SOIL VAPOR EXTRACTION TEST AND REMEDIATION EVALUATION REPORT

Service Station
123 Someplace Avenue
Hot Dang, Nevada

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For:

Environmental Services
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Hot Dang, Nevada

By:

AQUI-VER, INC.
Quantitative Environmental Hydrogeology

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PREAMBLE

This report provides soil vapor extraction (SVE) test results and remediation evaluation findings for the Service Station at 123 Someplace Avenue, Hot Dang, Nevada (Figure 1). On July 28, 1995, **AQUI-VER, INC.** (AVI) provided assistance to Bill's Environmental (BE) to refine SVE data collected at the site. Those data collected by BE are presented herein and are the basis, with existing site geologic and chemical data, for SVE remediation evaluations. This report exceeds AVI's Standard Level II effort for the following reasons. First, the site data and remediation calculations presented herein will aid AVI in defining SVE diffusion limitations in an arid desert environment, providing mutually beneficial information for future reference. Second, AVI aided BE in conducting a scheduled SVE test rather than conducting one separately. This resulted in a reduction in AVI's Level II field labor effort, the residual of which has been dedicated to more advanced SVE simulations to better evaluate the method at this site.

1.0 GENERAL PROTOCOLS AND EQUIPMENT

On July 28, 1995, BE conducted four SVE step pumping tests and one longer term constant rate SVE pump test. The step tests were conducted at three different depth intervals screened by well OW-1A/B/C and across the single well screen in slant well OW-2 (Figure 2; and Appendix A, Boring and Well Construction Logs [BE, 1995]). The constant rate SVE test used OW-2 as the pumping well, with transient vacuum propagation data collected at the three depth intervals crossed by OW-1 A/B/C. Vapor samples were collected by BE using a separate sample pump and Tedlar^{TM} gas bags.

SVE was performed using a Rotron^{TM} DR-4 regenerative blower with a capacity of 100 standard cubic feet per minute (scfm) and a maximum vacuum of 75 inches of water column (iw). The blower was powered using a trailer-mounted diesel generator. The SVE flow rate was maintained at the desired rate for each test using recirculation and atmospheric bleed valves. This allows precise flow control out of the SVE well without excessive strain on the blower. Flow rates for each pumping step or test were measured using a Dwyer flow anemometer inserted into the SVE influent stream off the wellhead and before dilution by control valves.

Vacuum data at the SVE pumping and observation wells were collected using Magnehelic^{TM} pressure gauges of the appropriate range. Before tests were initiated, background soil vacuum conditions were monitored so that the absolute change induced by SVE could be determined. Significant barometric imprints were not evident in the SVE response data and no corrections were necessary.

2.0 SOIL VAPOR EXTRACTION FLOW CAPACITY TESTS

SVE step pumping tests were conducted to determine the relationship between flow rate and applied vacuum. Pumping steps were approximately 10 minutes each, starting at low applied vacuum and increasing sequentially to the maximum system capability at a given wellhead. Four pumping steps were executed on OW-1A and OW-1C, two steps on OW-1B, and five steps on OW-2 (Figures 3 through 6). The vacuum versus flow rate data display an approximately linear relationship, as theoretically expected (Johnson et al., 1990). However, well efficiency losses at the higher vacuums skew the trend line slightly (Figures 3 and 6). This may explain why the data generally do not have a zero intercept as expected (i.e., zero flow at zero pressure).

The overall SVE pumping capacity appears similar between test wells OW-1 and OW-2, with the general slope of vacuum versus flow ranging between approximately 0.6 and 0.9. This suggests, in the absence of additional turbulence, that a flow rate of approximately 200 scfm is possible at a wellhead vacuum of 150 iw (Table 1). An exception to these high flow rates was the zone screened by OW-1B at 75 to 95 feet below grade (fbg). This zone attained a flow rate of only 15.5 scfm at a vacuum of 60 iw. The vacuum versus flow slope for OW-1B is 2.3 (about 1/3 the others), but the intercept is 24, the large value suggesting uncertainty in the slope accuracy. Further discussion is provided in Section 6.0.

TABLE 1
SVE STEP TEST SUMMARY

WELL ID	SCREEN INTERVAL[1]	MAXIMUM TEST FLOW[2]	MAXIMUM TEST VACUUM[3]	MAXIMUM FLOW CAPACITY[4]
OW-1A	33-63	51.6	42.0	180.5
OW-1B	75-95	15.5	60.0	54.3
OW-1C	105-125	57.8	44.0	179.3
OW-2	51-85[5]	72.3	40.0	251.8

NOTES:
1. Screened interval in feet below grade (fbg)
2. Flow in scfm
3. Vacuum in inches water column (iw)
4. Maximum flow at 150 i.w. vacuum
5. Corrected for 30 degrees off vertical drilling angle

3.0 CONSTANT RATE SVE FLOW TEST

One constant rate SVE test was conducted using OW-2 as the extraction well (Figure 2) to derive the parameters in the vadose zone controlling vapor flow. This method of SVE testing is analogous to constant rate aquifer pump testing. The test was conducted at a constant flow rate of 72 scfm at a corresponding wellhead vacuum of 40 iw.

Three vacuum propagation data sets were collected at OW-1A/B/C by monitoring the change in subsurface vacuum through time. OW-1A/B responded to SVE at OW-2, OW-1C did not display a measurable change in vacuum from background conditions and was therefore not analyzed. Since OW-2 is a 30° slant well, the distances between OW-1 and OW-2 were corrected based on the average screen depths in OW-1 and the corresponding change in lateral distance to slant well OW-2. At land surface, the total distance between OW-2 and OW-1 is approximately 85 ft (BE). The corrected distances between OW-2 and OW-1A at a depth of 48 fbg, and OW-1B at a depth of 85 fbg, is 58 and 36 feet respectively. The distance from the extraction well to the observation well is necessary to calculate vapor flow parameters.

Analytic curve fitting of the vacuum propagation data allows estimation of the vapor flow parameters of a potentially leaky system caused by air flow from ground surface or depth (Beckett & Huntley, 1994). Results of the analyses are presented in Table 2, with field data and curve fits in Appendix A. Analyses were performed using AQTESOLV (Geraghty & Miller), a computer program that aids in type-curve fitting. Vacuum drawdown is presented in equivalent feet of air head to make resultant parameter units correct (Equation 1). Since the density of air and water are approximately 1.22 x 10^{-3} and 1 g/cc (respectively), there are approximately 820 feet of air per foot of water head equivalent.

$$T_a = k_{ra} k_i \frac{\rho_a g}{\mu_a} b_a \qquad \textbf{(1)}$$

Where T_a *is the effective vapor transmissivity, "a" is an index indicating air-phase,* k_{ra} *is the relative vapor permeability scalar which varies with pore fluid saturation,* k_i *is the intrinsic permeability tensor of the soil,* μ_a *is the viscosity of air,* ρ_a *is the density air, g is the gravitational acceleration constant, and* b_a *is the thickness of the formation through with vapor flow occurs.*

When the soil is completely dry, k_{ra} is equal to one, otherwise it is some smaller value. The effective vapor transmissivity is analogous to native state air permeability, where the value depends both on intrinsic soil permeability and fluid content. High soil moisture or hydrocarbon concentrations reduce the effective vapor transmissivity by reducing the available vapor-filled pore space. In dry soil, the effective vapor transmissivity more closely represents the underlying soil intrinsic permeability. Based on site boring logs, the soil is suggested to be relatively dry and the effective vapor transmissivity values should be within 80% of the absolute vapor transmissivity (100% dry soil).

TABLE 2
SVE DATA CURVE FITTING RESULTS

Observation Well	T_a	S	r/B
OW-1A	0.67	5.5 x 10^{-4}	0.35
OW-1B	0.34	3.1 x 10^{-4}	0.35

Notes :
T_a *Effective vapor transmissivity (ft^2/min).*
S *Effective vapor storativity (unitless).*
r/B *Proportional to vertical vapor flow (unitless). A value of zero implies perfectly radial flow (no vertical component), with increasing values indicating greater vertical components.*

4.0 SOIL VAPOR LABORATORY TESTS

Four soil vapor samples were collected following SVE step tests, one from each screened section in OW-1A/B/C and one from OW-2. Vapor samples were analyzed for: 1) total fuel hydrocarbons (TFH) with benzene, toluene, ethyl benzene, and total xylenes (BTEX) distinction (Table 3, Figure 7); 2) fixed gases (Table 4, Figure 8); 3) hydrocarbon speciation (Table 5). Analyses were conducted by Carol's Analytical and Billy's Analytical Services (Appendix B). A limitation in interpreting short-term soil gas chemical data is that the soil pore space typically contains "stagnant" vapor representative of quasi-static conditions. However, the dynamic chemical equilibria are more important in discerning soil/vapor chemistry relationships. Short-term data is useful in projecting maximum SVE concentrations, release composition, and assessing potential biologic activity.

TABLE 3
LABORATORY RESULTS EPA T0-14 ANALYSES

WELL	TFH	Benzene	Toluene	Ethyl Benzene	Xylenes
OW-1A	11000	310	450	67	250
OW-1B	9700	340	400	39	250
OW-1C	6000	120	58	13	120

Notes:
All results in parts per million/volume (ppmv)
TFH = Total Fuel Hydrocarbons

TABLE 4
LABORATORY RESULTS FOR FIXED AND BIOLOGIC GASES

WELL	CO_2	CO	CH_4	O_2	N_2
OW-1A	8.3/9.4	ND/ND	ND/ND	6.0/6.72	78.0/83.9
OW-1B	8.1	ND	ND	6.6	79
OW-1C	7.3	ND	ND	ND	82
OW-2	7.9	ND	ND	4	88.1

Notes:
1. Results in volume percent
CO_2 = Carbon Dioxide   CO = Carbon Monoxide
CH_4 = Methane O_2 = Oxygen

TABLE 5
COMPOSITION OF HYDROCARBONS IN SOIL VAPOR SAMPLES

CARBON CHAIN LENGTH	OW-2	OW-1A
C4	6.30%	3.64%
C5	39.70%	43.54%
C6	41.50%	39.31%
C7	8.30%	9.20%
C8	4.00%	4.11%
C9	0.19%	0.20%
C10	ND	ND
C11	NA	NA

Notes:
ND= Not Detected NA= Not Analyzed

In general, soil vapor collected from OW-1A/B appears to have a fairly consistent composition and concentration (11,000 and 9,700 ppmv TFH, respectively). In contrast, deeper vapor collected from OW-1C has a different composition and lower concentration (6,000 ppmv TFH). The differences in composition in the deeper zone are indicated by comparing ratios of light to heavy molecular weight aromatic compounds and TFH (Figure 9). The difference in chemical composition may indicate that deeper hydrocarbons are older and more degraded, although a difference in release composition could also be responsible. Measured carbon ranges for samples OW-1A and OW-2 are compared to carbon ranges for a typical fresh and a typical weathered gasoline (Figure 10). Based on vapor samples and prior soil laboratory data, the subsurface fuels appear weathered.

All soil vapor samples showed elevated CO_2 and N_2 and depleted O_2 gas concentrations relative to atmospheric conditions (Table 3). This is often the result of aerobic biologic degradation of petroleum hydrocarbons in soil (Marrin, 1991). Although O_2 was not detected in OW-1C by the laboratory analysis (4.2% detection limit), field instrument readings suggested the presence of O_2 at 2%. The small or non-detectable O_2 concentration in OW-1C suggests more anaerobic (chemically reduced) conditions than in the overlying zones. It is possible that the high nitrogen concentrations relative to atmospheric conditions reflect denitrification reactions that can occur in semi-reduced environments. Methane, often indicative of fully anaerobic biologic respiration, was not detected in the samples collected at concentrations greater than the 50 ppmv (0.005%) detection limit. Methane concentrations greater than 1% are typically only measured in zones of free product or other large hydrocarbon impacts (Marrin, 1991).

Results from Carol's Analytical suggest the sum of fixed and hydrocarbon gases is approximately 94% for OW-1A and 95% for OW-1B and C. These sums assume that the concentrations of non-detected gases are equal to the detection limit. Therefore, the sums are likely an overestimation. Typically, inert gases in the atmosphere equal about 1% and maximum water vapor equals abut 0.4%. This leaves approximately 4 to 5% unaccounted for in the sum of measured gases, which should equal 100%. This discrepancy may suggest accuracy difficulties with laboratory measurements of fixed gas concentrations because hydrocarbon concentrations are a small percentage of the whole gas sample. Therefore, the accuracy of hydrocarbon measurements should not affect the total gas summation.

Potential sampling issues should not affect the gas summation because the laboratory will analyze the sample at one atmosphere, which is by definition equal to 100%. Billy's Analytical Services apparently normalizes results to 100% so the sum equals 100% by definition.

5.0 SVE REMEDIATION EVALUATIONS

SVE remediation evaluations were conducted based on data presented above and in prior site characterization reports. The following describes the model setup and presentation of model results. The mathematical basis for the model is presented in Appendix C.

