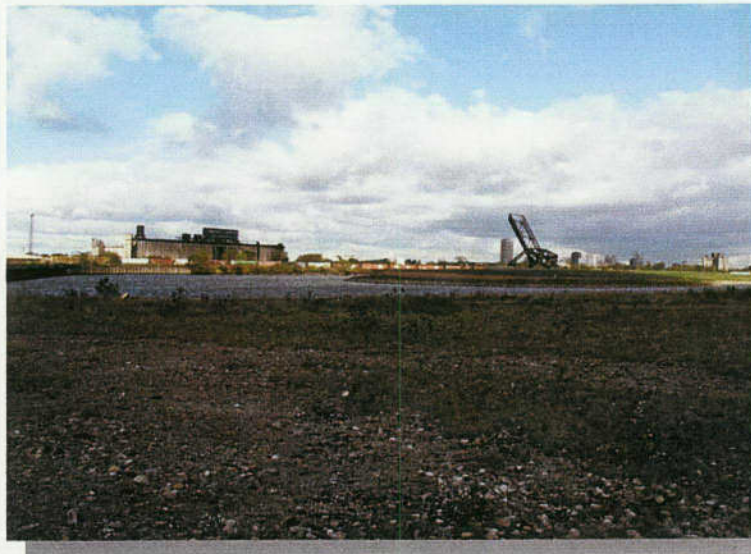


**STEEL MANUFACTURING SITE:
AREA I – FORMER REPUBLIC STEEL PLANT
PARCEL**



**Site Assessment Report and
Voluntary Cleanup Plan**

October 15, 1998

PREPARED FOR:

LTV Steel Company/Hanna Furnace Corporation

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50 FOUNTAIN PLAZA, SUITE 1350
BUFFALO, NEW YORK 14202

**SUPPLEMENTAL SITE ASSESSMENT AND VOLUNTARY
CLEAN-UP PLAN FOR AREA I
FORMER STEEL PLANT PARCEL**

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B	Steven Winter Associates Report
C	Subarea K and L Test Pit Logs for October 1998

1.0 INTRODUCTION

1.1 Background

LTV Steel Company owns, or co-owns with Hanna Furnace Corporation, a vacant industrial property located on the Buffalo River in Buffalo, New York (Figure 1-1 and Figure 1-2). The vacant industrial property, hereinafter referred to as the Steel Manufacturing Site or Site, was divided up into the following four parcels, shown on Figure 1-3, based on the operational and ownership history of each:

- Area I – Former Republic (LTV) Steel Plant
- Area II – Former Donner-Hanna Coke Plant
- Area III – Former Republic (LTV) Warehouse
- Area IV – Former Donner-Hanna Coke Yard

A Voluntary Cleanup Site Assessment Report (Malcolm Pirnie, 1997) was prepared to assess the environmental condition of the Steel Manufacturing Site and to establish a voluntary remediation plan to support future redevelopment of the Site as a light industrial/corporate park. Based on its review of the Voluntary Cleanup Site Assessment Report, the New York State Department of Environmental Conservation (NYSDEC) requested that additional investigations be performed at the Site to characterize perimeter groundwater conditions and to serve as a basis for formalizing a voluntary cleanup application and remedial design plans.

1.2 Purpose and Scope

The purpose of this report is to present a revised Voluntary Cleanup Plan for Area I based upon the results of the additional Area I investigations and site-specific risk-based cleanup levels proposed for the site.



FIGURE 1-1 : FORMER REPUBLIC STEEL PLANT AREA REGIONAL MAP

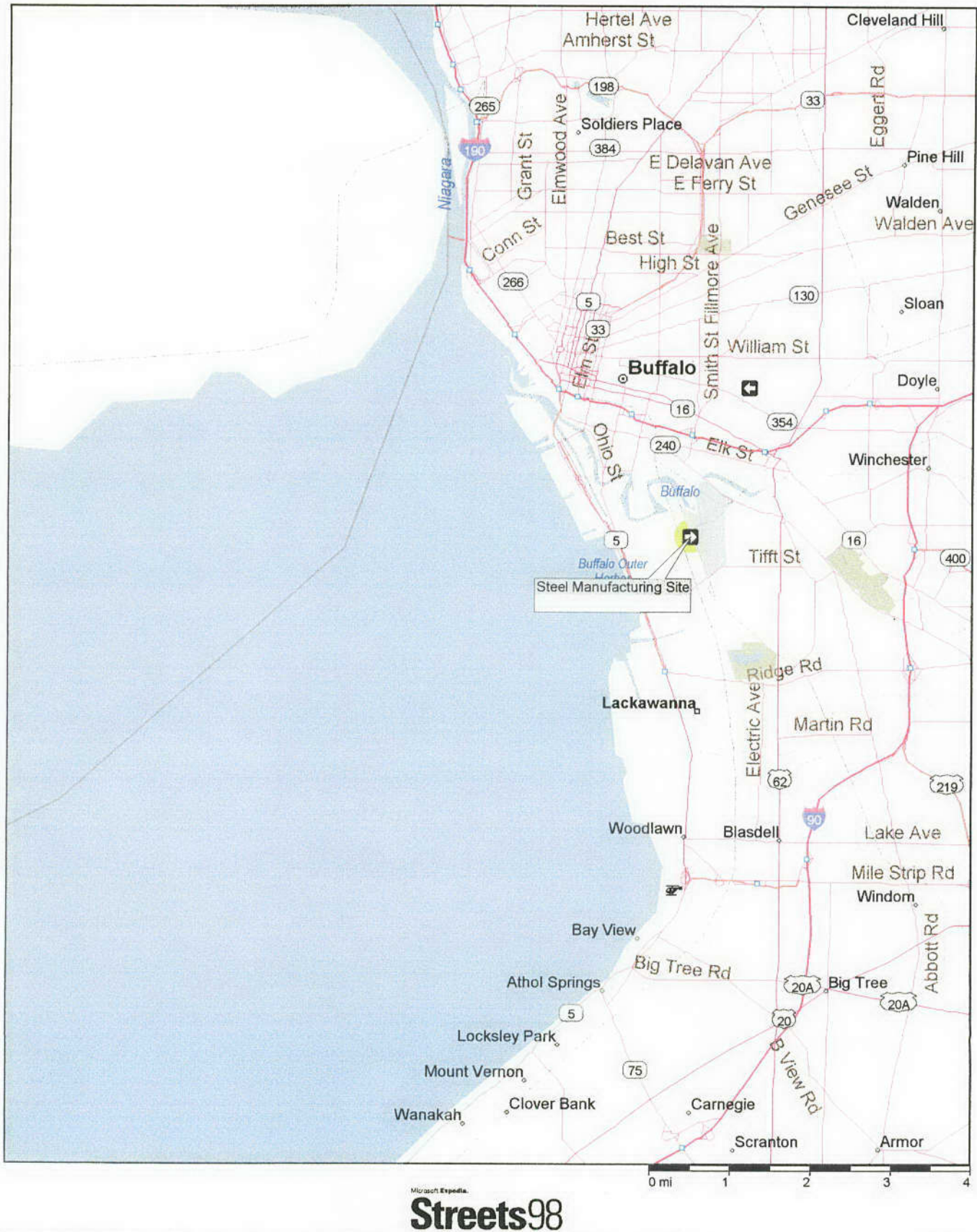


FIGURE 1-2 : STEEL MANUFACTURING SITE VICINITY MAP



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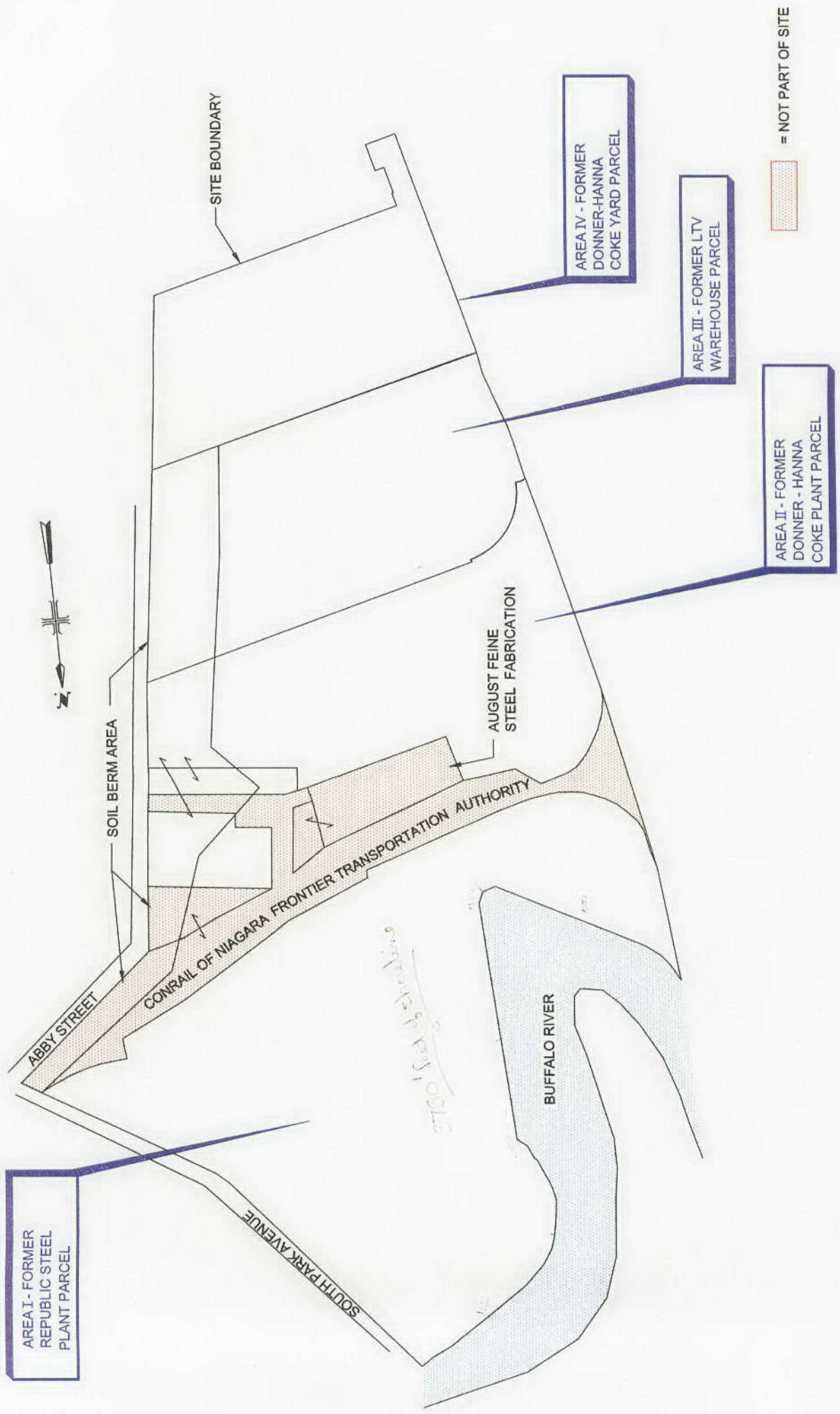
Supplemental investigations are on-going in Areas II, III, and IV. Revised Voluntary Cleanup Plans for these Areas will be prepared and presented to the NYSDEC upon completion scheduled for mid - to late - November 1998.

It is the intent of the Site owners to voluntarily cleanup the entire Steel Manufacturing Site. Area I was singled out for fast-track cleanup and redevelopment for the following reasons:

- The City of Buffalo and the Buffalo Economic Renaissance Corporation have urged the volunteers to make a major portion of the Site available for sale and redevelopment as soon as possible.
- Considerable interest has been expressed by prospective buyers/developers in the Steel Manufacturing Site.
- Based on site investigation results, Area I exhibits the fewest number of environmental conditions requiring cleanup.
- Cleanup of Area I can be completed and the Area made available for sale by the Summer of 1999 without delaying or interfering with cleanup of the remainder of the site.
- Area I is the natural choice for initial redevelopment based on existing infrastructure.



FIGURE 1-3



SCALE: 1 INCH = 500 FEET



REVISIONS	
NO.	DATE

LTV STEEL COMPANY / HANNA FURNACE
VOLUNTARY CLEANUP OF STEEL MANUFACTURING SITE
SUPPLEMENTAL SITE ASSESSMENT AND CLEANUP PLAN
FOR AREA I - FORMER STEEL PLANT PARCEL

STEEL MANUFACTURING SITE
SITE MAP

DATE OCTOBER 1998
SHEET 1 OF 1
CAG REF. NO. TNF0007.DWG

2.0 DEVELOPMENT OF SITE-SPECIFIC RISK-BASED SCREENING LEVELS

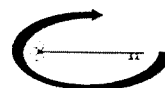
2.1 General

The LTV Steel/Donner-Hanna site is a Brownfields site intended for re-development for light industrial or corporate office uses under New York State's Voluntary Cleanup Program. Accordingly, the primary consideration in the determination of acceptable clean-up or screening levels for the site is the potential risk to human health posed by residual chemical constituents in the soils and groundwater. Specifically, the degree to which these analytes are likely to be directly or indirectly encountered, both during or following site development, and potentially impact human health due to their properties forms the basis for development of acceptable risk-based screening levels (RBSLs). The site-specific RBSLs derived herein will, in turn, provide a sound basis upon which decisions for voluntary cleanup and/or redevelopment can be made. As with all risk-based cleanup approaches, the calculated screening levels should be regarded as site-specific guidance values rather than definitive clean-up thresholds. Hence, the RBSLs should be regarded as screening values that, in combination with other site factors, will assist in determining of the suitability of the site parcels for commercial/light industrial redevelopment without further removal or clean-up actions.

A discussion of the site-specific parameters of interest and the proposed RBSLs for soils and groundwater at the LTV/Donner-Hanna site is presented in this section. Although discussed in the context of Area I, these RBSLs are intended to apply to all areas of the site.

2.2 Parameters of Interest

A comprehensive discussion of the nature and extent of contamination in Area I is presented in Sections 3 and 4. In general, analytes detected across the LTV/Donner-Hanna site at elevated concentrations are the common byproducts of coal handling, coke (or manufactured gas plant) processing, and steel manufacturing operations. These analytes or parameters of interest are summarized below:



- **Volatile Organic Compounds (VOCs)** - VOCs present in elevated concentrations in site soils and groundwater are limited to benzene, toluene, ethylbenzene, and xylene (i.e., BTEX).
- **Polynuclear Aromatic Hydrocarbons (PAHs)** - PAHs are byproducts of incomplete combustion and impurities in petroleum products. As such, they are commonly found in urban soil environments. They are present in site soils with elevated concentrations in certain areas of the LTV Steel/Donner-Hanna property. Specific PAH compounds that are known to represent a human health risk and/or are present in elevated concentrations are almost exclusively limited to benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)-fluoranthene, chrysene, and dibenzo(a,h)anthracene.
- **Inorganics** - or heavy metals are present in site soils and to a lesser extent in groundwater (primarily due to adsorption on particulates) in certain areas of the property. Most of these levels are commonly found in soils at trace levels. Inorganics present in site soils at elevated concentrations relative to "background" or typical concentrations include lead, arsenic, chromium, zinc, and copper. Mercury is also present in isolated instances.
- **Cyanide** - is present in stable form in certain areas of the site soils outside of Area I, and in lower concentrations in corresponding site groundwater. Cyanide is believed to be complexed with iron and other inorganics.

Area I exhibits certain indicator parameters as a result of its historical use as a steel manufacturing area. BTEX and PAH compounds are believed present in Area I as a result of petroleum product use and coal/coke handling. Similarly, inorganic indicator parameters and a number of other inorganic analytes are believed present in Area I as byproducts from past steel production processes. As indicated above, cyanide is not a parameter of concern in Area I, but is discussed in this section in the context of developing risk-based screening levels pertinent to the entire LTV Steel/Donner-Hanna site.



2.3 Determination of Risk-Based Screening Levels for Site Soils

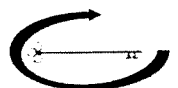
2.3.1 Organic Compounds

Risk-based screening levels are dependent on the nature of the contamination and the potential routes of exposure, both during and following site development. For organic compounds in soil media, potential routes of exposure to site workers would be through:

- incidental ingestion of contaminated soils
- direct skin contact with the contamination or contaminated soil
- inhalation of volatilized contaminants/airborne dust resulting from site redevelopment activity
- inhalation of contaminant vapors accumulating in buildings

Site improvements, including both proposed voluntary cleanup measures and site development (i.e., paving, covering the site with clean soils and vegetation following development, and vegetative landscaping) will mitigate the potential for exposure through the first three scenarios identified above. Exposure under these three scenarios may occur in the limited instances where: surficial, unvegetated soil contamination is released as airborne particulates (i.e., dust); direct release of volatile organics from contaminated soils; or when subsurface excavation is performed (e.g., by utility or foundation workers). The remaining scenario is unlikely and would only potentially occur if a building was constructed over areas containing elevated volatile organic concentrations and if engineering environmental controls (i.e., ventilation) were not installed in the building, such as in a shed or other structure not intended for routine occupancy.

Cleanup goals for organic-contaminated soils that are intended to be protective of human health under an ingestion exposure scenario are presented in the New York State Department of Environmental Conservation (NYSDEC) Technical and Administrative Guidance Memorandum (TAGM) 4046: Determination of Soil Cleanup Objectives and Cleanup Levels. TAGM 4046 identifies the following bases for deriving health risk-based cleanup objectives for organics:



- Human health-based levels for systemic toxicants, calculated from Reference Doses (i.e., RfDs, established as the amount of exposure an individual can experience without appreciable risk of health effects during a lifetime).
- Human health-based levels that correspond to excess lifetime cancer risks of 1 in 1,000,000 for Class A and Class B carcinogens, and 1 in 100,000 for Class C carcinogens. Classes A, B and C correspond to proven, probable and possible carcinogens, respectively.

For systemic toxicants, the NYSDEC TAGM 4046 recommended soil clean up objectives are based on a residential exposure scenario, whereby children of ages one to six years intake 200 milligrams of soil per day, 350 days per year, over a five year exposure period. The corresponding soil cleanup objective is therefore the maximum concentration of toxicant in the soil that can be ingested under this exposure scenario without experiencing appreciable health effects. Similarly, for carcinogens a residential exposure scenario is assumed whereby a child having an average body weight of 15 kg ingests 200 mg of soil per day, 350 days per year for the first 6 years of their life, then ingests 100 mg per day until age 30 at an average body weight of 70 kg. The corresponding soil cleanup objective is then determined as the maximum concentration of carcinogen that can be present in soil under this exposure scenario without experiencing appreciable increase in cancer risk. It should be noted, however, that the referenced excess lifetime cancer risk is a mathematical risk, not an actual risk. That is, the 1 in 1,000,000 excess cancer risk does not equate to the probability of one out of every 1 million persons exposed under this scenario will develop cancer. Rather, the 1 in 1,000,000 excess cancer risk estimate is a value determined by the Federal Food and Drug Administration (FDA) as representing an increase in an individual's risk of developing cancer that is so small as to be of negligible concern. U.S. Federal and State regulatory agencies have adopted a one-in-one-million excess cancer risk as being of negligible concern in situations where large populations (hundreds of millions) are involuntarily exposed to potential carcinogens, such as with food additives. When smaller populations are exposed in occupational settings, such as would be the case here, theoretical excess cancer risks of 1 in 10,000 have been considered acceptable by both Federal and State agencies (Ref 1).



Given the generic, residential basis for the cleanup goals presented in TAGM 4046, it is apparent that a more appropriate method for determining screening levels is to consider proposed site use, site-specific contaminants and exposure potential. The American Society of Testing and Materials (ASTM) provides a health risk-based methodology for development of screening levels for the organic parameters of concern at the site under ASTM E 1739 - 95 (see Appendix A). These screening levels can be calculated for commercial/industrial exposure scenarios which are more realistic, and consequently more appropriate for brownfields redevelopment than are the generic, residential-type cleanup goals presented in TAGM 4046. ASTM E 1739 - 95 provides for up to three (3) sequential evaluations, termed Tier 1 through Tier 3, with each successive evaluation incorporating a lesser degree of conservatism via more complex predictive modeling and credit for biodegradation, dilution, and other forms of natural attenuation. The Tier 1 evaluation incorporates use of standard exposure assessment methodology, such as suggested by USEPA, including standard commercial/industrial exposure parameters to develop Risk-Based Screening Levels (RBSLs). These RBSLs may then be used as cleanup goals if there is reasonable certainty that the soil concentrations will not increase with time. If the RBSLs are too restrictive, the ASTM method suggests performing the less conservative Tier 2 or Tier 3 analysis, as necessary.

To develop RBSLs that address the exposure scenarios discussed above, a Tier 1 analysis was performed for the LTV Steel/Donner-Hanna site in accordance with ASTM E 1739 - 95. The Tier 1 analysis prescribed by the standard involves comparison of assumptions used to develop the sample look-up table provided in the guidance with site-specific exposure and physical considerations. Specifically, the sample look-up table provides RBSLs for BTEX and benzo(a)pyrene, as well a listing of the assumed exposure values and physical/chemical values used in the development of those RBSLs. If the assumptions are considered valid, the published look-up values are used. For parameters where the assumptions are not considered valid or for which a look-up value is not published, the user is required to recalculate or derive the RBSL, as appropriate.

The results of the Tier 1 evaluation for organic indicator parameters at the LTV Steel/Donner-Hanna site are presented in Table 2-1, attached. As indicated in Table 2-1, the evaluation considered exposure through direct intake of contaminants via incidental



TABLE 2-1
SUPPLEMENTAL SITE ASSESSMENT AND VOLUNTARY CLEANUP PLAN FOR
AREA 1 - FORMER STEEL PLANT PARCEL

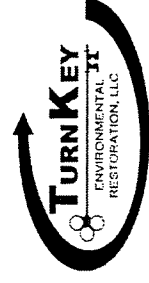
RISK-BASED SCREENING LEVELS FOR
ORGANIC PARAMETERS-OF-INTEREST

Parameter-of-Interest	Soil Ingestion, Inhalation, Skin Contact RBSL ⁽¹⁾ (mg/kg)		Indoor Soil Vapor Inhalation RBSL ^(1,3) (mg/kg)		Risk-Based Screening Level (mg/kg)
	Carcinogenic Effects ⁽²⁾	Toxic Effects	Carcinogenic Effects ⁽²⁾	Toxic Effects	
Volatile Organics					
Benzene	1,000	N/A	1.09	N/A	1.09
Toluene	N/A	18,700	N/A	55	55
Ethylbenzene	N/A	11,500	N/A	1,100	1,100
Xylene	N/A	208,000	N/A	>S	208,000
Poly-Aromatic Hydrocarbons					
Benzo(a)anthracene	304	23,800	>S	>S	304
Benzo(a)pyrene	30.4	23,800	>S	>S	30.4
Benzo(b)fluoranthene	304	23,800	>S	>S	304
Benzo(k)fluoranthene	3,040	23,800	>S	>S	3,040
Chrysene	3,040	23,800	>S	>S	3,040
Dibenzo(a,h)anthracene	30.4	23,800	>S	>S	30.4

1. RBSL = Risk-Based Screening Level, determined for commercial/industrial exposure scenario in accordance with ASTM E 1739 - 95.

2. Carcinogenic effects for 1 in Ten Thousand Risk (TR = 1.00 E-04).

3. >S = Selected risk level is not exceeded for pure compound present at any concentration.



ingestion, inhalation or contact with surface soils, as well as indirect exposure through inhalation of vapors entering unventilated buildings (less than 0.002 cubic feet per hour air exchange). The RBSLs provided in Table 2-1 for BTEX and benzo(a)pyrene were taken from the RBSL look-up table following review and confirmation of the appropriateness of the variables. For the remaining PAH compounds, the RBSLs were developed in accordance with the equations and methodology prescribed by the ASTM standard. Development of these RBSLs was performed by a risk assessment specialist and toxicologist with Steven Winter Associates (SWA). A report explaining the methodology used to derive the RBSL's for the PAHs is presented in Appendix B. As indicated in Table 2-1, RBSLs for the PAH's of interest at the site are driven by excess cancer risk associated with ingestion, whereas the RBSL for benzene is driven by inhalation risk. However, as discussed above, this indoor inhalation exposure pathway effectively assumes no building ventilation or other preventative engineering measures for mitigating vapor build-up in on-site structures. The implementation of standard ventilation as required by NY State building code for occupied structures significantly reduces this potential risk. Other rudimentary engineering controls such as foundation vents, membranes installed beneath floor slabs, or simply selectively building locations to avoid residual VOCs would also mitigate this pathway.

The RBSLs presented in Table 2-1 are appropriate for use at the LTV Steel/Donner-Hanna site as they follow the identical formula for the ingestion-based portion of the risk assessment as NYSDEC used to derive the health risk-based cleanup objectives provided in TAGM 4046. The differences between the TAGM 4046 health-risk based values and the ASTM-based RBSLs are strictly limited to:

- exposure frequency (350 days/year residential under the TAGM vs. 250 days/year occupational under the ASTM standard). It should be noted that for generalized worker scenarios, NYSDOH has considered as exposure frequency of 5 days/week for 8 months/year to be acceptable; this equates to 173 days per year. However; for conservatism 250 days/year was used in the calculations.
- intake level. For carcinogens, the TAGM assumes a residential intake of 200 mg soil/day at 15 kg body weight for 6 years + 100 mg/day at 70 kg body weight for 24 years. The ASTM Standard assumes an occupational intake of 50 mg/day at 70 kg body weight for 25 years, which is consistent with

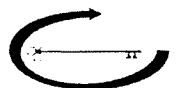


standard assumptions used by USEPA, NYSDOH and others. For toxicants, the TAGM assumes a reference dose exposure level for a 15 kg child ingesting 200 mg of soil/day; the ASTM standard assumes a reference dose exposure level for a 70 kg adult ingesting 50 mg of soil per day.

- excess cancer risk (1×10^{-6} under the TAGM vs. 1×10^{-4} under the ASTM Standard).
- non-ingestion factors. The TAGM does not consider other critical exposure pathways for organics (i.e., inhalation, skin contact). The ASTM Standard methodology significantly reduces the screening level concentration to account for these pathways in addition to the ingestion pathway.

Thus, the net difference between the TAGM health-risk based values and the ASTM RBSLs is simply a function of occupational vs. residential exposure levels, with the ASTM approach also considering the inhalation and skin contact pathways. In fact, SWA contacted Mr. Eric Obrecht at NYSDEC's Albany office to discuss the basis for TAGM 4046 cleanup levels for PAHs, as it was not apparent how certain TAGM values were derived. Mr. Obrecht explained that the current TAGM values for a number of the PAHs, including the PAHs of interest at this site, are outdated and will be re-calculated using more up-to-date and defensible oral slope values. He also indicated that TAGM 4046 will likely be revised in the near future to reflect oral slope values currently recommended by the New York State Department of Health (as explained in Appendix B, SJW used these same oral slope values in calculating the RBSLs for the PAHs).

In addition to being consistent with risk-based methodology employed by NYSDEC, the site-specific RBSLs described herein are conservative on the basis that the assumed exposure rates and pathways are positively biased. Specifically, the site-specific RBSLs assume working in dry, outdoor conditions every working day. They do not consider that site development will involve covering practically the entire site with asphalt, structures or soils, after which the potential for exposure to soil is practically eliminated. Natural re-vegetation, already occurring across large portions of the site, will also bind and shield soils from wind and erosion until final cover is placed. Utility and foundation worker exposure to trench soils will involve even lower exposure frequency than that assumed in the calculation, as development certainly will not involve continuous construction over a 25-year period. More likely, staged development efforts



by site developers and builders will limit individual construction workers to exposures on the order of several weeks or months.

On the basis of the above evaluations, it is proposed that the most restrictive RBSLs developed through ASTM E1739 and presented in Table 2-1 be used as Site-Specific Screening Levels for organic indicator parameters in the site soils.

2.3.2 Inorganics

The primary routes of worker exposure to inorganic contamination in site soils at the LTV/Donner-Hanna site essentially involve the same pathways as for organic contaminants, discounting significant exposure from inhalation of volatilized contaminant vapors. Thus, the major routes of exposure for inorganics in soils include:

- incidental ingestion of contaminated soils
- direct skin contact with the contamination or contaminated soils
- inhalation of wind-blown contaminated surface soils (i.e., dust)

NYSDEC's TAGM 4046 identifies the same basis for deriving health risk-based cleanup objectives for inorganic contaminants in soils as for organics in soils (i.e., human health-based levels for systemic toxicants, calculated from Reference Doses; and human health-based levels that correspond to excess lifetime cancer risks of 1 in 1,000,000 for Class A and B carcinogens, and 1 in 100,000 for Class C carcinogens). However, TAGM 4046 effectively acknowledges that with the exception of certain metal salts and hexavalent chromium compounds, none of which are known to be present at the LTV Steel/Donner-Hanna Site, background inorganic concentrations may exceed these health-based levels. The TAGM therefore recommends development of cleanup objectives for inorganics in soils based on either health (ingestion)-based values or background values, with the latter determined from site-specific background data or reference data for soils in eastern U.S./New York State.

