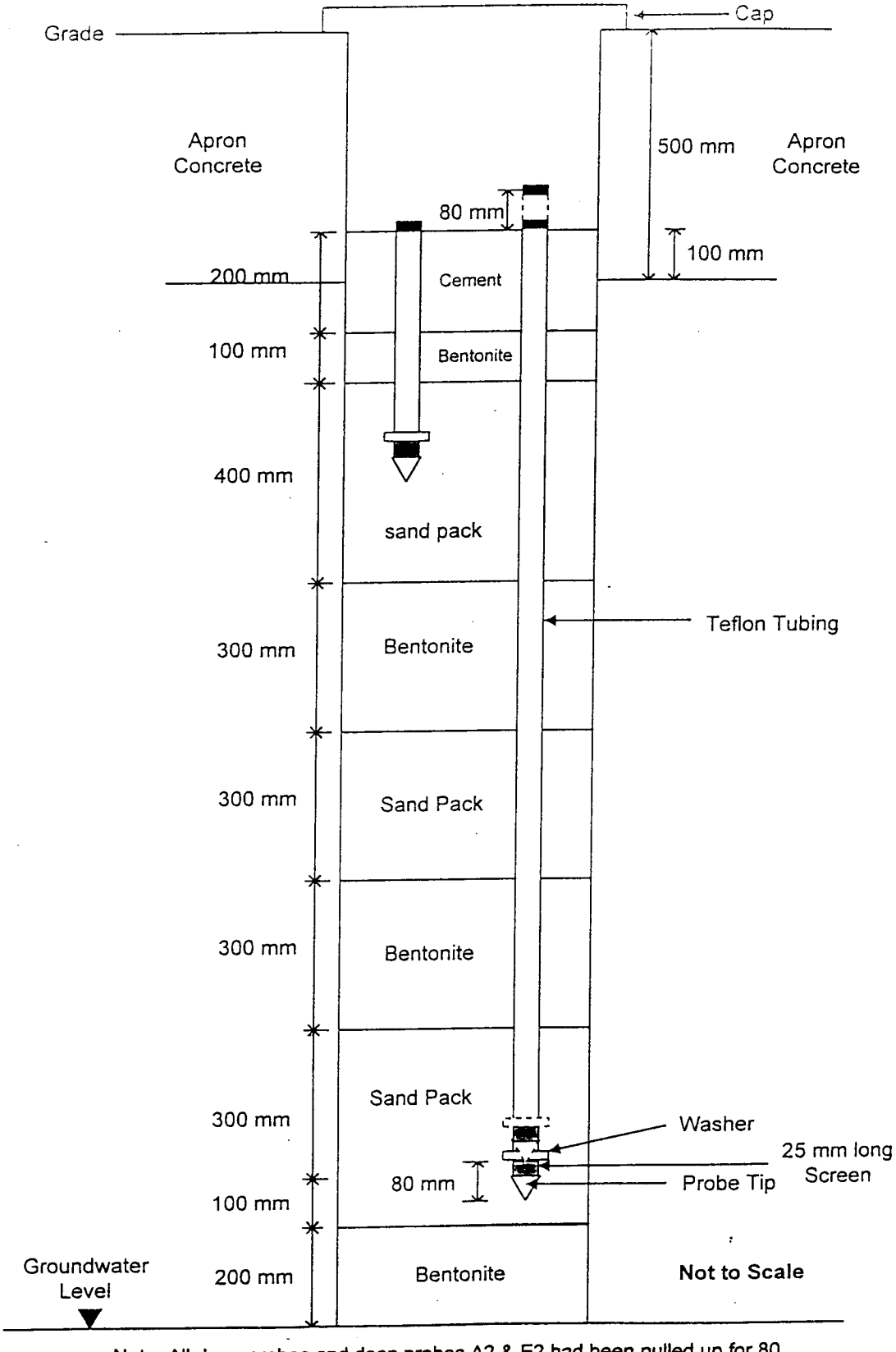
MAUNSELL ENVIRONMENTAL MANAGEMENT CONSULTANTS LTD

PROJECT NO	C418	FIGURE NO.	Figure 3.4
DESIGNED/ CHECKED	Eric Lai	DATE	Dec 1998



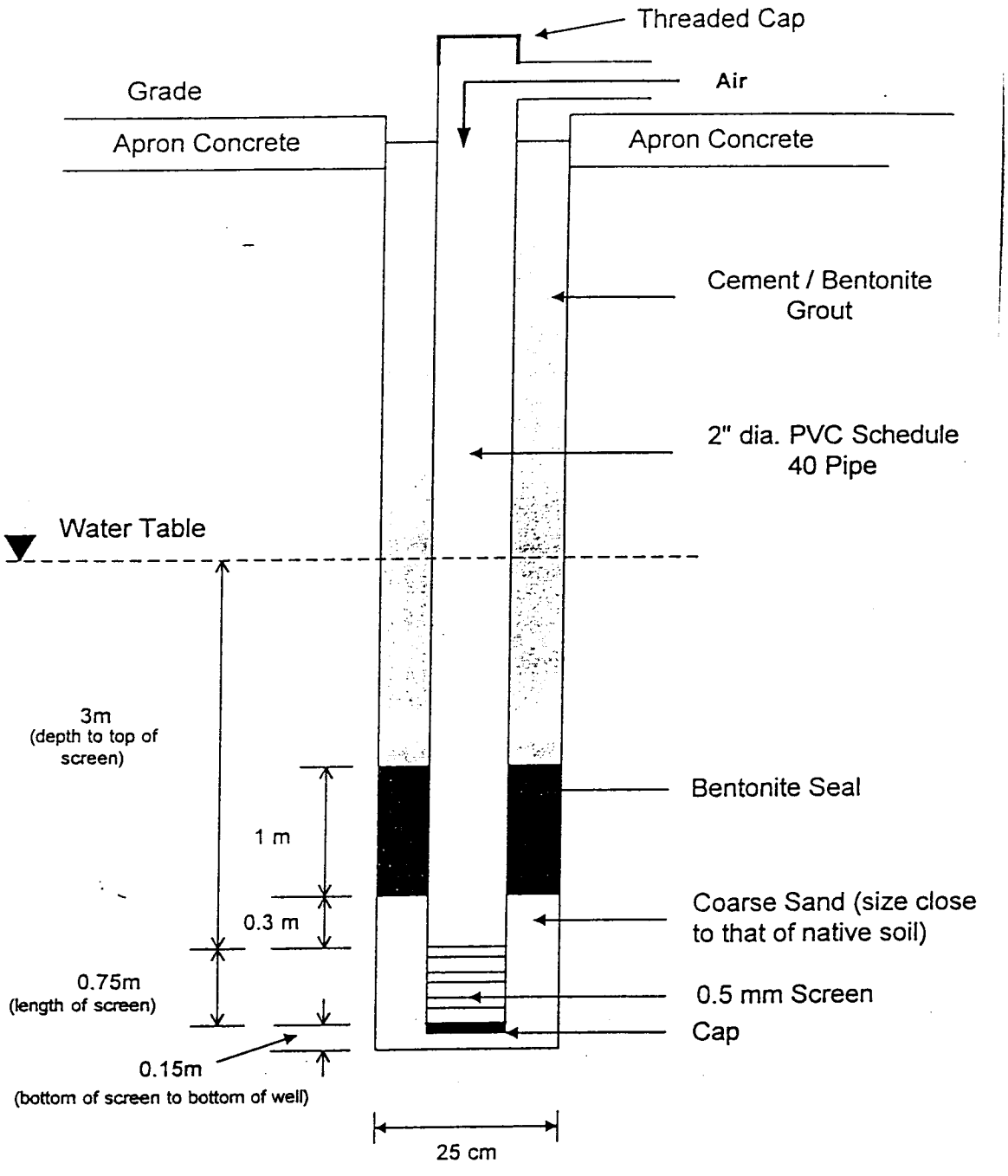
Pilot Test: Soil Vapour Extraction Well

Maunsell	TITLE: Schematic Diagram of Soil Vapour Extraction Well	MAUNSELL ENVIRONMENTAL MANAGEMENT CONSULTANTS LTD			
		PROJECT NO	C418	FIGURE NO.	Figure 3.5
		DESIGNED/ CHECKED	Eric Lai	DATE	Dec 1998



Note: All deep probes and deep probes A2 & E2 had been pulled up for 80 mm before commencement of Long-term SVE tests (re-test) at VT2 and VT3 respectively. The surface seals were then repaired immediately.