5.1 Model Setup

SVE evaluations are three dimensional and use a 37-component weathered gasoline approximation (Johnson et al., 1990) to model the response of volatile versus semi-volatile components through time. The use of weathered gasoline as the hydrocarbon compound is suggested by both soil and soil vapor laboratory analyses. The equations describing the physical basis of the model (Appendix C) indicate that a distribution of soil permeability and hydrocarbon impacts is needed to evaluate potential SVE cleanup strategies. Based on site geologic logging by Ground Water Technology, Inc. (GTI, 1991) and BE (1994, 1995), the site lithology is approximated by a six-layer sequence of low and high permeability layers (Figure 11). This distribution is approximate for two reasons. First, geologic interpretations through time have been made by several geologists, each with different interpretation techniques and sampling protocols. This makes cross-interpretation of lithologic properties difficult. Second, sample retrieval and laboratory analyses in gravelly sediment is a necessary but imperfect technique. It is difficult to accurately assess lithologic and hydrocarbon distributions on this sampling basis.

Historical soil sample analytical results were used to estimate a subsurface release volume of approximately 7,000 gallons of fuel hydrocarbons. This is only a rough estimate due to the geologic and sampling issues discussed above. The estimate is derived by taking the depth-averaged hydrocarbon concentrations at each boring location and interpolating across the site using a kriging algorithm (Figure 12). The resulting averaged concentrations are integrated to derive the average volumetric concentration. Then, the average volumetric hydrocarbon concentration is converted to liquid volume using an estimated soil density of 1.8 grams per cubic centimeter (g/cc) and a fuel density of 0.8 g/cc. Site data suggests that approximately 85% of the hydrocarbon impacts are distributed in the upper 60 feet, with the remaining 15% beneath. This generalized hydrocarbon distribution is not intended to accurately represent any single discrete samples, but rather a representative average based on the volume defined.

Five SVE simulations were performed (Table 6). Pumping and injection well locations for each simulation are graphically presented in Appendix C. The first two simulations pump simultaneously at OW-1A and B at pumping rates of 50 and 100 scfm, respectively, with no other pumping locations. The third and fourth simulations add two SVE injection wells located across the plume from OW-1 while SVE pumping continues at OW-1A and B at the same pumping rates used in simulations one and two, respectively. The fifth simulation applies a broader SVE well field consisting of two pumping and two injection wells each screened in the upper two coarse-grained intervals. All wells extract or inject vapor at 100 scfm. Together, the simulations allow physically based evaluations of different well field pumping strategies to suggest the most time and cost-effective cleanup strategy.

TABLE 6
SVE SIMULATION SETUP SUMMARY

Simulation	SVE Wells	SVE Rate (Per Well)	Layers	Inj. Wells	Rate	Layers
#1	1	50	3/5	0	na	na
#2	1	100	3/5	0	na	na
#3	1	50	3/5	2	50	3/5
#4	1	100	3/5	2	100	3/5
#5	2	100	3/5	2	100	3/5

Notes:
1. Number of SVE wells applies to one vertical location.
2. Number of layers indicates the screened sections each pumping at the given rate.
3. Rate = scfm.
4. Inj. Wells = Injection wells
na = not applicable
Refer to Appendix C for graphical representations of model and well locations.

5.2 SVE Modeling Results

Before discussing modeling results, a reminder is provided that the results are site specific but generalized based both on SVE testing and existing geologic information. As mentioned previously, interpretation of geologic and chemical continuity is uncertain. Therefore, the accuracy of the results discussed are also uncertain. Conversely, the physical and chemical processes modeled are known to be appropriately represented by Equations 2-4 and subsets thereof. For these reasons, there is confidence that the results are representative to the degree that geologic and chemical assumptions are valid. AVI has used site data and experience to deliver best estimates of possible SVE operating conditions.

Under all simulated SVE conditions, fine-grained sediments are cleaned up less effectively than coarse-grained materials. This is consistent with chemical and hydraulic differences between modeled lithologies. Therefore, no matter the SVE cleanup strategy applied, zones of significant impacts (e.g., less than 50% mass cleanup) are anticipated after 3 years of SVE operation (Figure 13). Selected 3-D model renderings are presented depicting this trend (Appendix C). The total mass in each model layer depends on average concentration and layer thickness, which is why more mass resides in deep layers having the same concentration as overlying thin layers. The same physical and chemical conditions that limit cleanup also limit hydrocarbon mass transport out of these units and it is possible that limited environmental risk remains.

Of the SVE strategies simulated, the fifth (Table 6) may be the most effective (Figure 13). This is true for both TPH and BTEX removal. Benzene in the pumped coarse-grained materials (Layers 3 and 5) is estimated to be reduced to less than 0.1% of its original mass after one year of SVE (Figure 14). Toluene is estimated to be reduced to approximately 0.3% and m-xylene 1% of their respective initial masses in the pumped coarse-grained soils (Layers 3 and 5) after the same period (Figure 14).

The mass of selected gasoline components remaining in all the layers over time is presented for each simulation (Figures 15-19). These data indicate that more mass is removed under simulation 5 compared to other simulations.

SVE inlet hydrocarbon concentrations from all pumped zones are estimated to be as high as approximately 40,000 ppmv (as hexane) on SVE start up for simulations 2 and 5 (Figure 20). SVE inlet benzene concentrations from all pumped zones are estimated to be as high as approximately 2,900 ppmv on SVE start up for simulations 2 and 5 (Figure 21). Peak hydrocarbon and benzene concentrations are suggested to decrease rapidly to less than 1,000 and 100 ppmv, respectively, in approximately 140 days. Mass recovery rate is the product of concentration and pumping rate. Therefore, simulation 5 is nearly twice as effective as simulation 2 at benzene recovery given their generally similar inlet concentration trends (Figure 21).

While the fifth simulation results in the greatest cleanup, it may not be the most cost-effective SVE strategy. The simulated cleanup would require the installation of three new wells with associated piping and pumping costs. A cost/benefit analysis could be performed after final determination of cleanup levels and time necessary to achieve those results.

SVE simulation results also suggest that the percentage cleanup in the lowermost model zone of coarse-grained soil (105-145 fbg) is not particularly effective without pumping in that zone. The best-case simulation relative to that zone suggests that only 45% of the initial hydrocarbon mass will be cleaned up through SVE in overlying zones. The initial concentrations in this deep zone are not high. However, the ineffective cleanup may leave a residual source that results in significant environmental impacts compared to fine-grained soil layers that do not readily transport hydrocarbons. Therefore, if additional wells are installed, it may prove beneficial to screen the deep interval in case cleanup is required in that zone.

6.0 SUMMARY AND RECOMMENDATIONS

The low pumping capacity of OW-1B is not consistent with the relatively large vapor transmissivity derived from transient data. This could suggest borehole smearing in the zone of OW-1B that would act to increase the vacuum relative to the flow rate. A limited zone of high permeability crossing the well screen would also result in a similar observation.

Zones OW-1A and B appeared to respond to SVE at OW-2, but Zone C did not. This indicates a lack of vapor flow in the deepest zone of OW-1 and probably reflects the fact that OW-2 is not screened across that deep interval (from 105 to 125 fbg). Relatively high vapor flow from OW-1-C during step pump testing indicates the capacity of that zone to sustain vapor flow, if needed for cleanup efforts.

Soil vapor appears representative of weathered gasoline. Biogenic vapors were detected that suggest aerobic and possibly denitrification reactions are occurring that are naturally consuming petroleum hydrocarbon components. The biologic activity is important since this is the primary mechanism for natural attenuation of subsurface petroleum hydrocarbons. Therefore, even if SVE is unsuccessful in cleaning up fine-grained deposits, natural biologic activity will act to lessen or eliminate potential impacts from the fine-grained residual sources.

Overall, the coarse-grained units without a significant fine-grained component exhibit high permeability and good amenability to SVE cleanup. The fine-grained units, including sands and gravels with significant silt and clay, do not appear suited for SVE cleanup. If cleanup in these lower permeability zones is necessary, a possible strategy would be to install discrete SVE wells screened only within fine-grained deposits. In a practical sense, this strategy is difficult to apply because fine-grained zones may be discontinuous or interbedded with coarser materials. Any coarse materials crossing the intended fine-grained SVE well will cause short-circuiting and defeat the purpose of the remediation strategy.

Because the fine-grained soils at the site do not appear well suited for SVE cleanup, it may be beneficial to Environmental Services to develop risk-based cleanup objectives before implementing SVE work at the site. By developing the cleanup objectives before the SVE work, Environmental Services can anticipate what additional remedial work may be necessary, if any, to protect potential health and environmental receptors. Environmental Services may also want to refine the well field design based on specific clean up objectives and specific time of clean up goals.

If additional vapor extraction wells are installed AVI strongly recommends that the well installation procedures include measures to reduce borehole wall smearing. A number of tools can be attached to either the hollow stem auger bit or the well casing to scratch the borehole wall. This provides better hydraulic communication between the formation and the well bore and is the vadose zone equivalent of ground water well development. Based on the step test results at this site and other sites borehole wall smearing is a likely cause of low well efficiency.

Once the well field is operating, a data collection program should be included in the operation and maintenance program. Influent concentrations and vacuum response data should be collected and compared to modeled predictions. Differences between actual and modeled results can help refine knowledge of site hydraulic and chemical conditions. This information can then be used to optimize the operating efficiency of the well field.

7.0 REFERENCES

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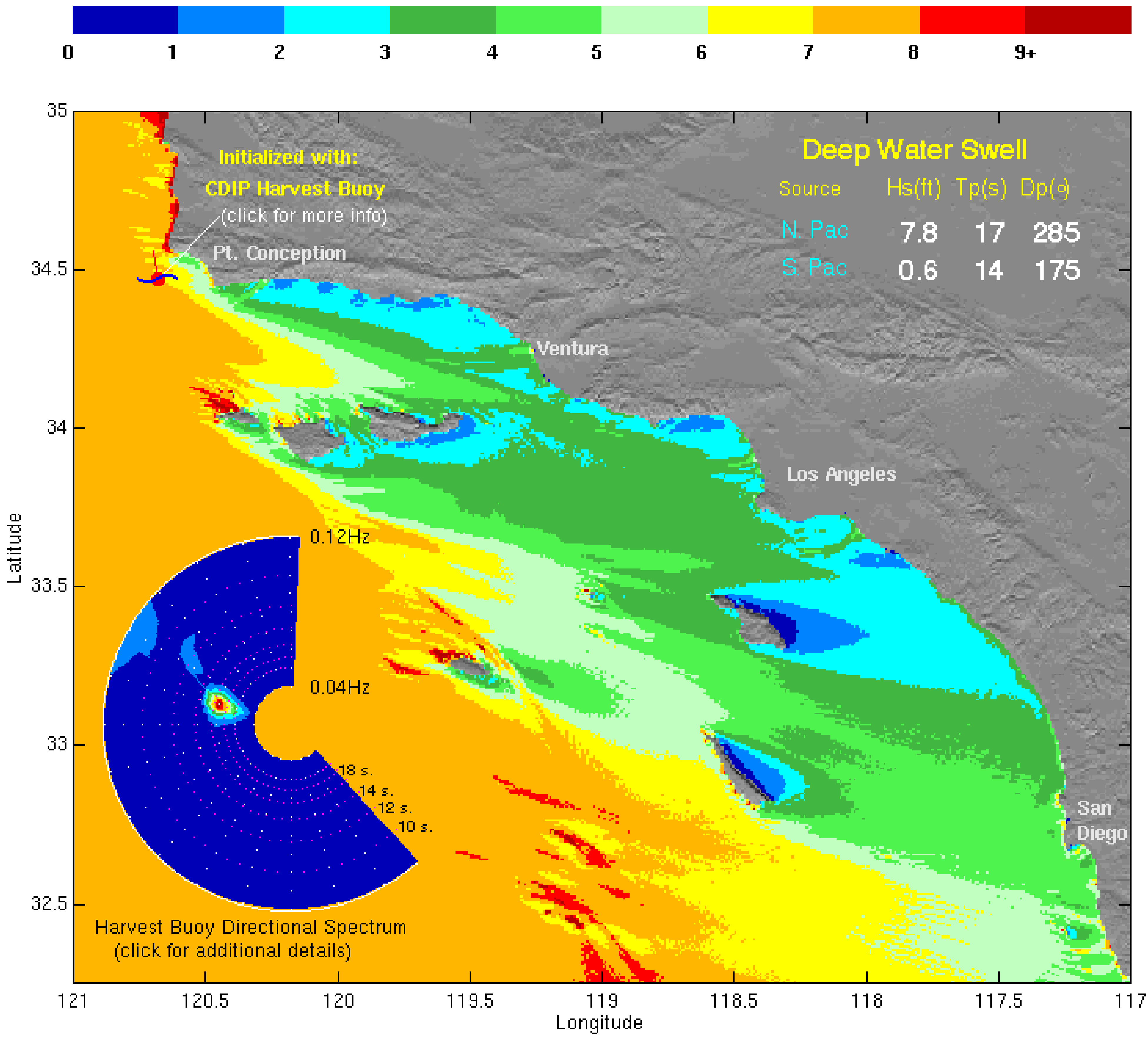
F:\AQUIVER\BOILER\DOCUMENT\SVE\SVE-II.01A