To determine appropriate health-risk based screening levels for inorganics consistent with the method endorsed by the TAGM, the ingestion-specific portion of the exposure formula for non-carcinogens presented in ASTM E 1739 - 95 was used (see



Table 2-2). The formula considers reference doses and occupational exposure criteria to derive risk-based screening levels protective of health impacts from incidental ingestion. The portion of the ASTM formula accounting for impact of volatilized particulates entering the lungs is not relevant for inorganics. Table 2-2 presents the RBSLs for those inorganic parameters where USEPA has published a chronic oral reference dose in its IRIS database.

For parameters where an oral reference dose has not been published by USEPA, it is recommended that screening levels be established based on the higher of reported values for background inorganic concentrations in the eastern U.S. and New York State, as presented in TAGM 4046, or site-specific values. Site-specific values are available from a sample collected at a property on South Park Avenue (i.e., the Truscon site). Selection of the upper value as the screening level is appropriate and conservative not only because future site development is likely to mitigate exposures to site soils, but also because the upper range background number typically represents residential background concentrations, albeit in a suburban or metropolitan area.

On the basis of the above discussion, Table 2-2 presents recommended Site Specific Screening Levels for the inorganic parameters of interest at the LTV Steel/Donner-Hanna site, as well as other inorganic parameters detected in the soils in Area I.

2.3.3 Cyanide

Potential exposure pathways for cyanide in the site soils are identical to those for the inorganic parameters of interest. In general, the toxicity of cyanide complexes is dependent on its availability to organisms, which is a function of the susceptibility of the compounds to chlorination, acidification, and hydrolysis. Measurement of the susceptibility of cyanide complexes to these phenomena is accomplished through comparison of the total cyanide concentrations in the site soils relative to amenable cyanide concentrations in the same material. The difference between the total and amenable cyanide concentrations reflects the amount of cyanide present as highly stable metal complexes, which are typically unavailable to living organisms (Ref. 2).



TABLE 2-2
SUPPLEMENTAL SITE ASSESSMENT AND VOLUNTARY CLEANUP PLAN FOR
AREA 1 - FORMER STEEL PLANT PARCEL

RISK-BASED SCREENING LEVELS
FOR INORGANIC PARAMETERS OF INTEREST⁽¹⁾

Parameter	RfD (mg/kg-d)	RBSL (mg/kg)	Max. Background Conc. ⁽²⁾ (mg/kg)	Screening Level (mg/kg)
Aluminum	N/A	N/A	33000	33000
Arsenic	3.00E-04	613.2	12	613
Barium	N/A	N/A	600	600
Beryllium	2.00E-03	4088	1.75	4088
Cadmium	N/A	N/A	1	1
Calcium	N/A	N/A	44400*	44,400
Chromium (trivalent)	1.5	3066000	40	Note 3
Cobalt	N/A	N/A	60	60
Copper	N/A	N/A	55.7*	55.7
Iron	N/A	N/A	550,000	550000
Lead	N/A	N/A	500	500
Magnesium	N/A	N/A	7920*	7920
Manganese	0.14	286160	5000	286160
Mercury	N/A	N/A	0.211*	0.211
Nickel	2.00E-02	40880	25	40880
Potassium	N/A	N/A	43000	43000
Selenium	5.00E-03	10220	12.7	10220
Silver	5.00E-03	10220	1.27	10220
Sodium	N/A	N/A	8000	8000
Vanadium	N/A	N/A	300	300
Zinc	0.3	613200	138	613200

1 - RBSL calculated based on ingestion risk in accordance with the following formula (derived from ASTM E 1739-95):

$$RBSL = \frac{THQ \times BW \times AT_N \times 365 \text{ days/yr} \times RfD}{EF \times ED \times 10^{-6} \text{ kg/mg} \times IR_{\text{soil}} \times RAF_o}$$

Where: THQ = Toxic Hazard Quotient = 1
 BW = Body Weight = 70 KG
 ATN = Averaging Time for Non-Carcinogens = 25 yrs
 RfD = Oral Reference Dose (chemical-specific, from IRIS)
 EF = Exposure Frequency = 250 days/year
 ED = Exposure Duration = 25 years
 IR_{soil} = Soil ingestion rate = 50 mg/day
 RAF_o = Oral relative absorption factor = 1

2 - Based on highest values of Eastern U.S./NY State background concentration data (per TAGM 4046) or site-specific background (from Truscon site).

Values flagged with an asterisk represent Truscon site data.

3 - Not Applicable - greater than 100%



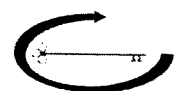
An additional indicator of the health hazard associated with cyanide complexes is the amount of the total matrix that is available to react with hydrogen (i.e., at low pH) to form hydrogen cyanide (HCN) gas. The cyanide reactivity test provides a measurement of the amount of hydrogen cyanide liberated by the soil or waste material as it is subjected to acidic conditions. A comparison of the mass of HCN liberated relative to the sample mass provides a cyanide reactivity value, which is used under the Federal RCRA program in support of determining whether the material is characteristically hazardous.

Several soil samples from Areas II and III of the LTV Steel/Donner-Hanna site that exhibited elevated total cyanide concentrations were also analyzed for amenable and reactive cyanide. In all instances, amenable cyanide was present at very low or non-detectable levels, and reactive cyanide was not detected. Thus, the cyanide present in soils at the LTV Steel/Donner-Hanna site appears to be in highly stable form, and poses negligible health threat.

TAGM 4046 acknowledges that toxicity of cyanide varies according to the stability of the complex, and that background cyanide concentrations are not considered an applicable factor in the determination of cleanup goals. Hence, the TAGM does not provide a generic cleanup goal for this material. In absence of any other NY State guidance for cyanide cleanup goals, pertinent USEPA guidance was reviewed. USEPA Region III and Region IX preliminary remediation levels for free cyanide in industrial soils are 41,000 mg/kg and 21,400 mg/kg, respectively, where free cyanide is essentially synonymous with amenable cyanide. Alternatively, USEPA's Soil Screening Guidance Technical Manual cites a generic screening level of 1,600 mg/kg for amenable cyanide. For purpose of conservatism, 1,600 mg/kg amenable cyanide is proposed as the cyanide Site Specific Screening Level for soils at the LTV Steel/Donner-Hanna site.

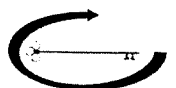
2.4 Groundwater

A detailed assessment of groundwater quality in Area I of the site is presented in Section 4. In general, groundwater contamination at the LTV Steel/Donner-Hanna site poses little potential for health impact to site workers. Since municipal potable water will be used for consumption, sanitary and process purposes, the only potential for significant intake of contaminants present in the groundwater would be through direct contact with



and/or inhalation of volatile organic contaminants during active groundwater management (viz., during dewatering activities, such as by utility or foundation workers).

Although direct contact with and/or volatilization from groundwater during active management may pose a short-term exposure scenario, this is generally controllable with appropriate personal protection, and will by no means represent a chronic occurrence. In fact, health-based groundwater remediation guidance values for acute exposure scenarios of this nature are not generally available, nor does ASTM E 1739 - 95 provide a method for deriving such values. It is therefore proposed that groundwater screening levels be based strictly upon potential impact to sensitive off-site receptors as addressed in Section 4 of this document.



3.0 SOIL ASSESSMENT

3.1 General

The Phase I Environmental Site Assessment for the LTV Steel/Donner-Hanna Site (Reference 3) originally identified 13 subareas within the former Republic Steel plant parcel (Area I) where past operations may have resulted in potential environmental conditions. Consequently, a Phase II investigation incorporating soil and groundwater sample collection and analysis was performed (Ref. 3) to ascertain whether impacts to the property had resulted from these past operations. The Phase II investigation determined that only three (3) of the thirteen subareas exhibited elevated parameter levels in the soils relative to USEPA Region III risk-based concentrations. These subareas, designated as E, K and L, represented the former machine shop/electric shop, the former fuel oil storage subarea, and the former stockhouse or tar/fuel oil underground piping subarea, respectively. Parameters elevated relative to USEPA Region III risk-based concentrations were primarily limited to the PAHs of concern discussed in Section 2.0, which were believed to be the result of former fuel oil transport and storage operations. In addition, several inorganic parameters were also detected across Area I in concentrations at or above background levels from a nearby property.

The Phase II results were summarized in the September 1997 Voluntary Cleanup Site Assessment Report prepared for LTV Steel Company and Hanna Furnace Corporation. In concert with the voluntary cleanup agreement, NYSDEC reviewed and provided technical comment on the report. Issues raised by NYSDEC relative to Area I included the need for further investigation of the former transformer subarea (i.e., subarea H), as well as concerns regarding the use of EPA Region III risk-based concentrations as screening values for the site soils. In addition, NYSDEC indicated that additional background data would be needed for comparison to site inorganic levels. A Supplemental Field Investigation was performed in March 1998 to provide additional characterization of subarea H and other areas of the site.

The following discussions present the Supplemental Field Investigation results for subarea H, as well as a comprehensive overview of all of the soil characterization data



obtained for Area I to date. A comparative discussion of the results relative to the site-specific risk-based screening levels (RBSLs) presented in Section 2 is also provided.

3.2 Transformer Area (Subarea H)

In accordance with the Supplemental Field Investigation Work Plan, a soil sample was collected from the former Area I transformer area (subarea H) in May 1998 for polychlorinated biphenyl (PCB) analysis. The sample, designated A1-SB-H3 (see Figure 3-2) was collected by advancing 4-1/4 inch hollow stem augers to a depth of four feet below ground surface. During borehole advancement, continuous split-spoon samples were collected to a depth of eight feet below ground surface. These split-spoon samples were inspected and described on a stratigraphic borehole log by an on-site geologist. Fill material, consisting primarily of silty sand, slag, and brick, was encountered to a depth of approximately 4.4 feet below ground surface. Native soil, described as brown, moist, clayey silt, was encountered beneath the fill. One composite soil sample was collected from the lower fill interval (2.7 to 4.4 feet below ground surface) and analyzed for PCBs.

The results of the analysis showed that no PCBs were present in the transformer subarea split-spoon sample with the exception of Aroclor 1254, which was detected at an estimated concentration of 0.029J mg/kg. This PCB concentration is significantly lower than the corresponding New York State Department of Environmental Conservation (NYSDEC) Technical Action Guidance Memorandum 4046 (TAGM 4046) value of 10 mg/kg for subsurface soils, and is not considered significant. Thus, the data indicates that no significant release of PCBs has occurred in the former transformer subarea. Accordingly, no cleanup of Subarea H soils is considered necessary.

3.3 Surface Soil/Fill

Surface soil samples collected during the Phase II investigation are discussed in the September 1997 Voluntary Cleanup Site Assessment Report (Ref. 3). The Phase II surface soil sampling program included investigation of various locations in Area I. The sample locations, designated SS-10 through SS-22, are shown on Figure 3-1. The samples were collected at locations of historical significance, at random locations, and/or

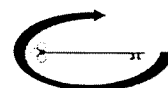
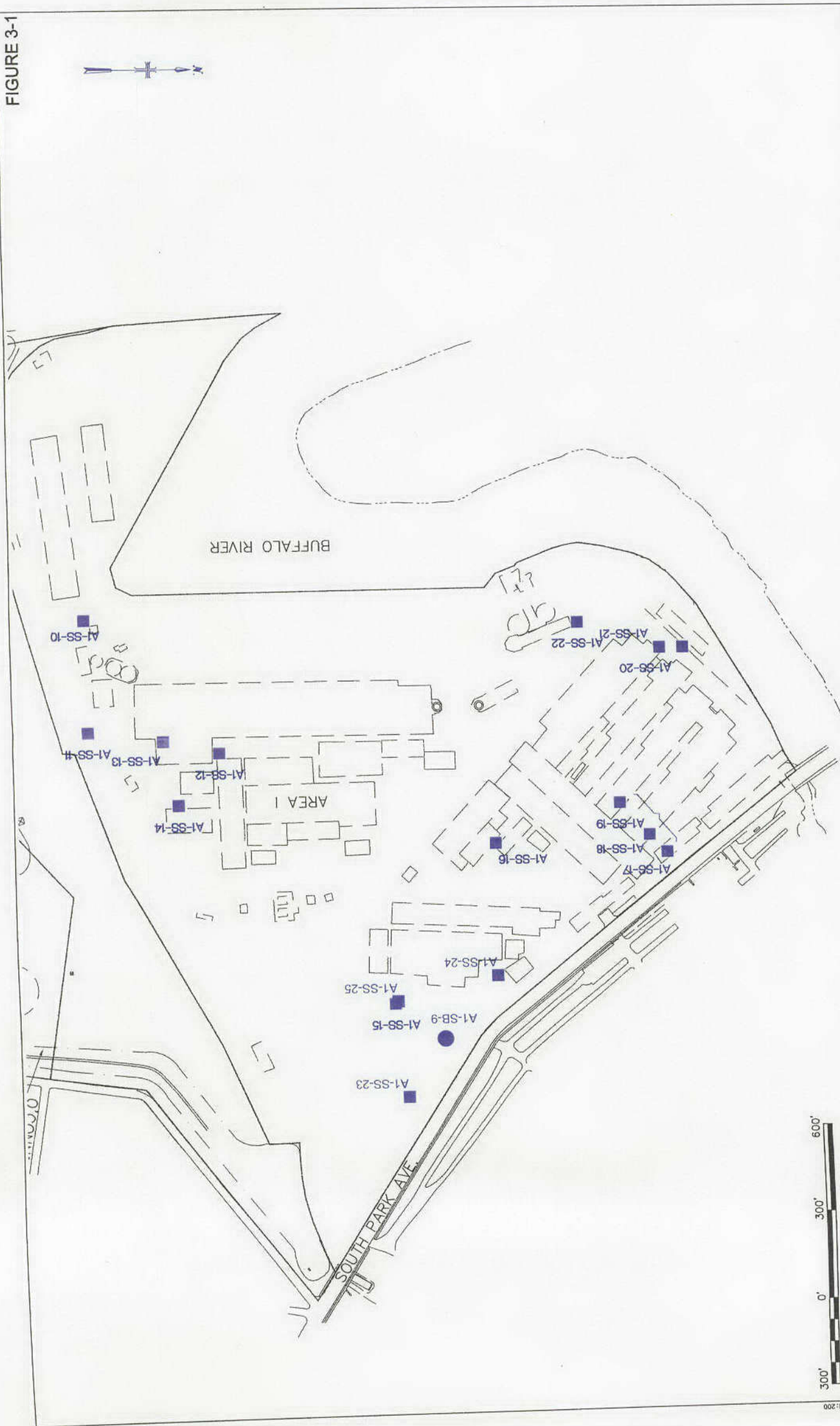


FIGURE 3-1



DATE OCTOBER 1998
SHEET 1 OF 1
CAD REF. NO. TNC002.DWG

SURFACE SOIL SAMPLE LOCATIONS

LTV STEEL COMPANY / HANNA FURNACE
VOLUNTARY CLEANUP OF STEEL MANUFACTURING SITE
SUPPLEMENTAL SITE ASSESSMENT AND CLEANUP PLAN
FOR AREA I - FORMER STEEL PLANT PARCEL

REVISIONS		DATE	BY	CHKD



where discoloration was evident to provide a comprehensive indication of the extent of surficial contamination, if any, in these areas. All Phase II surface soil samples were collected from 0-1 foot below grade using a 3-inch diameter split-spoon sampler, and were analyzed as either discrete or composite samples for Target Compound List (TCL) VOCs, SVOCs, and PCBs, as well as Target Analyte List (TAL) metals and cyanide. Sample analysis was performed in accordance with USEPA SW-846 methodology by a NYSDOH ELAP-certified laboratory. Table 3-1 provides a summary of the composite and discrete samples submitted for analysis and the corresponding analytical results.

Following the Phase II investigation, four (4) additional surface soil samples were collected and analyzed from Area I in January 1998 in response to a manufacturer's interest in leasing a portion of the property. The four sample locations, labeled A1-SS-23 through 25 and A1-SB-9 are shown on Figure 3-1. These samples, collected from 0-2 foot below grade via split-spoons, were analyzed as discrete samples for TCL VOCs, PAHs, TAL Metals, cyanide, and pH. Analytical results are presented in Table 3-1, excluding pH, which ranged from 8.2 to 10.6 at the four locations.

The data presented in Table 3-1 includes parameters detected in the surface soils at any of the above-described sample locations. Additionally, Table 3-1 presents a comparison of the sample concentrations to the corresponding risk-based screening levels (RBSLs) developed in Section 2. For organic parameters where site-specific RBSLs were not derived, NYSDEC TAGM 4046 health-risk based cleanup objectives were provided as an alternate comparative value. Similarly, as described in Section 2, USEPA has not published reference dose concentration values for many of the inorganics detected in Area I, therefore the background values presented in Section 2 have been provided as an alternative means for comparing inorganic concentrations. For both the organic and inorganic parameters, the concentration value is shaded if it exceeds the corresponding comparative or screening value.

As presented in Table 3-1, none of the organic parameters detected in the surface soils in Area I exceed the corresponding RBSLs, nor do those parameters for which an RBSL was not derived exceed the associated TAGM 4046 health-risk based cleanup value. In fact, in nearly all instances the concentrations detected fall below the

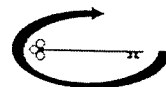


TABLE 3-1
LTV STEEL COMPANY/DONNER-HANNA
Supplemental Site Assessment and Voluntary Cleanup Plan for
Area I - Former Republic Steel Plant Parcel

SUMMARY OF SURFACE SOIL RESULTS

Parameter	Risk Based Screening Levels ⁽¹⁾	AREA 1 ⁽²⁾														A1-SB-9
		SS-10/11 ⁽²⁾	SS-12/13 ⁽³⁾	SS-14	SS-15	SS-16	SS-17	SS-18	SS-19	SS-17/18/19	SS-20/21 ⁽⁴⁾	SS-22	SS-23	SS-24	SS-25	
Volatile Organic Compounds (mg/kg)																
Methylene Chloride	93				0.009		0.009	0.008		Not						
1,1,1-Trichloroethane	7,000							0.021		Analyz.						
Semivolatile Organic Compounds (mg/kg)																
Acenaphthylene	-	4.6														
Anthracene	20,000	24	0.52													
Benzo(a)anthracene	304*	16	1.4		0.75	0.59				1.5		0.62	0.93			
Benzo(a)pyrene	30.4*	12	1.4	0.44	0.96	0.53				1.4		0.99	1.4	2.6		
Benzo(b)fluoranthene	304*	15	2.1	0.81	1.1	1.3	Not	Not		2.3	0.48	1.5	1.8	3.0		
Benzo(k)fluoranthene	3040*	8.5	1.1		0.67	0.74	Analyz	Analyz		1.4		0.84	1.4	2.9		
Benzo(g,h,i)perylene	-	5.4	0.67	0.45	0.6	0.6				0.92			0.56			
Bis(2-ethylhexyl)phthalate	50		0.42		1	0.39						0.76	0.53			
Carbazole	-	5.5														
Chrysene	3040*	21	1.4	0.53	0.8	1				1.6		0.72	1.1			
Fluoranthene	3,000	36	2.7	0.82	1.1	1.2				3	0.55	0.5	1.4	3.9		
Indeno(1,2,3-cd)pyrene	-	5.7	0.65		0.53	0.55				0.86		0.65	0.64			
Phenanthrene	-	19	2	0.53	0.65	1.3				1.9			0.57			
Pyrene	2,000	27	2.2	0.65	1.1	1.3				2.6	0.58	0.87	1.8	4.0		
PCB (mg/kg)																
PCB 1248	1	1							Not Analyzed							Not Analyzed

- NOTES:
- (1) Levels flagged by an * represent risk based screening levels from ASTM E1739-95 (see Section 2).
Non-flagged levels represent TAGM 4046 health-based cleanup levels.
 - (2) Composite sample from SS-10 and SS-11. Discrete VOC samples collected from each location. VOCs were not detected in either sample.
 - (3) Composite sample from SS-12 and SS-13. Discrete VOC samples collected from each location. VOCs were not detected in either sample.
 - (4) Composite sample from SS-20 and SS-21. Discrete VOC samples collected from each location. VOCs were not detected in either sample.
 - (5) Data from Phase I/II Environmental Site Assessment Report prepared by Malcolm Pirnie, Inc., September, 1997
- Blank space in data denotes parameter was not detected.
- Shading denotes concentration exceeds TAGM 4046 health-risk based values or site specific risk based screening levels.
- Data not available.



TABLE 3-1
LTV STEEL COMPANY/DONNER-HANNA
Supplemental Site Assessment and Voluntary Cleanup Plan for
Area I - Former Republic Steel Plant Parcel

SUMMARY OF SURFACE SOIL RESULTS

Parameter	Background (1)	Risk Based Screening Levels(5)	AREA I ⁽⁷⁾															AI-SB- 9	
			SS-10/11 ⁽²⁾	SS- 12/13 ⁽³⁾	SS-14	SS-15	SS-16	SS-17	SS-18	SS-19	SS- 17/18/19	SS- 20/21 ⁽⁴⁾	SS-22	SS-23	SS-24	SS-25			
Inorganic Compounds (mg/kg)																			
Aluminum	33,000		14600	14100	15700	11500	6730						10700	9390	8250	14800	19800	7980	33200
Antimony	-															27.8	8.51		
Arsenic		613	24.7	25.5	12.2	8.85	7.61						4.37	11.5	8.89	22.2	17.7	19.2	6.57
Barium	600		152	130	160	191	121						164	143	92.4	261	206	144	261
Beryllium		4088	2.87	3.5	2.19	2.39	1						1.91	1.93	1.4	4.37	3.62	3.05	6.02
Cadmium	1		1.51	1.79	0.831	2.89	3.77						2.37	2.94	1.27	8.55	2.3	8.93	1.55
Calcium	44,400		144000	139000	218000	202000	166000						193000	136000	50600	110,000	125000	129000	213000
Chromium		NA	257	197	434	636	891						635	891	73.1	158	67.8	699	45.1
Cobalt	60		6.5	24.8		6.14	8.19							11.5	6.78	13.7	6.75	14	
Copper	55.7		141	170	26.4	92.2	94.6						87.7	146	45.4	296	90.4	104	37.3
Iron	550,000		134000	165000	94100	97200	160000						144000	223000	64500	167000	56000	197000	46500
Lead	500		145	195	79.6	145	397						147	83.7	76.5	65000	251	434	72.2
Magnesium	7920		20000	24700	12300	22000	24200						19700	19100	7320	10000	18500	26400	23300
Manganese		286,160	5470	5420	10800	17000	26300						13600	17100	2340	7320	2520	16800	4540
Mercury	0.211															0.32	0.24	0.317	
Nickel		40880	78.7	122	11.3	63.2	52.8						28.5	57.8	19.3	83	37.8	44.3	13.7
Potassium	43,000		1060	1210	850	685	372						857	498	654	1060	1600	708	2720
Selenium		10220			21.9	24.6	46.3						57.1	61	8.38				
Silver		10220	1.65	1.69	2.53	2.14	4.16						3.05	2.96		1.71			
Sodium	8,000		505	617	341	336	333						452	366	268	358	491	255	988
Thallium	-															3.05			
Vanadium	300		53.5	125	201	386	289						203	210	35	116	17.2	281	6.19
Zinc		613,200	293	714	143	541	607						341	229	147	405	207	555	128
Cyanide		1600 ⁽⁶⁾	3.64	3.35	5.11	1.6	4.13						5.1	6.38	2.06			2.19	1.64

Notes: (1) Background inorganic soil concentrations from Truscon Property or TAGM (Eastern US/NYS) as described in Section 2

(2) Composite sample from SS-10 and SS-11.

(3) Composite sample from SS-12 and SS-13.

(4) Composite sample from SS-20 and SS-21.

(5) Levels derived from ASTM E1739-95 (see Section 2)

(6) See Section 2

(7) Data from Phase I/II Environmental Site Assessment Report prepared by Malcolm Pirnie, Inc., September, 1997

Shading denotes concentration exceeds risk based screening level or background TAGM 4046 values.

- Data Not available

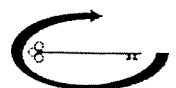
Blank space denotes parameter was not detected.

NA - Greater than 100%



RBSL/TAGM 4046 value by an order of magnitude or more. Thus, no remediation of surficial soils in Area I due to organic contamination will be performed.

Inorganic parameters detected in Area I surface soils were, with limited exception, well below the RBSL values. Likewise, nearly all the inorganic parameters for which an RBSL was not derived were below the respective background concentration, with the exception of cadmium, calcium, copper, magnesium and mercury. An isolated elevated lead concentration was also encountered at SS-23, however this value is believed to be anomalous based on comparison to other surface soil sample results. The lead concentration reported for SS-23 may have been biased by the sample matrix, as can occur if a lead-based article (viz., a shotgun pellet or lead-acid battery fragment) is introduced to the sample matrix and subject to digestion during sample preparation in the lab. For the remaining five metals, Table 1 shows that the concentrations detected in the surface soils were comparable to that of the associated background sample from the adjacent former Truscon property for magnesium, copper, calcium and mercury, and eastern U.S. soil quality for cadmium. Not un-expected, the cadmium concentrations on this former industrial property exceed eastern U.S. background concentrations, which are residential-based values. Observed cadmium and mercury concentrations in Area I surface soils are well below levels which would be indicative of a toxic characteristic under Federal and State regulations (i.e., 40 CFR Part 261 and 6NYCRR Part 373). Specifically, assuming a typical 1:20 ratio of leachable metal to total metal, cadmium and mercury concentrations in the soils would need to exceed 20 mg/kg and 4 mg/kg respectively to potentially pose a toxic leaching condition. Table 3-1 illustrates that cadmium concentrations were well below this value. In addition, as discussed in Sections 2 and 6, development of the property will result in soil and pavement coverage over the majority of the site, effectively precluding long-term contact with surficial soils. Therefore, no cleanup of surface soils is considered necessary for the planned redevelopment of Area I.