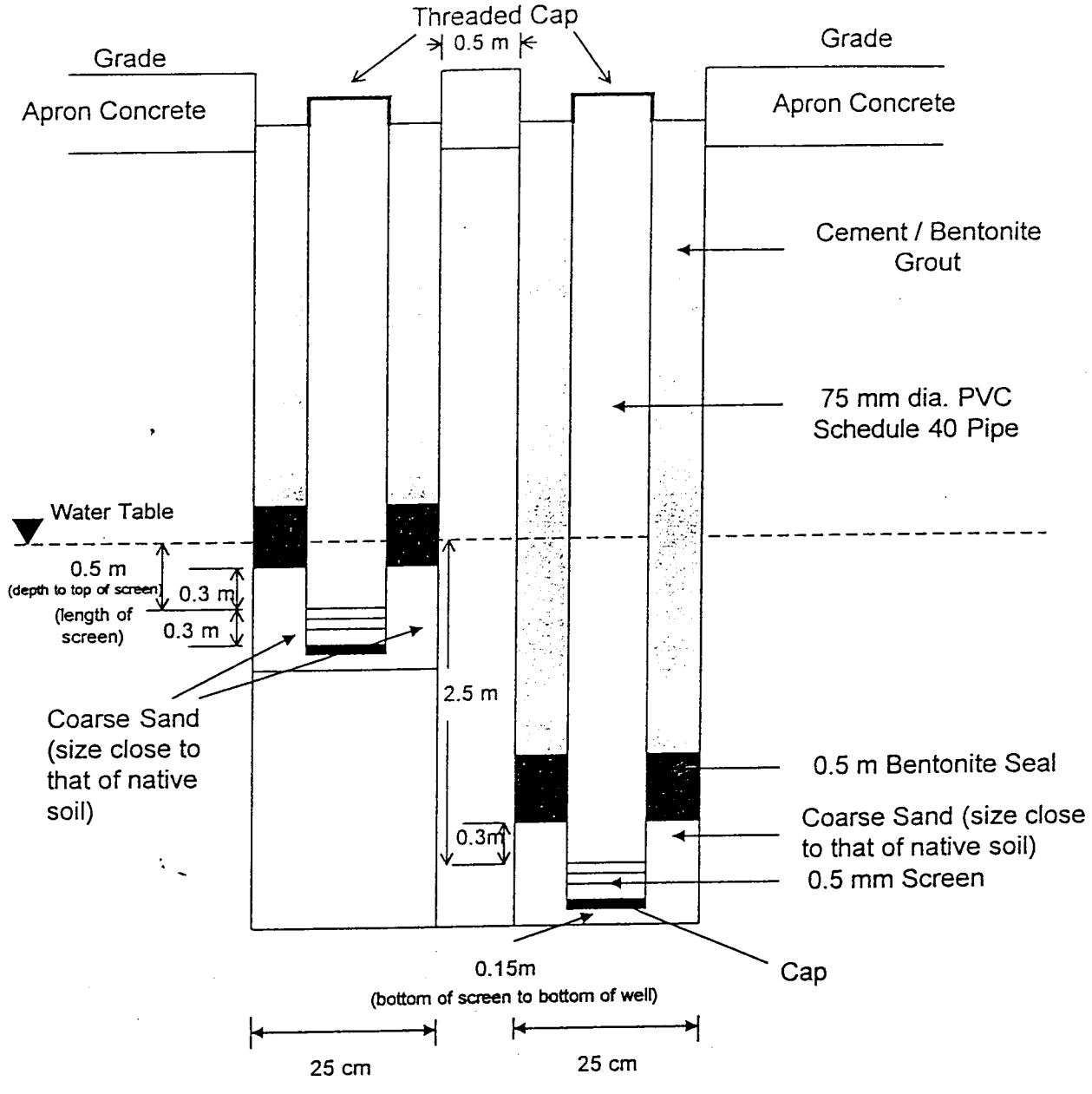
Maunsell	TITLE: Schematic Diagram of Soil Vapour Monitoring Well	MAUNSELL ENVIRONMENTAL MANAGEMENT CONSULTANTS LTD			
		PROJECT NO	C418	FIGURE NO.	Figure 3.6
		DESIGNED/ CHECKED	EL	DATE	Jan 1999