FIGURES

The Coastal Data Information Program
Center for Coastal Studies
SCRIPPS INSTITUTION OF OCEANOGRAPHY

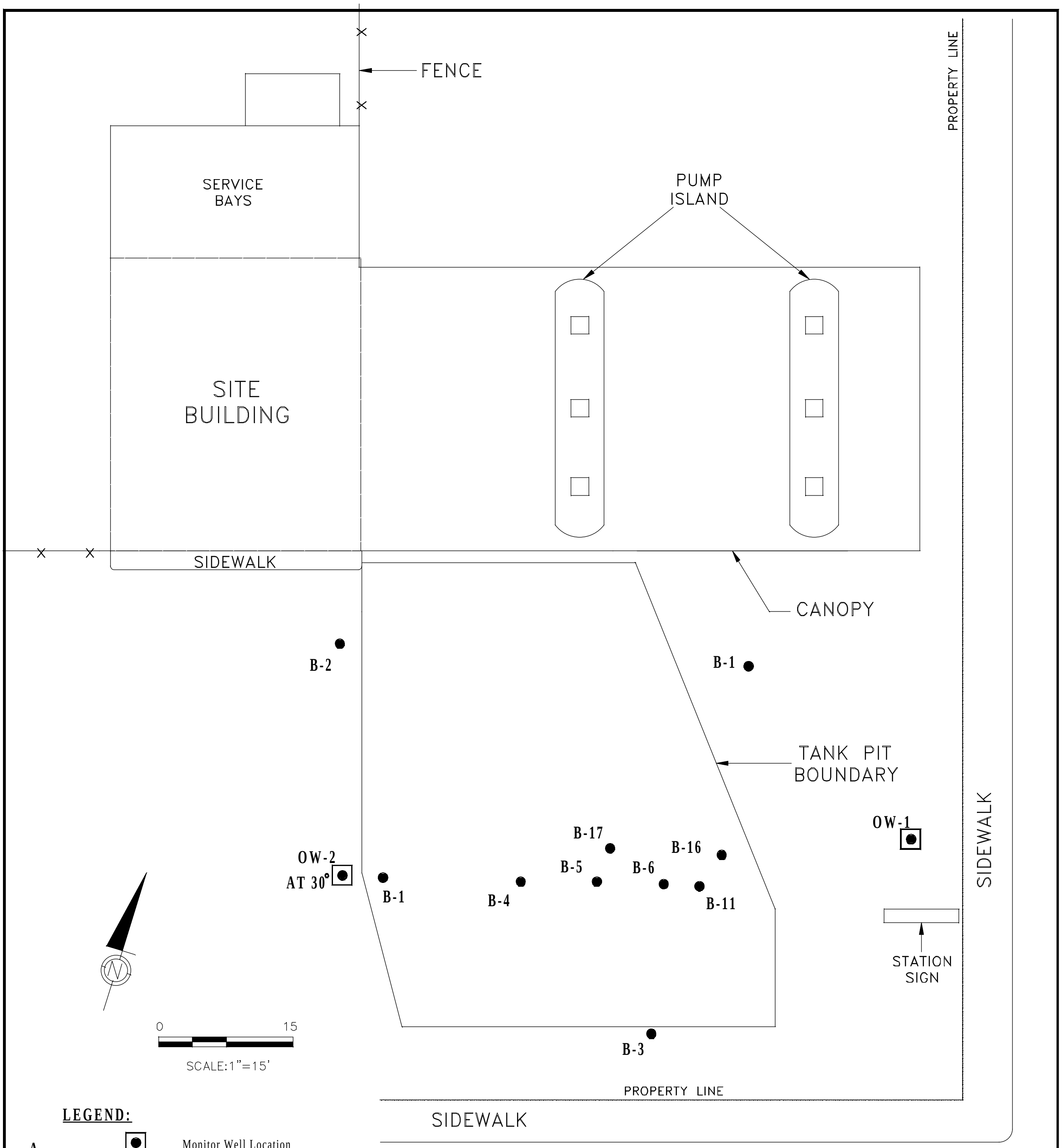
Analysis Time – 30 DEC 1998 : 1256 PST

Swell Height (ft) – Southern California Bight



Additional Information @ http://cdip.ucsd.edu/

California Department of Boating and Waterways
U.S. Army Corps of Engineers
Field Wave Gaging Program
Office of Naval Research
Advanced Wave Prediction Program



LEGEND:

A

● OW-1 Monitor Well Location

● B-4 Soil Boring Location

NOTES:

Digital Data Provided by Billy's Environmental Consultants.
Structure and Boring/Well Locations are Accurate To The Degree
That Digital Map and Data are Represenative Of True Conditions.

FIGURE 2

AQUI-VER, INC.
Quantitative Environmental Hydrogeology

MONITOR WELLS & SOIL BORINGS

SCALE	1"=15'-0"	PROJECT #	MHP
DRAWN BY	MHP	DATE	9/94
CHECKED BY	GDB	DATE	10/1/94
DRAWING NO.	BASEMAP		

FIGURE 5
SERVICE STATION SVE STEP PUMPING TEST
WELL OW-1C; SCREENED 105 - 125 fbg

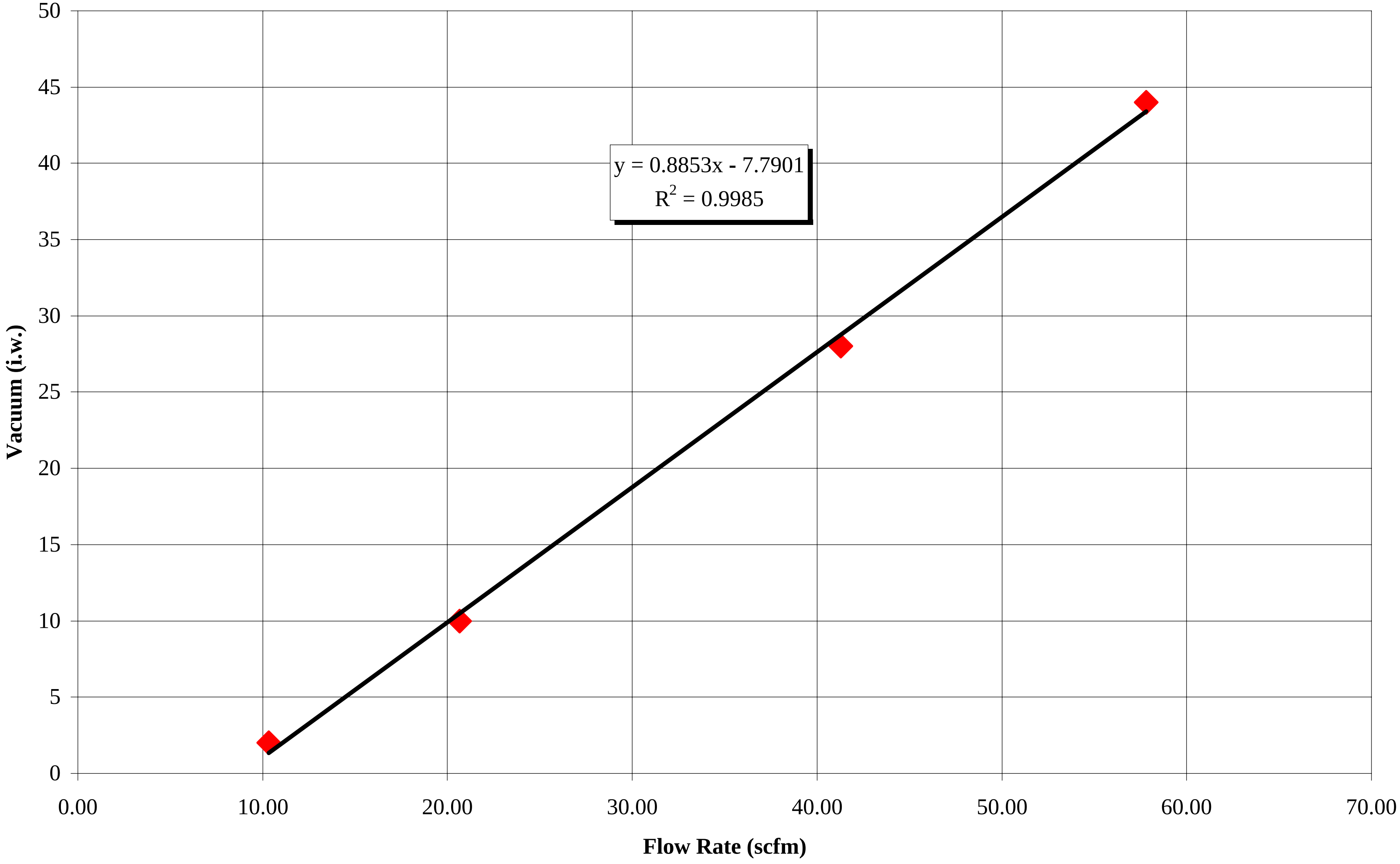


FIGURE 7
SERVICE STATION SOIL VAPOR CHEMICAL ANALYSES
TFH, BTEX

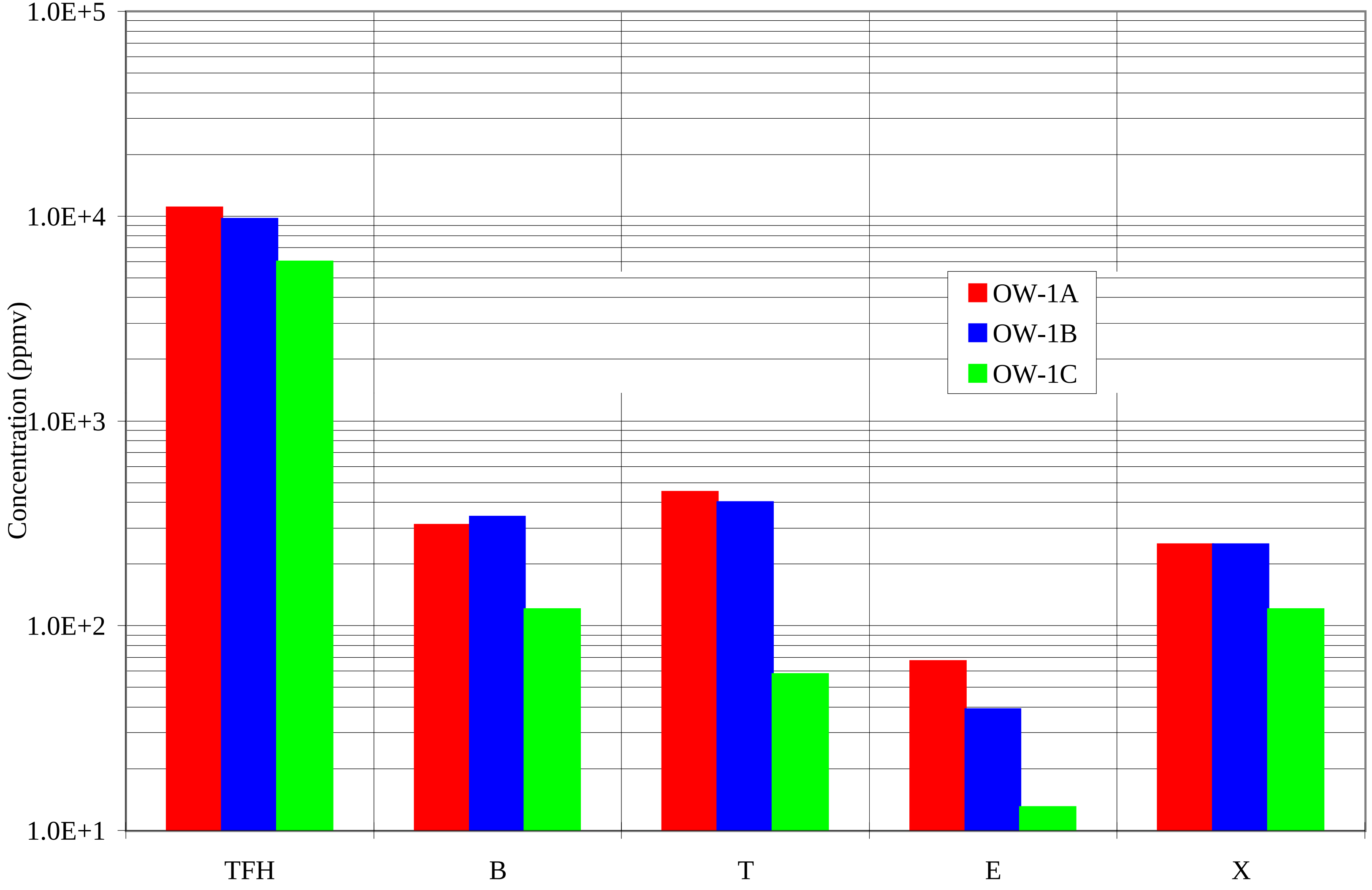


FIGURE 9
SERVICE STATION SOIL VAPOR CHEMICAL ANALYSES
TFH and BTEX Component Ratios