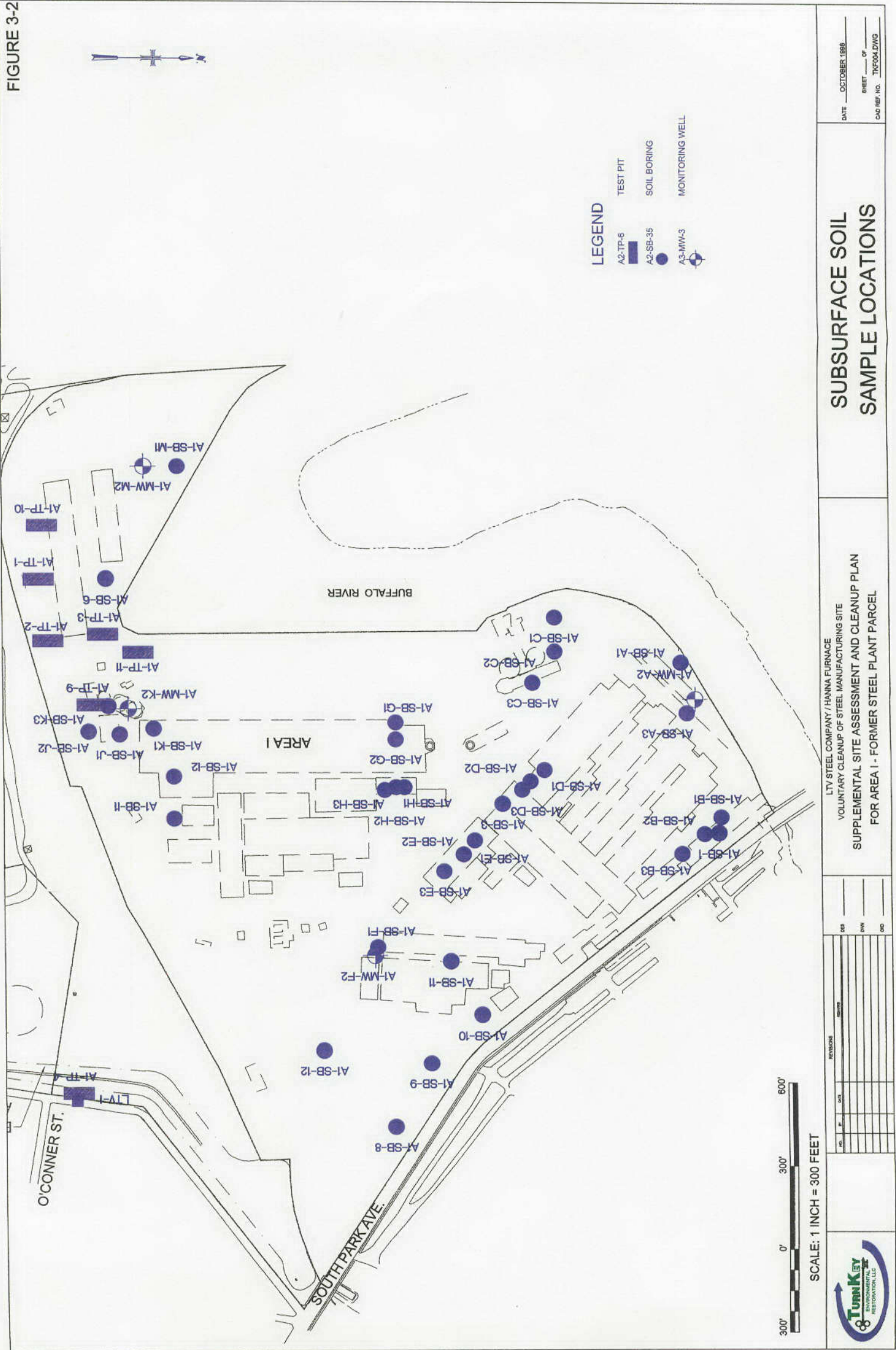
3.4 Subsurface Soil/Fill

A total of 29 subsurface soil/fill samples were collected from the 13 different historical subareas of interest during the Phase II performed in Area I. The analytical data was presented in the Voluntary Cleanup Site Assessment Report (Ref. 3) along with a detailed description of the investigation methodology. In general, the subsurface soil investigation encompassed a series of borings and test pits, including borings finished as monitoring wells. Borings in Area I were given the alpha-numeric designation A1 - (A series through M series), with the A through M character corresponding to the 13 subareas of historical interest. In lieu of borings in Subarea L, five (5) test pits designated TP-1, TP-2, TP-3, TP-10 and TP-11 were completed to a depth of 3-6 feet below grade in an attempt to locate oil pipelines or associated impacts in this subarea. An additional test pit (TP-9) was also completed to a depth of approximately 5 feet in Subarea K.

Boring and test pit locations are shown on Figure 3-2. All soil borings completed in Area I were advanced using 4-1/4 inch hollow stem augers to completion depths below the surficial fill unit and coincident with or below the fill/native soil contact. Samples from soil borings in each subarea of interest were generally composited and analyzed for TCL SVOCs and TAL inorganic parameters, including cyanide. A single discrete VOC sample was also collected and analyzed from one of the borings in each subarea. Selection of sample intervals for compositing and discrete VOC analysis was based on visual or olfactory evidence of contamination. Native soil located below the coarse fill was often submitted for analysis even if evidence of contamination was not apparent. For the test pit investigation, analysis involved visual and olfactory characterization of the soils, as well as screening the excavated spoils with a photoionization detector (PID) and/or performing headspace testing with the PID. In Subarea L, a composite sample of the fill material from TP-10 (the location exhibiting elevated head space readings) was collected and submitted for analysis of BTEX and PAHs. Table 3-2 provides a summary of the composite and discrete subsurface boring and test pit samples submitted for analysis and the corresponding analytical results. Only those parameters detected at any of the sample locations are presented in Table 3-2.



FIGURE 3-2



**SUBSURFACE SOIL
SAMPLE LOCATIONS**

LTV STEEL COMPANY / HANNA FURNACE
VOLUNTARY CLEANUP OF STEEL MANUFACTURING SITE
SUPPLEMENTAL SITE ASSESSMENT AND CLEANUP PLAN
FOR AREA I - FORMER STEEL PLANT PARCEL

DATE: OCTOBER 1998
SHEET: OF
CAD REF. NO.: TNY004.DWG

REV	DATE	BY	CHK	APP



TABLE 3-2
LTV STEEL COMPANY/DONNER-HANNA
Supplemental Site Assessment and Voluntary Cleanup Plan for
Area I - Former Republic Steel Plant Parcel

SUMMARY OF SUBSURFACE SOIL RESULTS

	Risk Based Screening Levels ⁽¹⁾	Area I ⁽¹⁴⁾												
		A1-SB(or MW)- A1,A2,A3	A1-SB- B1,B2,B3	A1-SB- C2	A1-SB- D1,D2,D3	A1-SB- E1,E2,E3	SB(or MW)- F1,F2	A1-SB-G1	A1-SB- H1,H2	A1-SB- I1,I2	A1-SB- J2	A1-SB(or MW)- K1,K2,K3	A1-SB(or MW)- M1/M2	
		8-12	10-14	12-14	10-14	4-8	4-6	8-10,11-11.5	8-10	8-13	10-12,8-10	6-8.5	4-5	6-6.5
Parameter														
Volatile Organic Compounds (mg/kg)														
Acetone	8,000	(2)	(3)	0.061			(6)	(7)	(8)	(9)	(10)	(11)	NA	0.11 ⁽¹³⁾
Benzene	1.09*				6.2 ⁽⁴⁾									
2-Butanone	4,000												NA	0.014 ⁽¹³⁾
cis-1,2-Dichloroethene	-					0.042 ⁽⁵⁾							NA	
Ethylbenzene	1,100*				7.7 ⁽⁴⁾								6.6	
Methylene Chloride	93												NA	0.007 ⁽¹³⁾
Toluene	55*				3.6 ⁽⁴⁾									
Total Xylenes	208,000*				25.0 ⁽⁴⁾								52	
Trichloroethene	64					0.150 ⁽⁵⁾							NA	

Notes:

(1) Levels flagged by an * represent risk based screening levels from ASTM E1739-95 (see Section 2).

Non-flagged levels represent TAGM 4046 health-based cleanup levels.

(2) Sample A1-MW-A2, 8-10 feet was analyzed for TCL VOCs. VOCs were not detected in the sample.

(3) Sample A1-SB-B2, 12-14 feet was analyzed for TCL VOCs. VOCs were not detected in the sample.

(4) Sample A1-SB-D3, 10-12 feet was analyzed for TCL VOCs. Concentrations of detected parameters are shown.

(5) Sample A1-SB-E2, 4-6 feet was analyzed for TCL VOCs. Concentrations of detected parameters are shown.

(6) Sample A1-SB-F1, 4-6 feet was analyzed for TCL VOCs. VOCs were not detected in the sample.

(7) Sample A1-SB-G1, 11-11.5 feet was analyzed for TCL VOCs. VOCs were not detected in the sample.

(8) Sample A1-SB-H1, 8-10 feet was analyzed for TCL VOCs. VOCs were not detected in the sample.

(9) Sample A1-SB-I2, 8-10 feet was analyzed for TCL VOCs. VOCs were not detected in the sample.

(10) Sample A1-SB-J2, 8-10 feet was analyzed for TCL VOCs. VOCs were not detected in the sample.

(11) Sample A1-MW-K2, 6.5-7 feet was analyzed for TCL VOCs. VOCs were not detected in the sample.

(12) A sample collected from 5-5.5 feet was analyzed for VOCs. VOCs were not detected in the sample at a dilution of 25 ppm.

(13) Sample A1-MW-M2, 6-6.5 feet was analyzed for TCL VOCs. Concentrations of detected parameters are shown.

(14) Data from Phase I/II Environmental Site Assessment Report prepared by Malcolm Pirnie, Inc., September 1997

Shading denotes concentration exceeds TAGM 4046 health-risk based values or site specific risk based screening levels.

Blank space denotes parameter was not detected.

- Data not available

NA - Not Analyzed

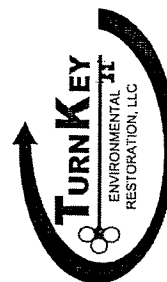


TABLE 3-2
LTV STEEL COMPANY/DONNER-HANNA
Supplemental Site Assessment and Voluntary Cleanup Plan for
Area I - Former Republic Steel Plant Parcel

SUMMARY OF SUBSURFACE SOIL RESULTS

Parameter	Risk Based Screening Levels (1)	Area 1 (2)												
		A1-SB(or MW)-A1,A2,A3	A1-SB-B1,B2,B3	A1-SB-C1	A1-SB-D1,D2,D3	A1-SB-E1,E2,E3	SB(or MW)-F1,F2	A1-SB-G1	A1-SB-H1,H2	A1-SB-I1,I2	A1-SB-J2	A1-SB(or MW)-K1,K2,K3	A1-SB(or MW)-M1/M2	
		8-12	10-14	10-12	10-14	4-8	4-6	8-10,11-11.5	8-10	8-13	10-12,8-10	6-8.5	4-5	6-6.5
Semivolatile Organic Compounds (mg/kg)														
Acenaphthene	5,000			3.1		0.69						10	380	
Acenaphthylene	-												2200	
Anthracene	20,000			2.1		1.6						7.4	2100	
Benzo(a)anthracene	304*					3.9			0.89			8.1	1700	0.6
Benzo(a)pyrene	30.4*					3.1			0.67			6.1	1400	0.56
Benzo(b)fluoranthene	304*					3.6	0.45		0.88				1600	0.94
Benzo(k)fluoranthene	3,040*					2.1							660	
Benzo(g,h,i)perylene	-					1.6								
Chrysene	3,040*					3.3			0.74			14	1400	0.67
Dibenzo(a,h)anthracene	30.4*					0.75								
Dibenzofuran	-					0.51							NA	
Fluoranthene	3,000					7.3	0.73	0.7	1.8		0.93	7.3	3900	0.98
Flourene	3,000			2.4		0.75					0.51	24	2500	
Indeno(1,2,3-cd)pyrene	-					1.6							640	
2-Methylnaphthalene	-			13								17	NA	
Napthalene	300					0.78					0.72		7300	
Phenanthrene	-	93		9.6		5.8	0.45	0.64	1.4		1.8	33	5100	1.1
Pyrene	2,000	42		2.8		6.4	0.66	0.61	1.4		0.7	28	3000	1.2

NOTES:

(1) Levels flagged by an * represent risk based screening levels from ASTM E1739-95 (see Section 2).

Non-flagged levels represent TAGM 4046 health-based cleanup levels.

(2) Data from Phase I/II Environmental Site Assessment Report prepared by Malcolm Pirnie, Inc., September 1997

Shading denotes concentration exceeds TAGM 4046 health-risk based values or site specific risk based screening levels.

Blank space denotes parameter was not detected.

- Data not available

NA - Not Analyzed

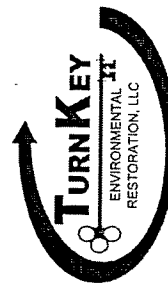


TABLE 3-2
LTV STEEL COMPANY/DONNER-HANNA
Supplemental Site Assessment and Voluntary Cleanup Plan for
Area I - Former Republic Steel Plant Parcel

SUMMARY OF SUBSURFACE SOIL RESULTS

Parameter	Background (1)	Risk Based Screening Levels(2)	Area 1 ⁽⁴⁾										A1-SB(or MW)-M1/M2
			A1-SB(or MW)-A1,A2,A3	A1-SB-B1,B2,B3	A1-SB-C1	A1-SB-D1,D2,D3	A1-SB-E1,E2,E3	SB(or MW)-F1,F2	A1-SB-G1	A1-SB-H1,H2	A1-SB-I1,I2	A1-SB-J2	A1-SB(or MW)-K1,K2,K3
Sample Depth, ft			8-12	10-14	10-12	10-14	4-8	4-6	8-10,11-11.5	8-10	8-13	10-12,8-10	4-5
Inorganic Compounds (mg/kg)													
Aluminum	33,000		29400	12900	7590	11600	25500	19100	9220	7180	15000	22000	9700
Antimony	-												
Arsenic		613			3.5	21.8		2.4		16.7			11.6
Barium	600		408	117	54.7	118	304	243	62.4	85.5	132	142	85.6
Beryllium		4088	3.82			1.03	3.18	1.5	2.9	1.26	0.751	0.928	1.36
Cadmium	1		1.29			1.25	1.8	1.05	4.72	5.05			1.3
Calcium	44,400		174000	14700	8180	39200	159000	56000	49400	16000	80800	12600	21900
Chromium		NA	101	25.9	11.3	20.2	328	71.7	42.6	45.3	22.3	24.8	37.4
Cobalt	60			10.9	7.68			11.3		8.88	9.01	11.6	Not Analyz.
Copper	55.7		50.1	26.7	19.8	51.5	204	40.2		97.9	25.6	14.2	48.4
Iron	550,000		69900	26500	18700	75000	117000	63500	275000	192000	23800	23800	84100
Lead	500		11.5	17.4	68.4	116	159	24.2	15.3	293	31.1	14.8	192
Magnesium	7920		15400	5180	2860	4490	8040	9930	3290	1880	21900	5210	2930
Manganese		286,160	3250	674	303	1010	7500	2360	4180	5370	642	449	1170
Mercury	0.211					0.323				2.37			
Nickel		40880	70.2	32.6	21.6	18.9	15.6	37.6		51.7	22.1	30.7	18.3
Potassium	43,000		912	2210	1160	1420	1680	2180	673	4830	2760	2060	1510
Selenium		10220	3.28	1.04			2.02				4.79	2.48	2.7
Silver		10220											
Sodium	8,000		956	206	206	224	553	418	165	503	345	372	320
Thallium	-								2.56				
Vanadium	300		19.6	23.1	13.3	19.3	69.6	37.5	26.7	33.3	26.9	23.7	46.4
Zinc		613,200	21.3	87.7	71.9	228	207	128	44	1760	76.3	101	174
Cyanide		1600 ⁽³⁾					2.79			3.07			3.78

NOTES: (1) Background inorganic soil concentrations from Truscon Property or TAGM (Eastern US/NYS) as described in Section 2

Blank space denotes parameter was not detected.

(2) Levels derived from ASTM E1739-95 (see Section 2)

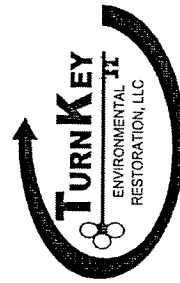
(3) See Section 2

(4) Data from Phase I/II Environmental Site Assessment Report prepared by Malcolm Pirnie, Inc., September 1997

Shading denotes concentration exceeds risk based screening level or background TAGM 4046 values.

- Data not available

NA - Greater than 100%



Subsequent to completion of the Phase II investigation, subareas E, K and L were identified as potential areas of concern due to elevated PAH levels as compared to USEPA Region III risk-based concentrations. Comparison of the subsurface sample results for these and other subareas to the same criteria as the surface soils samples (i.e. RBSLs/TAGM 4046 health-based criteria for organics, RBSLs/background data for inorganics) is presented in Table 3-2. As indicated in Table 3-2, organic parameters detected in the subsurface soils were typically below the associated RBSL or TAGM health risk-based value with the exception of the sample from test pit 10 (i.e., subarea L). At this location, several PAHs exceeded corresponding comparative values, likely as a result of historic fuel oil transport in this portion of the site.

Similar to the surface soils, inorganic concentrations in all subsurface soil samples were below the respective RBSL values. Inorganic concentrations were also below background levels with the exception of cadmium, calcium, magnesium and, to a lesser extent, mercury and copper. Again, however, these values were comparable to that of the corresponding background concentration, and are not indicative of a toxic characteristic under Federal or State regulations (i.e., 40 CFR Part 261, 6NYCRR Part 373). Consequently, no cleanup due to inorganic contamination will be performed for the subsurface soils in Area I.

To better quantify the extent of subsurface soils in and around Subarea L which contain PAHs, a supplemental investigation in this subarea was undertaken during the week of October 5, 1998. Excavation of additional test pits was performed to delineate the lateral and vertical extent of contamination, with confirmatory sampling to verify the edge of the impacted area. A similar investigation was performed in Subarea K to verify whether and how much soil from this former No. 6 fuel oil storage area may require removal and/or treatment. Figure 3-3 presents the location of the additional test pits. As indicated on Figure 3-3, test pits TP-12 through TP-23 were associated with Subarea L, and test pits TP-24 through TP-31 were associated with Subarea K. Each test pit was excavated to the lower of the top of native soil or the groundwater table, or to refusal. Test pit logs from the October 1998 investigation are presented in Appendix C.

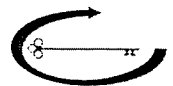
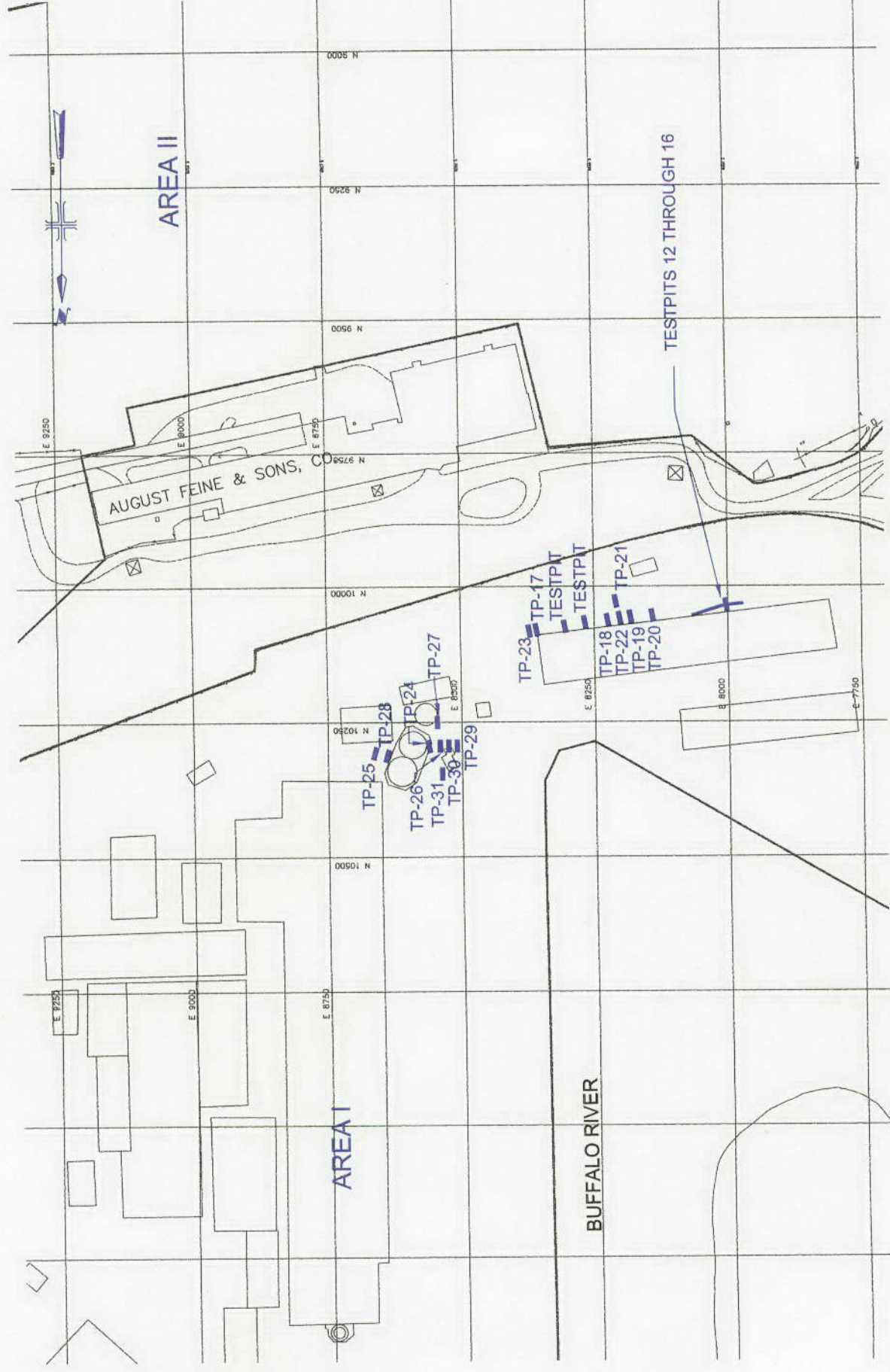


FIGURE 3-3



SCALE: 1 INCH = 200 FEET



TurnKey
ENVIRONMENTAL
RESTORATION, LLC

LTV STEEL COMPANY / HANNA FURNACE CORPORATION

**SITE ASSESSMENT REPORT AND VOLUNTARY CLEANUP PLAN
FOR AREA 1 - FORMER STEEL PLANT PARCEL**

SUBAREAS K AND L
TESTPIT INVESTIGATION

DATE OCTOBER 1998

SHEET — OF —

TKF010.DWG

Test pits excavated in Subarea L indicated a narrow band of visual contamination, consisting of tar product and/or stained soils, beginning at TP-17 and running parallel to the former building foundation toward TP-13. Several soil samples were strategically collected from the test pits and analyzed for TCL SVOCs so as to verify the observed limits of the contamination. Concurrent analysis for total petroleum hydrocarbons (TPH) was also performed to provide an indication of the relationship between TPH and SVOC concentrations. This may allow the cleanup contractor to identify and segregate clean excavation spoils from impacted materials via an inexpensive TPH test, thereby saving hauling costs. Table 3-3 presents the results of sample analyses for Subarea L. Samples collected from intervals where no visual contamination was detected are noted on the table. In general, these samples represent composites collected across the entire test pit depth to the top of native soil or the water surface. In addition, a number of composite samples were collected from fill soils below or above the tar to provide an indication of the impact, if any, to underlying materials. In the instance of TP-12, TP-13 and TP-15, the test pits were elongated and oriented at an angle away from the tar to provide an indication of the width of the impacted area, as illustrated on Figure 3-3. The TP-13, 0-5.5' and TP-15, 0-5' samples are composites that were collected upon reaching the apparent outer boundary of the staining (i.e., from the ends of these test pits opposite the product/staining).

In general, all samples from Subarea L with the exception of the sample collected directly within the stained product exhibited non-detectable to low concentrations of SVOCs, and were below the corresponding RBSLs. Thus, the data indicates that impacted soils in Subarea L are limited to the narrow band exhibiting obvious staining or product as described above.

Similar to the supplemental investigation of Subarea L, eight (8) additional test pits were completed in Subarea K (i.e., test pits TP-24 through TP-31 - see Figure 3-3). These test pits were excavated to the lower of native soils or groundwater, or to refusal. An area of petroleum staining, approximately 60 to 80 feet in diameter with varied depth was observed from approximately 4.5 to 5 feet

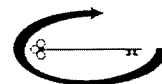


Table 3-3
LTV STEEL COMPANY/DONNER-HANNA
Supplemental Site Assessment Voluntary Cleanup Plan for
Area I - Former Republic Steel Plant

SUMMARY OF SOIL SAMPLING RESULTS IN SUBAREA L (2)

Parameter	Risk Based Screening Levels (1)	Description of Sampled Interval	A1-TP-12 0-5'	A1-TP-13 1-5'	A1-TP-13 0-5.5'	A1-TP-15 1.5-5'	A1-TP-15 0-5'	A1-TP-17 0-3'	A1-TP-17 3-5'	A1-TP-19 0-2'	A1-TP-22 0-4'
Semivolatile Organic Compounds (mg/kg)											
Acenaphthene	5,000		3.7 U	3.9 U	0.4 U	7.8	3.8 U	0.39 U	350	3.6 U	0.43 U
Acenaphthylene	-		13	6.5	1.1	78	7.8	1.5	1900	12	0.43 U
Anthracene	20,000		12	6.5	0.67	68	4.7	0.82	920	14	0.43 U
Benzo(a)anthracene	304*		26	13	1.7	94	9.3	0.81	790	14	0.43 U
Benzo(b)fluoranthene	304*		33	12	2.0	130	11	0.74	760	14	0.43 U
Benzo(k)fluoranthene	3,040*		25	17	2.4	75	13	0.94	770	15	0.78
Benzo(ghi)perylene	-		17	8.3	1.1	46	6.8	0.39 U	330	5.5	0.51
Benzo(a)pyrene	30.4*		30	14	2.2	100	11	0.84	860	15	0.8
Carbazole	-		3.7 U	3.9 U	0.4 U	18	3.8 U	0.5	610	4.6	0.43 U
Chrysene	3,040*		26	12	1.7	84	9.1	0.69	690	13	0.46
Dibenzo(a,h)anthracene	30.4*		7.1	3.9 U	0.49	23	3.8 U	0.39 U	210 U	3.6 U	0.43 U
Dibenzofuran	-		3.7 U	3.9 U	0.4 U	32	3.8 U	0.83	1100	6.3	0.43 U
2,4-Dimethylphenol	-		7.5 U	7.9 U	0.81 U	16 U	7.6 U	0.8 U	430 U	7.3 U	0.87 U
Fluoranthene	3,000		62	37	4.2	210	24	2.9	2600	42	0.9
Fluorene	3,000		4.3	3.9 U	0.4 U	57	3.8 U	1.3	1500	15	0.43 U
Indeno(1,2,3-cd)pyrene	-		19	8.6	1.2	55	7.8	0.4	380	6.6	0.55
2-Methylnaphthalene	-		7.5 U	7.9 U	0.81 U	16 U	7.6 U	0.8 U	1200	7.3 U	0.87 U
2-Methylphenol	-		7.5 U	7.9 U	0.81 U	16 U	7.6 U	0.8 U	430 U	7.3 U	0.87 U
Naphthalene	300		3.7 U	3.9 U	0.4 U	130	3.8 U	3.4	6000	3.6 U	0.43 U
Pentachlorophenol	2,000		15 U	15 U	1.6 U	31 U	15 U	1.5 U	830 U	14 U	1.7 U
Phenanthrene	-		36	24	2.3	180	14	3.4	3300	43	0.43 U
Pyrene	2,000		39	21	2.6	140	15	1.4	1300	23	0.57
Total Petroleum Hydrocarbons			296	67	73.2	271	691	39.2 U	1700	167	43 U

Notes:

(1) Levels flagged by an * represent risk based screening levels from ASTM E1739-95 (see Section 2).

Non-flagged levels represent TAGM 4046 health-based cleanup levels.

(2) Data collected and analyzed by TurnKey Environmental Restoration, LLC during investigations performed in October, 1998

(3) No visual contamination present.

Shading denotes concentration exceeds TAGM 4046 health-risk based values or site specific risk based screening levels.

U-Indicates compound was analyzed for but was not detected.

- Data not available



below grade in the vicinity of TP-30, TP-26 and TP-24. Analytical results for soil samples collected from supplemental test pits in Subarea K are presented in Table 3-4. Only those parameters which exhibited a detectable concentration at one of the sample locations are presented. Elevated concentrations of TCL SVOCs were observed from 4.5 - 5' below grade in TP-30. Samples from the remaining test pits, located outside the observed area of staining, exhibited substantially lower SVOC concentrations. All samples collected from Subarea K test pits were below the corresponding RBSLs.

A discussion of the estimated volumes of soil in Subareas K and L that may require cleanup is presented in Section 6.

