

# HEALTH RISK ANALYSIS CARRIED OUT IN AN OIL STORAGE AND DISTRIBUTION STATION IN EASTERN CENTRAL MEXICO TO DETERMINE REQUIRED CLEANING LEVELS

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## ABSTRACT

Subsoil of an oil storage and distribution station (ODSS) located in Eastern Central Mexico was characterized in terms of total petroleum hydrocarbons (TPHs), the 16 polynuclear aromatic hydrocarbons (PAHs) suggested by USEPA as priority contaminants, benzene, ethyl benzene, toluene, and xylenes (BTEX), methyl tert butyl ether (MTBE) tertamyl methyl ether (TAME), and four metals *i.e.*, Fe, V, Pb, Ni and Zn. ODSS resulted contaminated mainly by TPHs in a concentration higher than that legislated in Mexico (NOM-EM-138-ECOL-2002). It was detected the presence of BTEX and 11 of the 16 PAHs suggested by USEPA as prioritary pollutants. MTBE was found in only one sampling point, but TAME was not found anywhere. Metals were under the suggested limits, so they do not need to be reduced. The health risk assessment carried out indicated that only dibenzo(a,h)anthracene is in a concentration that exceeds the previously fixed maximum acceptable risk of  $1 \times 10^{-5}$ . Hence, dibenzo(a,h)anthracene must be reduced from 2.36 mg/kg to 2.0 mg/kg. Soil must be treated to reduce the TPHs actual concentration up to a value of 2,000 mg/kg, as suggested by the Mexican Norm.

## INTRODUCTION

Petróleos Mexicanos (PEMEX) is very concerned of the environmental problems associated to the exploration, extraction, refining, distribution and storage of crude oil and its fractions.

Our research group has developed different media characterizations of refineries and ODSS along the country (Iturbe *et al.*, 2003 a, b, c, d, among others). In most sites, after soil and water characterization, risk health assessment has been carried out to

determine the state of the facilities and the required cleaning levels for industrial soil uses. After that stage the appropriated remediation methodologies to clean-up soils and aquifers affected by hydrocarbon pollution have been suggested. Pilot plant-level treatments as well as full-scale remediation processes have been carried out in some of those sites.

The aim of this work is to show the entire characterization process carried out in Eastern central Mexico ODSS subsoil. A step-by-step health risk assessment HRA procedure is showed. The tools for this HRA procedure were ASTM RBCA Tools Kit for Chemical Releases (GSI, 2000).

## **MATERIALS AND METHODS**

### **Soil sampling procedure**

Soil samples were taken in 19 points distributed in the ODSS area, at different depths. Samples were taken at 1.0 - 3.8 m below surface. They were extracted with pneumatic perforation equipment. This equipment has a 12 HP motor, variable speed and 2,000 pounds working pressure. A helicoidal 3-inch tube was employed for drilling. For sampling, a 0.6 m long and 1.5 in diameter tube screwed on both sides was used and was driven into the soil at the bottom of a borehole by means of a 63.5 hammer having a free ball of 760 mm similar to that used in standard penetration test (SPT). Inside there is an aluminum tube where the sample is accumulated. In that way, there is no contact between the soil and air. Samples were stored at low temperature (4 °C) until they were analyzed. Parameters evaluated in the soil samples were total petroleum hydrocarbons (TPH); hydrocarbons profile, including diesel fraction, gasoline fraction, methyl tertbutyl ether (MTBE), and tertamyl methyl ether (TAME); and BTEX (benzene, toluene, ethyl benzene, and xylenes). Additionally, 16 polynuclear aromatic hydrocarbons (PAH) were analyzed: Acenaphthene, phenanthrene, fluoranthene, fluorene, anthracene, indene(1,2,3-cd)pyrene, acenaphthylene, naphthalene, pyrene, benzo(a)anthracene, benzo(a)pyrene, benzo(a)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, chrysene and dibenzo(a,h)anthracene. Finally, four metals were measured—Zn, Cr, Fe, and Pb.

### **Analytical methods**

Soil samples were evaluated in accordance to USEPA analytic techniques: EPA418.1 for TPH concentrations; EPA6010 for Pb, Cr, Fe and Zn; EPA8240 for hydrocarbons *i.e.* diesel and gasoline, MTBE, and BTEX. PAHs were analyzed using the EPA8100 method.

### **Explosivity index**

19 sampling points were distributed in the ODSS, for evaluating explosivity indexes. Explosivity index was measured with a COSMOS XP-311 ALPHA A system (New Cosmos Electric Co. LTD; Japan). Measurements were done at the same depth than the rest of the parameters.

## Health risk assessment

In order to establish soil and groundwater clean-up levels protective to the health of the population exposed (workers of the facility and residents living in the neighborhood) the HRA approach was carried out by means of RBCA Tool Kit for Chemical Releases v 1.3. HRA considers four main steps: 1) Hazard Identification, 2) Dose-Response or Toxicity Assessment, 3) Exposure Assessment, and 4) Risk Characterization (Boguski 2001, Kaplan & McTernan 1995), and depending on the site specific conditions, the chemical characteristics, and the risk that is set as *acceptable* the clean up remediation goals can be more or less restrictive.

# RESULTS AND DISCUSSION

## Site characterization

### *Hydrocarbons distribution*

Table 1 shows the minimum, maximum, average (including standard deviations) concentrations found at the Eastern Mexico ODSS as well as the number of points where contaminates were detected. As shown, TPH concentrations ranged between 7,452 and 21,307 mg/kg (average of 13,360 +/- 5,346 mg/kg). These hydrocarbons were detected in only 6 points of the studied area. Diesel fraction was found at 7 sampling points in the range of 2.83-478 mg/kg (average of 279.02 +/- 189.05 mg/kg). Gasoline fraction was detected at 6 points between 3.2 and 629 mg/kg (average of 175.58 +/- 23.07 mg/kg). BTEX were found in 8-15 ODSS sampling points in the following intervals. Benzene: 0.001 to 7.93 mg/kg, ethyl benzene: 0.001 to 58.4 mg/kg, toluene: 0.001 to 1.79 mg/kg, and xylenes: 0.001 to 74.66 mg/kg.