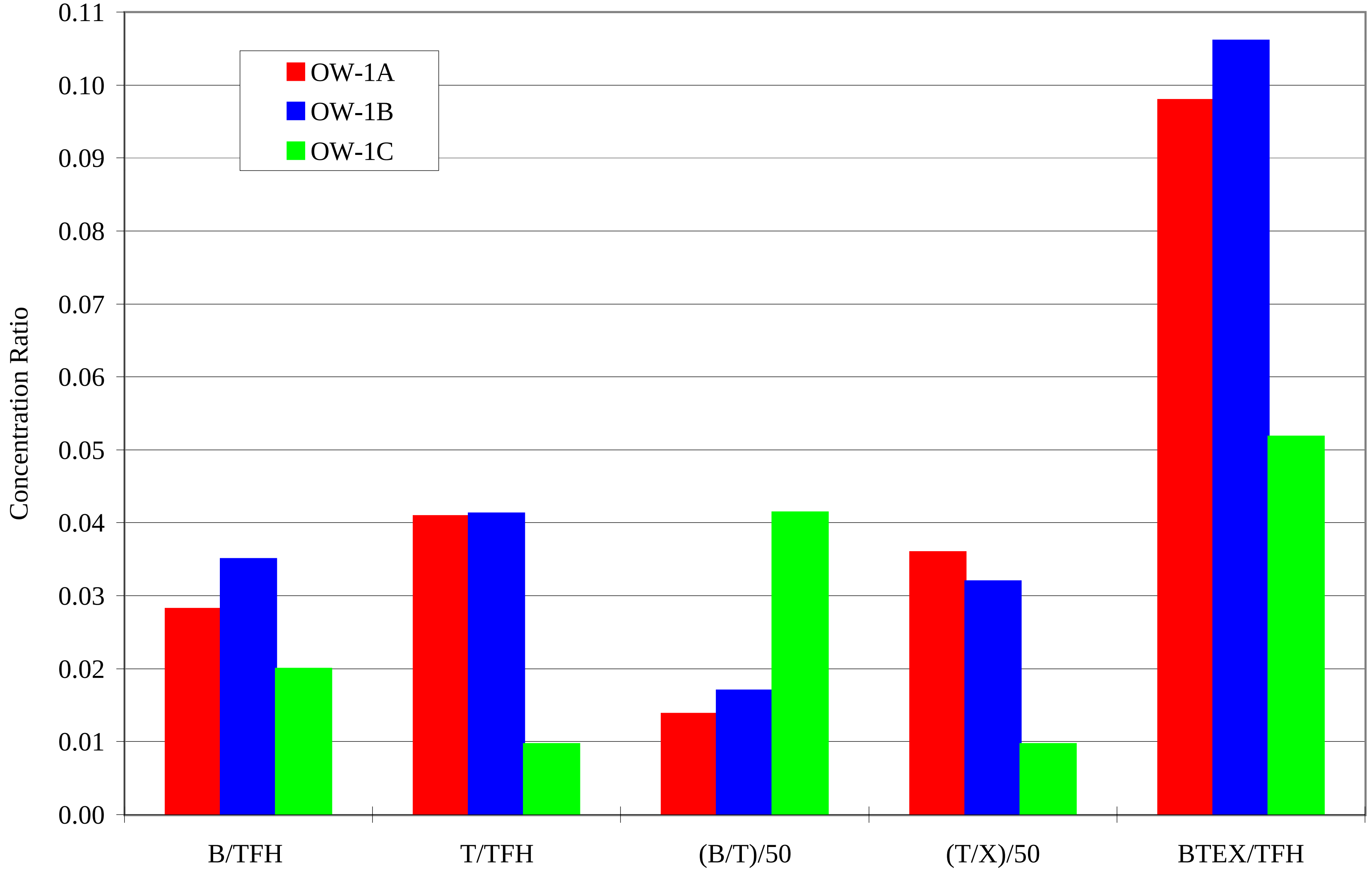
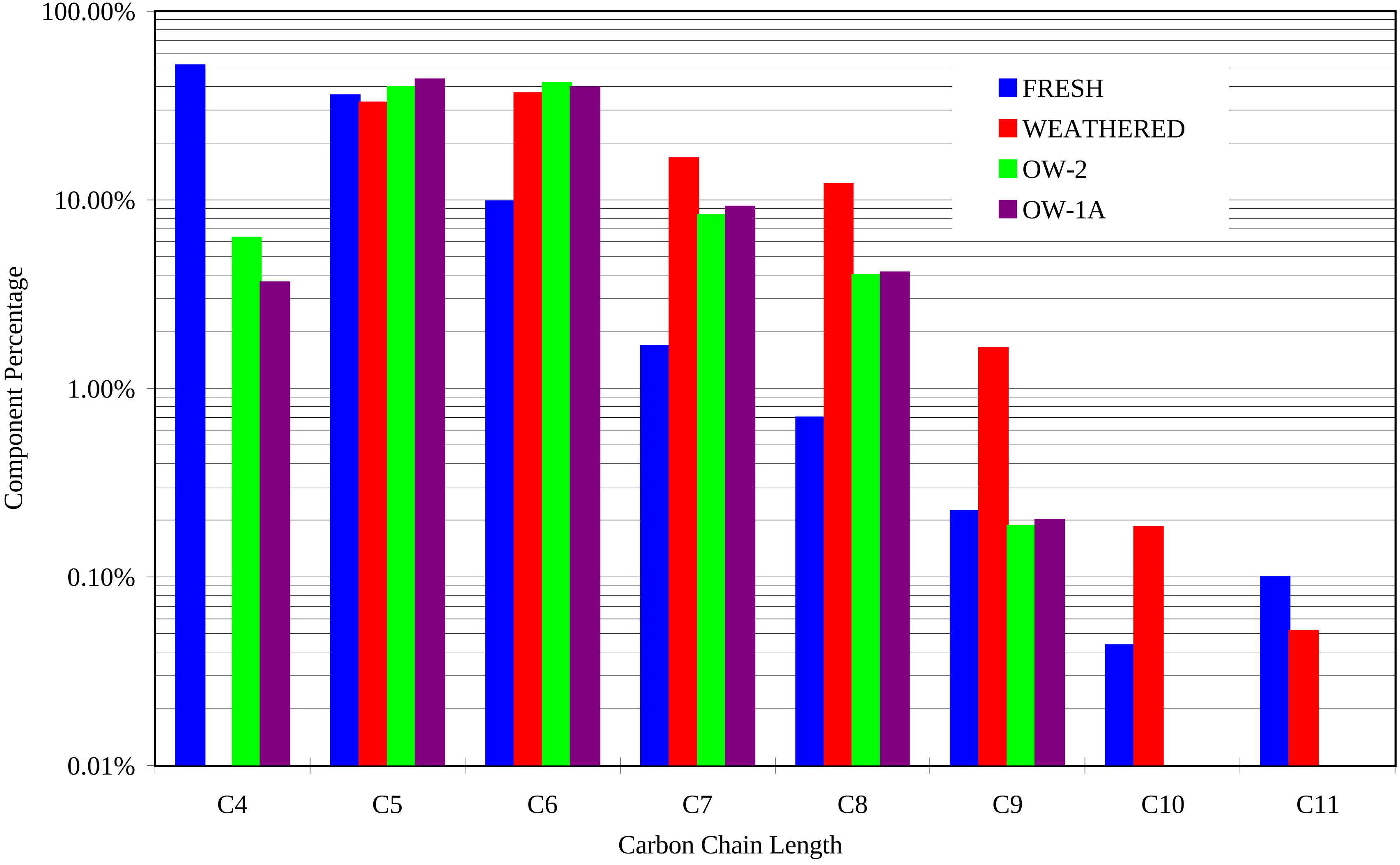


FIGURE 10
HYDROCARBON VAPOR SPECIATION RESULTS
And Comparison to Fresh and Weathered Composite Fuels



hccomp

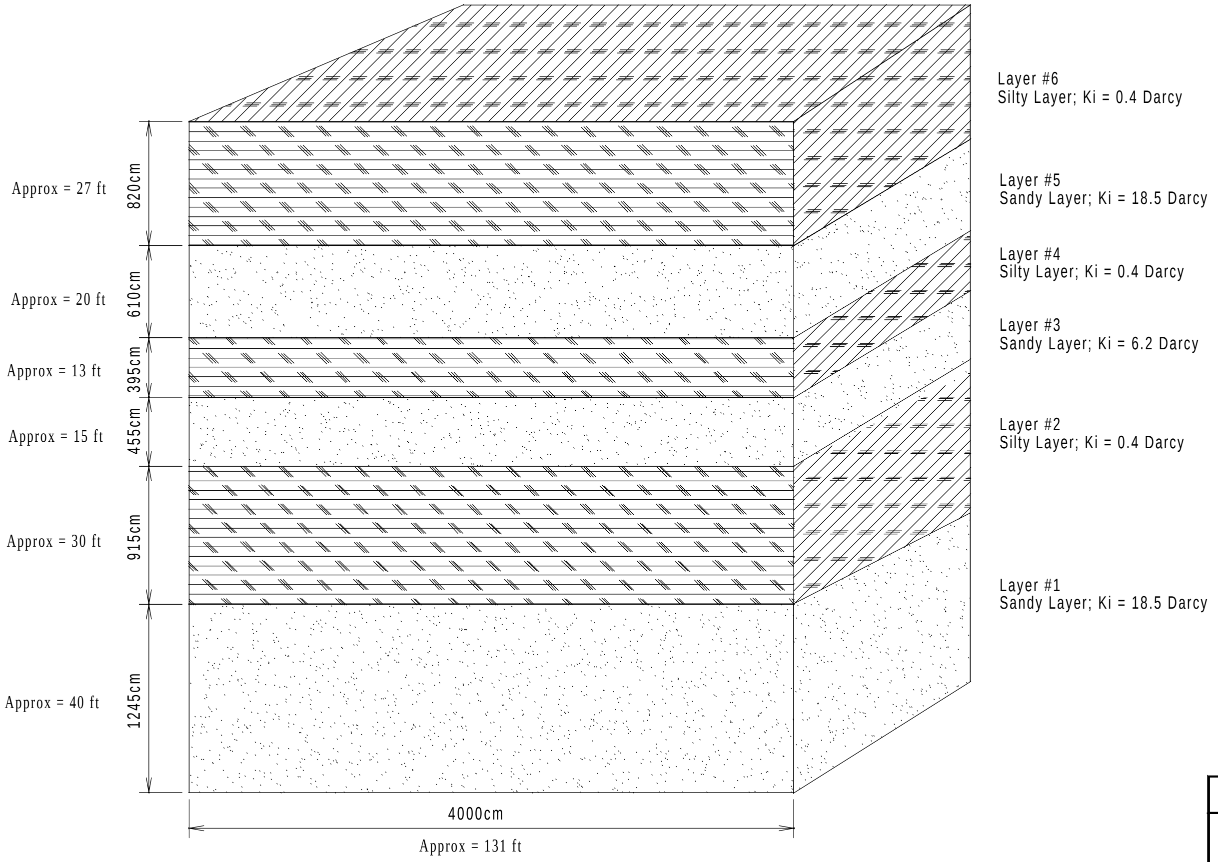


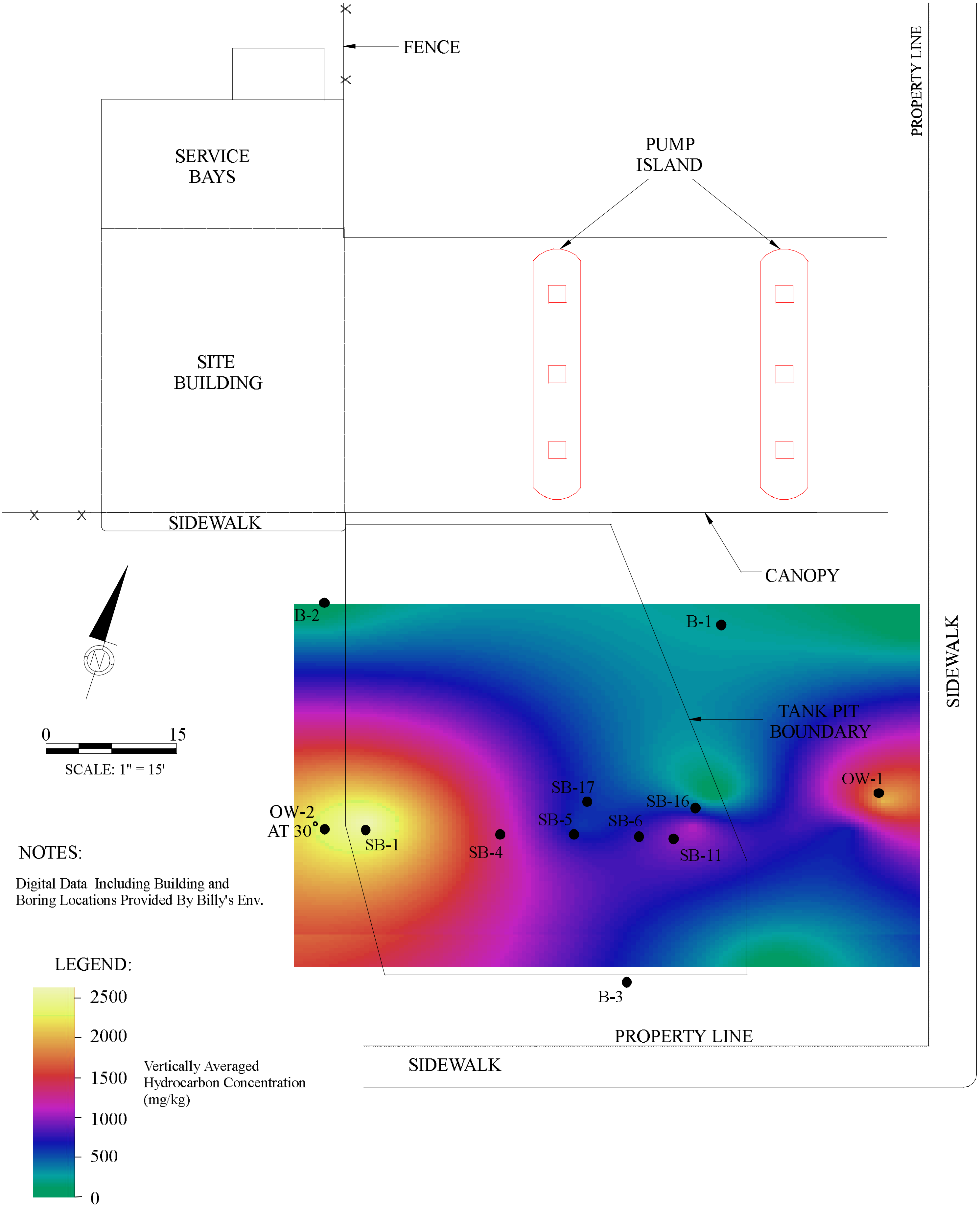
FIGURE 11

AQUI-VER, INC.