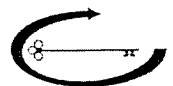


Table 3-4
LTV STEEL COMPANY/DONNER-HANNA
Supplemental Site Assessment Voluntary Cleanup Plan for
Area I - Former Republic Steel Plant

SUMMARY OF SOIL SAMPLING RESULTS IN SUBAREA K (2)

Parameter	Risk Based Screening Levels (1)	Description of Sampled Interval	A1-TP-24 1-4'	A1-TP-30 0-4.5'	A1-TP-30 4.5-5'	A1-TP-31 0-6'
Semivolatile Organic Compounds (mg/kg)						
Acenaphthene	5,000		7.8 U	0.39 U	18 U	0.37 U
Acenaphthylene	-		7.8 U	0.39 U	65	0.37 U
Anthracene	20,000		7.8 U	0.39 U	33	0.37 U
Benzo(a)anthracene	304*		8.1	0.66	31	0.64
Benzo(b)fluoranthene	304*		8.7	0.79	22	1.1
Benzo(k)fluoranthene	3,040*		9.7	1.1	32	1.1
Benzo(ghi)perylene	-		7.8 U	0.42	18 U	0.51
Benzo(a)pyrene	30.4*		9.9	0.85	30	0.83
Carbazole	-		7.8 U	0.39 U	19	0.37 U
Chrysene	3,040*		8.2	0.75	31	0.87
Dibenzo(a,h)anthracene	30.4*		7.8 U	0.39 U	18 U	0.37 U
Dibenzofuran*	-		7.8 U	0.39 U	37	0.37 U
2,4-Dimethylphenol	-		16 U	0.79 U	37 U	0.75 U
Fluoranthene	3,000		27	1.5	84	1.6
Fluorene	3,000		7.8 U	0.39 U	57	0.37 U
Indeno(1,2,3-cd)pyrene	-		7.8 U	0.44	18 U	0.52
2-Methylnaphthalene	-		16 U	0.79 U	73	0.75 U
2-Methylphenol	-		16 U	0.79 U	37 U	0.75 U
Naphthalene	300		13	0.39 U	240	0.37 U
Pentachlorophenol	2,000		31 U	1.5 U	72 U	1.5 U
Phenanthrene	-		21	1.0	140	0.85
Pyrene	2,000		15	1.1	63	1.2
Total Petroleum Hydrocarbons			823	392	62300	1010

Notes:

(1) Levels flagged by an * represent risk based screening levels from ASTM E1739-95 (see Section 2).

Non-flagged levels represent TAGM 4046 health-based cleanup levels.

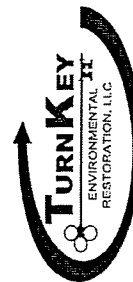
(2) Data collected and analyzed by TurnKey Environmental Restoration, LLC during investigations performed in October, 1998

(3) No visual contamination present.

Shading denotes concentration exceeds TAGM 4046 health-risk based values or site specific risk based screening levels.

U-Indicates compound was analyzed for but was not detected.

- Data not available



4.0 GROUNDWATER ASSESSMENT

4.1 General

The NYSDEC has identified concerns regarding off-site groundwater migration and potential impacts on sensitive downgradient receptors. The Buffalo River is adjacent to and downgradient of Area I, the former Republic Steel Plant, based upon shallow groundwater potentiometric data. The Buffalo River is considered a “sensitive downgradient sensor” by the NYSDEC. As such, the Supplemental Field Investigation Work Plan (Malcolm Pirnie, February, 1998) delineated a perimeter groundwater investigation to address the following specific objectives relating to Area I:

- Define the shallow groundwater flow and quality in Area I adjacent to the Buffalo River.
- Determine whether subsurface petroleum-contamination in Subareas L, K, and E soils/fill are adversely impacting groundwater quality to the extent that there may be an impact on the Buffalo River.
- Calculate the rate of groundwater migration and annual mass load of contaminants migrating from the Site to the Buffalo River under current conditions.

4.2 Perimeter Groundwater Investigation Activities

In general accordance with the Supplemental Field Investigation Work Plan (Malcolm Pirnie, February 1998) the following field activities were performed in Area I:

- Installation of monitoring wells A1-MW-1, A1-MW-2, and A1-MW-3 along the Buffalo River (refer to Figure 4-1 for locations).

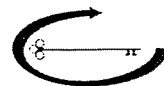
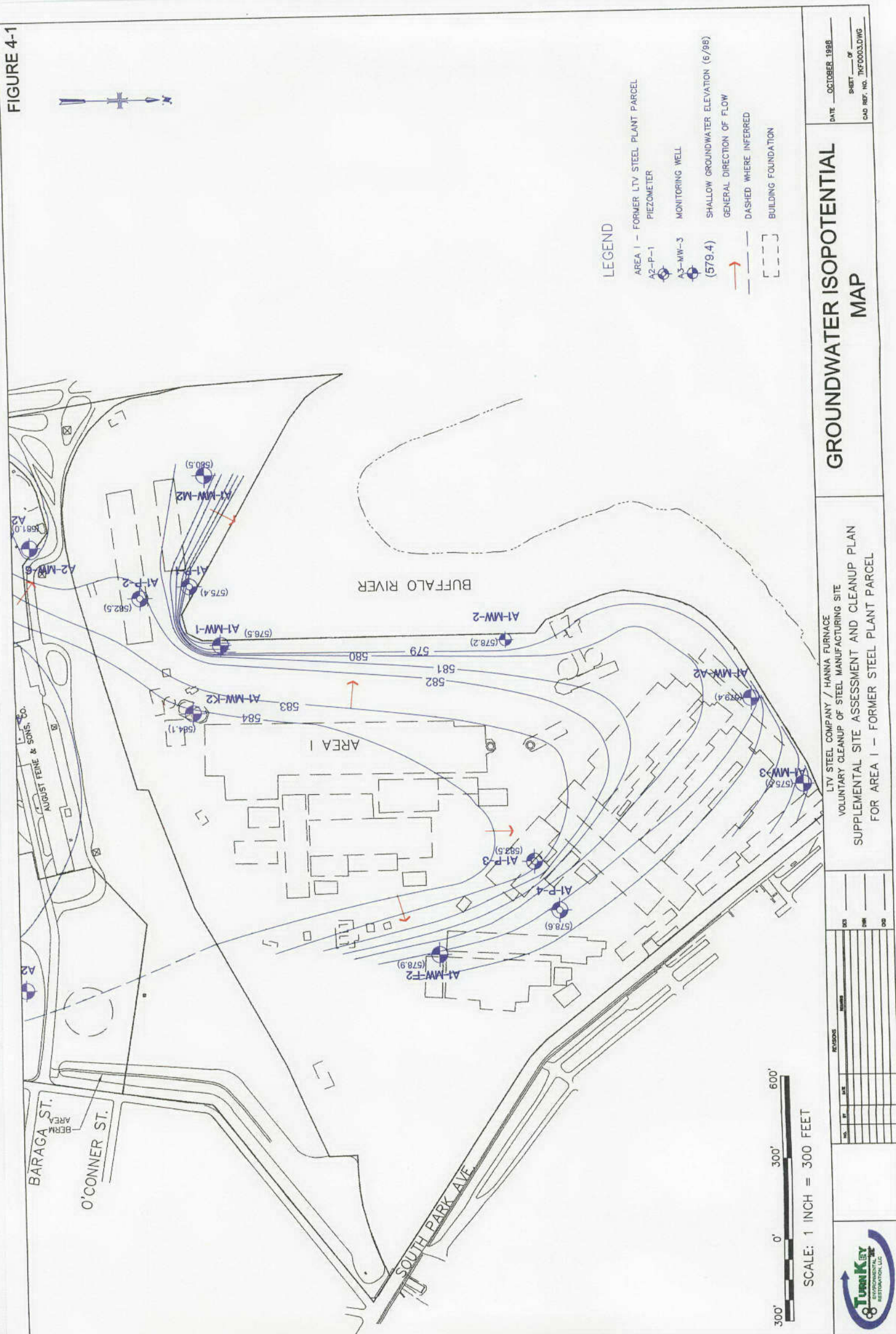


FIGURE 4-1



- Installation of temporary piezometers A1-P-1, A1-P-2, A1-P-3, and A1-P-4 (refer to Figure 4-1 for locations).
- Measuring and recording static water level measurements for all Area I monitoring wells and piezometers.
- Slug testing the following monitoring wells and piezometers: A1-MW-1, A1-MW-2, A1-MW-3, A1-MW-M2, A1-MW-K2, A1-P-1, A1-P-2, A1-P-3, and A1-P-4 to calculate hydraulic conductivity in the shallow aquifer.
- Sampling the following wells for site specific parameters of interest (i.e., benzene, toluene, ethylbenzene, and xylene [BTEX], polynuclear aromatic hydrocarbons [PAHs], phenol, and cyanide,): A1-MW-2, A1-MW-3, and A1-MW-A2 and sampling of A1-MW-K2, A1-MW-1, A1-P-1, A1-P-2, A1-P-3, and A1-P-4 for the same parameters of interest and iron.

4.3 Perimeter Groundwater Flow

Static groundwater level measurement results are presented in Table 4-1 and Area I groundwater isopotential contours are shown on Figure 4-1. Groundwater occurs at varying depths within Area I. Groundwater depths adjacent to the Buffalo River are greater than approximately 9 feet below grade. In the middle portion of the site groundwater is typically found at between 4 to 6 feet below grade. Figure 4-1 shows groundwater elevations and inferred flow directions based on depth-to-groundwater measurements collected June 8, 1998. As shown on Figure 4-1, shallow groundwater migrates toward the Buffalo River with a varying gradient as calculated and presented in Table 4-5. Hydraulic conductivity measurements for Area I are presented in Table 4-2. Hydraulic conductivity results for the monitoring wells in Area I range from 0.12 ft/day in A1-MW-M2 to 595.3 ft/day in A1-P-1. This indicates that the fill in Area I has a highly variable grain size distribution.

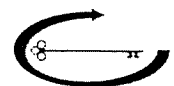


TABLE 4-1
LTV STEEL COMPANY/DONNER-HANNA
Supplemental Site Assessment and Voluntary Cleanup Plan for
Area I - Former Republic Steel Plant Parcel

SUMMARY OF STATIC GROUNDWATER LEVELS ⁽¹⁾

<i>Well Designation</i>	<i>Groundwater Elevation ⁽²⁾ msl</i>
A1-MW-A2	579.35
A1-MW-F2	578.92
A1-MW-K2	584.12
A1-MW-M2	580.47
A1-MW-1	576.45
A1-MW-2	578.19
A1-MW-3	575.52
A1-P-1	575.36
A1-P-2	582.46
A1-P-3	583.48
A1-P-4	578.63

NOTES: (1) Water Levels recorded on June 8, 1998
(2) Water Levels were recorded by Malcolm Pirnie, Inc.
during Supplemental Field Invest. Performed March-April, 1998

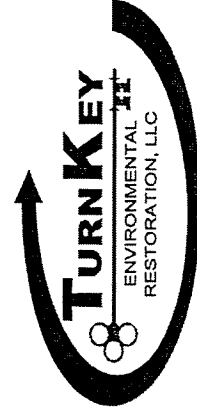
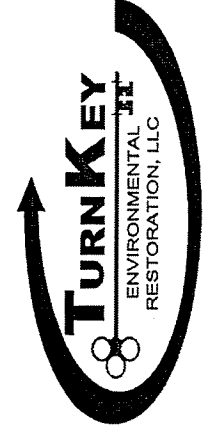


TABLE 4-2
LTV STEEL COMPANY/DONNER-HANNA
Supplemental Site Assessment and Voluntary Cleanup Plan for
Area I - Former Republic Steel Plant Parcel

SUMMARY OF SLUG TESTING RESULTS ⁽¹⁾

<i>Well Designation</i>	<i>Hydraulic Conductivity ft/d</i>
A1-MW-A2	-
A1-MW-K2	82.2
A1-MW-M2	0.12
A1-MW-1	133.2
A1-MW-2	425.2
A1-MW-3	11.6
A1-P-1	595.3
A1-P-2	121.9
A1-P-3	311.8
A1-P-4	0.68

NOTES: (1) Slug tests were performed by Malcolm Pirnie, Inc.
during Supplemental Field Invest. Performed March-April, 1998



4.4 Groundwater Quality

Analytical results of groundwater quality testing in Area I are presented in Table 4-3. Figure 4-2 presents the location of monitoring wells and piezometers that were sampled. Site specific parameters of interest (i.e., polynuclear aromatic hydrocarbons [PAHs], phenol, cyanide, benzene, toluene, ethylbenzene, and xylene [BTEX] and iron) were analyzed and used as the basis for calculation of average contaminant loadings to the Buffalo River presented in the following section.

4.5 Site-Specific Contaminant Loadings to Buffalo River

Data collected during the supplemental field investigation was used to estimate the groundwater contaminant loading to the Buffalo River. The calculation of groundwater contaminant mass loading from the Site to the Buffalo River is based upon the following assumptions:

- The shoreline of the Buffalo River on the Site was approximated as three straight lines. Each line was further divided into three segments as shown on Figure 4-3 and described below:

Line 1: Segment 1-1 from the northernmost point on the property to monitoring well A1-MW-3 (approximately 135 feet long). Segment 1-2 from monitoring well A1-MW-3 to monitoring well A1-MW-A2 (approximately 357 feet long). Segment 1-3 from monitoring well A1-MW-A2 to the bend in the Buffalo River (approximately 250 feet long).

Line 2: Segment 2-1 from the bend in the Buffalo River to monitoring well A1-MW-2 (approximately 760 feet). Segment 2-2 from monitoring well A1-MW-2 to monitoring well A1-MW-1 (approximately 1,050 feet). Segment 2-3 from monitoring well A1-MW-1 to approximately 230 feet south.



TABLE 4-3
LTV STEEL COMPANY/DONNER HANNA
 Supplemental Site Assessment and Voluntary Cleanup Plan for
 Area I - Former Republic Steel Plant Parcel
SUMMARY OF GROUNDWATER SAMPLING RESULTS IN AREA I ⁽²⁾

Parameter		NYS Class GA Groundwater Quality Stds ^(v)	Wells Located Adjacent to the Buffalo River					Wells Located in Area I Interior			
			AI-MW-1	AI-MW-2	AI-MW-3	AI-MW-A2	AI-P-1	AI-MW-K2	AI-P-2	AI-P-3	AI-P-4
Volatile Organic Compounds (µg/L)											
Benzene	0.7		5 U	5 U	5 U	5 U	5 U	5 U	6	5 U	5 U
Ethylbenzene	5		5 U	2 J	5 U	5 U	5 U	5 U	5 U	5 U	5 U
Toluene	5		5 U	5 U	5 U	7	5 U	5 U	1 J	5 U	5 U
Xylene (Total)	5		15 U	1 J	15 U	14 J	15 U	15 U	15 U	15 U	15 U
Semivolatile Organic Compounds (µg/L)											
Acenaphthene	20		10 U	15	10 U	4 J	0.8 J	3 J	10 U	10 U	10 U
Acenaphthylene	-		10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U
Anthracene	50		10 U	10 U	10 U	10 U	1 J	10 U	10 U	10 U	10 U
Benzo(a)anthracene	0.002		10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U
Benzo(b)fluoranthene	0.002		10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U
Benzo(k)fluoranthene	0.002		10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U
Benzo(ghi)perylene	-		10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U
Benzo(a)pyrene	-		10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U
Chrysene	0.002		10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U
Dibenzo(a,h)anthracene	-		10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U
Fluoranthene	50		10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U
Fluorene	50		10 U	24	10 U	6 J	10 U	5 J	10 U	10 U	10 U
Indeno(1,2,3-cd)pyrene	0.002		10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U
2-Methylnaphthalene	-		10 U	120	10 U	21	10 U	4 J	10 U	10 U	10 U
Naphthalene	10		1 J	66	10 U	9 J	10 U	10 U	4 J	10 U	10 U
Phenanthrene	50		10 U	40	10 U	8 J	1 J	10 U	10 U	10 U	10 U
Pyrene	50		10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U
Phenol	1		10 U	10 U	10 U	2 J	10 U	10 U	10 U	10 U	10 U
Inorganic Compounds (mg/L)											
Iron	0.3		4.0	NA	NA	NA	0.066	3.4	0.11	0.03 U	0.19
Cyanide	0.1		0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.027	0.01 U	0.01 U	0.01 U

Notes: (1) Value represents either a Groundwater Standard or a Guidance Value. (2) Data collected & analyzed by Malcolm Pirnie, Inc during Supplemental Field Investigation performed in March & April, 1998

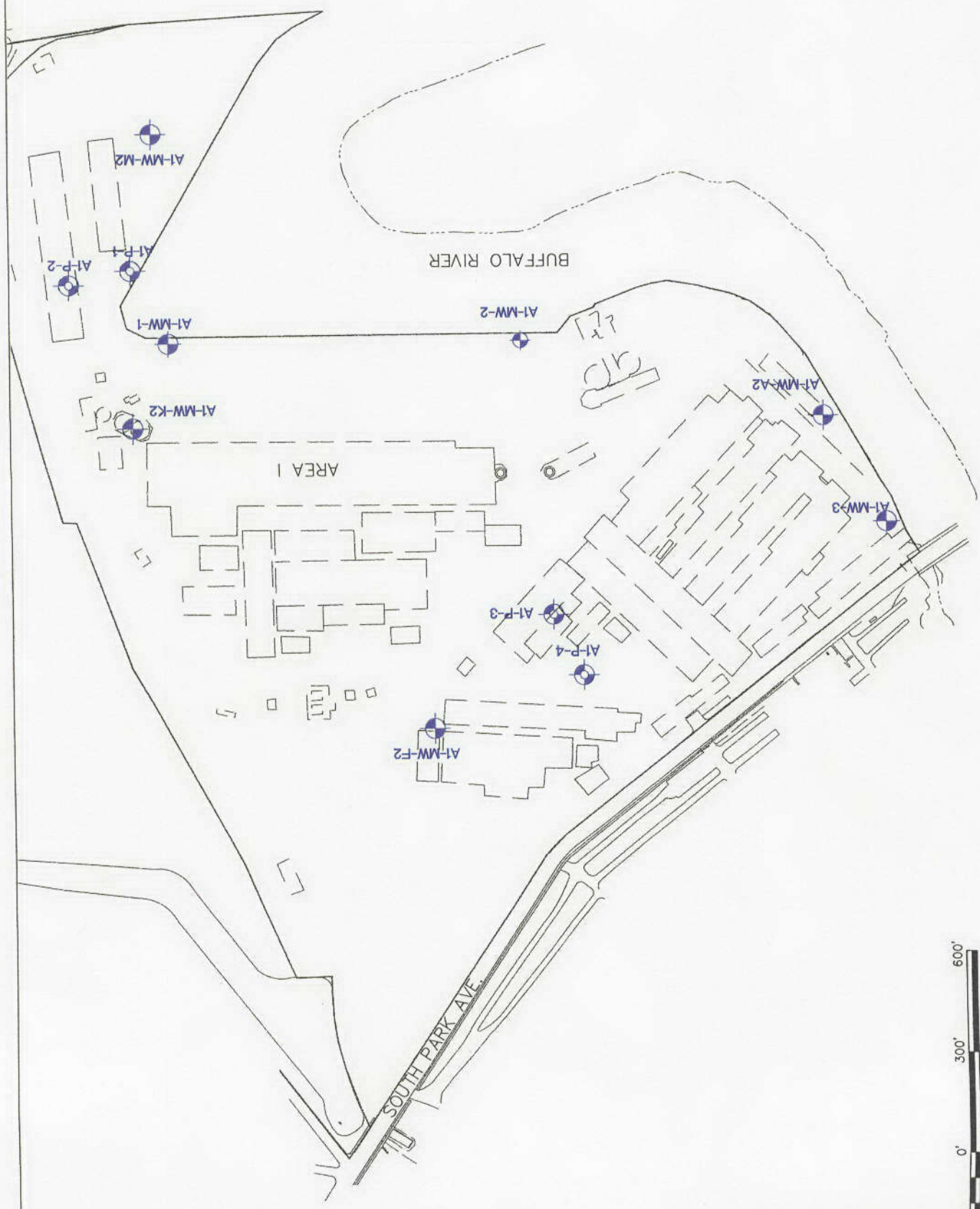
U - Compound was analyzed for but was not detected.

- NYS Guidance Value or Standard not available.

J - Analyte was positively identified; the associated numerical value is the approx. concentration of the analyte in the sample.



FIGURE 4-2



300' 0' 300' 600'

SCALE: 1 INCH = 300 FEET



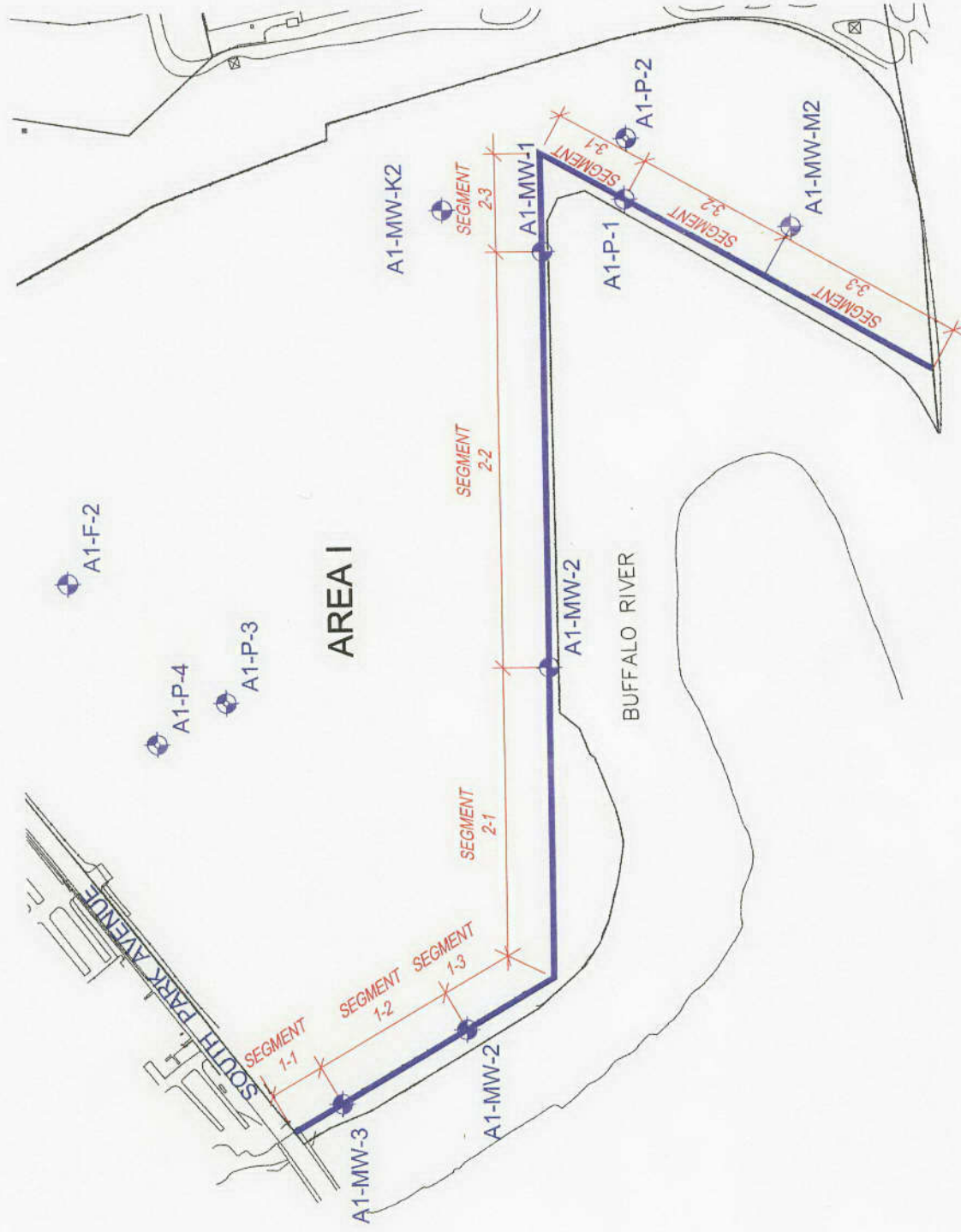
REVISIONS			
NO.	BY	DATE	DESCRIPTION

LTV STEEL COMPANY / HANNA FURNACE
VOLUNTARY CLEANUP OF STEEL MANUFACTURING SITE
SUPPLEMENTAL SITE ASSESSMENT AND CLEANUP PLAN
FOR AREA I - FORMER STEEL PLANT PARCEL

GROUNDWATER
SAMPLE LOCATIONS

DATE OCTOBER 1998
SHEET 1 OF 1
GAS REF. NO. TRF001.DWG

FIGURE 4-3



SCALE: 1 INCH = 300 FEET



LTV STEEL COMPANY / HANNA FURNACE
VOLUNTARY CLEANUP OF STEEL MANUFACTURING SITE
SUPPLEMENTAL SITE ASSESSMENT AND CLEANUP PLAN
FOR AREA 1 - FORMER STEEL PLANT PARCEL

BUFFALO RIVER BOUNDARY GROUNDWATER FLOW SEGMENTS

DATE OCTOBER 1998
SHEET OF
CAD REF. NO. TKF0006.DWG

[illegible]

Line 3: Segment 3-1 from 230 feet south of monitoring well A1-MW-1 to A1-P-1 (approximately 250 feet). Segment 3-2 from A1-P-1 to monitoring well A1-MW-M2 (approximately 377 feet). Segment 3-3 from monitoring well A1-MW-M2 approximately 583 feet northwest.

- Only groundwater in the uppermost-saturated zone (fill material) is contributing contaminants to the Buffalo River.
- The hydraulic conductivity, hydraulic gradient, and groundwater constituent concentration for each segment was calculated by taking the arithmetic average of the specific variable for each of the wells that define the segment (these values are presented in Table 4-4 and 4-5).
- The north end point of Segment 1-1 and the west end point of Segment 3-3 were assumed to have the same hydraulic and chemical properties as monitoring wells A1-MW-3 and A1-MW-M2, respectively.
- The hydraulic properties of A1-MW-A2 were estimated by interpolating data between A1-MW-3 and A1-MW-2.
- The hydraulic and chemical properties of the south end of Segment 1-3 and the north end of Segment 2-1 were estimated by interpolating data between A1-MW-3 and A1-MW-2.
- The hydraulic and chemical properties of south end of Segment 2-3 and the west end of Segment 3-1 were estimated by interpolating data between A1-MW-1 and A1-P-1.

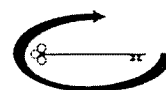


TABLE 4-4
LTV STEEL COMPANY/DONNER-HANNA
Supplemental Site Investigation and Voluntary Cleanup Plan for
Area I - Former Steel Plant Parcel

Calculated Average Groundwater Constituent Concentrations By Segment

Constituent	Segment 1-1	Segment 1-2	Segment 1-3	Segment 2-1	Segment 2-2	Segment 2-3	Segment 3-1	Segment 3-2	Segment 3-3
Volatile Organic Compounds (ug/L):									
Benzene	0	0	0	0	0	0	0	0	0
Ethylbenzene	0	0	0	1	1	0	0	0	0
Toluene	0	3.5	7	3.5	0	0	0	0	0
Xylene (total)	0	7	14	7.5	0.5	0	0	0	0
Acetone	0	0	0	0	0	0	0	11.5	23
Semivolatile Organic Compounds (ug/L):									
Acenaphthene	0	2	4	9.5	7.5	0	0.4	0.4	0
Anthracene	0	0	0	0	0	0	0.5	0.5	0
Fluorene	0	3	6	15	12	0	0	0	0
2-Methylnaphthalene	0	10.5	21	70.5	60	0	0	0	0
Naphthalene	0	4.5	9	37.5	33.5	1	0.5	0	0
Phenanthrene	0	4	8	24	20	0	0.5	0.5	0
Phenol	0	1	2	1	0	0	0	0	0



TABLE 4-5
LTV STEEL COMPANY/DONNER-HANNA
Supplemental Site Assessment and Voluntary Cleanup Plan for
Area I - Former Steel Plant Parcel

Calculation of Groundwater Flow Contribution to Buffalo River from Area I

Description	k (ft/day)	I (ft/ft)	A (ft ²)	Groundwater Flow (ft ³ /day)
Line 1:				
North End Line 1 ⁽¹⁾	11.6	0.0099	-	-
A1-MW-3	11.6	0.0099	-	-
A1-MW-A2 ⁽²⁾	117.4	0.0102	-	-
Line 2:				
North End Line 2 ⁽³⁾	189.3	0.0123	-	-
A1-MW-2	425.2	0.0215	-	-
A1-MW-1	133.2	0.0389	-	-
Line 3:				
East End Line 3 ⁽⁴⁾	325.8	0.0413	-	-
A1-P-1	595.3	0.0432	-	-
A1-MW-M2	0.12	0.0428	-	-
West End Line 3 ⁽⁵⁾	0.12	0.0428	-	-
Line 1:				
Segment 1-1	11.6	0.0099	430.65	50
Segment 1-2	64.5	0.01005	1399.44	907
Segment 1-3	153.4	0.01125	1206.25	2081
Total				3038
Line 2:				
Segment 2-1	307.2	0.0169	4373.8	22711
Segment 2-2	279.2	0.0302	3417.75	28819
Segment 2-3	229.5	0.0401	0	0
Total				51530
Line 3:				
Segment 3-1	460.5	0.04225	142.5	2773
Segment 3-2	297.7	0.043	623.935	7987
Segment 3-3	0.12	0.0428	1265.11	6
Total				10766



Using the data described above, the groundwater flow rate from the northern boundary of the site to the Buffalo River was estimated for each segment using Darcy's Law:

$$Q = kiA$$

where:

Q = Groundwater flow rate

k = average hydraulic conductivity of the segment

i = average hydraulic gradient of the segment

A = saturated cross-sectional area

The estimated groundwater flows from each segment were then combined to give the total estimated groundwater flow rate from the Site to the River of 65,335 cubic feet per day. Groundwater flow rate calculations are summarized in Table 4-5.