TAME was not found anywhere, but MTBE was detected in one point at a concentration of 0.0085 mg/kg. Regarding the 16 PAHs considered by USEPA as priority pollutants, 11 were found at the ODSS in rather low concentrations. The most abundant PAH was naphthalene (found at 6 sampling points) in concentrations between 5.37 and 14.51 mg/kg. Dibenzo(a,h)anthracene was detected in only two points, in concentrations between 0.01 and 2.36 mg/kg. Phenanthrene in the third place of abundance appeared in 6 sampling points in concentrations between 3.26 and 6.62 mg/kg. Naphthalene and phenanthrene are non-carcinogenic compounds, but dibenzo(a,h)anthracene is considered as carcinogenic, as well as chrysene, benzo(a)anthracene, benzo(a)pyrene, benzo(k)fluoranthene, and indene(1,2,3,c,d)pyrene, also present in some points at the ODSS. Explosivity was detected in 7 sampling points in values from 20 to 100%.

Figure 1 shows a spatial distribution of TPH inside the ODSS. As observed, high TPH values are quite located at specific zones inside the ODSS. There seems to be two hot spots where TPH concentrations are higher. Those points correspond to sampling points 1 (815,773 mg/kg), and 4 (21,307 mg/kg). Both points are located on the railroad. From these points on, TPH concentrations tend to vanish gradually up to 2,000-5,000 mg/kg concentrations. Figure 2 shows the distribution of PAHs on the ODSS. As noted,

points where PAHs were identified are located also on the railroad. They correspond to points 1, 4, 5 and B. Total PAHs concentrations for these points are 13.62, 11.35, 26.18 and 31.47 mg/kg, respectively.

#### *Metals distribution and accumulation indexes*

Regarding the metals analyzed, Fe, V, Pb, Ni and Zn were measured in the soil samples. Fe fluctuated between 4,598 and 20,976 mg/kg, V between 16.2 and 56 mg/kg. On the other hand, Pb was in the 3.4 to 29.9 mg/kg, Ni in the range of 4.8 to 14.8 mg/kg, and Zn between 12.7 and 47.6 mg/kg (see table 1).

Metals were present in all the sampled points, as expected, but concentrations were quite variable along the studied zone. Figure 3 shows the vanadium concentrations along the ODSS. It is remarkable that there is a hot spot located on sampling point number 6. Figure 4 shows the explosivity levels higher than 50% at the ODSS. It is noteworthy the fact that explosivity values higher than 50% are located on the railroad, coinciding with the high TPH concentration hot spots. Points where this condition was achieved are 1, 4, 5, and A.

On table 2, sampling points where no hydrocarbons were detected are showed (*i.e.* TPH, gasoline fraction, diesel fraction, BTEX, PAH, MTBE). Ten points are in this category. Average and standard deviations for every metal were calculated and reported on Table 2. Detection limits for every metal are reported in the same table. As observed, standard deviations are rather high. They represent 17.2, 21.3, 36.2, 14.6, and 19.5% of the average, for Fe, V, Pb, Ni, and Zn, respectively. These average values will be assigned as the metal background concentrations. In an effort to discuss the possibility of metal contamination (due to oil spills inside the ODSS), the equation proposed by Muller (1969) for calculation of geo-accumulation will be employed:

$$I\text{-geo} = \log_2 (C_n/1.5B_n) \quad (1)$$

Where  $C_n$  is the analyzed metal concentration, and  $B_n$  is the background content for the metal.

From table 2, it is noticeable that I-geo values for Fe, V, Pb, Ni and Zn are -0.3402, -0.4237, 0.3535, -0.4288, and -0.2311. It is clear that only Pb seems to be accumulated in the ODSS soil, *i.e.*, shows a positive value.

#### *Relationship between organic compounds and metals*

With the purpose of getting more information in order to explain some organic compounds and metal distribution behaviors in the ODSS, relationships among TPH, diesel fraction, gasoline fraction, BTEX, PAHs, MTBE, and the five measured metals were investigated. Most interesting relationships are reported on Table 3. As shown, TPHs seems to be not related with gasoline, but with diesel, though  $r^2$  coefficient is not good enough, (-0.1088 and 0.7001, respectively). Diesel fraction seems to be related with naphthalene (again,  $r^2$  coefficient is not very good *i.e.*, 0.7355), but not with Fe or Pb ( $r^2$  coefficients of -0.1493 and -0.2861, respectively). Gasoline fraction, on the other hand, seems to be related with benzene, ethyl benzene toluene, and xylenes, as expected ( $r^2$  coefficients of 0.9601, 0.7515, 0.9569, and 0.9624, respectively). Finally, gasoline

resulted related with lead ( $r^2$  coefficient of 0.9464), and perhaps with iron ( $r^2$  coefficient of 0.7057).

In an effort of understanding the relationship between gasoline and these two last mentioned metals *i.e.*, Fe and Pb, they were plotted as a function of the gasoline fraction concentration on Figure 5. As observed on figure 5, a) Fe has the tendency of augment as the gasoline fractions increases, but  $r^2$  coefficient is not very good. The explanation for this behavior could be related with the fact that where contamination with gasoline is present, allows the movement of Fe more freely, concentrating the metal in some hot spots. This behavior was found in the study of other ODSS in Mexico (Iturbe *et al.*, 2003a and b). b) Pb has also the tendency of growing as the gasoline fraction increases, with a quite good  $r^2$  coefficient (0.8958), which means that the lead contamination in the ODSS soil is probably coming from gasoline contamination. The use of gasoline in Mexico started since the 1930's to the end of 1990's, approximately in 1997 (Thomas *et al.*, 1999), when unleaded gasolines (*Magna sin* and *Premium*) substituted the old leaded gasolines (*Nova* was the last one of a list). Regarding the amount of lead present in gasolines was quite variable. From 1988 to 1993 it was reduced from 0.2 to 0.06 g/L (Thomas *et al.*, 1999). These arguments are confirmed by the fact that Pb was the only one metal that seems to be geo-accumulated at the ODSS soil.