Quantitative Environmental Hydrogeology

MODEL DIMENSIONS AND LITHOLOGIES

SCALE	PROJECT #
DRAWN BY MHP	DATE 8/14/95
CHECKED BY	DATE
DRAWING NO. MODBASE.SKD	



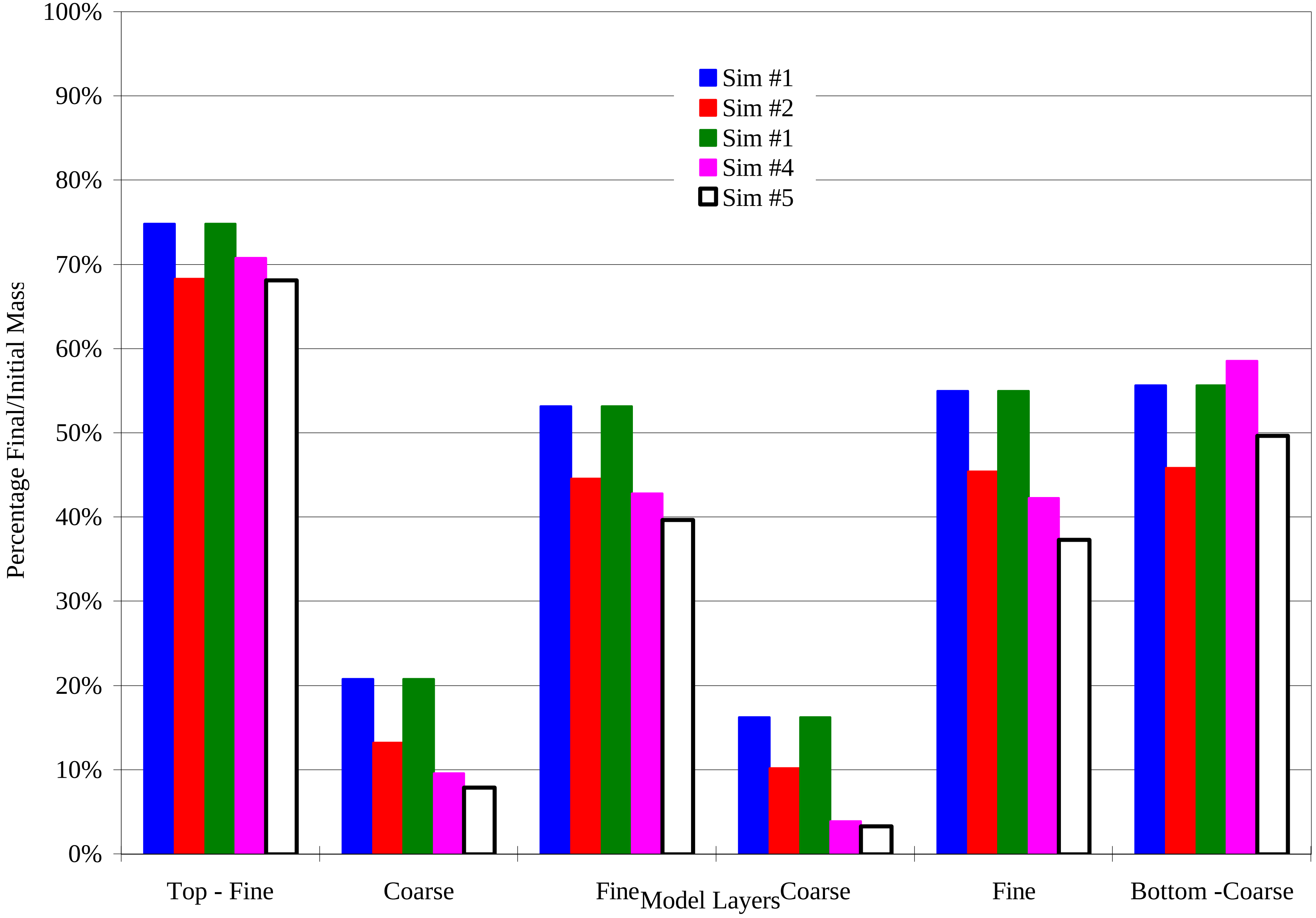
NOTES:

Digital Data Including Building and Boring Locations Provided By Billy's Env.

FIGURE 12
Vertically Averaged Hydrocarbon Concentrations in Soil, Initial Conditions

FIGURE 13
SERVICE STATION SVE SIMULATION SUMMARY

Predicted Percentage of Remaining TPH After Three Years: (See Table 6 For Descriptions)



sim1mass.xls

FIGURE 19
SERVICE STATION SVE SIMULATION SUMMARY
Selected Component Response to SVE Simulation #5, See Table 6

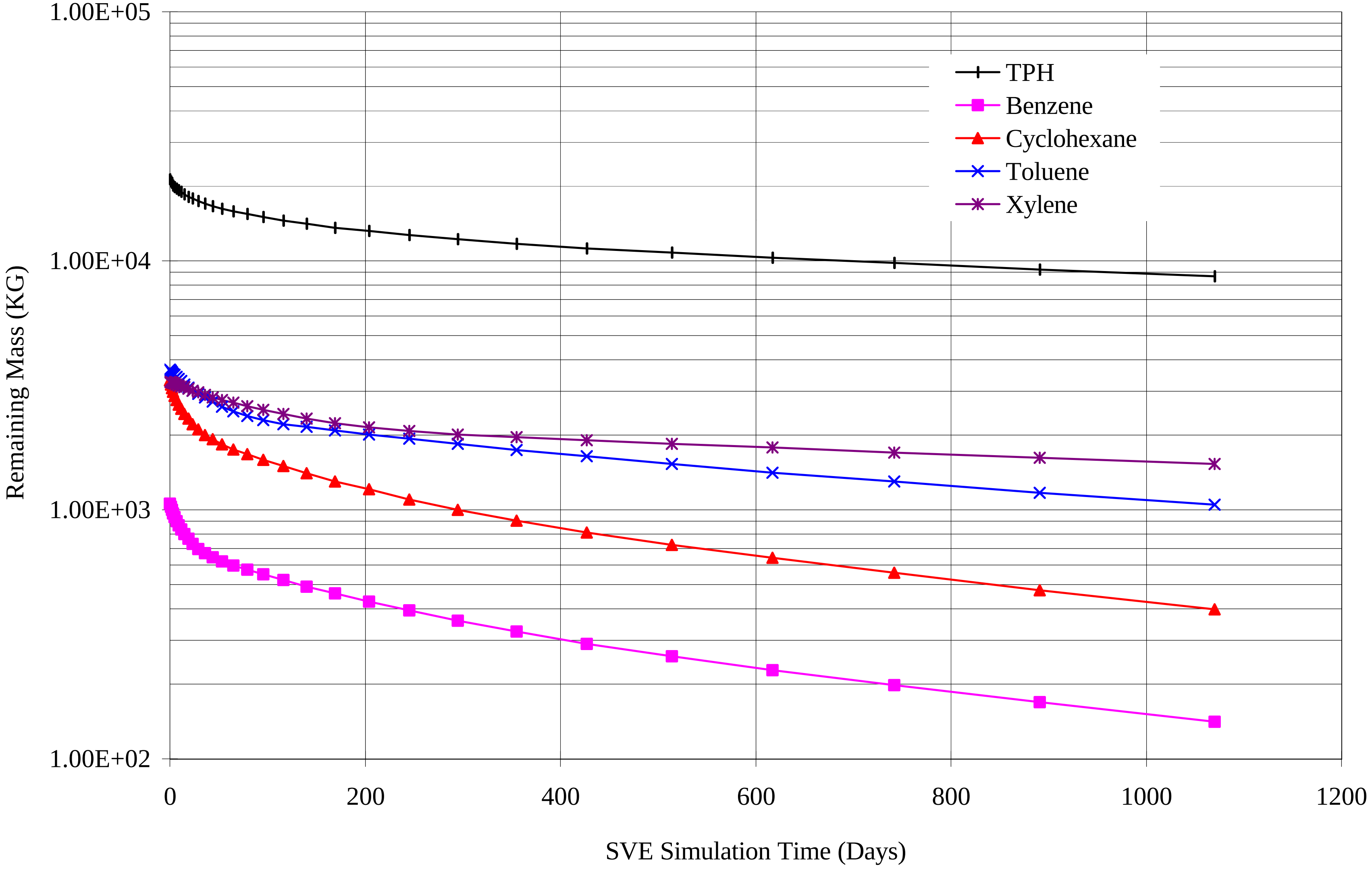
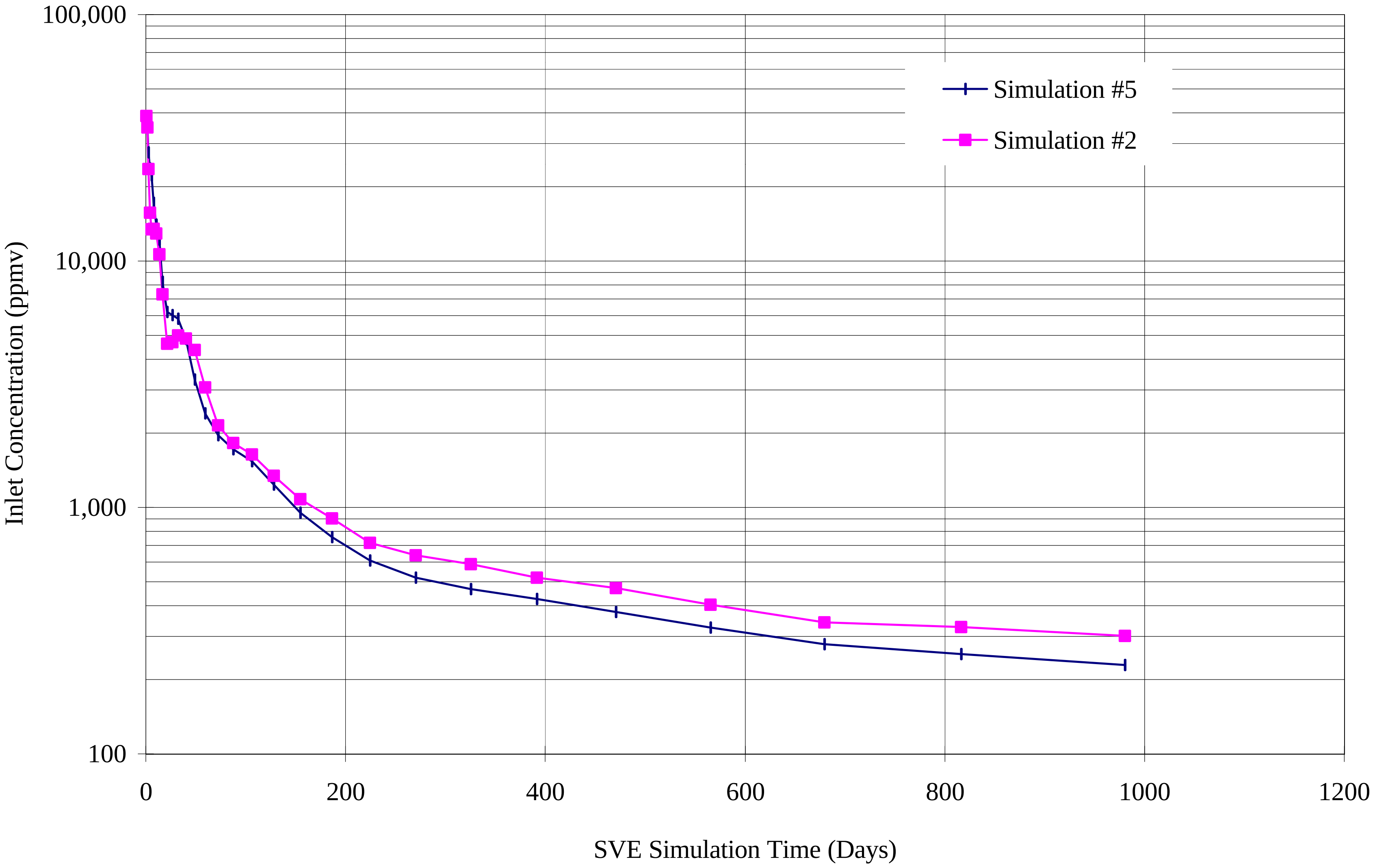