Given the groundwater flow rate and the estimated groundwater concentrations for each segment, the off-site contaminant loading was calculated using the following equation:

$$(\text{Mass Loading})_{ij} = (6.243 \times 10^{-8}) Q_i C_{ij}$$

where:

$(\text{Mass Loading})_{ij}$ = mass loading of constituent j in segment i (lb/day)

Q_i = groundwater flow rate through segment i (ft³/day)

C_{ij} = concentration of constituent j in segment i (ug/l)

6.243×10^{-8} = conversion factor to lb/day

Calculations of off-site groundwater contaminant mass loadings for each segment are summarized in Table 4-6 and total off-site contaminant mass loadings from the Site to the Buffalo River are summarized in Table 4-7. As shown on Table 4-7, the total off-site VOC and SVOC loadings to the Buffalo River are estimated to be approximately 0.0288 lb/day and 0.472 lb/day, respectively.

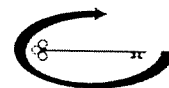


TABLE 4-6
LTV STEEL COMPANY/DONNER-HANNA
Supplemental Site Assessment and Voluntary Cleanup Plan for
Area I - Former Steel Plant Parcel

Groundwater Contaminant Loading to Buffalo River

Constituent	Segment 1-1	Segment 1-2	Segment 1-3	Segment 2-1	Segment 2-2	Segment 2-3	Segment 3-1	Segment 3-2	Segment 3-3
Volatile Organic Compounds (lb/day):									
Ethylbenzene	0.000E+00	0.000E+00	0.000E+00	1.418E-03	1.799E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Toluene	0.000E+00	1.983E-04	9.094E-04	4.962E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Xylene (total)	0.000E+00	3.965E-04	1.819E-03	1.063E-02	8.996E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Acetone	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	5.734E-03	9.256E-06
Total VOC Loading	0.000E+00	5.948E-04	2.728E-03	1.701E-02	2.699E-03	0.000E+00	0.000E+00	5.734E-03	9.256E-06
Semivolatile Organic Compounds (lb/day):									
Acenaphthene	0.000E+00	1.131E-04	5.197E-04	1.347E-02	1.349E-02	0.000E+00	6.924E-05	1.995E-04	0.000E+00
Anthracene	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	8.655E-05	2.493E-04	0.000E+00
Fluorene	0.000E+00	1.697E-04	7.795E-04	2.127E-02	2.159E-02	0.000E+00	0.000E+00	0.000E+00	0.000E+00
2-Methylnaphthalene	0.000E+00	5.939E-04	2.728E-03	9.996E-02	1.080E-01	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Naphthalene	0.000E+00	2.545E-04	1.169E-03	5.317E-02	6.027E-02	0.000E+00	8.655E-05	0.000E+00	0.000E+00
Phenanthrene	0.000E+00	2.262E-04	1.039E-03	3.403E-02	3.598E-02	0.000E+00	8.655E-05	2.493E-04	0.000E+00
Phenol	0.000E+00	5.656E-05	2.598E-04	1.418E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Total SVOC Loading	0.000E+00	1.414E-03	6.496E-03	2.233E-01	2.393E-01	0.000E+00	3.289E-04	6.981E-04	0.000E+00
Total Organic Loading	0.000E+00	2.009E-03	9.224E-03	2.403E-01	2.420E-01	0.000E+00	3.289E-04	6.432E-03	9.256E-06



TABLE 4-7
LTV STEEL COMPANY/DONNER-HANNA
Supplemental Site Assessment and Voluntary Cleanup Plan
Area I - Former Steel Plant Parcel

Estimated Increase in Downstream Constituent Concentration

Constituent	Total Loading (lb/day)	Estimated Increase In Downstream Constituent Concentration (ug/L) ⁽¹⁾	New York State Class D Water Quality Standard/Guidance Value (ug/L)	New York State Class A Water Quality Standard/Guidance Value (ug/L)
Volatile Organic Compounds:				
Ethylbenzene	0.00322	0.008	-	5
Toluene	0.00607	0.015	-	5
Xylene (total)	0.0137	0.034	-	5
Acetone	0.00574	0.014	-	50
Total VOCs	0.0288	0.587	-	-
Semivolatile Organic Compounds:				
Acenaphthene	0.0279	0.068	-	20
Anthracene	0.000336	0.007	-	50
Fluorene	0.0438	0.894	-	50
2-Methylnaphthalene	0.211	4.311	-	-
Naphthalene	0.115	2.346	-	10
Phenanthrene	0.0716	1.461	-	50
Phenol	0.00173	0.035	5	1
Total SVOCs	0.472	9.623	-	-
Total VOCs and SVOCs	0.500	10.211	-	-

Notes:

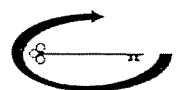
- (1) Assumes the average daily flow rate of the Buffalo River during the summer is 49 million gallons per day. Source: Buffalo River Remedial Action Plan, NYSDEC, November 1989.
- No New York State Water Quality Standard or Guidance Value.



4.6 Assessment of Groundwater Impacts on Buffalo River Quality

Based upon the groundwater contaminant loadings presented above, the estimated increase in downstream constituent concentrations in the Buffalo River at average summer flow rates of 49 million gallons per day (Source: Buffalo River Remedial Action Plan, NYSDEC, November 1989), were calculated. These estimated increases in downstream constituent concentrations were then compared with New York State Class "D" Water Quality Standards or Guidance Values. As shown in Table 4-7, estimated increases in downstream constituent concentrations are at least two orders of magnitude below New York State Class "D" Water Quality Standards or Guidance Values. In addition, a comparison of increases in downstream constituent concentrations with Class "A" Water Quality Standards or Guidance Values shows that increases in downstream constituent concentrations are not likely to adversely affect any potential future upgrade in classification of the Buffalo River to a Class "A" stream since estimated increases are at least an order of magnitude below Class "A" Water Quality Standards or Guidance Values.

The results of the loading analysis are consistent with historical Buffalo River water quality data collected from April 1982 through March 1986 which indicate that none of the VOCs or SVOCs evaluated in the Buffalo River loading analysis were detected in the Buffalo River.



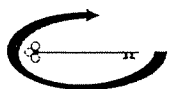
5.0 UNDERGROUND PIPELINE INVESTIGATION

The NYSDEC requested that an investigation be performed to evaluate the former oil transfer pipelines which extended from the large No. 6 fuel oil tanks on the Truscon property to Subarea K in Area I and to the south toward Subarea L. The investigation was planned to evaluate the potential contents of the pipe and to inspect the soil around the pipe to evaluate possible releases from the pipeline.

A total of ten test pits were excavated on March 10, 1998 and March 17, 1998. Test pit locations were selected based on historical site drawings which indicated that the oil transfer pipeline in Area I ran parallel to the Buffalo River either above or below ground. Test pits were excavated perpendicular to the axis of the pipe and of sufficient length so that the pipe, if present, would be intersected by the excavation. If pipe was encountered during the excavation, the pipe was tapped to determine whether it contained oil. Soil was logged and inspected by a project hydrogeologist. The following summarizes the findings of each test pit labeled as Pipe-1 through Pipe-10 (see Figure 5-1 for locations):

- Pipe-1, Pipe-3, Pipe-5, Pipe-7, Pipe-8, and Pipe-9 – Test pits excavated to a depth of 5 to 8 feet. No pipe encountered.
- Pipe-2 and Pipe-4 – Encountered a single, empty 6-inch pipe.
- Pipe-6 and Pipe-10 – Encountered two, 6-inch pipes in each test pit. One pipe, a plastic-coated steel pipe, contained water. The other pipe, a rusty steel pipe, contained mostly water with an oil skim.
- No oil-impacted soil was encountered at any of the test pit locations.

Additional test pits were excavated to determine the extent of the oil encountered in the rusty steel pipe. The results of the additional pipeline investigation are shown on Figure 5-1. As shown on Figure 5-1, in addition to the plastic-coated pipe and rusty pipe which appear to travel towards Subarea K where the above-ground tanks were formerly located, one additional pipe was found near the sharp bend in the Buffalo River traversing to the south,



as expected, toward Subarea L. Very stiff oil (likely aged No. 6 fuel oil) was encountered in this additional pipe. As a result of very compact fill, excavation refusal was encountered in the direction toward Subarea K. Numerous test pits were excavated in Subarea L and did not encounter pipeline. Therefore it appears that the approximate limits of oil filled pipeline have been found.

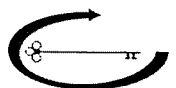
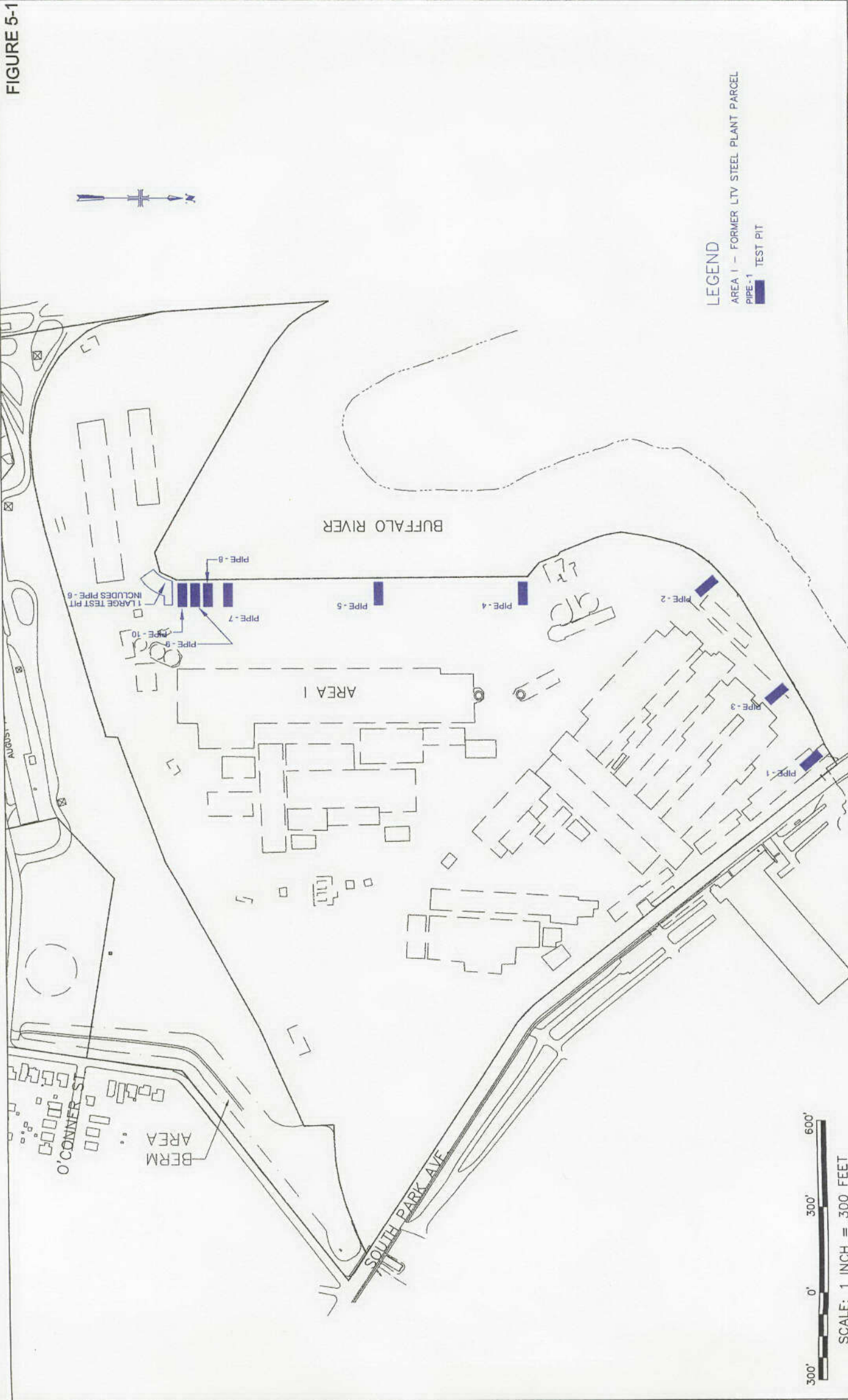


FIGURE 5-1



TRANSFER PIPELINE INVESTIGATION

LTV STEEL COMPANY / HANNA FURNACE
VOLUNTARY CLEANUP OF STEEL MANUFACTURING SITE
SUPPLEMENTAL SITE ASSESSMENT AND CLEANUP PLAN
FOR AREA I - FORMER STEEL PLANT PARCEL

DATE OCTOBER 1998
SHEET 07
CAD REF. NO. TXF005.DWG

NO.	REV.	DATE	BY	CHKD.	APP.



SCALE: 1 INCH = 300 FEET



6.0 VOLUNTARY CLEAN-UP PLAN

6.1 Environmental Conditions

Area I, at approximately 91 acres, is the largest and northernmost of the four parcels which collectively comprise the South Buffalo Steel Manufacturing Site. The former Republic Steel Plant was located in this parcel. It is currently owned by LTV Steel Company, Inc.

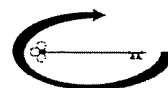
Extensive research of the parcel's operations and regulatory history was documented as part of a Phase I Environmental Site Assessment (ESA) [Ref 3]. The Phase I ESA identified 13 subareas of potential environmental concerns. Extensive environmental sampling was performed in these 13 subareas of the Former Republic Steel Plant parcel to define the Area's hydrogeology and to assess potential environmental impacts associated with historic uses of the Area. Based upon soil gas, surface soil/fill, subsurface soil/fill, and groundwater analyses, the Phase II ESA narrowed the environmental concerns in Area I to surface and/or subsurface soils in:

- Subarea E – Former Machine/Electrical Shop
- Subarea K – Former No. 6 Fuel Oil Storage Tanks
- Subarea L – Former Stockhouse (Fuel Oil and Tar Pipelines)

In addition, the underground No. 6 fuel oil pipeline was found to be in good condition, but was identified as containing some residual product.

Specific parameters of concern identified in the soil/fill from the above subareas were petroleum-derived polynuclear aromatic hydrocarbons (PAHs) and possibly several metals. Off-site groundwater impacts on the Buffalo River were also identified by the NYSDEC as a potential environmental concern.

Supplemental field investigations performed by Malcolm Pirnie, Inc. and subsequently by TurnKey Environmental Restoration, LLC and documented herein, eliminate off-site groundwater concerns and further refines the environmental concerns associated with the planned redevelopment of Area I to PAHs in subsurface soils in



limited portions of Subareas K and L and the remaining underground fuel oil piping in and around Subareas K and L.

6.2 Pre-Development Petroleum-Contaminated Soils Excavation Plan

Based on the October 1998 supplemental field investigations described in Section 3, Figure 6-1 depicts the extent of the impacted soil/fill in these subareas. As discussed in Section 3, the impacted soils are generally in zones within surface to 8 feet below grade in both Subareas. Sample results for both Subareas K and L show that elevated SVOC concentrations are associated with visually-impacted soils, and that the materials outside these visually-impacted zones have substantially lower concentrations, well below the respective RBSLs.

Excavation of petroleum-contaminated soils will be performed in the areas illustrated on Figure 6-1 in accordance with the following procedures. The total volume of material to be removed from both areas is conservatively estimated to be 5,000 cubic yards.

- Excavation/stripping and stockpiling of clean, surficial soil/fill material within the limits of the proposed petroleum-contaminated excavation area will be performed (depth of cover varies).
- Excavation will be limited to vadose zone (unsaturated) soil/fill, where visual impacts are evident.
- Excavation beyond the limits shown on Figure 6-1 will continue if residual oil is observed along the perimeter of the excavation.
- Excavation will be terminated inside the limits of excavation shown on Figure 6-2, where there is no evidence of contamination and no previous testing location that indicated contamination beyond the excavation face.
- Backfilling of excavation subgrade will be performed with bioremediated Truscon soils or "clean" off-site borrow material.

Excavated contaminated soils removed from these subareas will be transferred to the southern portion of the Area II – Former Donner-Hanna coke plant parcel (i.e. in the former coal/coke stockpile subarea). It will be stockpiled in this subarea for eventual

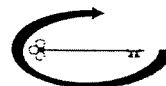
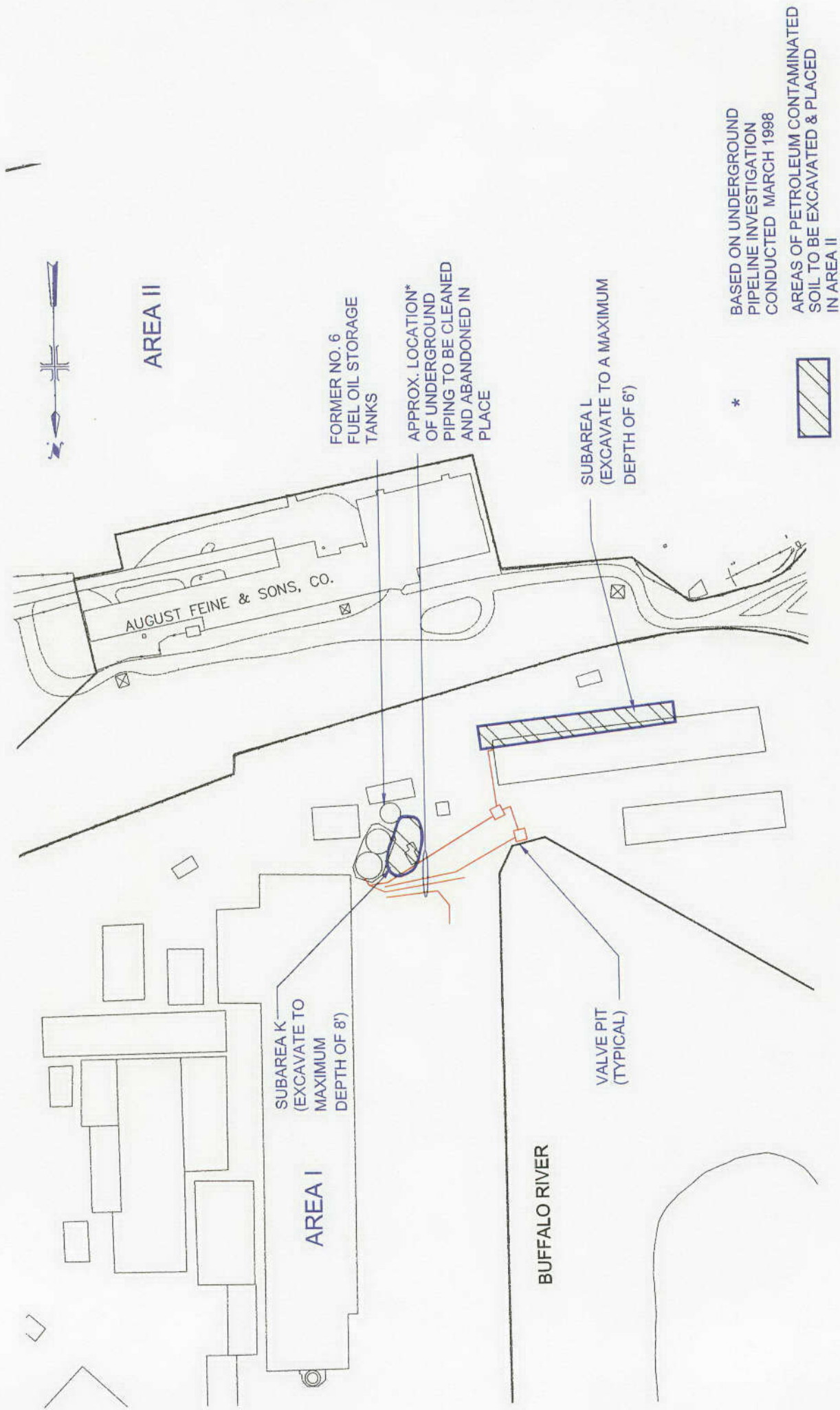


FIGURE 6-1



200' 0' 200' 400'

SCALE: 1 INCH = 200 FEET



LTV STEEL COMPANY / HANNA FURNACE
VOLUNTARY CLEANUP OF STEEL MANUFACTURING SITE
SUPPLEMENTAL SITE ASSESSMENT AND CLEANUP PLAN
FOR AREA I - FORMER STEEL PLANT PARCEL

PROPOSED AREA I REMEDIATION ACTIVITIES

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placement under the low permeability soil cover system planned for construction over the northern portion of the Area II parcel. Due to the phased nature of the Voluntary Clean-Up Plan, excavated Area I soils will remain stockpiled in Area II until completion of the installation of a perimeter groundwater collection and pretreatment system (planned as the initial phase of remedial activities in Area II).

The stockpiled soils will be then be spread and compacted along with soil/fill excavated during the installation of the Area II groundwater collection system and from other areas of the site as subgrade material for the cover system. Prior to capping with a low-permeability cover, the combined subgrade materials may be inoculated and fertilized to augment and accelerate the natural biological degradation processes anticipated within the capped Area II soil/fill matrix.

6.3 Underground Piping

Approximately six partial sections of former fuel oil transfer lines, varying in length from 30 to 300 feet (total estimated length – 1000 feet), were located as part of the supplement field investigations performed in March 1998. The pipes (shown in red on Figure 6-1) led to and from the two former 500,000 gallon fuel oil storage tanks and associated valve pits and were found to contain a combination of thickened residual oil or water mixed with a smaller quantity of residual oil. Each segment of the remaining fuel oil pipes will be cleaned (pigged) and the residual oil/water will be collected and removed for off-site disposal. The pipes will be abandoned in place.

Supplemental field investigations performed in October 1998 by TurnKey Environmental Restoration in Subarea L adjacent to the south side of the former Stockhouse have also identified small-diameter (i.e. 4-inch) tar pipeline segments that were abandoned in place. These pipe segments will be removed in areas contiguous with areas of petroleum-contaminated soil excavation. Residual tar from the small-diameter piping will be drained and collected (to the extent possible) and both the tar and piping will be transported off-site for appropriate disposal.

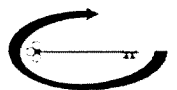


6.4 Future Development Considerations

Substantial concrete foundations, floor slabs and steel or timber pilings remain in place in the Area I parcel. To a lesser extent, abandoned underground utility piping is also prevalent in many areas of this parcel. Future development of this parcel must take into account and plan for these potential obstacles accordingly.

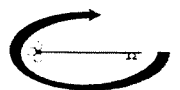
Furthermore, due to the long industrial history of the site and its sheer size, it is reasonable to assume areas of localized contamination or “hotspots” may be encountered during site development that were not identified during the field investigations. It is anticipated that contaminated soil encountered under this scenario and exceeding the site-specific RBSLs may be transferred to Area II for placement under the proposed soil cover system. This is another example of the value of the phased Site cleanup and redevelopment plan with the construction of the Area II cover system scheduled in the latter phases of the site cleanup. As such, the Area II on-site containment system would be available to receive soils/fill exceeding RBSLs encountered during initial site redevelopment. After completion of the Area II containment cell, contaminated soils/fill excavated from this or other Areas would require appropriate off-site disposal.

Beyond these considerations, it should be recognized that the natural course of redevelopment will result in substantial coverage of Area I with structures, roadways, parking areas, lawns and landscaping. Natural revegetation, already occurring across the site, will also continue to spread and provide coverage. Thus, the potential for exposure to site soils and any associated human health risks will be nearly eliminated with time.



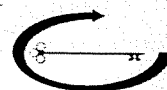
7.0 REFERENCES

1. ASTM E 1739 - 95: Standard Guide for Risk-Based Corrective Action at Petroleum Release Sites.
2. Gas Research Institute - "Management of Manufactured Gas Plant Sites". Vol. 1. Published by Amherst Scientific Publishers, 1996.
3. South Buffalo Redevelopment Plan - Voluntary Cleanup Site Assessment Report. Malcolm Pirnie, Inc. September 1997.



APPENDIX A

ASTM E1739-95: Standard Guide for Risk-Based Corrective Action at Petroleum Release Sites





Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites¹

This standard is issued under the fixed designation E 1739; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This is a guide to risk-based corrective action (RBCA), which is a consistent decision-making process for the assessment and response to a petroleum release, based on the protection of human health and the environment. Sites with petroleum release vary greatly in terms of complexity, physical and chemical characteristics, and in the risk that they may pose to human health and the environment. The RBCA process recognizes this diversity, and uses a tiered approach where corrective action activities are tailored to site-specific conditions and risks. While the RBCA process is not limited to a particular class of compounds, this guide emphasizes the application of RBCA to petroleum product releases through the use of the examples. Ecological risk assessment, as discussed in this guide, is a qualitative evaluation of the actual or potential impacts to environmental (nonhuman) receptors. *There may be circumstances under which a more detailed ecological risk assessment is necessary* (see Ref (1)).²

1.2 The decision process described in this guide integrates risk and exposure assessment practices, as suggested by the United States Environmental Protection Agency (USEPA), with site assessment activities and remedial measure selection to ensure that the chosen action is protective of human health and the environment. The following general sequence of events is prescribed in RBCA, once the process is triggered by the suspicion or confirmation of petroleum release:

1.2.1 Performance of a site assessment;

1.2.2 Classification of the site by the urgency of initial response;

1.2.3 Implementation of an initial response action appropriate for the selected site classification;

1.2.4 Comparison of concentrations of chemical(s) of concern at the site with Tier 1 Risk Based Screening Levels (RBSLs) given in a look-up table;

1.2.5 Deciding whether further tier evaluation is warranted, if implementation of interim remedial action is warranted or if RBSLs may be applied as remediation target levels;

1.2.6 Collection of additional site-specific information as necessary, if further tier evaluation is warranted;

1.2.7 Development of site-specific target levels (SSTLs) and point(s) of compliance (Tier 2 evaluation);

1.2.8 Comparison of the concentrations of chemical(s) of concern at the site with the Tier 2 evaluation SSTL at the determined point(s) of compliance or source area(s);

1.2.9 Deciding whether further tier evaluation is warranted, if implementation of interim remedial action is warranted, or if Tier 2 SSTLs may be applied as remediation target levels;

1.2.10 Collection of additional site-specific information as necessary, if further tier evaluation is warranted;

1.2.11 Development of SSTL and point(s) of compliance (Tier 3 evaluation);

1.2.12 Comparison of the concentrations of chemical(s) of concern at the site at the determined point(s) of compliance or source area(s) with the Tier 3 evaluation SSTL; and

1.2.13 Development of a remedial action plan to meet the SSTL, as applicable.

1.3 The guide is organized as follows:

1.3.1 Section 2 lists referenced documents.

1.3.2 Section 3 defines terminology used in this guide.

1.3.3 Section 4 describes the significance and use of this guide.

1.3.4 Section 5 is a summary of the tiered approach.

1.3.5 Section 6 presents the RBCA procedures in a step-by-step process.

1.3.6 Appendix X1 details physical/chemical and toxicological characteristics of petroleum products.

1.3.7 Appendix X2 discusses the derivation of a Tier 1 RBSL Look-Up Table and provides an example.

1.3.8 Appendix X3 describes the uses of predictive modeling relative to the RBCA process.

1.3.9 Appendix X4 discusses considerations for institutional controls, and

1.3.10 Appendix X5 provides examples of RBCA applications.

1.4 This guide describes an approach for RBCA. It is intended to compliment but not supersede federal, state, and local regulations. Federal, state, or local agency approval may be required to implement the processes outlined in this guide.

1.5 The values stated in either inch-pound or SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 ASTM Standard:

¹ This guide is under the jurisdiction of ASTM Committee E-50 on Environmental Assessment and is the direct responsibility of Subcommittee E50.01 on Storage Tanks.

Current edition approved Sept. 10, 1995. Published November 1995. Originally published as E538 - 94. Last previous edition E538 - 94.

² The boldface numbers in parentheses refer to the list of references at the end of this guide.

E 1599 Guide for Corrective Action for Petroleum Releases³

2.2 NFPA Standard:

NFPA 329 Handling Underground Releases of Flammable and Combustible Liquids⁴

3. Terminology

3.1 Descriptions of Terms Specific to This Standard:

3.1.1 *active remediation*—actions taken to reduce the concentrations of chemical(s) of concern. Active remediation could be implemented when the no-further-action and passive remediation courses of action are not appropriate.