## Health risk assessment results

The general scenario considered for the evaluation was set in two kinds of receptors: On-site and Off-site, the first ones are the workers of the facility and the latter ones are the neighbors living in the houses located next to the facility (at the north and west sides of the facility) with an estimated population of 2,000 people. Land use for the On-Site receptors was classified as industrial and for the Off-Site receptors was set as residential. Information regarding to geo-hydrological and climatic conditions was gathered, and physical and chemical properties of the soil were measured. A summary of this information is presented on Table 4.

For the HRA, the maximum soil concentrations found were used. These results are shown on third column, Table 1. No samples of groundwater were analyzed because the aquifer beneath the facility is about 200 m depth and the water used by the workers and the neighbors come from a well located 10 km down gradient the facility.

Soil sampling showed the presence of contaminants in the soil and subsoil (PAHs were found at 3.8 m depth). The migration pathways considered for the site were air and groundwater migration, considering soil to air volatilization or particulate re-suspension due to the action of the wind, and leaching from soil to groundwater; the latter one was considered even though the aquifer is very depth because it was established the worst scenario for the extraction well located down-gradient the facility, where the drinking water comes from. The exposure routes considered were dermal contact and ingestion of soil, vapor and particulate inhalation, and ingestion of water (water contaminated due to the leaching of substances from soil to groundwater).

The software calculates the doses received by the population considered to be exposed (workers of the facility on an industrial land use, and neighbors on a residential land use) through the different exposure routes (ingestion, inhalation and dermal contact), and calculates the Hazard Quotient for non carcinogen effects (exposure dose/ RfD), and

the Risk for carcinogen effects (exposure dose x SF). Acceptable HQ was set as 1, and acceptable Risk was set as  $1 \times 10^{-5}$ .

The HQ calculated by the software, ranged from  $2.1 \times 10^{-10}$  (Naphthalene, On-Site receptors dedicated to construction operations, via inhalation of vapors and particulates) to  $2.2 \times 10^{-1}$  (Fluoranthene, Off-Site receptors with residential land use, via ingestion of groundwater contaminated by the leaching from soil). This shows that none of the contaminants is expected to be above the HQ established as acceptable, therefore the population exposed under the scenario proposed for the site is not likely to present the systemic effects associated to the contaminants

The Risks calculated by the software (Table 8) ranged from  $6.7 \times 10^{-15}$  (Benzo(k)fluoranthene, Off-Site receptors with residential land use, via ingestion of groundwater contaminated by the leaching from soil) to  $1.2 \times 10^{-5}$  (Dibenzo(a,h)anthracene, On-Site receptors dedicated to construction operations, via soil ingestion and dermal contact). This shows that only the On-Site population is at risk of developing cancer (Risk value established as acceptable,  $1 \times 10^{-5}$ , was exceeded), and this happens by the soil exposure to Dibenzo(a,h)anthracene, so it is necessary to reduce soil concentration of this contaminant to a level that assures that the acceptable Risk is not going to be exceeded.

Table 9 shows soil concentrations necessary for all the contaminants to assure that the HQ and Risks are not going to be exceeded; comparing these concentrations to the actual concentrations present at the site. On the same table, the Mexican NOM values, and Louisiana State (USA) Standards are included for comparison purposes. It is concluded that only Dibenzo(a,h)anthracene soil concentration has to be reduced from 2.36 mg/kg to the value suggested by HRA, *i.e.*, 2.0 mg/kg. If maximum concentrations found at ODSS are compared to the Mexican NOM, only TPHs value overpasses the suggested value of 2,000 mg/kg. If the same concentrations are compared to the Louisiana State Standards, TPHs, benzene, dibenzo(ah)anthracene, and naphthalene exceed those standards (*i.e.*, 500, 3.2, 0.36, and 5.2 mg/kg, respectively).

From the HRA, and Mexican NOM, it was concluded that TPHs concentrations must be under 2,000 mg/kg, and dibenzo(a,h)anthracene must be reduced up to 2 mg/kg. Lead is not present in a harmful concentration. The ODSS under study can be remedied using available techniques so in a short period ODSS soil can be in conditions for any industrial use.

Biopiles and soil washing are widely recommended; since they have showed their easiness and cost-effective development in treating similar refineries or ODSS contaminated soils in Mexico (Iturbe *et al.*, 2001; Iturbe *et al.*, 2003d)

## CONCLUSIONS

Main conclusions derived form this study are the following.

- The ODSS under study resulted contaminated in terms of TPHs, BTEX, diesel and gasoline fractions, and some PAHs *i.e.*, phenanthrene, fluoranthene, fluorene, naphthalene, pyrene and chrysene. Explosivity indexes higher than 50% were

observed. Fe, V, Pb, Ni and Zn concentrations are high, but at this point it is not clear if they are geologically determined or they are contamination product.

- There seems to be two hot spots where TPH concentrations are higher. Those points correspond to sampling points 1 (815,773 mg/kg), and 4 8 (21,307 mg/kg). Both points are located on the railroad. Explosivity index higher than 50% are located in the same area (over the railroad).
- Geo-accumulation indexes values for Fe, V, Pb, Ni and Zn are  $-0.3402$ ,  $-0.4237$ ,  $0.3535$ ,  $-0.4288$ , and  $-0.2311$ . In basis to these indexes, it can be concluded that only Pb seems to be accumulated in the ODSS soil, *i.e.*, shows a positive value.
- TPHs seem to be not related with gasoline, but with diesel. This fraction seems to be related with naphthalene, but not with Fe or Pb. Gasoline fraction, on the other hand, seems to be related with BTEX, as expected. Finally, gasoline resulted related with lead and perhaps with iron. This would mean that gasoline is responsible of metal and BTEX concentration in a major way, and diesel would be for PAHs and TPH contamination.
- Only dibenzo(a,h)anthracene soil concentration represents a risk to the health of the population exposed. Even though the soil is permeable, there are some attenuating factors as the depth of the exploitable aquifer and the distance to the point of contact (extraction well), which reduces the magnitude of the potential impacts.
- From the HRA, and Mexican Norm, it was concluded that ODSS TPHs concentrations may be reduced up to 2,000 mg/kg and dibenzo(a,h)anthracene must be reduced up to 2 mg/kg. Lead is not present in a harmful concentration.