Not to Scale

Pilot Test: Air Sparging Well

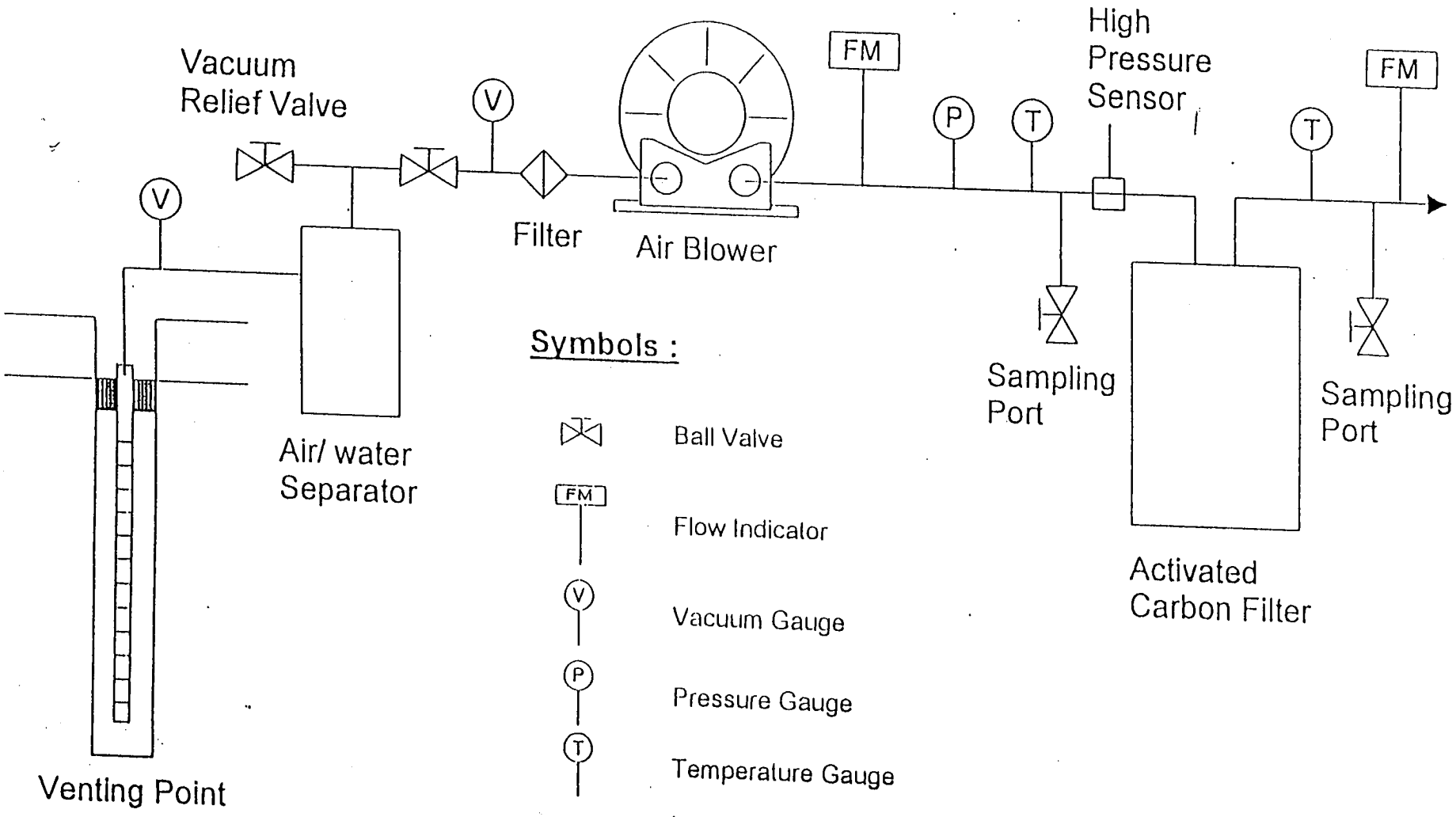
Maunsell	TITLE: Schematic Diagram of Air Sparging Well	MAUNSELL ENVIRONMENTAL MANAGEMENT CONSULTANTS LTD		
		PROJECT NO	C418	FIGURE NO. Figure 3.7
		DESIGNED/ CHECKED	Eric Lai	DATE Dec 1998



Not to Scale

Pilot Test: Groundwater Monitoring Well

Maunsell	TITLE: Schematic Diagram of Groundwater Monitoring Well	MAUNSELL ENVIRONMENTAL MANAGEMENT CONSULTANTS LTD		
		PROJECT NO: C418	FIGURE NO.: Figure 3.8	
		DESIGNED/ CHECKED: Eric Lai	DATE: Dec 1998	