FIGURE 20
SERVICE STATION SVE SIMULATION SUMMARY
Predicted SVE Total Inlet Hydrocarbon Concentration as Hexane

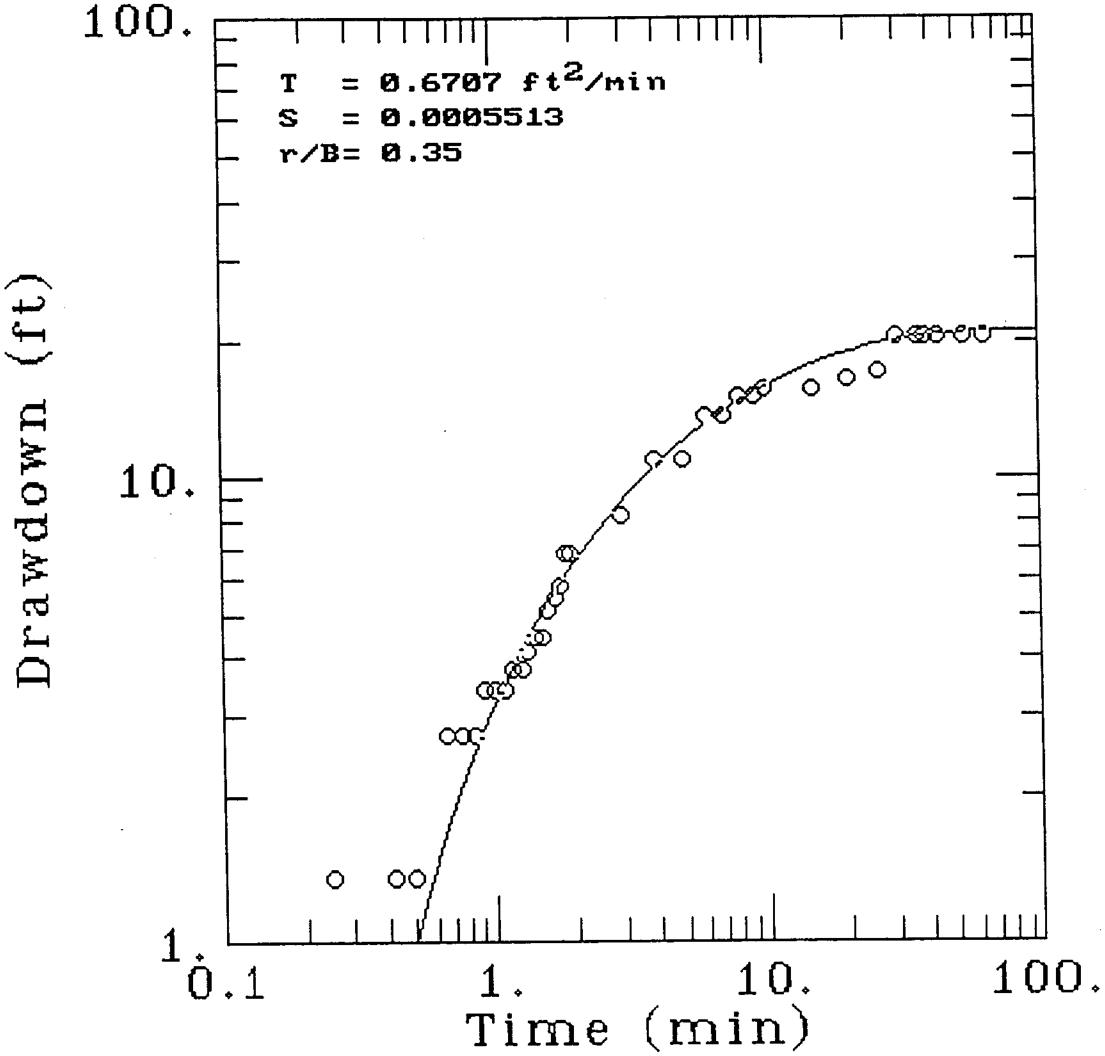


sim5-inl.xls

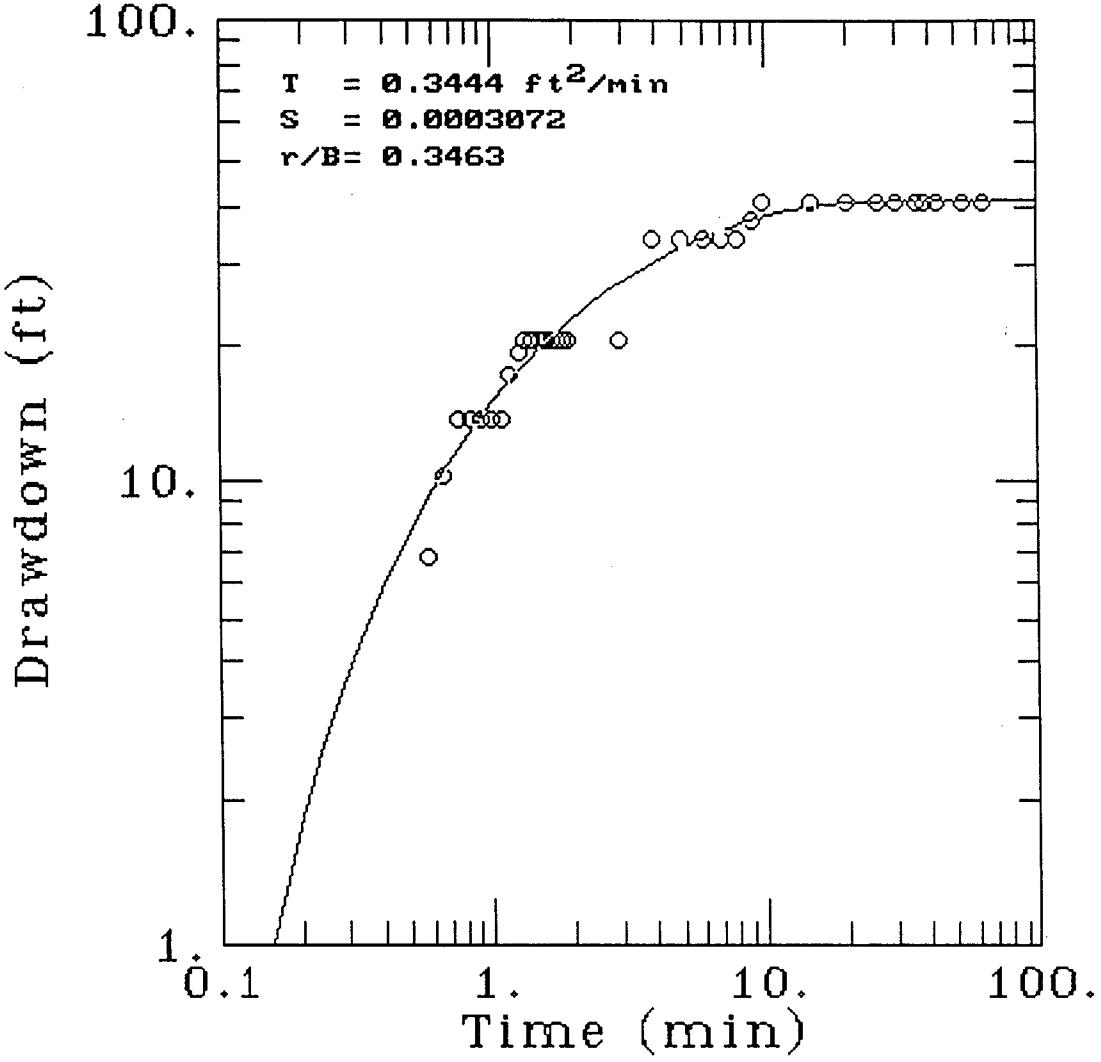
APPENDIX A

SOIL VAPOR EXTRACTION HYDRAULIC DATA AND LITHOLOGIC DATA

SVE TEST: W1-A DATA



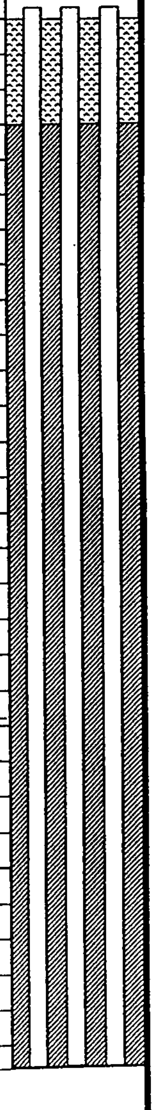
SVE TEST: W1-B DATA



REFER TO BORING LOCATION MAP

BORING/WELL LOG I.D.: NW1

Date(s):	4/3/95			Project Name:	Texaco/Grand Avenue
Start Time:	09 : 35	Finish Time:	16 : 30	Project Number:	11-00951-015
Logged By:	D.C.	Drilling Company:	H-F drilling	Page	1 of 5
Elevation: (ft. amsl)		Vapor Detector:	PID		
Drilling Method:	HSA F-10	Sampling Method:	Split Spoon		
Filter Pack:	22 Bags #3 Sand	Bentonite Seal:	14 Bags	Sanitary Seal:	Grout 0-4'
Casing Type:	SCH 40 PVC	Diameter:	2"	Boring Dia.:	10'
Water Initial	None				
Screen Type:	SCH 40 PVC	Slot Size:	0.020"	Diameter:	2"
Total Depth:	145'	Water Final	None		

Depth (feet)	LITHOLOGIC DESCRIPTION UNIT: Color, moisture, rel. density, texture (USCS Symbol), details. Odor, variations.	Sample Depth /Blows	Sample Type	Sample Designation	Screen Type	Screen Vapor (ppm)	Time	Boring/Well Completion
0	Asphalt 5"							
5	**ALLUVIUM:** Moderate brown (5YR4/4), damp, firm, fine grained sandy silt (CL), plastic, trace of angular pebbles. No petroleum hydrocarbon odor (PHO).	17 58 80	☒	NW1-5'			10:07	
10	Moderate brown (5YR4/4), damp, stiff, sandy silt (CL), plastic, trace of caliche, hard drilling not much recovery in sample tube. No PHO.		☒	NW1-10'			10:15	
15	Medium size rock 1-2.5". No recovery (NR) Driller suspects rocks in auger. No PHO.	58	■	NW1-15'			11:04	
20								
25	Pale yellowish brown (10YR6/2), damp, loose, fine grained silty sand (20,80%) (SM), trace pebbles. No PHO.	18 24 27	☒	NW1-25'			11:17	
30	Same as above	18 25 35	☒	NW1-30'				

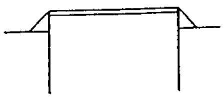
LEGEND

Sample Type
☒ Sleeve
◩ Grab
⍂ Discard

Screen Type
A - Ambient
B - Bag
C - Cuttings
H - Head Space

▨ Bentonite Grout
▨ Bentonite Seal
▨ Filter Pack
------- Contact - Dashed where Inferred

≡ Perforations
| | Well Casing
▬ Locking Cap
▽ Water Table


Traffic Rated Well Cover

Start Time: 09:30	Finish Time: 16:30	Project Number: 11-00951-015
Logged By: D.C.	Drilling Company: H-F drilling	Page 2 of 5

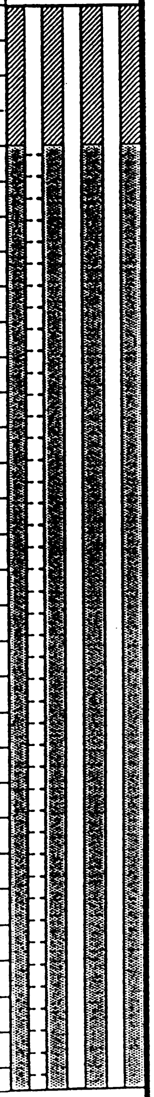
Elevation: (ft. amsl)	Vapor Detector: PID	Drilling Method: HSA F-10	Sampling Method: Split Spoon

Filter Pack: 22 Bags #3 Sand
Bentonite Seal: 14 Bags
Sanitary Seal: Grout 0-4'

Casing Type: SCH 40 PVC	Diameter: 2"	Boring Dia.: 10'	Water Initial None
Screen Type: SCH 40 PVC, Slot Size: 0.020"	Diameter: 2"	Total Depth: 145'	Water Final None