## ACKNOWLEDGEMENTS

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**Figure 1. TPHs distribution at the ODSS.**

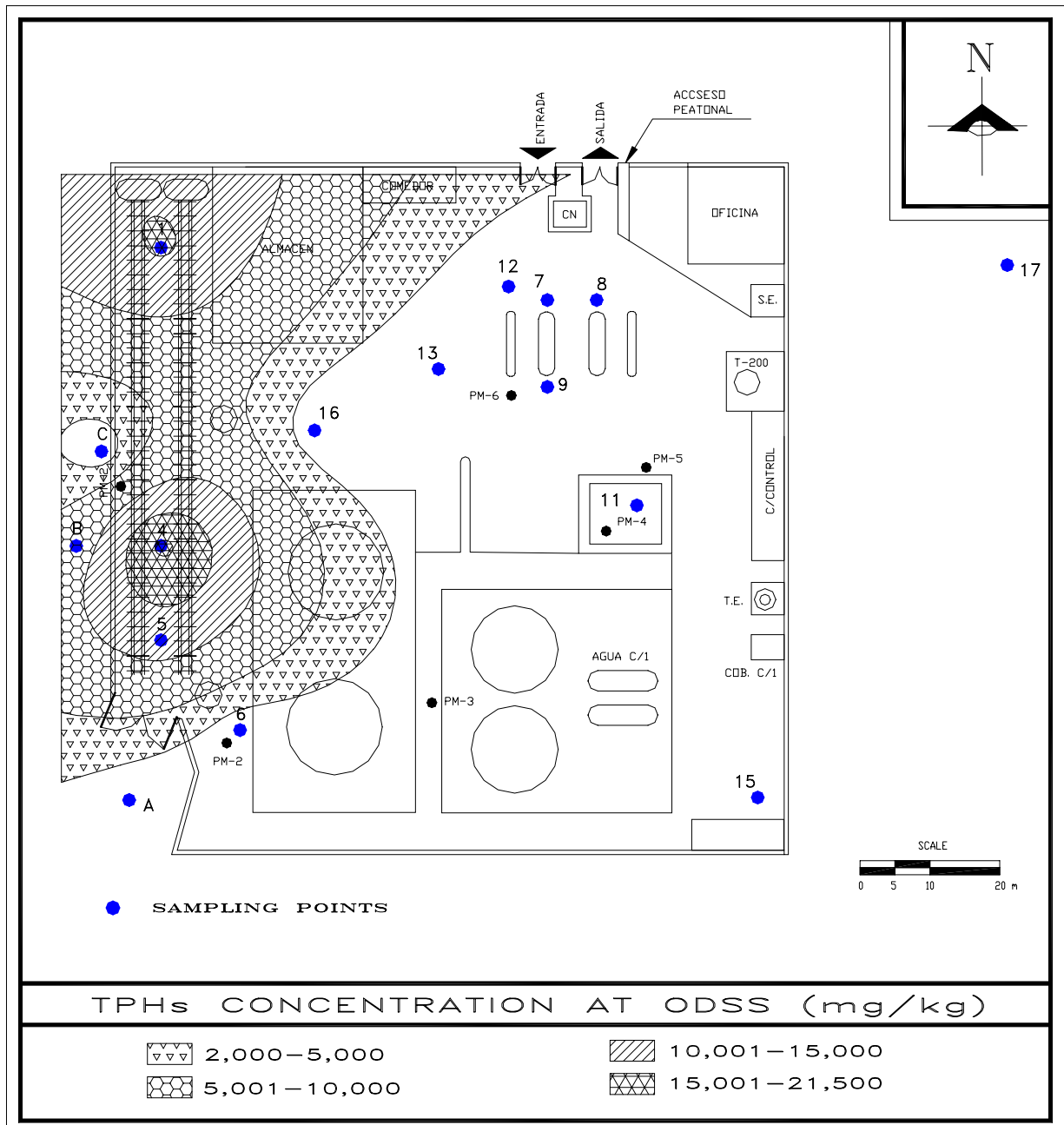


Figure 2. PAHs distribution at the ODSS.