3.1.2 *attenuation*—the reduction in concentrations of chemical(s) of concern in the environment with distance and time due to processes such as diffusion, dispersion, absorption, chemical degradation, biodegradation, and so forth.

3.1.3 *chemical(s) of concern*—specific constituents that are identified for evaluation in the risk assessment process.

3.1.4 *corrective action*—the sequence of actions that include site assessment, interim remedial action, remedial action, operation and maintenance of equipment, monitoring of progress, and termination of the remedial action.

3.1.5 *direct exposure pathways*—an exposure pathway where the point of exposure is at the source, without a release to any other medium.

3.1.6 *ecological assessment*—a qualitative appraisal of the actual or potential effects of chemical(s) of concern on plants and animals other than people and domestic species.

3.1.7 *engineering controls*—modifications to a site or facility (for example, slurry walls, capping, and point of use water treatment) to reduce or eliminate the potential for exposure to a chemical(s) of concern.

3.1.8 *exposure*—contact of an organism with chemical(s) of concern at the exchange boundaries (for example, skin, lungs, and liver) and available for absorption.

3.1.9 *exposure assessment*—the determination or estimation (qualitative or quantitative) of the magnitude, frequency, duration, and route of exposure.

3.1.10 *exposure pathway*—the course a chemical(s) of concern takes from the source area(s) to an exposed organism. An exposure pathway describes a unique mechanism by which an individual or population is exposed to a chemical(s) of concern originating from a site. Each exposure pathway includes a source or release from a source, a point of exposure, and an exposure route. If the exposure point differs from the source, a transport/exposure medium (for example, air) or media also is included.

3.1.11 *exposure route*—the manner in which a chemical(s) of concern comes in contact with an organism (for example, ingestion, inhalation, and dermal contact).

3.1.12 *facility*—the property containing the source of the chemical(s) of concern where a release has occurred.

3.1.13 *hazard index*—the sum of two or more hazard quotients for multiple chemical(s) of concern or multiple exposure pathways, or both.

3.1.14 *hazard quotients*—the ratio of the level of exposure of a chemical(s) of concern over a specified time period to a

reference dose for that chemical(s) of concern derived for a similar exposure period.

3.1.15 *incremental carcinogenic risk levels*—the potential for incremental carcinogenic human health effects due to exposure to the chemical(s) of concern.

3.1.16 *indirect exposure pathways*—an exposure pathway with at least one intermediate release to any media between the source and the point(s) of exposure (for example, chemicals of concern from soil through ground water to the point(s) of exposure).

3.1.17 *institutional controls*—the restriction on use or access (for example, fences, deed restrictions, restrictive zoning) to a site or facility to eliminate or minimize potential exposure to a chemical(s) of concern.

3.1.18 *interim remedial action*—the course of action to mitigate fire and safety hazards and to prevent further migration of hydrocarbons in their vapor, dissolved, or liquid phase.

3.1.19 *maximum contaminant level (MCL)*—a standard for drinking water established by USEPA under the Safe Drinking Water Act, which is the maximum permissible level of chemical(s) of concern in water that is delivered to any user of a public water supply.

3.1.20 *Monte Carlo simulation*—a procedure to estimate the value and uncertainty of the result of a calculation when the result depends on a number of factors, each of which is also uncertain.

3.1.21 *natural biodegradation*—the reduction in concentration of chemical(s) of concern through naturally occurring microbial activity.

3.1.22 *petroleum*—including crude oil or any fraction thereof that is liquid at standard conditions of temperature and pressure (60°F and 14.7 lb/in.² absolute; (15.5°C and 10 335.6 kg/m²)). The term includes petroleum-based substances comprised of a complex blend of hydrocarbons derived from crude oil through processes of separation, conversion, upgrading, and finishing, such as motor fuels, jet oils, lubricants, petroleum solvents, and used oils.

3.1.23 *point(s) of compliance*—a location(s) selected between the source area(s) and the potential point(s) of exposure where concentrations of chemical(s) of concern must be at or below the determined target levels in media (for example, ground water, soil, or air).

3.1.24 *point(s) of exposure*—the point(s) at which an individual or population may come in contact with a chemical(s) of concern originating from a site.

3.1.25 *qualitative risk analysis*—a nonnumeric evaluation of a site to determine potential exposure pathways and receptors based on known or readily available information.

3.1.26 *reasonable maximum exposure (RME)*—the highest exposure that is reasonably expected to occur at a site. RMEs are estimated for individual pathways or a combination of exposure pathways.

3.1.27 *reasonable potential exposure scenario*—a situation with a credible chance of occurrence where a receptor may become directly or indirectly exposed to the chemical(s) of concern without considering extreme or essentially impossible circumstances.

3.1.28 *reasonably anticipated future use*—future use of a site or facility that can be predicted with a high degree of

³ Annual Book of ASTM Standards, Vol. 11.04.

⁴ Available from National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269.

certainty given current use, local government planning, and zoning.

3.1.29 *receptors*—persons, structures, utilities, surface waters, and water supply wells that are or may be adversely affected by a release.

3.1.30 *reference dose*—a preferred toxicity value for evaluating potential noncarcinogenic effects in humans resulting from exposure to a chemical(s) of concern.

3.1.31 *remediation/remedial action*—activities conducted to protect human health, safety, and the environment. These activities include evaluating risk, making no-further-action determinations, monitoring institutional controls, engineering controls, and designing and operating cleanup equipment.

3.1.32 *risk assessment*—an analysis of the potential for adverse health effects caused by a chemical(s) of concern from a site to determine the need for remedial action or the development of target levels where remedial action is required.

3.1.33 *risk reduction*—the lowering or elimination of the level of risk posed to human health or the environment through interim remedial action, remedial action, or institutional or engineering controls.

3.1.34 *risk-based screening level/screening levels (RBSLs)*—risk-based site-specific corrective action target levels for chemical(s) of concern developed under the Tier 1 evaluation.

3.1.35 *site*—the area(s) defined by the extent of migration of the chemical(s) of concern.

3.1.36 *site assessment*—an evaluation of subsurface geology, hydrology, and surface characteristics to determine if a release has occurred, the levels of the chemical(s) of concern, and the extent of the migration of the chemical(s) of concern. The site assessment collects data on ground water quality and potential receptors and generates information to support remedial action decisions.

3.1.37 *site classification*—a qualitative evaluation of a site based on known or readily available information to identify the need for interim remedial actions and further information gathering. Site classification is intended to specifically prioritize sites.

3.1.38 *site-specific target level (SSTL)*—risk-based remedial action target level for chemical(s) of concern developed for a particular site under the Tier 2 and Tier 3 evaluations.

3.1.39 *site-specific*—activities, information, and data unique to a particular site.

3.1.40 *source area(s)*—either the location of liquid hydrocarbons or the location of highest soil and ground water concentrations of the chemical(s) of concern.

3.1.41 *target levels*—numeric values or other performance criteria that are protective of human health, safety, and the environment.

3.1.42 *Tier 1 evaluation*—a risk-based analysis to develop non-site-specific values for direct and indirect exposure pathways utilizing conservative exposure factors and fate and transport for potential pathways and various property use categories (for example, residential, commercial, and industrial uses). Values established under Tier 1 will apply to all sites that fall into a particular category.

3.1.43 *Tier 2 evaluation*—a risk-based analysis applying the direct exposure values established under a Tier 1 evaluation

at the point(s) of exposure developed for a specific site and development of values for potential indirect exposure pathways at the point(s) of exposure based on site-specific conditions.

3.1.44 *Tier 3 evaluation*—a risk-based analysis to develop values for potential direct and indirect exposure pathways at the point(s) of exposure based on site-specific conditions.

3.1.45 *user*—an individual or group involved in the RBCA process including owners, operators, regulators, underground storage tank (UST) fund managers, attorneys, consultants, legislators, and so forth.

4. Significance and Use

4.1 The allocation of limited resources (for example, time, money, regulatory oversight, qualified professionals) to any one petroleum release site necessarily influences corrective action decisions at other sites. This has spurred the search for innovative approaches to corrective action decision making, which still ensures that human health and the environment are protected.

4.2 The RBCA process presented in this guide is a consistent, streamlined decision process for selecting corrective actions at petroleum release sites. Advantages of the RBCA approach are as follows:

4.2.1 Decisions are based on reducing the risk of adverse human or environmental impacts.

4.2.2 Site assessment activities are focussed on collecting only that information that is necessary to making risk-based corrective action decisions.

4.2.3 Limited resources are focussed on those sites that pose the greatest risk to human health and the environment at any time.

4.2.4 The remedial action achieves an acceptable degree of exposure and risk reduction.

4.2.5 Compliance can be evaluated relative to site-specific standards applied at site-specific point(s) of compliance.

4.2.6 Higher quality, and in some cases faster, cleanups than are currently realized, and

4.2.7 A documentation and demonstration that the remedial action is protective of human health, safety, and the environment.

4.3 Risk assessment is a developing science. The scientific approach used to develop the RBSL and SSTL may vary by state and user due to regulatory requirements and the use of alternative scientifically based methods.

4.4 Activities described in this guide should be conducted by a person familiar with current risk and exposure assessment methodologies.

4.5 In order to properly apply the RBCA process, the user should avoid the following:

4.5.1 Use of Tier 1 RBSLs as mandated remediation standards rather than screening levels.

4.5.2 Restriction of the RBCA process to Tier 1 evaluation only and not allowing Tier 2 or Tier 3 analyses.

4.5.3 Placing arbitrary time constraints on the corrective action process; for example, requiring that Tiers 1, 2, and 3 be completed within 30-day time periods that do not reflect the actual urgency of and risks posed by the site.

4.5.4 Use of the RBCA process only when active remediation is not technically feasible, rather than a process that is applicable during all phases of corrective action.

4.5.5 Requiring the user to achieve technology-based remedial limits (for example, asymptotic levels) prior to requesting the approval for the RBSL or SSTL.

4.5.6 The use of predictive modelling that is not supported by available data or knowledge of site conditions.

4.5.7 Dictating that corrective action goals can only be achieved through source removal and treatment actions, thereby restricting the use of exposure reduction options, such as engineering and institutional controls.

4.5.8 The use of unjustified or inappropriate exposure factors.

4.5.9 The use of unjustified or inappropriate toxicity parameters.

4.5.10 Neglecting aesthetic and other criteria when determining RBSLs or SSTLs.

4.5.11 Not considering the effects of additivity when screening multiple chemicals.

4.5.12 Not evaluating options for engineering or institutional controls, exposure point(s), compliance point(s), and carcinogenic risk levels before submitting remedial action plans.

4.5.13 Not maintaining engineering or institutional controls, and

4.5.14 Requiring continuing monitoring or remedial action at sites that have achieved the RBSL or SSTL.

5. Tiered Approach to Risk-Based Corrective Action (RBCA) at Petroleum Release Sites

5.1 RBCA is the integration of site assessment, remedial action selection, and monitoring with USEPA-recommended risk and exposure assessment practices. This creates a process by which corrective action decisions are made in a consistent manner that is protective of human health and the environment.

5.2 The RBCA process is implemented in a tiered approach, involving increasingly sophisticated levels of data collection and analysis. The assumptions of earlier tiers are replaced with site-specific data and information. Upon evaluation of each tier, the user reviews the results and recommendations and decides whether more site-specific analysis is warranted.

5.3 *Site Assessment*—The user is required to identify the sources of the chemical(s) of concern, obvious environmental impacts (if any), any potentially impacted humans and environmental receptors (for example, workers, residents, water bodies, and so forth), and potentially significant transport pathways (for example, ground water flow, utilities, atmospheric dispersion, and so forth). The site assessment will also include information collected from historical records and a visual inspection of the site.

5.4 *Site Classification*—Sites are classified by the urgency of need for initial response action, based on information collected during the site assessment. Associated with site classifications are initial response actions that are to be implemented simultaneously with the RBCA process. Sites should be reclassified as actions are taken to resolve concerns or as better information becomes available.

5.5 *Tier 1 Evaluation*—A look-up table containing screening level concentrations is used to determine whether site conditions satisfy the criteria for a quick regulatory closure or warrant a more site-specific evaluation. Ground

water, soil, and vapor concentrations may be presented in this table for a range of site descriptions and types of petroleum products (for example, gasoline, crude oil, and so forth). The look-up table of RBSL is developed in Tier 1 or, if a look-up table has been previously developed and determined to be applicable to the site by the user, then the existing RBSLs are used in the Tier 1 process. Tier 1 RBSLs are typically derived for standard exposure scenarios using current RME and toxicological parameters as recommended by the USEPA. These values may change as new methodologies and parameters are developed. Tier 1 RBSLs may be presented as a range of values, corresponding to a range of risks or property uses.

5.6 *Tier 2 Evaluation*—Tier 2 provides the user with an option to determine SSTLs and point(s) of compliance. It is important to note that both Tier 1 RBSL and Tier 2 SSTLs are based on achieving similar levels of protection of human health and the environment (for example, 10^{-4} to 10^{-6} risk levels). However, in Tier 2 the non-site-specific assumptions and point(s) of exposure used in Tier 1 are replaced with site-specific data and information. Additional site-assessment data may be needed. For example, the Tier 2 SSTL can be derived from the same equations used to calculate the Tier 1 RBSL, except that site-specific parameters are used in the calculations. The additional site-specific data may support alternate fate and transport analysis. At other sites, the Tier 2 analysis may involve applying Tier 1 RBSLs at more probable point(s) of exposure. Tier 2 SSTLs are consistent with USEPA-recommended practices.

5.7 *Tier 3 Evaluation*—Tier 3 provides the user with an option to determine SSTLs for both direct and indirect pathways using site-specific parameters and point(s) of exposure and compliance when it is judged that Tier 2 SSTLs should not be used as target levels. Tier 3, in general, can be a substantial incremental effort relative to Tiers 1 and 2, as the evaluation is much more complex and may include additional site assessment, probabilistic evaluations, and sophisticated chemical fate/transport models.

5.8 *Remedial Action*—If the concentrations of chemical(s) of concern at a site are above the RBSL or SSTL at the point(s) of compliance or source area, or both, and the user determines that the RBSL or SSTL should be used as remedial action target levels, the user develops a remedial action plan in order to reduce the potential for adverse impacts. The user may use remediation processes to reduce concentrations of the chemical(s) of concern to levels below or equal to the target levels or to achieve exposure reduction (or elimination) through institutional controls discussed in Appendix X4, or through the use of engineering controls, such as capping and hydraulic control.

6. Risk-Based Corrective Action (RBCA) Procedures

6.1 The sequence of principal tasks and decisions associated with the RBCA process are outlined on the flowchart shown in Fig. 1. Each of these actions and decisions is discussed as follows.

6.2 *Site Assessment*—Gather the information necessary for site classification, initial response action, comparison to the RBSL, and determining the SSTL. Site assessment may be conducted in accordance with Guide E 1599. Each successive tier will require additional site-specific data and information that must be collected as the RBCA process

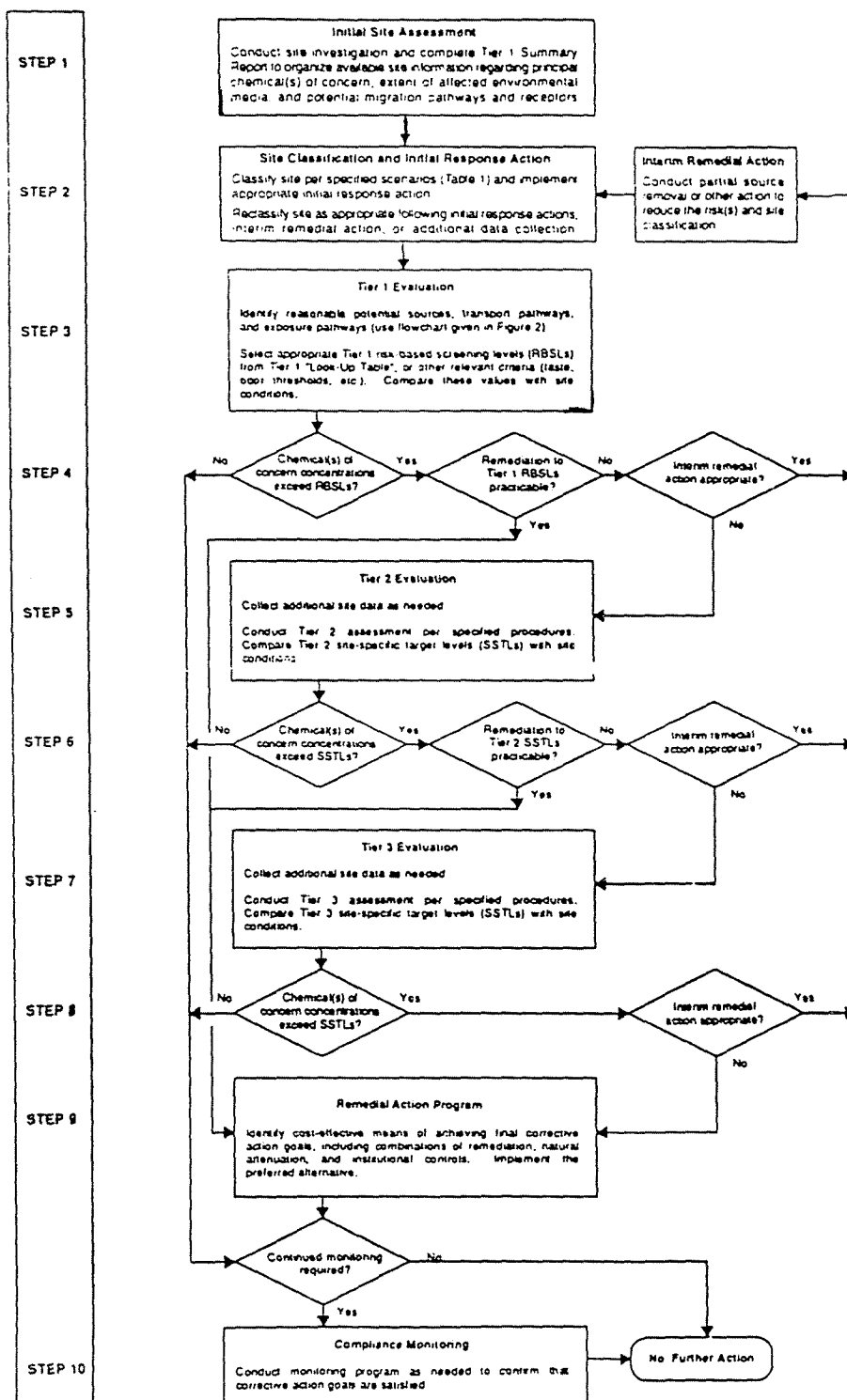


FIG. 1 Risk-Based Corrective Action Process Flowchart

proceeds. The user may generate site-specific data and information or estimate reasonable values for key physical characteristics using soil survey data and other readily available information. The site characterization data should be summarized in a clear and concise format.

6.2.1 The site assessment information for Tier 1 evaluation may include the following:

6.2.1.1 A review of historical records of site activities and past releases;

6.2.1.2 Identification of chemical(s) of concern;

6.2.1.3 Location of major sources of the chemical(s) of concern;

6.2.1.4 Location of maximum concentrations of chemical(s) of concern in soil and ground water;

6.2.1.5 Location of humans and the environmental receptors that could be impacted (point(s) of exposure);

6.2.1.6 Identification of potential significant transport and exposure pathways (ground water transport, vapor migration through soils and utilities, and so forth);

6.2.1.7 Determination of current or potential future use of the site and surrounding land, ground water, surface water, and sensitive habitats;

6.2.1.8 Determination of regional hydrogeologic and geologic characteristics (for example, depth to ground water, aquifer thickness, flow direction, gradient, description of confining units, and ground water quality); and

6.2.1.9 A qualitative evaluation of impacts to environmental receptors.

6.2.2 In addition to the information gathered in 6.2.1, the site assessment information for Tier 2 evaluation may include the following:

6.2.2.1 Determination of site-specific hydrogeologic and geologic characteristics (for example, depth to ground water, aquifer thickness, flow direction, gradient, description of confining units, and ground water quality);

6.2.2.2 Determination of extent of chemical(s) of concern relative to the RBSL or SSTL, as appropriate;

6.2.2.3 Determination of changes in concentrations of chemical(s) of concern over time (for example, stable, increasing, and decreasing); and

6.2.2.4 Determination of concentrations of chemical(s) of concern measured at point(s) of exposure (for example, dissolved concentrations in nearby drinking water wells or vapor concentrations in nearby conduits or sewers).

6.2.3 In addition to the information gathered in 6.2.1 and 6.2.2, the site assessment information for Tier 3 evaluation includes additional information that is required for site-specific modeling efforts.

6.3 Site Classification and Initial Response Action—As the user gathers data, site conditions should be evaluated and an initial response action should be implemented, consistent with site conditions. This process is repeated when new data indicate a significant change in site conditions. Site urgency classifications are presented in Table 1, along with example classification scenarios and potential initial responses. *Note that the initial response actions given in Table 1 may not be applicable for all sites. The user should select an option that best addresses the short-term health and safety concerns of the site while implementing the RBCA process.*

6.3.1 The classification and initial response action scheme given in Table 1 is an example. It is based on the current and

projected degree of hazard to human health and the environment. This is a feature of the process that can be customized by the user. "Classification 1" sites are associated with immediate threats to human health and the environment; "Classification 2" sites are associated with short-term (0 to 2-year) threats to human health, safety, and the environment; "Classification 3" sites are associated with long-term (greater than 2-year) threats to human health, safety, and the environment; "Classification 4" sites are associated with no reasonable potential threat to human health or to the environment.

6.3.2 Associated with each classification scenario in Table 1 is an initial response action; the initial response actions are implemented in order to eliminate any potential immediate impacts to human health and the environment as well as to minimize the potential for future impacts that may occur as the user proceeds with the RBCA process. Note that initial response actions do not always require active remediation; in many cases the initial response action is to monitor or further assess site conditions to ensure that risks posed by the site do not increase above acceptable levels over time. The initial response actions given in Table 1 are examples, and the user is free to implement other alternatives.

6.3.3 The need to reclassify the site should be evaluated when additional site information is collected that indicates a significant change in site conditions or when implementation of an interim response action causes a significant change in site conditions.

6.4 Development of a Tier 1 Look-Up Table of RBSL—If a look-up table is not available, the user is responsible for developing the look-up table. If a look-up table is available, the user is responsible for determining that the RBSLs in the look-up table are based on currently acceptable methodologies and parameters. The look-up table is a tabulation for potential exposure pathways, media (for example, soil, water, and air), a range of incremental carcinogenic risk levels ($10E-4$ to $10E-6$ are often evaluated as discussed in Appendix X1) and hazard quotients equal to unity, and potential exposure scenarios (for example, residential, commercial, industrial, and agricultural) for each chemical(s) of concern.

6.4.1 The RBSLs are determined using typical, non-site-specific values for exposure parameters and physical parameters for media. The RBSLs are calculated according to methodology suggested by the USEPA. For each exposure scenario, the RBSLs are based on current USEPA RME parameters and current toxicological information given in Refs (2, 3) or peer-reviewed source(s). Consequently, the RBSL look-up table is updated when new methodologies and parameters are developed. For indirect pathways, fate and transport models can be used to predict RBSLs at a source area that corresponds to exposure point concentrations. An example of the development of a Tier 1 Look-Up Table and RBSL is given in Appendix X2. *Figure 2 and Appendix X2 are presented solely for the purpose of providing an example development of the RBSL, and the values should not be viewed as proposed RBSLs.*

6.4.2 Appendix X2 is an example of an abbreviated Tier 1 RBSL Look-Up Table for compounds of concern associated with petroleum releases. The exposure scenarios selected in the example case are for residential and industrial/commercial scenarios characterized by USEPA RME parameters for

TABLE 1 Example Site Classification and Initial Response Actions^a

Criteria and Prescribed Scenarios	Example Initial Response Actions ^b
<p>1. Immediate threat to human health, safety, or sensitive environmental receptors</p> <ul style="list-style-type: none"> Explosive levels, or concentrations of vapors that could cause acute health effects, are present in a residence or other building Explosive levels of vapors are present in subsurface utility system(s), but no building or residences are impacted Free-product is present in significant quantities at ground surface, on surface water bodies, in utilities other than water supply lines, or in surface water runoff An active public water supply well, public water supply line, or public surface water intake is impacted or immediately threatened Ambient vapor/particulate concentrations exceed concentrations of concern from an acute exposure or safety viewpoint A sensitive habitat or sensitive resources (sport fish, economically important species, threatened and endangered species, and so forth) are impacted and affected. 	<p>Notify appropriate authorities, property owners, and potentially affected parties and only evaluate the need to</p> <ul style="list-style-type: none"> Evacuate occupants and begin abatement measures such as subsurface ventilation or building pressurization Evacuate immediate vicinity and begin abatement measures such as ventilation Prevent further free-product migration by appropriate containment measures, institute free-product recovery, and restrict area access Notify user(s), provide alternate water supply, hydraulically control contaminated water, and treat water at point-of-use Install vapor barrier (capping, foams, and so forth), remove source or restrict access to affected area Minimize extent of impact by containment measures and implement habitat management to minimize exposure.
<p>2. Short-term (0 to 2 years) threat to human health, safety, or sensitive environmental receptors</p> <ul style="list-style-type: none"> There is potential for explosive levels, or concentrations of vapors that could cause acute effects, to accumulate in a residence or other building Shallow contaminated surface soils are open to public access, and dwellings, parks, playgrounds, day-care centers, schools, or similar use facilities are within 500 ft (152 m) of those soils. A non-potable water supply well is impacted or immediately threatened. Ground water is impacted, and a public or domestic water supply well producing from the impacted aquifer is located within two-years projected ground water travel distance down gradient of the known extent of chemical(s) concern. Ground water is impacted, and a public or domestic water supply well producing from a different interval is located within the known extent of chemicals of concern. Impacted surface water, storm water, or ground water discharges within 500 ft (152 m) of a sensitive habitat or surface water body used for human drinking water or contact recreation. 	<p>Notify appropriate authorities, property owners, and potentially affected parties and only evaluate the need to</p> <ul style="list-style-type: none"> Assess the potential for vapor migration (through monitoring/modeling) and remove source (if necessary), or install vapor migration barrier. Remove soils, cover soils, or restrict access. Notify owner/user and evaluate the need to install point-of-use water treatment, hydraulic control, or alternate water supply Institute monitoring and then evaluate if natural attenuation is sufficient, or if hydraulic control is required. Monitor ground water well quality and evaluate if control is necessary to prevent vertical migration to the supply well Institute containment measures, restrict access to areas near discharge, and evaluate the magnitude and impact of the discharge.
<p>3. Long-term (>2 years) threat to human health, safety, or sensitive environmental receptors</p> <ul style="list-style-type: none"> Subsurface soils (>3 ft (0.9 m) BGS) are significantly impacted, and the depth between impacted soils and the first potable aquifer is less than 50 ft (15 m). Ground water is impacted, and potable water supply wells producing from the impacted interval are located >2 years ground water travel time from the dissolved plume Ground water is impacted, and non-potable water supply wells producing from the impacted interval are located >2 years ground water travel time from the dissolved plume. Ground water is impacted, and non-potable water supply wells that do not produce from the impacted interval are located within the known extent of chemical(s) of concern. Impacted surface water, storm water, or ground water discharges within 1500 ft (457 m) of a sensitive habitat or surface water body used for human drinking water or contact recreation. Shallow contaminated surface soils are open to public access, and dwellings, parks, playgrounds, day-care centers, schools, or similar use facilities are more than 500 ft (152 m) of those soils 	<p>Notify appropriate authorities, property owners, and potentially affected parties and only evaluate the need to</p> <ul style="list-style-type: none"> Monitor ground water and determine the potential for future migration of the chemical(s) concerns to the aquifer Monitor the dissolved plume and evaluate the potential for natural attenuation and the need for hydraulic control. Identify water usage of well, assess the effect of potential impact, monitor the dissolved plume, and evaluate whether natural attenuation or hydraulic control are appropriate control measures. Monitor the dissolved plume, determine the potential for vertical migration, notify the user, and determine if any impact is likely Investigate current impact on sensitive habitat or surface water body, restrict access to area of discharge (if necessary), and evaluate the need for containment/control measures Restrict access to impact soils.
<p>4. No demonstrable long-term threat to human health or safety or sensitive environmental receptors</p> <p>Priority 4 scenarios encompass all other conditions not described in Priorities 1, 2, and 3 and that are consistent with the priority description given above. Some examples are as follows:</p> <ul style="list-style-type: none"> Non-potable aquifer with no existing local use impacted. Impacted soils located more than 3 ft (0.9 m) BGS and greater than 50 ft (15 m) above nearest aquifer Ground water is impacted, and non-potable wells are located down gradient outside the known extent of the chemical(s) of concern, and they produce from a nonimpacted zone. 	<p>Notify appropriate authorities, property owners, and potentially affected parties, and only evaluate the need to</p> <ul style="list-style-type: none"> Monitor ground water and evaluate effect of natural attenuation on dissolved plume migration. Monitor ground water and evaluate effect of natural attenuation on leachate migration. Monitor ground water and evaluate effect of natural attenuation on dissolved plume migration.