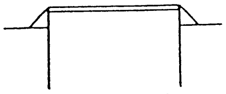
Depth (feet)	LITHOLOGIC DESCRIPTION UNIT: Color, moisture, rel. density, texture (USCS Symbol), details. Odor, variations.	Sample Depth /Blows	Sample Type	Sample Designation	Screen Type	Screen Vapor (ppm)	Time
30							
35	Moderate yellowish brown (10YR5/4), damp, loose, coarse upper-very coarse lower sands (SW) (Subangular grains). PHO odor.	10 18 45	☒	NW1-35'		2,450	11:17
40	Moderate yellowish brown (10YR5/4), damp, loose, coarse upper-very coarse lower sands with some silts (SM) (50,35,15%) PHO.	12 15 35	☒	NW1-40'		2,500	11:40
45	Moderate yellowish brown (10YR5/4), damp, silty sand (ML) well sorted (moderate plastic) loose. PHO.	15 50 70	☒	NW1-45'	B	1,650	11:47
50	No recovery		■				
55	Moderate yellowish brown (10YR5/4), damp, silty sand (ML) (non plastic) loose. Strong PHO	20 50 55	☒	NW1-55'	B	1,750	12:37
60	Moderate yellowish brown (10YR5/4), damp, sandy silt (ML), loose, (moderate plastic). Strong PHO.	50 65 90	☒	NW1-60'	B	1,587	12:43

Boring/Well Completion



LEGEND

Sample Type	Screen Type				
☒ Sleeve	A - Ambient	▤	Bentonite Grout	☰	Perforations
◪ Grab	B - Bag	▨	Bentonite Seal	| |	Well Casing
⧅ Discard	C - Cuttings	▩	Filter Pack	▬	Locking Cap
■ No Recovery	H - Head Space	-------	Contact - Dashed where inferred.	∇	Water Table



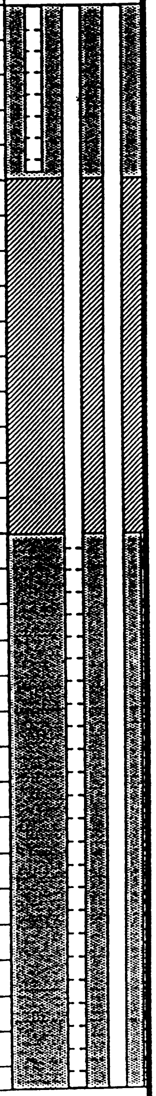
Traffic Rated Well Cover

Drawn By: M.J.L.	Date: April 1995	Approved By:	Date:	RG Number:	Fig. No.:

Start Time: 09 : 30	Finish Time: 16 : 30	Project Number: 11-00951-015			
Logged By: D.C.	Drilling Company: H-F drilling	Page 3 of 5			
Elevation: (ft. amsl)	Vapor Detector: PID	Drilling Method: HSA F-10	Sampling Method: Split Spoon		
Filter Pack: 22 Bags #3 Sand	Bentonite Seal: 14 Bags	Sanitary Seal: Grout 0-4'			
Casing Type: SCH 40 PVC	Diameter: 2"	Boring Dia.: 10'	Water Initial: None		
Screen Type: SCH 40 PVC	Slot Size: 0.020"	Diameter: 2"	Total Depth: 145'	Water Final: None	

Depth (feet)	LITHOLOGIC DESCRIPTION UNIT: Color, moisture, rel. density, texture (USCS Symbol), details. Odor, variations.	Sample Depth /Blows	Sample Type	Sample Designation	Screen Type	Screen Vapor (ppm)	Time
60	Moderate yellowish brown (10YR5/4), damp, sandy silt (ML), loose, (moderate plastic). Strong PHO	30 65 70	☒	NW1-65'		1,650	13:00
65	Moderate yellowish brown (10YR5/4), damp, loose, upper coarse-lower very coarse sands, PHO.						
70	Same as above, some rocks up to 1" in size, very loose, PHO.	75 100	☒	NW1-70'		450	13:07
		125 60 50	☒	NW1-75'	B	520	13:31
75	Moderate yellowish brown (10YR5/4), moist, firm, fine grained, silty clay, clay silt (ML), well sorted, plastic. PHO.						
80	Same as above	100 50 60	☒	NW1-80'	B	98	13:45
			■				
85	Same as above						
90			☒	NW1-90'	B	250	14:00

Boring/Well Completion



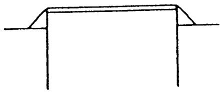
LEGEND

Sample Type
- ☒ Sleeve
- ⧄ Grab
- ⧅ Discard
- ■ No Recovery

Screen Type
- A - Ambient
- B - Bag
- C - Cuttings
- H - Head Space

- ▒ Bentonite Grout
- ▨ Bentonite Seal
- ▓ Filter Pack
- ---- Contact - Dashed where inferred.

- ☰ Perforations
- | | Well Casing
- ▬ Locking Cap
- ▽ Water Table



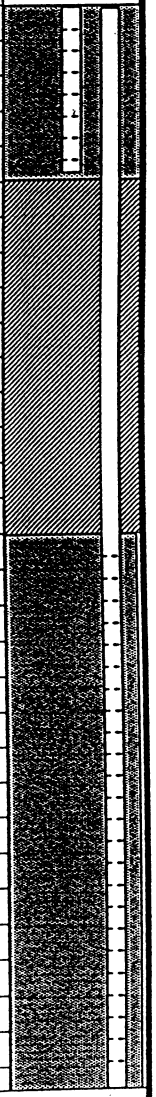
Traffic Rated Well Cover

Drawn By: M.J.L.	Date: April 1995	Approved By:	Date:	RG Number:	Fig. No.:

Start Time: 09:30	Finish Time: 16:30	Project Number: 11-00951-015	
Logged By: D.C.	Drilling Company: H-F drilling	Page 4 of 5	
Elevation: (ft. amsl)	Vapor Detector: PID	Drilling Method: HSA F-10	Sampling Method: Split Spoon
Filter Pack: 22 Bags #3 Sand	Bentonite Seal: 14 Bags	Sanitary Seal: Grout 0-4'	
Casing Type: SCH 40 PVC	Diameter: 2"	Boring Dia.: 10'	Water Initial: None
Screen Type: SCH 40 PVC	Slot Size: 0.020" Diameter: 2"	Total Depth: 145'	Water Final: None

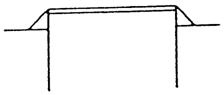
Depth (feet)	LITHOLOGIC DESCRIPTION UNIT: Color, moisture, rel. density, texture (USCS Symbol), details. Odor, variations.	Sample Depth /Blows	Sample Type	Sample Designation	Screen Type	Screen Vapor (ppm)	Time
90	Grayish orange (10YR7/4), damp, firm, crumbly (caliche) silty sand (SM). Slight PHO. Chunks of cemented matrix.						
			☒	NW1-95'	B	150	14:14
95	Pale yellowish brown (10YR6/2), firm, silty sand (SM). Slight PHO. Various chunks of cemented matrix.						
		35 50 60	☒	NW1-100'	B	113	14:33
100	Same as above						
		30 65 90	☒	NW1-105'	B	5.5	15:10
105	Pale yellowish brown (10YR6/2), damp, medium dense, lower to upper medium coarse sands, well sorted. No PHO, some fines 20%.						
110	Pale yellowish brown (10YR6/2), damp, loose, medium coarse upper to very coarse sands (GM) poor sorted, no PHO, some fines.	100 50 60	☒	NW1-110'	B	2.8	15:23
115	Pale yellowish brown, (10YR6/2), damp, loose, medium upper to coarse lower sand (GM), no PHO, some fines.	30 60 60	☒	NW1-115'			15:36
120	Pale yellowish brown (10YR6/2), damp, firm, silty sand with some rocks up to 3/4"; poor sorted. No PHO.	60 140	☒	NW1-120'			

Boring/Well Completion



LEGEND

Sample Type	Screen Type		
☒ Sleeve	A - Ambient	▒ Bentonite Grout	≡ Perforations
▨ Grab	B - Bag	▨ Bentonite Seal	| | Well Casing
⧅ Discard	C - Cuttings	▓ Filter Pack	▬ Locking Cap
■ No Recovery	H - Head Space	------ Contact - Dashed where inferred.	▽ Water Table



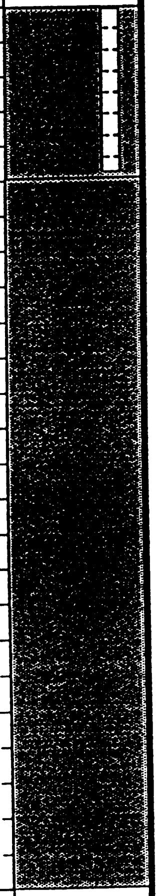
Traffic Rated Well Cover

Drawn By: M.J.L.	Date: April 1995	Approved By:	Date:	RG Number:	Fig. No.:

REFER TO BORING LOCATION MAP		**BORING/WELL LOG I.D.: NW1**	
		Date(s): 4/3/95	Project Name: Texaco/Grand Avenue
		Start Time: 09 : 30	Finish Time: 16 : 30
		Project Number: 11-00951-015	
		Logged By: D.C.	Drilling Company: H-F drilling
		Page 5 of 5	
Elevation: (ft. amsl)	Vapor Detector: PID	Drilling Method: HSA F-10	Sampling Method: Split Spoon
Filter Pack: 22 Bags #3 Sand	Bentonite Seal: 14 Bags	Sanitary Seal: Grout 0-4'	
Casing Type: SCH 40 PVC	Diameter: 2"	Boring Dia.: 10'	Water Initial None
Screen Type: SCH 40 PVC	Slot Size: 0.020" Diameter: 2"	Total Depth: 145'	Water Final None

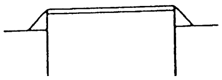
Depth (feet)	LITHOLOGIC DESCRIPTION **UNIT:** Color, moisture, rel. density, texture (USCS Symbol), details. Odor, variations.	Sample Depth /Blows	Sample Type	Sample Designation	Screen Type	Screen Vapor (ppm)	Time
120							
125	**ALLUVIUM:** Grayish orange (10YR7/4), damp, loose lower coarse silty sand (ML) well sorted, no PHO. Buff colored grains, mica flakes.	30 60 60	☒	NW1-125'	B	0ppm	07:52
130	Same as above	40 45 60	☒	NW1-130'	B	3.5	07:56
135	Pale yellowish brown (10YR6/2), damp, loose, medium coarse grained sand with micaceous material, some pebbles to 1/2" (SW), moderate sorted, no PHO. Buff colored graines.	30 60 85	☒	NW1-135'	B	5.4	
140	Same as above	20 30 45	☒	NW1-140'			
145	Same as above Total Depth=150'	25 39 60	☒	NW1-145'			
150							

Boring/Well Completion



END

Sample Type	Screen Type		
☒ Sleeve	A - Ambient	▒ Bentonite Grout	☰ Perforations
		▨ Bentonite Seal	| | Well Casing



APPENDIX B

SOIL VAPOR CHEMISTRY RESULTS

APPENDIX C

SOIL VAPOR EXTRACTION MODELING

PHYSICAL EQUATIONS GOVERNING SVE

Three-dimensional SVE modeling entails the coupling of advective flow and chemical transport processes in the vapor phase while maintaining mass balance with the VOC release. The vapor flow equation in three dimensions may be written (C-1):

$$\frac{\delta}{\delta x}\left(k_r k_x \frac{\delta P^2}{\delta x} \right) + \frac{\delta}{\delta y}\left(k_r k_y \frac{\delta P^2}{\delta y} \right) + \frac{\delta}{\delta z}\left(k_r k_z \frac{\delta P^2}{\delta z} \right) = \frac{2\mu WRT}{\delta x \;\delta y \;\delta z \; l} \qquad \textbf{(C-1) Baehr, 1989}$$

Where k_i is the soil permeability tensor in the I-direction, k_r is the relative vapor permeability (e.g., Equation C-2), P is pressure, µ is soil gas viscosity, W is a soil gas source/sink, R is the ideal gas constant, T is temperature, M_w is the molecular weight of soil gas. In English, the equation says that a change in flow into or out of an elemental volume must be equaled by a change in soil gas storage. Notice that without a source/sink term (i.e., an extraction well), the right-hand side of the equation is equal to zero and there is no change in flow conditions through time. The equation is analogous to the steady-state ground water flow equation except that the pressure term is squared because of gas compressibility.