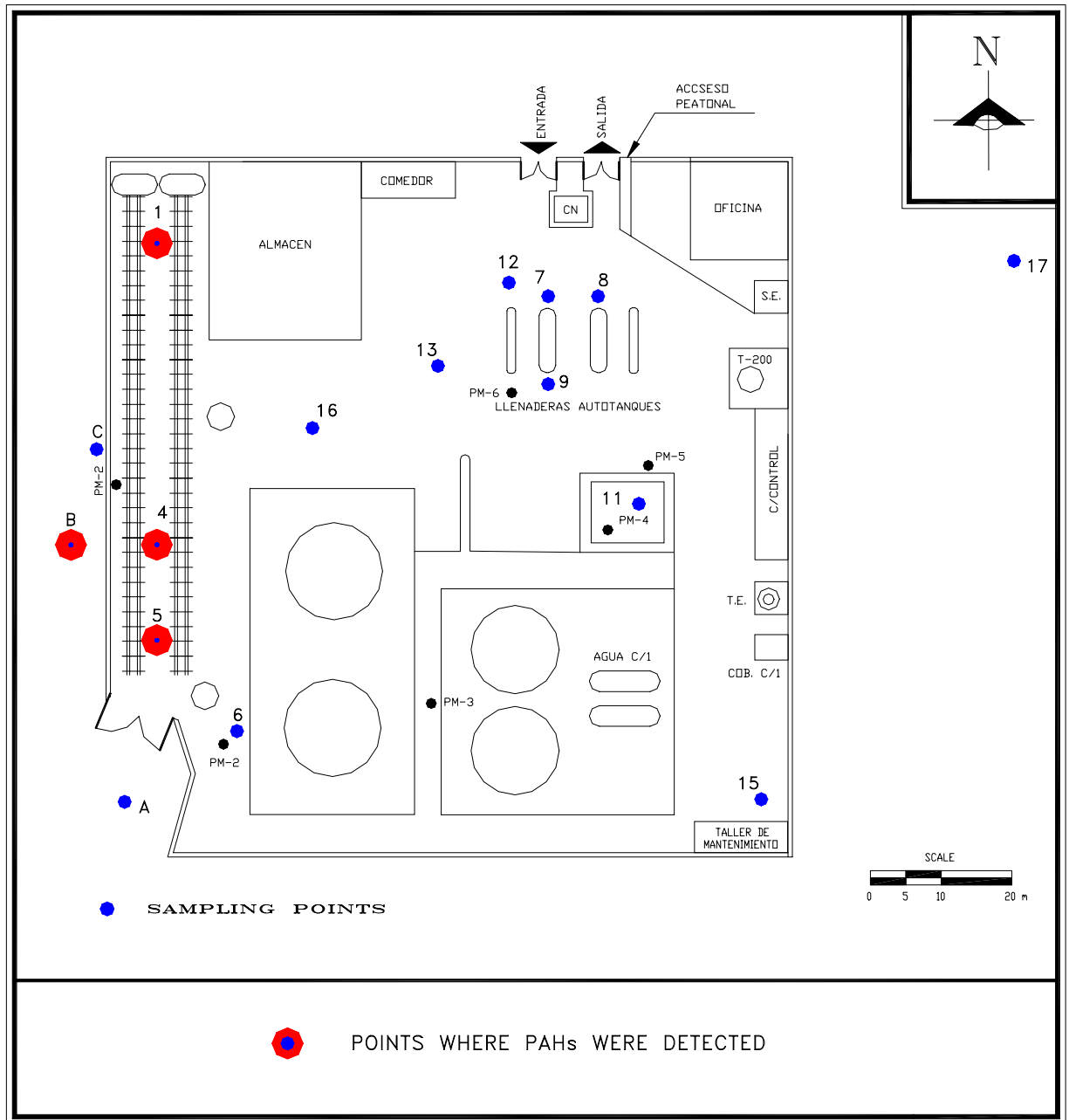
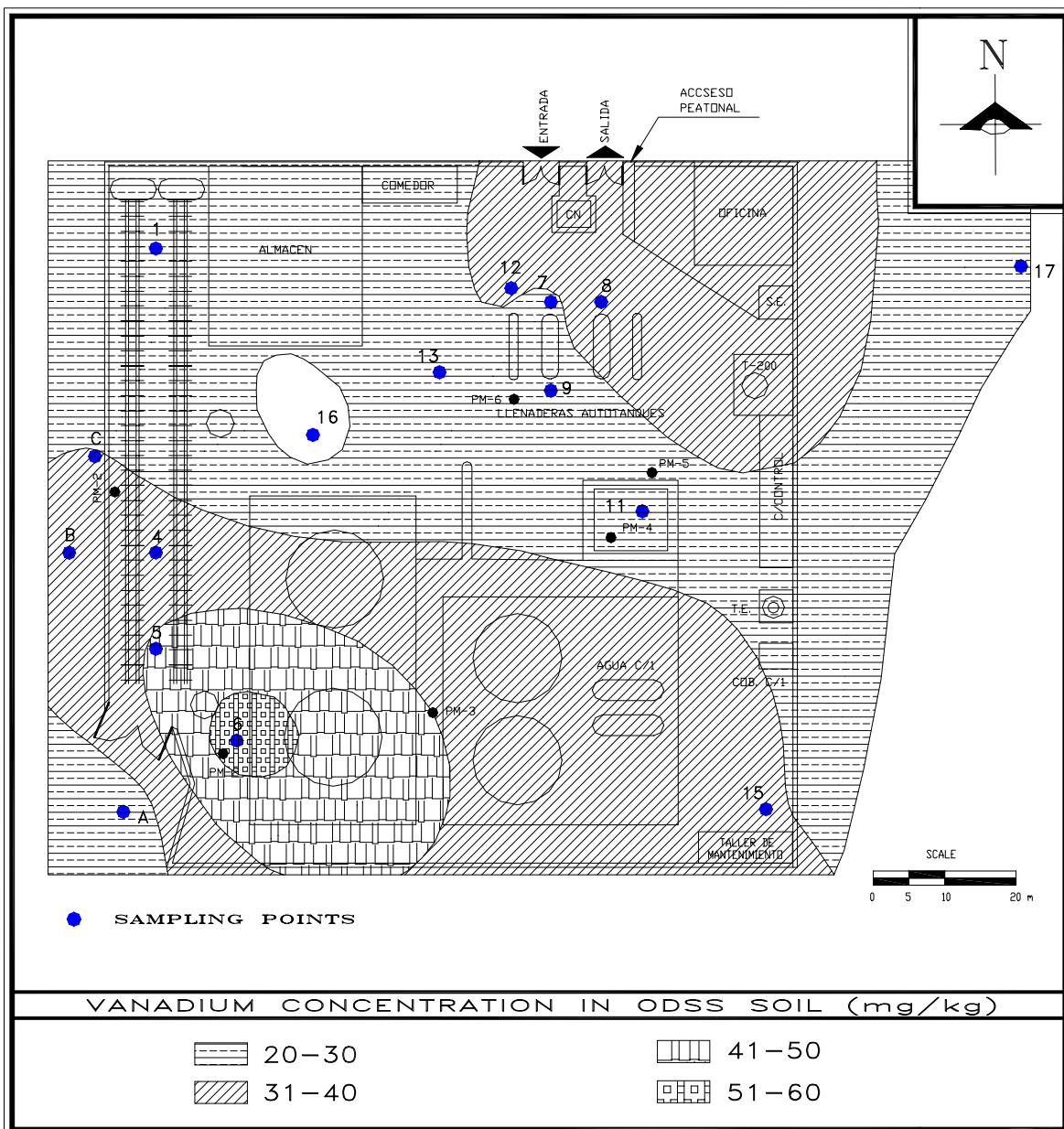


Figure 3. Vanadium distribution at the ODSS.