^a Johnson, D. C., DeVault, G. E., Ettinger, R. A., MacDonald, R. L. M., Stanley, C. C., Westby, T. S., and Conner, J., "Risk-Based Corrective Action Tier 1 Guidance Manual," Shell Oil Co., July 1993.

^b Note that these are potential initial response actions that may not be appropriate for all sites. The user is encouraged to select options that best address the short-term health and safety concerns of the site, while the RBCA process progresses.

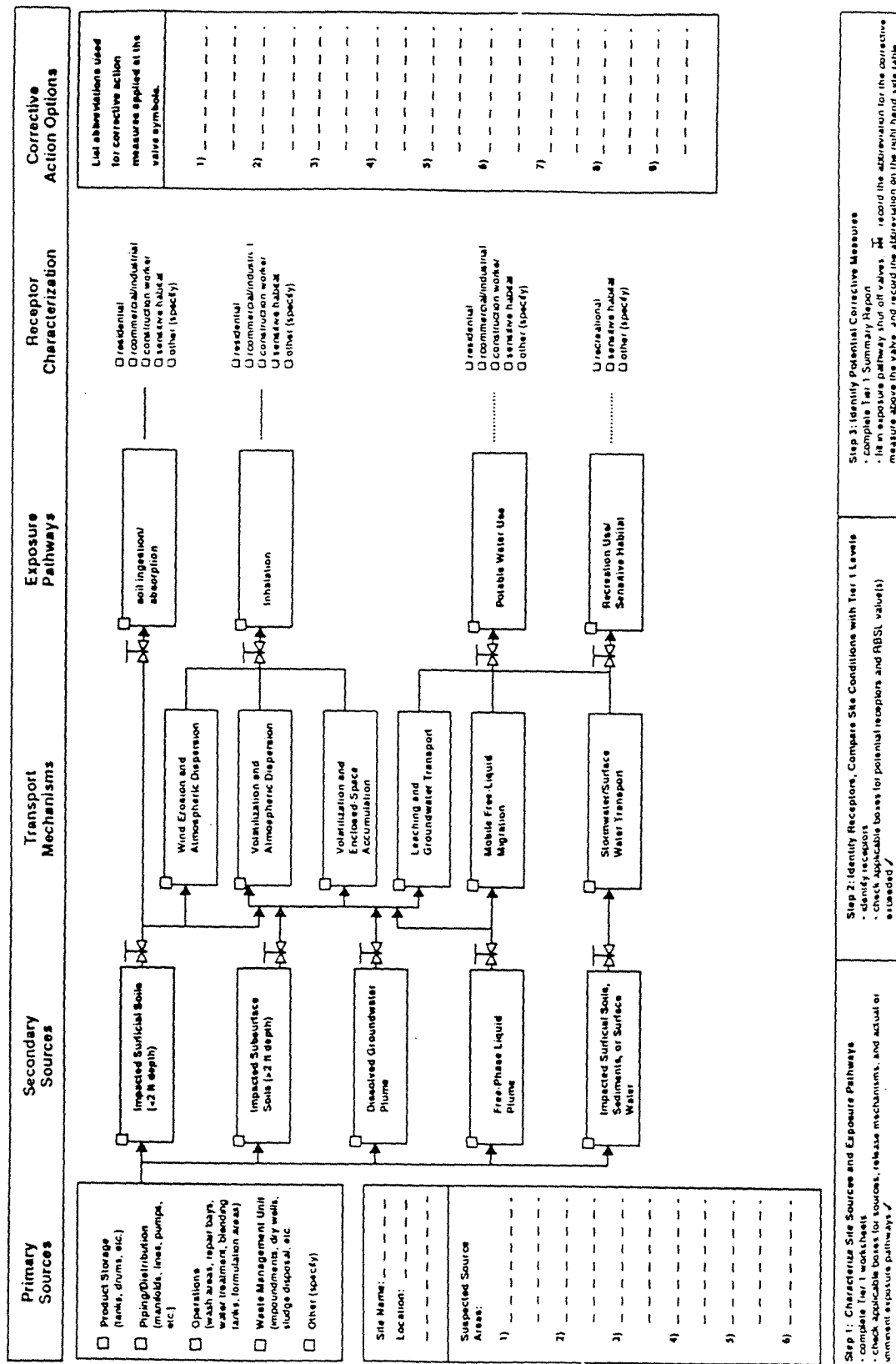


FIG. 2 Exposure Scenario Evaluation Flowchart

adult males. The assumptions and methodology used in deriving the example are discussed in Appendix X2. Note that not all possible exposure pathways are considered in the derivation of the example. *The user should always review the assumptions and methodology used to derive values in a look-up table to make sure that they are consistent with reasonable exposure scenarios for the site being considered as well as currently accepted methodologies.* The value of creating a look-up table is that users do not have to repeat the exposure calculations for each site encountered. The look-up table is only altered when RME parameters, toxicological information, or recommended methodologies are updated. Some states have compiled such tables for direct exposure pathways that, for the most part, contain identical values (as they are based on the same assumptions). Values for the cross-media pathways (for example, volatilization and leaching), when available, often differ because these involve coupling exposure calculations with predictive equations for the fate and transport of chemicals in the environment. As yet, there is little agreement in the technical community concerning non-site-specific values for the transport and fate model parameters, or the choice of the models themselves. *Again, the reader should note that the example is presented here only as an abbreviated example of a Tier 1 RBSL Look-Up Table for typical compounds of concern associated with petroleum products.*

6.4.3 Use of Total Petroleum Hydrocarbon Measurements—Various chemical analysis methods commonly referred to as total petroleum hydrocarbons (TPHs) are often used in site assessments. These methods usually determine the total amount of hydrocarbons present as a single number and give no information on the types of hydrocarbon present. The TPHs should not be used for risk assessment because the general measure of TPH provides insufficient information about the amounts of individual chemical(s) of concern present.

6.5 Comparison of Site Conditions with Tier 1 Risk-Based Screening Levels (RBSL)—In Tier 1, the point(s) of exposure and point(s) of compliance are assumed to be located within close proximity to the source area(s) or the area where the highest concentrations of the chemical(s) of concern have been identified. Concentrations of the chemical(s) of concern measured at the source area(s) identified at the site should be compared to the look-up table RBSL. If there is sufficient site assessment data, the user may opt to compare RBSLs with statistical limits (for example, upper confidence levels) rather than maximum values detected. Background concentrations should be considered when comparing the RBSLs, to the site concentrations as the RBSLs may sometimes be less than background concentrations. Note that additivity of risks is not explicitly considered in the Tier 1 evaluation, as it is expected that the RBSLs are typically for a limited number of chemical(s) of concern considered at most sites. Additivity may be addressed in Tier 2 and Tier 3 analyses. To accomplish the Tier 1 comparison:

6.5.1 Select the potential exposure scenario(s) (if any) for the site. Exposure scenarios are determined based on the site assessment information described in 6.2:

6.5.2 Based on the impacted media identified, determine the primary sources, secondary sources, transport mechanisms, and exposure pathways;

6.5.3 Select the receptors (if any) based on current and anticipated future use. Consider land use restrictions and surrounding land use when making this selection.

6.5.4 Identify the exposure scenarios where the measured concentrations of the chemical(s) of concern are above the RBSL.

6.6 Exposure Evaluation Flowchart—During a Tier 1 evaluation, the risk evaluation flowchart presented in Fig. 2 may be used as a tool to guide the user in selecting appropriate exposure scenarios based on site assessment information. This worksheet may also be used in the evaluation of remedial action alternatives. To complete this flowchart:

6.6.1 Characterize site sources and exposure pathways, using the data summarized from Tier 1 to customize the risk evaluation flowchart for the site by checking the small checkbox for every relevant source, transport mechanism, and exposure pathway.

6.6.2 Identify receptors, and compare site conditions with Tier 1 levels: For each exposure pathway selected, check the receptor characterization (residential, commercial, and so forth) where the concentrations of the chemical(s) of concern are above the RBSL. Consider land use restrictions and surrounding land use when making this selection. Do not check any boxes if there are no receptors present, or likely to be present, or if institutional controls prevent exposure from occurring and are likely to stay in place.

6.6.3 Identify potential remedial action measures. Select remedial action options to reduce or eliminate exposure to the chemical(s) of concern.

6.6.4 The exposure evaluation flowchart (Fig. 2) can be used to graphically portray the effect of the Tier 1 remedial action. Select the Tier 1 remedial action measure or measures (shown as valve symbols) that will break the lines linking sources, transport mechanisms, and pathways leading to the chemical(s) of concern above the RBSL. Adjust the mix of remedial action measures until no potential receptors have concentrations of chemical(s) of concerns above the RBSL with the remedial action measures in place. Show the most likely Tier 1 remedial action measure(s) selected for this site by marking the appropriate valve symbols on the flowchart and recording a remedial action measure on the right-hand-side of this figure.

6.7 Evaluation of Tier Results—At the conclusion of each tier evaluation, the user compares the target levels (RBSLs or SSTLs) to the concentrations of the chemical(s) of concern at the point(s) of compliance.

6.7.1 If the concentrations of the chemical(s) of concern exceed the target levels at the point(s) of compliance, then either remedial action, interim remedial action, or further tier evaluation should be conducted.

6.7.1.1 Remedial Action—A remedial action program is designed and implemented. This program may include some combination of source removal, treatment, and containment technologies, as well as engineering and institutional controls. Examples of these include the following: soil venting, bioventing, air sparging, pump and treat, and natural attenuation/passive remediation. When concentrations of chemical(s) of concern no longer exceed the target levels at the point of compliance, then the user may elect to move to 6.7.3.

6.7.1.2 *Interim Remedial Action*—If achieving the desired risk reduction is impracticable due to technology or resource limitations, an interim remedial action, such as removal or treatment of "hot spots," may be conducted to address the most significant concerns, change the site classification, and facilitate reassessment of the tier evaluation.

6.7.1.3 *Further Tier Evaluation*—If further tier evaluation is warranted, additional site assessment information may be collected to develop SSTLs under a Tier 2 or Tier 3 evaluation. Further tier evaluation is warranted when:

- (1) The basis for the RBSL values (for example, geology, exposure parameters, point(s) of exposure, and so forth) are not representative of the site-specific conditions; or
- (2) The SSTL developed under further tier evaluation will be significantly different from the Tier 1 RBSL or will significantly modify the remedial action activities; or
- (3) Cost of remedial action to RBSLs will likely be greater than further tier evaluation and subsequent remedial action.

6.7.2 If the concentrations of chemicals of concern at the point of compliance are less than the target levels, but the user is not confident that data supports the conclusion that concentrations will not exceed target levels in the future, then the user institutes a monitoring plan to collect data sufficient to confidently conclude that concentrations will not exceed target levels in the future. When this data is collected, the user moves to 6.7.3.

6.7.3 If the concentrations of chemicals of concern at the point of compliance are less than target levels, and the user is confident that data supports the conclusion that concentrations will not exceed target levels in the future, then no additional corrective action activities are necessary, and the user has completed the RBCA process. In practice, this is often accompanied by the issuing of a no-further-action letter by the oversight regulatory agency.

6.8 *Tier 2*—Tier 2 provides the user with an option to determine the site-specific point(s) of compliance and corresponding SSTL for the chemical(s) of concern applicable at the point(s) of compliance and source area(s). Additional site assessment data may be required; however, the incremental effort is typically minimal relative to Tier 1. If the user completes a Tier 1 evaluation, in most cases, only a limited number of pathways, exposure scenarios, and chemical(s) of concern are considered in the Tier 2 evaluation since many are eliminated from consideration during the Tier 1 evaluation.

6.8.1 In Tier 2, the user:

6.8.1.1 Identifies the indirect exposure scenarios to be addressed and the appropriate site-specific point(s) of compliance. A combination of assessment data and predictive modeling results are used to determine the SSTL at the source area(s) or the point(s) of compliance, or both; or

6.8.1.2 Applies Tier 1 RBSL Look-Up Table values for the direct exposure scenarios at reasonable point(s) of exposure (as opposed to the source area(s) as is done in Tier 1). The SSTLs for source area(s) and point(s) of compliance can be determined based on the demonstrated and predicted attenuation (reduction in concentration with distance) of compounds that migrate away from the source area(s).

6.8 An example of a Tier 2 application is illustrated in Appendix X5.

6.8.2 Tier 2 of the RBCA process involves the development of SSTL based on the measured and predicted attenuation of the chemical(s) of concern away from the source area(s) using relatively simplistic mathematical models. The SSTLs for the source area(s) are generally not equal to the SSTL for the point(s) of compliance. The predictive equations are characterized by the following:

6.8.2.1 The models are relatively simplistic and are often algebraic or semianalytical expressions;

6.8.2.2 Model input is limited to practicably attainable site-specific data or easily estimated quantities (for example, total porosity, soil bulk density); and

6.8.2.3 The models are based on descriptions of relevant physical/chemical phenomena. Most mechanisms that are neglected result in predicted concentrations that are greater than those likely to occur (for example, assuming constant concentrations in source area(s)). Appendix X3 discusses the use of predictive models and presents models that might be considered for Tier 2 evaluation.

6.8.3 *Tier 2 Evaluation*—Identify the exposure scenarios where the measured concentrations of the chemical(s) of concern are above the SSTL at the point(s) of compliance, and evaluate the tier results in accordance with 6.7.

6.9 *Tier 3*—In a Tier 3 evaluation, SSTLs for the source area(s) and the point(s) of compliance are developed on the basis of more sophisticated statistical and contaminant fate and transport analyses, using site-specific input parameters for both direct and indirect exposure scenarios. Source area(s) and the point(s) of compliance SSTLs are developed to correspond to concentrations of chemical(s) of concern at the point(s) of exposure that are protective of human health and the environment. Tier 3 evaluations commonly involve collection of significant additional site information and completion of more extensive modeling efforts than is required for either a Tier 1 or Tier 2 evaluation.

6.9.1 Examples of Tier 3 analyses include the following:

6.9.1.1 The use of numerical ground water modeling codes that predict time-dependent dissolved contaminant transport under conditions of spatially varying permeability fields to predict exposure point(s) of concentrations;

6.9.1.2 The use of site-specific data, mathematical models, and Monte Carlo analyses to predict a statistical distribution of exposure and risks for a given site; and

6.9.1.3 The gathering of sufficient data to refine site-specific parameter estimates (for example, biodegradation rates) and improve model accuracy in order to minimize future monitoring requirements.

6.9.2 *Tier 3 Evaluation*—Identify the exposure scenarios where the measured concentrations of the chemical(s) of concern are above the SSTL at the point(s) of compliance, and evaluate the tier results in accordance with 6.7 except that a tier upgrade (6.7.5) is not available.

6.10 *Implementing the Selected Remedial Action Program*—When it is judged by the user that no further assessment is necessary, or practicable, a remedial alternatives evaluation should be conducted to confirm the most cost-effective option for achieving the final remediation target levels (RBSLs or SSTLs, as appropriate). Detailed design specifications may then be developed for installation and operation of the selected measure. The remedial action must continue until such time as monitoring indicates that

concentrations of the chemical(s) of concern are not above the RBSL or SSTL, as appropriate, at the points of compliance or source area(s), or both.

6.11 *RBCA Report*—After completion of the RBCA activities, a RBCA report should be prepared and submitted to the regulatory agency. The RBCA report should, at a minimum, include the following:

- 6.11.1 An executive summary;
- 6.11.2 A site description;
- 6.11.3 A summary of the site ownership and use;
- 6.11.4 A summary of past releases or potential source areas;
- 6.11.5 A summary of the current and completed site activities;
- 6.11.6 A description of regional hydrogeologic conditions;
- 6.11.7 A description of site-specific hydrogeologic conditions;
- 6.11.8 A summary of beneficial use;
- 6.11.9 A summary and discussion of the risk assessment (hazard identification, dose response assessment, exposure assessment, and risk characterization), including the methods and assumptions used to calculate the RBSL or SSTL, or both;
- 6.11.10 A summary of the tier evaluation;
- 6.11.11 A summary of the analytical data and the appropriate RBSL or SSTL used;
- 6.11.12 A summary of the ecological assessment;
- 6.11.13 A site map of the location;

6.11.14 An extended site map to include local land use and ground water supply wells;

6.11.15 Site plan view showing location of structures, aboveground storage tanks, underground storage tanks, buried utilities and conduits, suspected/confirmed sources, and so forth;

6.11.16 Site photos, if available;

6.11.17 A ground water elevation map;

6.11.18 Geologic cross section(s); and

6.11.19 Dissolved plume map(s) of the chemical(s) of concern.

6.12 *Monitoring and Site Maintenance*—In many cases, monitoring is necessary to demonstrate the effectiveness of implemented remedial action measures or to confirm that current conditions persist or improve with time. Upon completion of this monitoring effort (if required), no further action is required. In addition, some measures (for example, physical barriers such as capping, hydraulic control, and so forth) require maintenance to ensure integrity and continued performance.

6.13 *No Further Action and Remedial Action Closure*—When RBCA RBSLs or SSTLs have been demonstrated to be achieved at the point(s) of compliance or source area(s), or both, as appropriate, and monitoring and site maintenance are no longer required to ensure that conditions persist, then no further action is necessary, except to ensure that institutional controls (if any) remain in place.

APPENDIXES

(Nonmandatory Information)

XI. PETROLEUM PRODUCTS CHARACTERISTICS: COMPOSITION, PHYSICAL AND CHEMICAL PROPERTIES, AND TOXICOLOGICAL ASSESSMENT SUMMARY

X1.1 *Introduction*:

X1.1.1 Petroleum products originating from crude oil are complex mixtures of hundreds to thousands of chemicals; however, practical limitations allow us to focus only on a limited subset of key components when assessing the impact of petroleum fuel releases to the environment. Thus, it is important to have a basic understanding of petroleum properties, compositions, and the physical, chemical, and toxicological properties of some compounds most often identified as the key chemicals or chemicals of concern.

X1.1.2 This appendix provides a basic introduction to the physical, chemical, and toxicological characteristics of petroleum products (gasoline, diesel fuel, jet fuel, and so forth)^a and other products focussed primarily towards that information which is most relevant to assessing potential impacts due to releases of these products into the subsurface. Much of the information presented is summarized from the references listed at the end of this guide. For specific topics, the reader is referred to the following sections of this appendix:

X1.1.2.1 *Composition of Petroleum Fuels*—See X1.2.

X1.1.2.2 *Physical, Chemical, and Toxicological Properties of Petroleum Fuels*—See X1.3.

X1.1.2.3 *Chemical of Concern*—See X1.4.

X1.1.2.4 *Toxicity of Petroleum Hydrocarbons*—See X1.5.

X1.1.2.5 *Profiles of Select Compounds*—See X1.6.

X1.2 *Composition of Petroleum Products*:

X1.2.1 Most petroleum products are derived from crude oil by distillation, which is a process that separates compounds by volatility. Crude oils are variable mixtures of thousands of chemical compounds, primarily hydrocarbons; consequently, the petroleum products themselves are also variable mixtures of large numbers of components. The biggest variations in composition are from one type of product to another (for example, gasoline to motor oil); however, there are even significant variations within different samples of the same product type. For example, samples of gasoline taken from the same fuel dispenser on different days, or samples taken from different service stations, will have different compositions. These variations are the natural result of differing crude oil sources, refining processes and conditions, and kinds and amount of additives used.

^a "Alternative products," or those products not based on petroleum hydrocarbons (or containing them in small amounts), such as methanol or M85, are beyond the scope of the discussion in this appendix.

X1.2.2 Components of Petroleum Products—The components of petroleum products can be generally classified as either hydrocarbons (organic compounds composed of hydrogen and carbon only) or as non-hydrocarbons (compounds containing other elements, such as oxygen, sulfur, or nitrogen). Hydrocarbons make up the vast majority of the composition of petroleum products. The non-hydrocarbon compounds in petroleum products are mostly hydrocarbon-like compounds containing minor amounts of oxygen, sulfur, or nitrogen. Most of the trace levels of metals found in crude oil are removed by refining processes for the lighter petroleum products.

X1.2.3 Descriptions and Physical Properties of Petroleum Products—In order to simplify the description of various petroleum products, boiling point ranges and carbon number (number of carbon atoms per molecule) ranges are commonly used to describe and compare the compositions of various petroleum products. Table X1.1 summarizes these characteristics for a range of petroleum products. Moving down the list from gasoline, increases in carbon number range and boiling range and decreases in volatility (denoted by increasing flash point) indicate the transition to "heavier products." Additional descriptions of each of these petroleum products are provided as follows.

X1.2.4 Gasoline—Gasoline is composed of hydrocarbons and "additives" that are blended with the fuel to improve fuel performance and engine longevity. The hydrocarbons fall primarily in the C4 to C12 range. The lightest of these are highly volatile and rapidly evaporate from spilled gasoline. The C4 and C5 aliphatic hydrocarbons rapidly evaporate from spilled gasoline (hours to months, depending primarily on the temperature and degree of contact with air). Substantial portions of the C6 and heavier hydrocarbons also evaporate, but at lower rates than for the lighter hydrocarbons.

X1.2.4.1 Figure X1.1 shows gas chromatograms of a fresh gasoline and the same gasoline after simulated weathering; air was bubbled through the gasoline until 60 % of its initial volume was evaporated. In gas chromatography, the mixture is separated into its components, with each peak representing different compounds. Higher molecular weight components appear further to the right along the x-axis. For reference, positions of the *n*-aliphatic hydrocarbons are indicated in Fig. X1.1. The height of, and area under, each peak are measures of how much of that component is present in the mixture. As would be expected by their higher volatilities, the lighter hydrocarbons (up to about C7) evaporate first and are greatly reduced in the weathered gasoline. The gas chromatogram of a fuel oil is also shown for comparison.

X1.2.4.2 The aromatic hydrocarbons in gasoline are primarily benzene (C₆H₆), toluene (C₇H₈), ethylbenzene (C₈H₁₀), and xylenes (C₈H₁₀); these are collectively referred to as "BTEX." Some heavier aromatics are present also, including low amounts of polyaromatic hydrocarbons (PAHs). Aromatics typically comprise about 10 to 40 % of gasoline.

X1.2.4.3 Oxygenated compounds ("oxygenates") such as alcohols (for example, methanol or ethanol) and ethers (for example, methyl tertiarybutyl ether—MTBE) are sometimes added to gasoline as octane boosters and to reduce carbon monoxide exhaust emissions. Methyl tertiarybutyl ether has been a common additive only since about 1980.

X1.2.4.4 Leaded gasoline, which was more common in the past, contained lead compounds added as octane "boosters." Tetraethyl lead (TEL) is one lead compound that was commonly used as a gasoline additive. Other similar compounds were also used. Sometimes mixtures of several such compounds were added. Because of concerns over atmospheric emissions of lead from vehicle exhaust, the EPA has reduced the use of leaded gasolines. Leaded gasolines were phased out of most markets by 1989.

X1.2.4.5 In order to reduce atmospheric emissions of lead, lead "scavengers" were sometimes added to leaded gasolines. Ethylene dibromide (EDB) and ethylene dichloride (EDC) were commonly used for this purpose.

X1.2.5 Kerosene and Jet Fuel—The hydrocarbons in kerosene commonly fall into the C11 to C15 range, and distill at approximately 150 to 250°C. Special winter cuts (that is, having broader boiling range) kerosenes and low-flash kerosenes are also marketed. Both aliphatic and aromatic hydrocarbons are present, including more multi-ring compounds and kerosene.

X1.2.5.1 Commercial jet fuels JP-8 and Jet A have similar compositions to kerosene. Jet fuels JP-4 and JP-5 are cuts used by the military. They contain lighter distillates and have some characteristics of both gasoline and kerosene.

X1.2.5.2 Aromatic hydrocarbons comprise about 10 to 20 % of kerosene and jet fuels.

X1.2.6 Diesel Fuel and Light Fuel Oils—Light fuel oils include No. 1 and No. 2 fuel oils, and boil in the range from 160 to 400°C. Hydrocarbons in light fuel oils and diesel fuel typically fall in the C10 to C20 range. Because of their higher molecular weights, constituents in these products are less volatile, less water soluble, and less mobile than gasoline- or kerosene-range hydrocarbons.

X1.2.6.1 About 25 to 35 % of No. 2 fuel oil is composed of aromatic hydrocarbons, primarily alkylated benzenes and naphthalenes. The BTEX concentrations are generally low.

X1.2.6.2 No. 1 fuel oil is typically a straight run distillate.

X1.2.6.3 No. 2 fuel oil can be either a straight run distillate, or else is produced by catalytic cracking (a process in which larger molecules are broken down into smaller ones). Straight run distillate No. 2 is commonly used for home heating fuel, while the cracked product is often used for industrial furnaces and boilers. Both No. 1 and No. 2 fuel oils are sometimes used as blending components for jet fuel or diesel fuel formulations.

X1.2.7 Heavy Fuel Oils—The heavy fuel oils include Nos. 4, 5, and 6 fuel oils. They are sometimes referred to as "gas oils" or "residual fuel oils." These are composed of hydrocarbons ranging from about C19 to C25 and have a boiling range from about 315 to 540°C. They are dark in color and considerably more viscous than water. They typically contain 15 to 40 % aromatic hydrocarbons, dominated by alkylated phenanthrenes and naphthalenes. Polar compounds containing nitrogen, sulfur, or oxygen may comprise 15 to 30 % of the oil.

X1.2.7.1 No. 6 fuel oil, also called "Bunker Fuel" or "Bunker C," is a gummy black product used in heavy industrial applications where high temperatures are available to fluidize the oil. Its density is greater than that of water.

X1.2.7.2 Nos. 4 and 5 fuel oils are commonly produced by blending No. 6 fuel oil with lighter distillates.

X1.2.8 Motor Oils and Other Lubricating Oils—Lubricating oils and motor oils are predominately comprised of compounds in the C20 to C45 range and boil at approximately 425 to 540°C. They are enriched in the most complex molecular fractions found in crude oil, such as cycloparaffins and PNAs having up to three rings or more. Aromatics may make up to 10 to 30 % of the oil. Molecules containing nitrogen, sulfur, or oxygen are also common. In addition, used automotive crankcase oils become enriched with PNAs and certain metals.

X1.2.8.1 These oils are relatively viscous and insoluble in ground water and relatively immobile in the subsurface.

X1.2.8.2 Waste oil compositions are even more difficult to predict. Depending on how they are managed, waste oils may contain some portion of the lighter products in addition to heavy oils. Used crankcase oil may contain wear metals from engines. Degreasing solvents (gasoline, naphtha, or light chlorinated solvents, or a combination thereof) may be present in some wastes.

X1.3 Physical, Chemical, and Toxicological Characteristics of Petroleum Products:

X1.3.1 Trends in Physical/Chemical Properties of Hydrocarbons—In order to better understand the subsurface behavior of hydrocarbons it is helpful to be able to recognize trends in important physical properties with increasing number of carbon atoms. These trends are most closely followed by compounds with similar molecular structures, such as the straight-chained, single-bonded aliphatic hydrocarbons. In general, as the carbon number (or molecule size) increases, the following trends are observed:

X1.3.1.1 Higher boiling points (and melting points),

X1.3.1.2 Lower vapor pressure (volatility),

X1.3.1.3 Greater density,

X1.3.1.4 Lower water solubility, and

X1.3.1.5 Stronger adhesion to soils and less mobility in the subsurface.

X1.3.2 Table X1.2 lists physical, chemical, and toxicological properties for a number of hydrocarbons found in petroleum products. In general:

X1.3.2.1 Aliphatic petroleum hydrocarbons with more than ten carbon atoms are expected to be immobile in the subsurface, except when dissolved in nonaqueous phase liquids (NAPLs), due to their low water solubilities, low vapor pressures, and strong tendency to adsorb to soil surfaces.