$$k_r = \left(\frac{\epsilon}{\nu} \right)^3 \qquad \textbf{C-2 Falta, 1989}$$

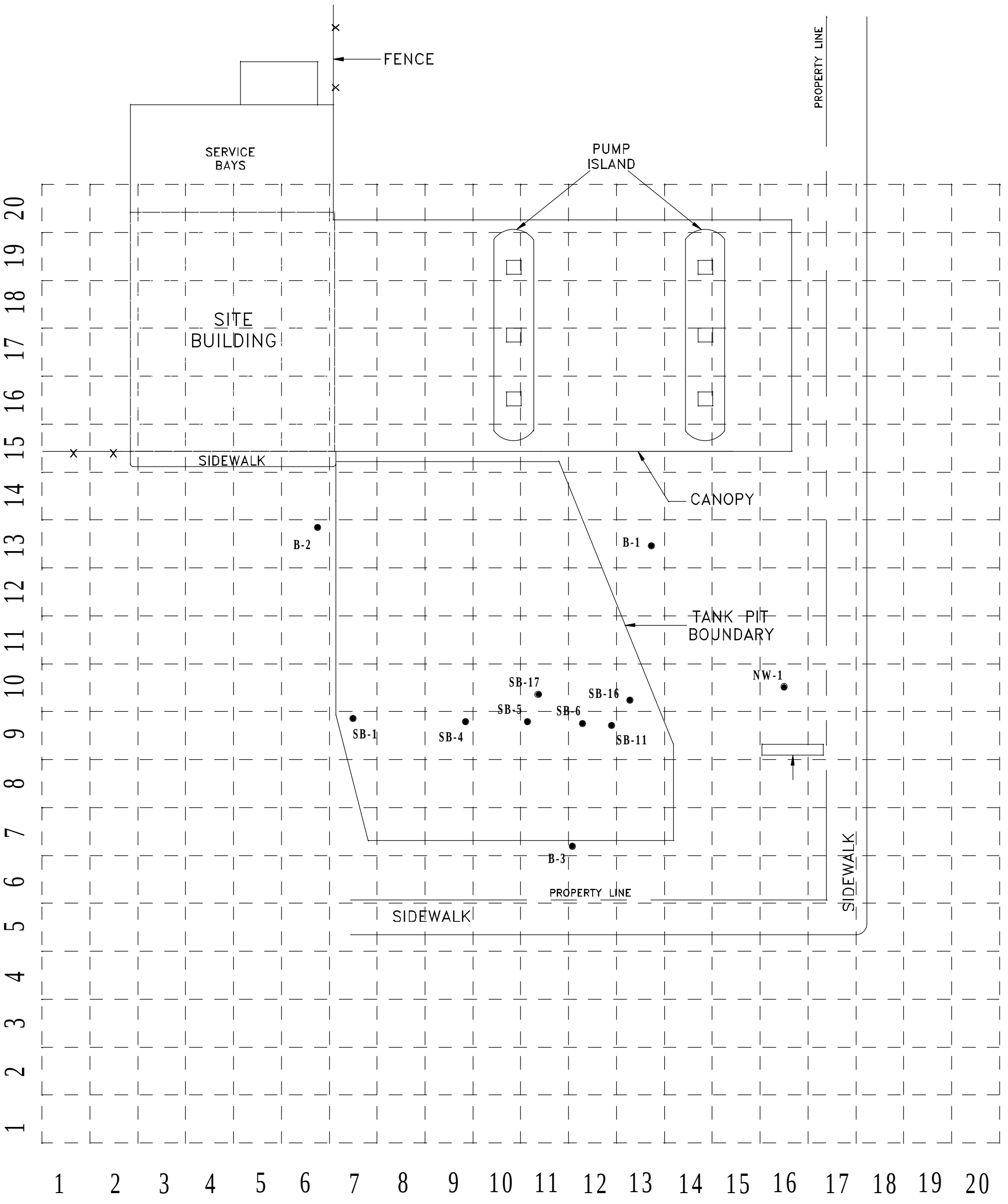
Where ϵ is air filled porosity and ν is total porosity. This expression is a simplification of the Brooks-Corey relationship (Falta, 1989) and is used to solve for changing relative permeability as a function of soil pore fluid content. Other relative permeability functions are available (e.g., Mualem, 1976; Stone, 1969; Gardner, 1959) that describe a similar relationship between moisture content and relative permeability.

From equation (1), Section 3.0, the pressure distribution and flow vectors can be determined in three dimensions. Flow can then be linked to vapor-phase transport using the advection-dispersion equation (C-3), which is written in tensor notation to save ink and grief:

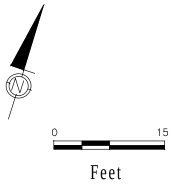
$$\nabla(Dij \;\; \nabla C_n - q_i C_n) = \frac{\delta M_n}{\delta t} + F_n \qquad \textbf{(1)}\text{ Ref}$$

Where ∇ is the gradient operator; D_{ij} is the dispersivity tensor; C_n is the molar vapor concentration of species "n"; q_i is the velocity vector in the I-direction; M_n is the total molar concentration of species "n" in soil; t is time; and F_n is a chemical source/sink term accounting for species degradation or source input.

The model VENT3D (Benson, 1995) solves equations (C-1) through (C-3) using a finite difference iterative solver. The model can calculate the distribution of soil contamination as a function of stratigraphy, cleanup time, SVE pumping rates, and other necessary relationships within the scope of this work. The code is particularly useful in that it accounts for up to 50 individual chemical species within a single product, such as gasoline. Persistent readers are directed to Benson et al., 1994; Johnson et al., 1990; and Baehr, 1976; for further theoretical and tedious development.



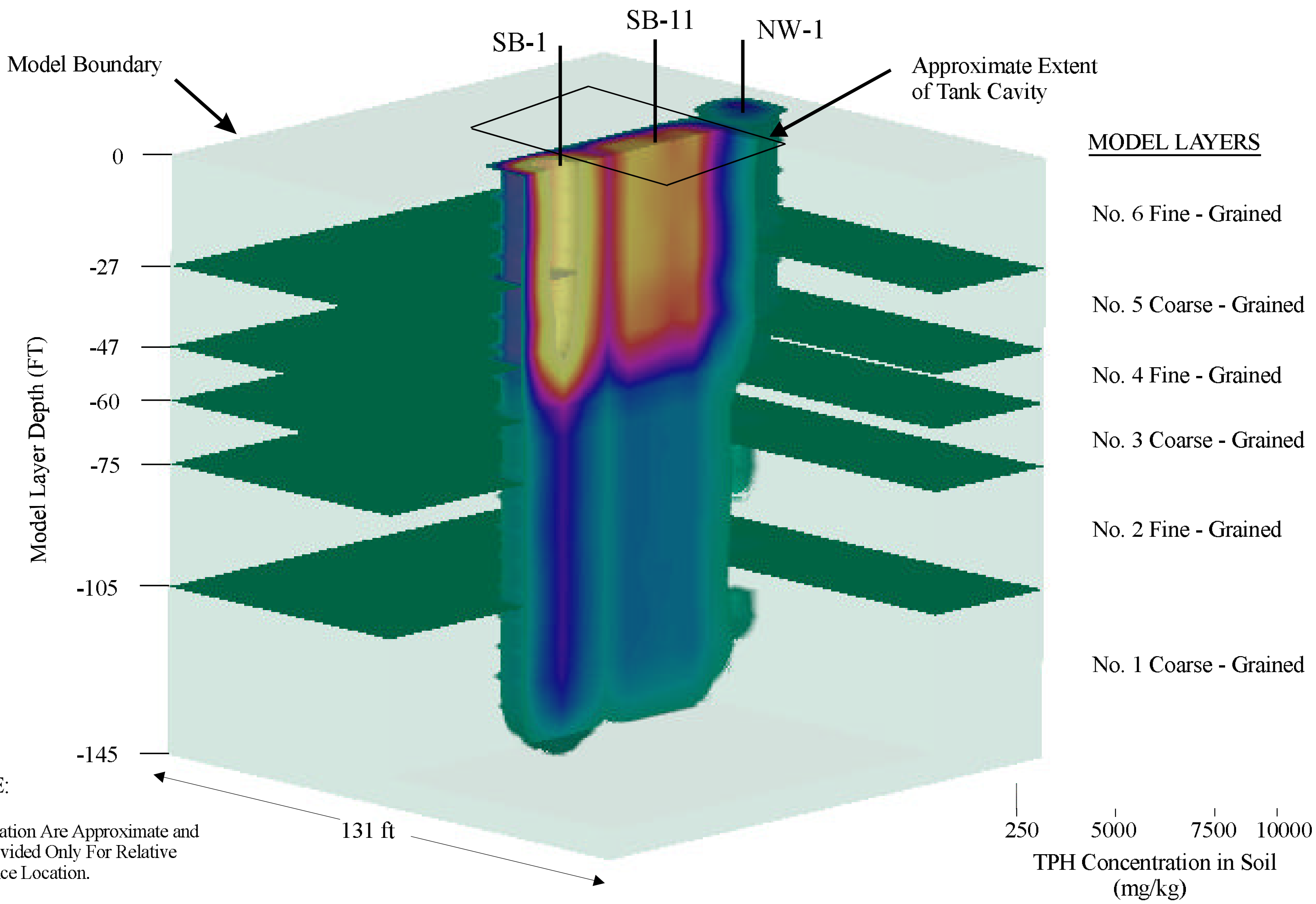
PLAN VIEW
MODEL GRID



SERVICE STATION
123 Someplace Ave.
Hot Dang, Nevada

AQUI-VER, INC.

SVE Simulation No. 2, Time = 0 Days
Service Station; Hot Dang, Nevada



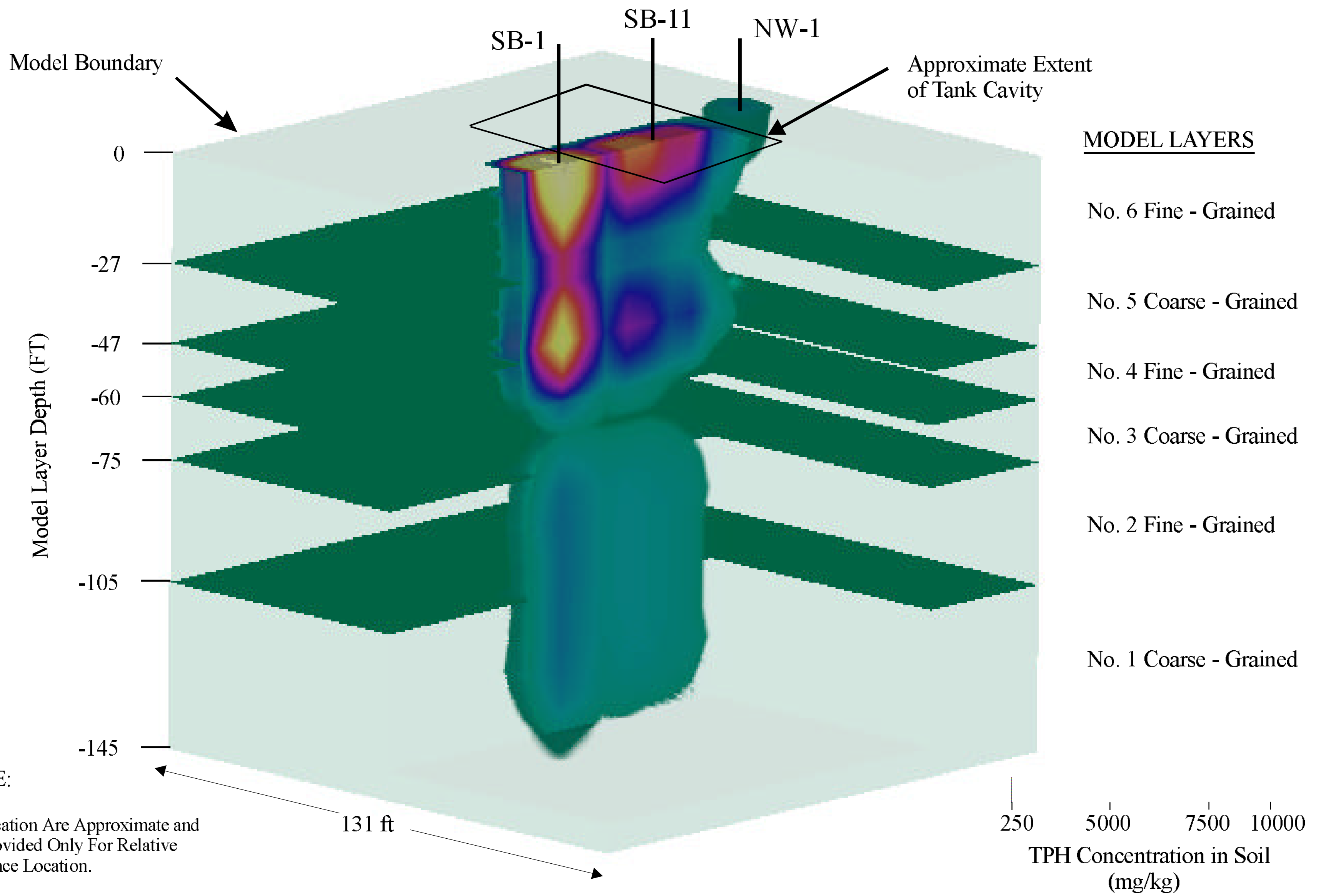
NOTE:

All Location Are Approximate and Are Provided Only For Relative Reference Location.

TPH = Total Petroleum Hydrocarbons

AQUI-VER, INC.

SVE Simulation No. 2, Time = 1070 Days
Service Station; Hot Dang, Nevada



NOTE:

All Location Are Approximate and Are Provided Only For Relative Reference Location.

TPH = Total Petroleum Hydrocarbons

AQUI-VER, INC.