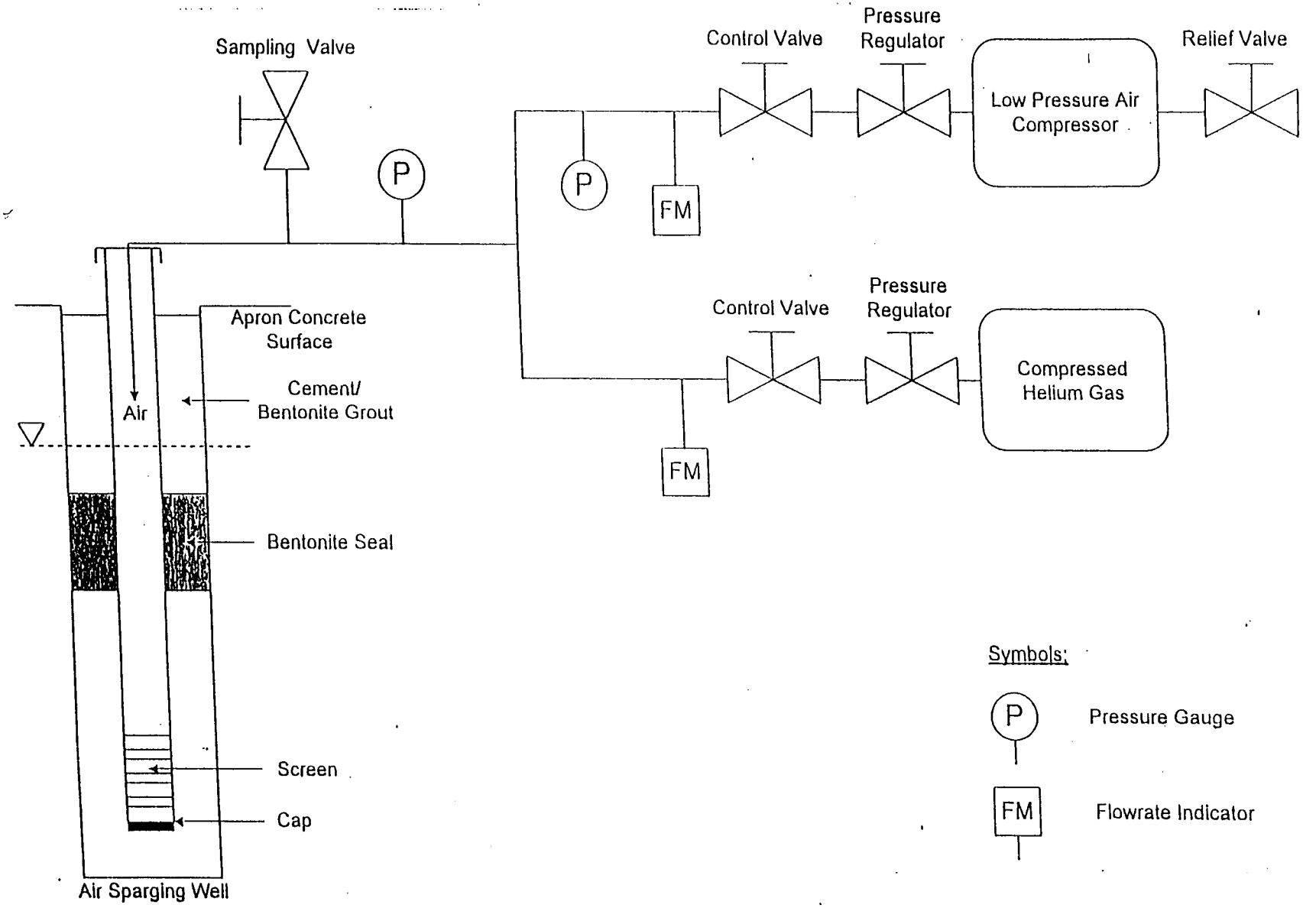
Maunsell

TITLE

Schematic Configuration of Soil Vapour Extraction System

MAUNSELL ENVIRONMENTAL MANAGEMENT CONSULTANTS LTD

PROJECT NO	C418	FIGURE NO.	Figure 3.9
DESIGNED/ CHECKED		DATE	Dec 1998



Maunsell

TITLE

Schematic Configuration of Air Sparging System

MAUNSELL ENVIRONMENTAL MANAGEMENT CONSULTANTS LTD			
PROJECT NO	C418	FIGURE NO	Figure 3.10
DESIGNED/ CHECKED	Eric Lai	DATE	Dec 1998