**Figure 4. Explosivity values distribution at the ODSS.**

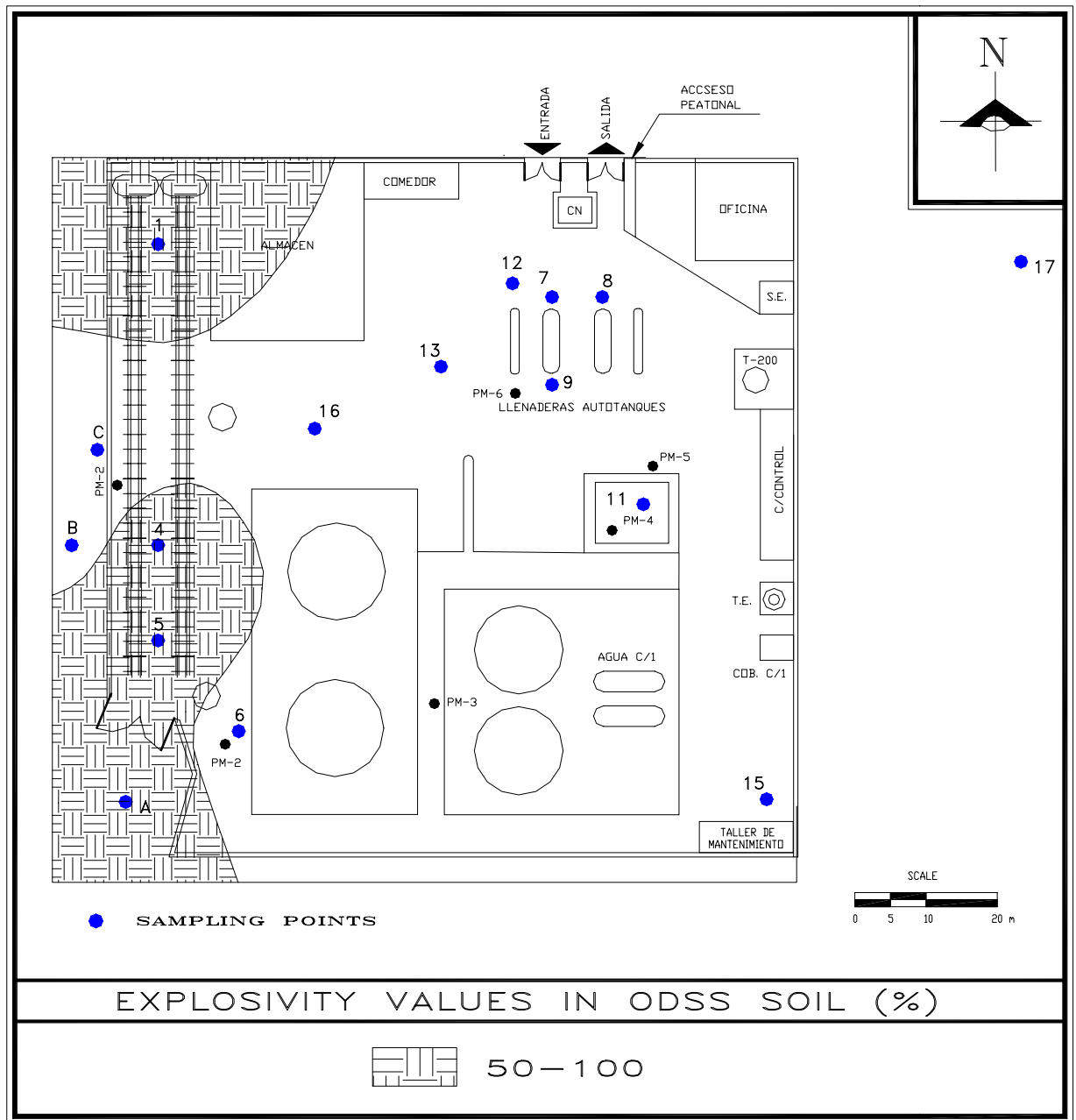
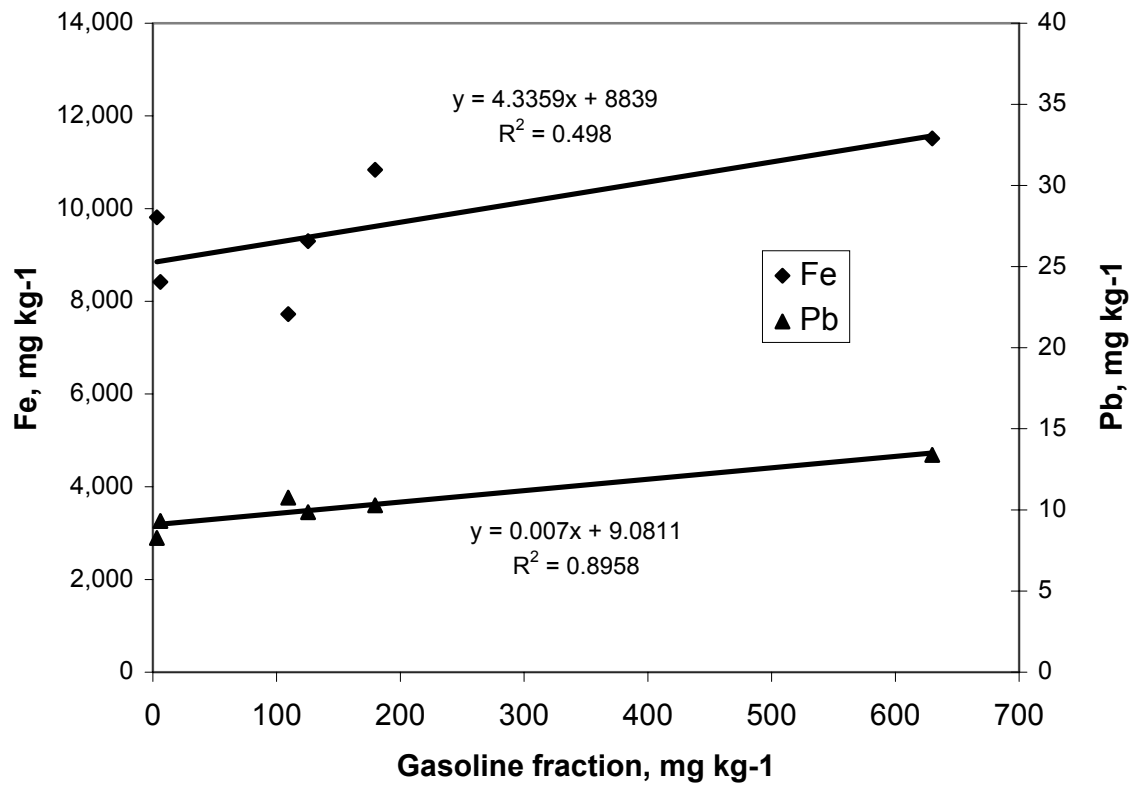


Figure 5. Gasoline-lead and iron relationship in the ODSS soil



## TABLES

**Table 1.** Characterization of the 19 sampling points.  
All in mg/kg, except explosivity (%)

Parameter	Min value	Max value	Ave value	Std deviation	Number of points where compound appeared
TPH	7,452	21,307	13,360	5,346	6
Diesel fraction	2.83	478.50	279.02	189.05	7
Gasoline fraction	3.20	629.74	175.58	233.07	6
Benzene	0.001	7.93	1.02	2.79	8
Ehtylbenzene	0.001	58.40	6.63	16.96	14
Toluene	0.001	1.79	0.14	0.48	14
Xylenes	0.001	74.66	5.43	19.17	15
MTBE	0.008	0.008	0.008	0.0	1
Dibenzo(a)anthracene	0.01	2.36	1.19	1.66	2
Phenanthrene	3.26	6.62	4.38	1.44	6
Fluoranthene	0.22	0.80	0.40	0.20	6
Fluorene	1.55	3.12	2.13	0.61	6
Indene(1,2,3- cd)pyrene	2.31	2.31	2.31	0.0	1
Naphthalene	5.37	14.51	8.97	3.98	6
Pyrene	0.62	1.65	0.89	0.39	6
Benzo(k)fluoranthene	0.32	0.32	0.32	0.0	1
Benzo(a) pyrene	0.23	0.23	0.23	0.0	1
Benzo(ghi)perylene	2.05	2.05	2.05	0.0	1
Chrysene	0.34	0.41	0.38	0.05	2
Explosivity	20	100	88.57	3.24	7
Fe	4,598	20,976	9,136	3,268	19
V	16.19	56.08	30.64	8.70	19
Pb	3.41	29.91	10.55	0.63	16
Ni	4.84	14.79	8.32	1.96	19
Zn	12.76	47.62	25.56	8.98	19

**Table 2.** Background metal concentrations for the ODSS (mg/kg)

<b>Point</b>	<b>Fe</b>	<b>V</b>	<b>Pb</b>	<b>Ni</b>	<b>Zn</b>
7	8,419	27.58	9.58	8.53	27.84
8	9,731	38.68	NR	7.96	21.32
9 A	6,978	25.06	NR	7.35	17.44
11	8,119	28.73	5.33	8.00	20.88
12	8,319	31.66	5.67	8.62	20.62
13	7,769	26.96	3.98	7.69	19.24
15	8,405	30.26	5.46	7.74	22.56
16	4,598	16.19	3.41	4.48	12.76
17	8,254	26.32	4.99	6.78	19.67
A	6,509	22.87	NR	7.01	17.53
Aver	7,710	27.43	5.49	7.45	20.00
Std dev	1,325	5.85	1.99	1.09	3.90
I-geo	-0.3402	-0.4237	0.3635	-0.4288	-0.2311
Detect limit	4.00	5.31	6.37	3.31	3.72

**Table 3.** Relationships among metals and organic compounds at the ODSS subsoil. Values of R<sup>2</sup>

	<b>TPHs</b>	<b>Diesel</b>	<b>Gasoline</b>	<b>B</b>	<b>E</b>	<b>T</b>	<b>X</b>	<b>Naph.</b>	<b>Fe</b>	<b>Pb</b>
TPHs	*	-0.1088	0.7001	0.7001	<i>0.8117</i>	0.7344	0.7422		0.1875	<i>0.8184</i>
Diesel		*						0.7355	-0.1493	-0.2861
Gasoline			*	<i>0.9601</i>	<i>0.7515</i>	<i>0.9569</i>	<i>0.9624</i>		0.7057	<i>0.9464</i>

**Table 4.** Geo-hydrological parameters describing site characteristics

<b>Parameter</b>	<b>Value</b>
Area of contaminated soil (m <sup>2</sup> )	9300
Soil type	Silty sand
Total porosity (dimensionless)	0.49
Soil bulk density (g/cm <sup>3</sup> )	1.36
Water table depth (m)	200
Ground water direction	E-W
Hydraulic gradient (dimensionless)	0.001
Soil organic carbon fraction (dimensionless)	0.0054
Soil pH (dimensionless)	6.5
Mean precipitation (cm/year)	54
Wind speed (m/s)	2.77
Wind direction	NE-SO

**Table 6.** Comparison among HRA required levels, Mexican NOM, USA standards (Louisiana State), and ODSS maximum concentrations

<b>Compound</b>	<b>HRA level (mg/kg)</b>	<b>NOM (mg/kg)</b>	<b>USA Standards (mg/kg)</b>	<b>Maximum conc. found at ODSS (mg/kg)</b>
TPHs	NC	2,000	500	21,307
Benzene	9.8	50.0	3.2	7.93
Benzo(a)anthracene	20.0	8.0	3.6	0.36
Benzo(a)pyrene	2.0	0.8	0.36	0.23
Benzo(ghi)perylene	>6.0	NC	61,300	2.05
Benzo(k)fluoranthene	20.0	80.0	35.0	0.32
Chrysene	13.0	800.0	400.0	0.45
Dibenzo(ah)anthracene	2.0	NC	0.36	2.36
Ethyl benzene	2,200	NC	230.0	58.4
Phenanthrene	>120.0	NC	61,300	6.62
Flouranthene	>42.0	NC	3,600	0.89
Fluorene	>66.0	NC	3,100	3.12
Iron	285,000	NC	613,000	20,976
Indene(123cd)pyrene	20.0	NC	36	2.31
MTBE	2,300	NC	480.0	0.089
Naphthalene	72.0	NC	5.2	16.03
Nickel	150,000	NC	3,700	47.42
Pyrene	>33.0	NC	2,700	1.74
Lead*	435.0	NC	1,700	29.21
Toluene	770.0	100	480.0	1.79
Vanadium	140,000	NC	1,300	56.08
Xylenes	17,000	100.0	150.0	74.6
Zinc	230,000	NC	56,000	14.79

NC, not considered

\*From Adult Lead Methodology (USEPA)

> Means risk based target concentration is greater than constituent residual saturation value

**Table 5.** Risk and clean up levels

Compound	Class	HQ Risk	Risk or risk index (HI)							Risk-based Clean-up level Soil mg kg <sup>-1</sup>
			Soil		Ground water		Air			
			On site (0 m)	Work	On site (0 m)	Off site (10 km)	On site (0 m)	Work	Off site (65 m)	
Benzene	A	HQ	3.3E-02	3.3E-02	3.9E-02	1.1E-01	1.9E-01	7.8E-01	1.8E-01	9.8E0
		RISK	1.0E-06	4.2E-08	1.2E-06	4.2E-10	1.6E-06	2.7E-07	1.9E-06	
Benzo (a)anthracene	B2	HQ	NA	NA	NA	NA	7.6E-09	6.3E-09	8.2E-09	2.0E01
		RISK	1.8E-07	7.6E-09	8.8E-011	3.0E-14	2.4E-10	7.9E-12	3.1E-10	
Benzo(a)pyrene	B2	HQ	NA	NA	NA	NA	1.6E-09	13.3E-09	1.7E-09	2.0E0
		RISK	1.1E-06	4.9E-08	7.6E-10	2.6E-13	1.3E-08	4.2E-10	1.6E-08	
Benzo(g,h,I)perylene	D	HQ	1.3E-04	1.4E-04	5.6E-08	1.6E-11	NA	NA	NA	>6.0E0
		RISK	NA	NA	NA	NA	NA	NA	NA	
Benzo(k)fluoranthene	B2	HQ	NA	NA	NA	NA	8.2E-08	6.8E-08	8.8E-08	2.0E02
		RISK	1.6E-08	6.8E-10	2.0E-11	6.7E-15	2.6E-11	8.6E-13	3.3E-11	
Chrysene	B2	HQ	NA	NA	NA	NA	2.2E-02	1.9E-02	2.4E-02	1.3E01
		RISK	3.5E-07	1.5E-08	1.2E-09	4.1E-13	2.4E-09	7.9E-11	3.1E-09	
Dibenzo(a,h)anthracene	B2	HQ	NA	NA	NA	NA	2.3E-07	1.9E-07	2.5E-07	2.0E0
		RISK	1.2E-05	5.0E-07	1.1E-08	3.7E-12	NA	NA	NA	
Ethyl benzene	D	HQ	7.4E-03	7.5E-03	1.9E-03	5.4E-07	8.2E-03	1.9E-02	8.0E-03	2.2E03
		RISK	NA	NA	NA	NA	NA	NA	NA	
Phenanthrene	D	HQ	4.2E-04	4.5E-04	2.0E-05	5.7E-09	NA	NA	NA	>1.2E02
		RISK	NA	NA	NA	NA	NA	NA	NA	
Fluoranthene	D	HQ	4.2E-05	4.5E-05	7.5E-07	2.1E-10	NA	NA	NA	>4.2E01
		RISK	NA	NA	NA	NA	NA	NA	NA	
Fluorene	D	HQ	1.5E-04	1.6E-04	1.4E-05	3.9E-09	NA	NA	NA	>6.6E01
		RISK	NA	NA	NA	NA	NA	NA	NA	
Fe	SC	HQ	5.7E-02	6.6E-02	2.4E-03	6.9E-07	NA	NA	NA	2.85E05
		RISK	NA	NA	NA	NA	NA	NA	NA	
Indene(1,2,3,c,d)Pyrene	B2	V HQ	NA	NA	NA	NA	5.9E-09	4.9E-09	6.3E-09	2.0E01
		RISK	1.1E-06	4.9E-08	2.3E-11	7.8E-15	2.0E-10	6.8E-12	2.6E-10	
MTBE	SC	HQ	1.4E-04	1.4E-04	3.9E-04	1.1E-07	4.1E-06	1.0E-05	4.1E-06	2.3E02
		RISK	NA	NA	NA	NA	NA	NA	NA	
Naphthalene	C	HQ	5.2E-04	6.2E-04	5.2E-04	1.5E-07	2.1E-01	1.7E-01	2.2E-01	7.2E01
		RISK	NA	NA	NA	NA	NA	NA	NA	
Ni	A	HQ	1.4E-03	1.7E-03	3.3E-04	9.3E-08	NA	NA	NA	1.5E05

		RISK	NA	NA	NA	NA	1.1E-10	7.6E-13	1.6E-10	
Pyrene	D	HQ	1.1E-04	1.2E-04	2.0E-06	5.6E-10	NA	NA	NA	>3.3E01
		RISK	NA	NA	NA	NA	NA	NA	NA	
Pb	B2	NA	NA	NA	NA	NA	NA	NA	NA	NC
Toluene	D	HQ	1.4E-04	1.4E-04	7.1E-05	2.0E-08	6.3E-04	2.2E-03	6.1E-04	7.7E02
		RISK	NA	NA	NA	NA	NA	NA	NA	
V	SC	HQ	4.7E-03	5.6E-03	3.9E-04	1.1E-07	NA	NA	NA	1.4E05
		RISK	NA	NA	NA	NA	NA	NA	NA	
Xylenes	D	HQ	5.0E-04	5.0E-04	1.8E-04	5.1E-08	1.5E-03	3.9E-03	1.5E-03	1.7E04
		RISK	NA	NA	NA	NA	NA	NA	NA	
Zn	D	HQ	2.9E-05	3.5E-05	6.5E-06	1.9E-09	NA	NA	NA	2.3E06
		RISK	NA	NA	NA	NA	NA	NA	NA	
Total HI	-		1.1E-01	1.2E-01	4.6E-02	1.3E-05	4.2E-01	9.9E-01	4.4E-01	
Total risk	-		1.6E-05	6.6E-07	1.2E-06	4.2E-10	1.6E-06	2.7E-07	1.9E-06	

Comm, commercial use

Work, construction workers

Resid, residential use

NA, not applicable

NC, not calculated

> Means risk based target concentration is greater than constituent residual saturation value