X1.3.2.2 Aromatic hydrocarbons are more water soluble and mobile in water than aliphatic hydrocarbons of similar molecular weight.

X1.3.2.3 Oxygenates generally have much greater water solubilities than hydrocarbons of similar molecular weight, and hence are likely to be the most mobile of petroleum fuel constituents in leachate and ground water. The light alcohols, including methanol and ethanol, are completely miscible with water in all proportions.

X1.3.3 Properties of Mixtures—It is important to note that the partitioning behavior of individual compounds is affected by the presence of other hydrocarbons in the subsurface. The maximum dissolved and vapor concentrations achieved in the subsurface are always less than that of any pure compound, when it is present as one of many constituents of a petroleum fuel. For example, dissolved

benzene concentrations in ground water contacting gasoline impacted soils rarely exceed 1 to 3 % of the ~1800-mg/l pure component solubility of benzene.

X1.3.4 Trends in Toxicological Properties of Hydrocarbons—A more detailed discussion of toxicological assessment is given in X1.5 (see also Appendix X3), followed by profiles for select chemicals found in petroleum products given in X1.6. Of the large number of compounds present in petroleum products, aromatic hydrocarbons (BTEX, PAHs and so forth) are the constituents that human and aquatic organisms tend to be most sensitive to (relative to producing adverse health impacts).

X1.4 Chemicals of Concern for Risk Assessments

X1.4.1 It is not practicable to evaluate every compound present in a petroleum product to assess the human health or environmental risk from a spill of that product. For this reason, risk management decisions are generally based on assessing the potential impacts from a select group of "indicator" compounds. It is inherently assumed in this approach that a significant fraction of the total potential impact from all chemicals is due to the chemicals of concern. The selection of chemicals of concern is based on the consideration of exposure routes, concentrations, mobilities, toxicological properties, and aesthetic characteristics (taste, odor, and so forth). Historically, the relatively low toxicities and dissolved-phase mobilities of aliphatic hydrocarbons have made these chemicals of concern of less concern relative to aromatic hydrocarbons. When additives are present in significant quantities, consideration should also be given to including these as chemicals of concern.

X1.4.2 Table X1.3 identifies chemicals of concern most often considered when assessing impacts of petroleum products, based on knowledge of their concentration in the specific fuel, as well as their toxicity, water solubility, subsurface mobility, aesthetic characteristics, and the availability of sufficient information to conduct risk assessments. The chemicals of concern are identified by an "X" in the appropriate column.

X1.5 Toxicity of Petroleum Hydrocarbons:

X1.5.1 The following discussion gives a brief overview of origin of the toxicity parameters (reference doses (RfDs)), and slope factors (SFs), a justification for common choices of chemicals of concern and then, in X1.6, a brief summary of the toxicological, physical, and chemical parameters associated with these chemicals of concern.

X1.5.2 How Toxicity Is Assessed: Individual Chemicals Versus Mixtures—The toxicity of an individual chemical is typically established based on dose-response studies that estimate the relationship between different dose levels and the magnitude of their adverse effects (that is, toxicity). The dose-response data is used to identify a "safe dose" or a toxic level for a particular adverse effect. For a complex mixture of chemicals, the same approach can be used. For example, to evaluate the toxicity of gasoline, a "pure" reference gasoline would be evaluated instead of the individual chemical. This "whole-product" approach to toxicity assessment is strictly applicable only to mixtures identical to the evaluated mixture; gasolines with compositions different from the reference gasoline might have toxicities similar to the reference, but some differences would be expected. In addition, as the composition of gasoline released to the environment changes

through natural processes (volatilization, leaching, biodegradation), the toxicity of the remaining portion may change also.

X1.5.3 An alternative to the "whole-product" approach for assessing the toxicity of mixtures is the "individual-constituent" approach. In this approach, the toxicity of each individual constituent (or a selected subset of the few most toxic constituents, so-called chemicals of concern) is separately assessed and the toxicity of the mixture is assumed to be the sum of the individual toxicities using a hazard index approach. This approach is often used by the USEPA; however, it is inappropriate to sum hazard indices unless the toxicological endpoints and mechanisms of action are the same for the individual compounds. In addition, the compounds to be assessed must be carefully selected based on their concentrations in the mixture, their toxicities, how well their toxicities are known, and how mobile they are in the subsurface. Lack of sufficient toxicological information is often an impediment to this procedure.

X1.5.4 Use of TPH Measurements in Risk Assessments—Various chemical analysis methods commonly referred to as TPH are often used in site assessments. These methods usually determine the total amount of hydrocarbons present as a single number, and give no information on the types of hydrocarbon present. Such TPH methods may be useful for risk assessments where the whole product toxicity approach is appropriate. However in general, *TPH should not be used for "individual constituent" risk assessments because the general measure of TPH provides insufficient information about the amounts of individual compounds present.*

X1.5.5 Toxicity Assessment Process—Dose-response data are used to identify a "safe dose" or toxic level for a particular observed adverse effect. Observed adverse effects can include whole body effects (for example, weight loss, neurological observations), effects on specific body organs, including the central nervous system, teratogenic effects (defined by the ability to produce birth defects), mutagenic effects (defined by the ability to alter the genes of a cell), and carcinogenic effects (defined by the ability to produce malignant tumors in living tissues). Because of the great concern over risk agents which may produce incremental carcinogenic effects, the USEPA has developed weight-of-evidence criteria for determining whether a risk agent should be considered carcinogenic (see Table X1.2).

X1.5.6 Most estimates of a "safe dose" or toxic level are based on animal studies. In rare instances, human epidemiological information is available on a chemical. Toxicity studies can generally be broken into three categories based on the number of exposures to the risk agent and the length of time the study group was exposed to the risk agent. These studies can be described as follows:

X1.5.6.1 Acute Studies—Acute studies typically use one dose or multiple doses over a short time frame (24 h). Symptoms are usually observed within a short time frame and can vary from weight loss to death.

X1.5.6.2 Chronic Studies—Chronic studies use multiple exposures over an extended period of time, or a significant fraction of the animal's (typically two years) or the individual's lifetime. The chronic effects of major concern are carcinogenic, mutagenic, and teratogenic effects. Other

chronic health effects such as liver and kidney damage are also important.

X1.5.6.3 Subchronic Studies—Subchronic studies use multiple or continuous exposures over an extended period (three months is the usual time frame in animal studies). Observed effects include those given for acute and chronic studies.

X1.5.6.4 Ideally, safe or acceptable doses are calculated from chronic studies, although, due to the frequent paucity of chronic data, subchronic studies are used.

X1.5.6.5 For noncarcinogens, safe doses are based on no observed adverse effect levels (NOAELs) or lowest observed adverse effect levels (LOAELs) from the studies.

X1.5.6.6 Acceptable doses for carcinogens are determined from mathematical models used to generate dose-response curves in the low-dose region from experimentally determined dose-response curves in the high-dose region.

X1.5.7 Data from the preceding studies are used to generate reference doses (RfDs), reference concentrations (RfCs), and slope factors (SFs) and are also used in generating drinking water maximum concentration levels (MCLs) and goals (MCLGs), health advisories (HAs), and water quality criteria. These terms are defined in Table X1.4 and further discussed in X3.6.

X1.5.8 Selection of Chemicals of Concern—The impact on human health and the environment in cases of gasoline and middle distillate contamination of soils and ground water can be assessed based on potential receptor (that is, aquatic organisms, human) exposure to three groups of materials: light aromatic hydrocarbons, PAHs, and in older spills, lead. Although not one of the primary contaminants previously described, EDB and EDC were used as lead scavengers in some leaded gasolines and may be considered chemicals of concern, when present.

X1.5.9 The light aromatics, benzene, toluene, xylenes, and ethylbenzene have relatively high water solubility and sorb poorly to soils. Thus, they have high mobility in the environment, moving readily through the subsurface. When released into surface bodies of water, these materials exhibit moderate to high acute toxicity to aquatic organisms. Although environmental media are rarely contaminated to the extent that acute human toxicity is an issue, benzene is listed by the USEPA as a Group A Carcinogen (known human carcinogen) and, thus, exposure to even trace levels of this material is considered significant.

TABLE X1.1 Generalized Chemical and Physical Characterization of Petroleum Products

	Predominant Carbon No. Range	Boiling Range, °C	Flash Point, °C ^a
Gasoline	C4 to C12	25 to 215	-40
Kerosene and Jet Fuels	C11 to C13	150 to 250	<21, ^b 21 to 55, ^c >55 ^d
Diesel Fuel and Light Fuel Oils	C10 to C20	160 to 400	>35
Heavy Fuel Oils	C19 to C25	315 to 540	>50
Motor Oils and Other Lubricating Oils	C20 to C45	425 to 540	>175

^a Typical values

^b Jet-B, AVTAG and JP-4

^c Kerosene, Jet A, Jet A-1, JP-8 and AVTUR

^d AVCAT and JP-5

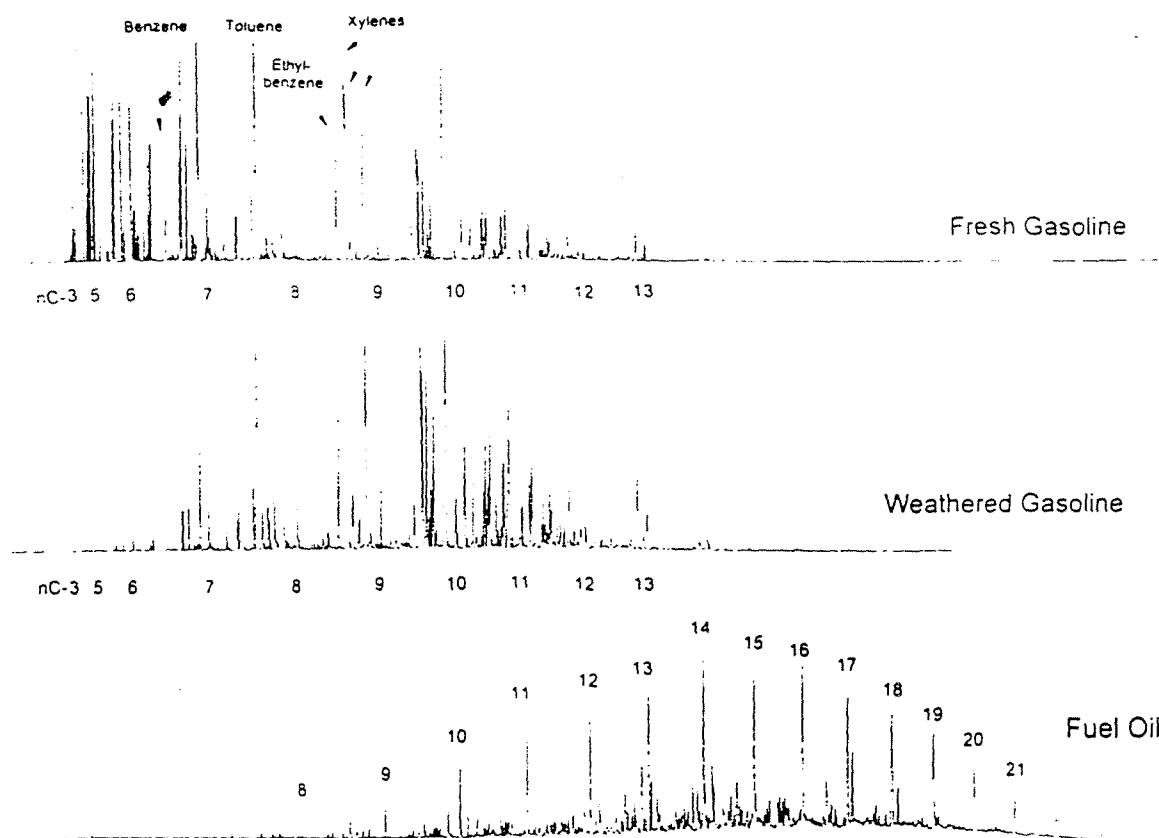


FIG. X1.1 Gas Chromatograms of Some Petroleum Fuels

X1.5.10 Polycyclic aromatics can be broken into two categories: naphthalenes and methylnaphthalenes (diaromatics) have moderate water solubility and soil sorption potential and, thus, their movement through the subsurface tends to be less than monoaromatics, but substantial movement can still occur. When released into surface bodies of water, these materials have moderate to high toxicity to aquatic organisms. The PAHs with three or more condensed rings have very low solubility (typically less than 1 mg/L) and sorb strongly to soils. Thus, their movement in the subsurface is minimal. Several members in the group of three to six-ring PAHs are known or suspected carcinogens and, thus, exposure to low concentrations in drinking water or through the consumption of contaminated soil by children is significant. In addition, materials containing four to six-ring PAHs are poorly biodegradable and, coupled with the potential to bioaccumulate in tissues of aquatic organisms, these materials have the potential to bioconcentrate (be found at levels in living tissue far higher than present in the general surroundings) in the environment.

X1.5.11 Although almost totally eliminated from use in gasolines in the United States, lead is found associated with older spills. Lead was typically added to gasoline either as tetraethyl or tetramethyl lead and may still be found in its original form in areas containing free product. Typically outside the free product zones, these materials have decom-

posed into inorganic forms of lead. Lead is a neurotoxin and lead in the blood of children has been associated with reduced intellectual development. The ingestion by children of lead-contaminated soils is an exposure route of great concern, as is the consumption of lead-contaminated drinking water. Ethylene dibromide and ethylene dichloride, used as lead scavengers in gasolines, are of concern because of their high toxicity (potential carcinogens) and their high mobility in the environment.

X1.5.12 In summary, benzene and benzo(a)pyrene (and in some cases EDB and EDC) are chemicals of concern because of their carcinogenicity. Other PAHs may also be grouped with B(a)P because of uncertainties in their carcinogenicity and because they may accumulate (bioconcentrate) in living tissue.

X1.5.13 *Toxicity and Physical/Chemical Properties for Chemicals of Concern*—A summary of health effects and physical/chemical properties for a number of chemicals of concern is provided in Table X1.2. This table provides toxicological data from a variety of sources, regardless of data quality. A refined discussion for selected chemicals of concern is given as follows. The reader is cautioned that this information is only current as of the dates quoted, and the sources quoted may have been updated, or more recent information may be available in the peer-reviewed literature.

TABLE X1.2 Chemical and Toxicological Properties of Selected Hydrocarbons

Compounds	Weight of Evidence Class ^a	Oral RfD, mg/kg-day	Inhalation RfC, mg/m ³	Oral Slope Factor, ^a mg/kg-day ⁻¹	Drinking Water MCL, ^a mg/L	Solubility, ^b mg/L	Octanol/Water Partition Coefficient, ^b log K _{ow}	Organic Carbon Adsorption Coefficient ^b log K _{oc}
Benzene	A	E	E G	0.029 ^G	0.005	1750	2.13	1.58
Toluene	D	0.2 ^A	0.4 ^A	...	1	535	2.65	2.13
Ethylbenzene	D	0.1 ^A	1 ^A	...	0.7	152	3.13	1.98
Xylenes	D	2 ^A	0.3 ^{C,E}	...	10.0	198	3.26	2.38
n-Hexane	E	0.06 ^C , 0.6 ^D	0.2 ^D	...	...	13 ^L	...	...
MTBE	...	E	3 ^A	...	...	48 000 ^M	1.06-1.30 ^M	1.08 ^D
MEK	D	0.6 ^A	1 ^A	...	...	268 000	0.26	0.65
MIBK	...	0.05 ^C , 0.5 ^D	0.08 ^{C,E} , 0.8 ^D	...	...	...	...	...
Methanol	...	0.5 ^A	E	...	...	...	...	...
Ethanol	...	...	...	...	...	1 000 000	-0.032	0.34
TBA	...	...	...	...	...	...	...	...
Lead	B2	...	...	...	0.015 ^J	...	...	...
EDC	B2	...	...	0.091	0.006	8 520	1.48	1.15
EDB	B2	...	E	85	0.00006	4 300	1.76	1.64
PNAs:								
Pyrene	D	0.03 ^A	...	...	...	0.132	4.88	4.58
Benzo(a)pyrene	B2	...	...	7.3	0.0002 ^K	0.00120	5.98	5.59
Anthracene	D	0.3 ^A	...	...	...	0.0450	4.45	4.15
Phenanthrene	D	...	...	...	...	1.00	4.46	4.15
Naphthalene	D ^E	0.004 ^C , 0.04 ^D	...	...	...	31.0 ^L	3.28 ^L	3.11 ^P
Chrysene	B2	...	...	1.15 ^M	0.0002	0.00180	5.61	5.30
Benzo(k)fluoranthene	B2	...	...	...	0.0002 ^K	0.430	6.06	5.74
Fluorene	D	0.04 ^A	...	...	...	1.69	4.20	3.86
Fluoranthene	D	0.04 ^A	...	...	...	0.206	4.90	4.58
Benzo(g,h,i)perylene	D	...	...	...	...	0.000700	6.51	6.20
Benzo(b)fluoranthene	B2	...	...	...	0.0002 ^K	0.0140	6.06	5.74
Benz(a)anthracene	B2	...	...	...	0.0002 ^K	0.00670	5.60	6.14

^a See Ref (2).^b See Ref (4).^c Chronic effect. See Ref (5).^d Subchronic effect. See Ref (5).^e The data is pending in the EPA-IRIS database.^f The data has been withdrawn in the EPA-IRIS database.^g The inhalation unit risk for benzene is 8.3×10^{-3} (mg/m³)⁻¹. The drinking water unit is 8.3×10^{-4} (mg/L).^h See Ref (6). Health-based criteria for carcinogenic polycyclic aromatic compounds (PAHs) with the exception of dibenzo(a,h)anthracene are set at one tenth of the level of benzo(a)pyrene due to their recognized lesser potency.ⁱ Listed in the January 1991 Drinking Water Priority List and may be subject to future regulation (56 FR 1470, 01/14/91).^j USEPA, May 1993. Office of Drinking Water. 15 µg/L is an action level; standard for tap water.^k Proposed standard.^l See Ref (7).^m See Ref (8).ⁿ See Ref (9).^o Estimation Equation (from (10)):(1) $\log K_{oc} = -0.55 \log S + 3.64$, where S = water solubility (mg/L).(2) $\log K_{oc} = 0.544 \log P + 1.377$ ^p See Ref (11).

X1.5.13.1 The RfD or SF values are generally obtained from a standard set of reference tables (for example, Integrated Risk Information System, IRIS (2), or the Health Effects Assessment Summary Tables, HEAST (3)). Except as noted, the toxicity evaluations that follow were taken from IRIS (2) because these are EPA-sanctioned evaluations. The information in IRIS (2), however, has typically only been peer-reviewed within the EPA and may not always have support from the external scientific community. The information in IRIS may also be subject to error (as exemplified by recent revisions in the slope factor for B(a)P and RfC for MTBE).

X1.5.13.2 HEAST (3) is a larger database than IRIS (2) and is often used as a source of health effects information. Whereas the information in IRIS (2) has been subject to data quality review, however, the information in the HEAST (3) tables has not. The user is expected to consult the original assessment documents to appreciate the strengths and limitations of the data in HEAST (3). Thus, care should be exercised in using the values in HEAST (3).

TABLE X1.3 Commonly Selected Chemicals of Concern for Petroleum Products

	Unleaded Gasoline	Leaded Gasoline	Kerosene/ Jet Fuels	Diesel/ Light Fuel Oils	Heavy Fuel Oils
Benzene	X	X	X	...	...
Toluene	X	X	X	...	...
Ethylbenzene	X	X	X	...	...
Xylene	X	X	X	...	...
MTBE, TBA, MEK, MIBK, methanol, ethanol	when suspected ^a	when suspected ^a	...	...	...
Lead, EDC, EDB	...	X	...	...	...
PNAs ^b	...	...	X	X	X

^a For example, when these compounds may have been present in the spilled gasoline. These additives are not present in all gasolines.^b A list of selected PNAs for consideration is presented in Table X1.2.

tations of the data in HEAST (3). Thus, care should be exercised in using the values in HEAST (3).

X1.5.13.3 References for the physical/chemical properties

are provided in Table X1.2. All Henry's law constants quoted in text are from Ref (11) except MTBE which is from estimation: $H = (1.0 \times 10^{-3}) / 760(S)$, where MW is the molecular weight, $P_v = 414$ mmHg at 100°F , and $S = 48\,000$ mg/L.

X1.6 Profiles of Select Compounds

X1.6.1 Benzene

X1.6.1.1 *Toxicity Summary*—Based on human epidemiological studies, benzene has been found to be a human carcinogen (classified as a Group A carcinogen, known human carcinogen by the USEPA). An oral slope factor of 2.9×10^{-2} (mg/kg/day) $^{-1}$ has been derived for benzene based on the observance of leukemia from occupational exposure by inhalation. The USEPA has set a drinking water maximum contaminant level (MCL) at $5\text{ }\mu\text{g/L}$. The maximum contaminant level goal (MCLG) for benzene is set at zero.

X1.6.1.2 Although the EPA does not usually set long-term drinking water advisories for carcinogenic materials (no exposure to carcinogens is considered acceptable), a ten-day drinking water health advisory for a child has been set at 0.235 mg/L based on hematological impairment in animals. The EPA is in the process of evaluating noncancer effects and an oral RfD for benzene is pending.

X1.6.1.3 In situations in which both aquatic life and water are consumed from a particular body of water, a recommended EPA water quality criterion is set at $0.66\text{ }\mu\text{g/L}$. When only aquatic organisms are consumed, the criterion is $40\text{ }\mu\text{g/L}$. These criteria were established at the one-in-one-million risk level (that is, the criteria represent a one-in-one-million estimated incremental increase in cancer risk over a lifetime).

X1.6.1.4 *Physical/Chemical Parameter Summary*—Benzene is subject to rapid volatilization (Henry's law constant $= 5.5 \times 10^{-3}\text{ m}^3\text{-atm/mol}$) under common above-ground environmental conditions. Benzene will be mobile in soils due to its high water solubility ($2.75 \times 10^6\text{ }\mu\text{g/L}$) and relatively low sorption to soil particles ($\log K_{oc} = 1.92$) and, thus, has the potential to leach into ground water. Benzene has a relatively low $\log K_{ow}$ value (2.12) and is biodegradable. Therefore, it is not expected to bioaccumulate. In laboratory tests, when a free gasoline phase was in equilibrium with water, typical benzene concentrations in water ranged from 2.42×10^4 to $1.11 \times 10^5\text{ }\mu\text{g/L}$.

X1.6.2 Toluene

X1.6.2.1 *Toxicity Summary*—Using data from animal studies, the USEPA has set an oral RfD for toluene at 0.2 mg/kg/day . In converting a NOAEL from an animal study, in which the critical effect observed was changes in liver and kidney weights, an uncertainty factor of 1000 and a modifying factor of 1 were used. The EPA has assigned an overall medium level of confidence in the RfD because, although the principal study was well performed, the length of the study corresponded to only subchronic rather than a chronic evaluation, and reproductive aspects were lacking. Based on the RfD and assuming 20 % exposure from drinking water, the EPA has set both drinking water MCL and MCLG of $1000\text{ }\mu\text{g/L}$. Drinking water health advisories range from 1 mg/L (lifetime equivalent to the RfD) to 20 mg/L (one-day advisory for a child).

X1.6.2.2 In situations in which both aquatic life and

water are consumed from a particular body of water, the recommended water quality criterion is set at $1.43 \times 10^2\text{ }\mu\text{g/L}$. When only aquatic organisms are consumed, the criterion is $4.24 \times 10^2\text{ }\mu\text{g/L}$.

X1.6.2.3 An inhalation RfC of 0.4 mg/m^3 was derived based on neurological effects observed in a small worker population. An uncertainty factor of 300 and a modifying factor of 1 were used to convert the lowest observed adverse effect level (LOAEL) to the RfC. The overall confidence in the RfC was established as medium because of the use of a LOAEL and because of the paucity of exposure information.

X1.6.2.4 *Physical/Chemical Parameter Summary*—Toluene is expected to volatilize rapidly, under common above-ground environmental conditions, due to its relatively high Henry's law constant ($6.6 \times 10^{-3}\text{ m}^3\text{-atm/mol}$). It will be mobile in soils based on an aqueous solubility of $5.35 \times 10^5\text{ }\mu\text{g/L}$ and relatively poor sorption to soils (estimated $\log K_{oc} = 2.48$) and, hence, has a potential to leach into ground water. Toluene has a relatively low $\log K_{ow}$ (2.73) and is biodegradable. Bioaccumulation of toluene is, therefore, expected to be negligible. In laboratory tests, when a free gasoline phase was in equilibrium with water, typical toluene concentrations in water ranged from 3.48×10^4 to $8.30 \times 10^4\text{ }\mu\text{g/L}$.

X1.6.3 Xylenes

X1.6.3.1 *Toxicity Summary*—Using data from animal studies, the USEPA has set an oral RfD for xylenes at 2.0 mg/kg/day . In converting a NOAEL from the animal study, in which the critical effects observed were hyperactivity, decreased body weight, and increased mortality (among male rats), an uncertainty factor of 100 and a modifying factor of 1 were used. The EPA has assigned an overall medium level of confidence in the RfD because, although the principal study was well designed and performed, supporting chemistry was not performed. A medium level of confidence was also assigned to the database. Based on the RfD and assuming 20 % exposure from drinking water, the EPA has set both drinking water MCL and MCLG of $10\,000\text{ g/L}$. Drinking water health advisories of 10 mg/L (lifetime, adult) and 40 mg/L (one-day, ten-day, and long-term child) are quoted by the EPA's Office of Drinking Water. No USEPA ambient water criteria are available for xylenes at this time. Evaluation of an inhalation RfC is pending.

X1.6.3.2 *Physical/Chemical Parameter Summary*—Xylenes are expected to rapidly volatilize under common above-ground environmental conditions based on their Henry's law constants (for *o*-xylene, $H = 5.1 \times 10^{-3}\text{ m}^3\text{-atm/mol}$). Xylenes have a moderate water solubility (1.46 to $1.98 \times 10^5\text{ }\mu\text{g/L}$) (pure compound) as well as moderate capacities to sorb to soils (estimated $\log K_{oc}$ 2.38 to 2.79) and, therefore, they will be mobile in soils and may leach into ground water. Xylenes are biodegradable, and with $\log K_{ow}$ values in the range from 2.8 to 3.3, they are not expected to bioaccumulate.

X1.6.4 Ethylbenzene

X1.6.4.1 *Toxicity Summary*—Using data from animal studies, the USEPA has set an oral RfD for ethylbenzene at 0.1 mg/kg/day . In converting a NOAEL from the animal study, in which the critical effects observed were liver and kidney toxicity, an uncertainty factor of 1000 and a modifying factor of 1 were used. The EPA has assigned an overall

TABLE X1.4 Weight of Evidence Criteria for Carcinogens

Category	Criterion
A	Human carcinogen, with sufficient evidence from epidemiological studies
B1	Probable human carcinogen, with limited evidence from epidemiological studies
B2	Probable human carcinogen, with sufficient evidence from animal studies and inadequate evidence or no data from epidemiological studies
C	Possible human carcinogen, with limited evidence from animal studies in the absence of human data
D	Not classifiable as to human carcinogenicity, owing to inadequate human and animal evidence
E	Evidence of noncarcinogenicity for humans, with no evidence of carcinogenicity in at least two adequate animal tests in different species, or in both adequate animal and epidemiological studies

low level of confidence in the RfD because the study was poorly designed and confidence in the supporting database is also low. Based on the RfD and assuming 20 % exposure from drinking water, the EPA has set both drinking water MCL and MCLG of 700 µg/L. Drinking water health advisories range from 700 µg/L (lifetime equivalent to the RfD) to 32 mg/L (one-day advisory for a child). In situations in which both aquatic life and water are consumed from a particular body of water, a recommended ambient water criterion is set at 1400 µg/L. When only aquatic organisms are consumed, the criterion is 3280 µg/L. An inhalation RfC of 1 mg/m³ was derived based on developmental toxicity effects observed in rats and rabbits. An uncertainty factor of 300 and a modifying factor of 1 were used to convert the NOAEL to the RfC. Both the study design and database were rated low and, thus, the overall confidence in the RfC was established as low.

X1.6.4.2 Physical/Chemical Parameter Summary—Ethylbenzene has a relatively high Henry's law constant (8.7×10^{-3} m³-atm/mol) and, therefore, can rapidly volatilize under common above-ground environmental conditions. Based on its moderate water solubility (1.52×10^5 µg/L) and moderate capacity to sorb to soils (estimated $\log K_{oc} = 3.04$), it will have moderate mobility in soil and may leach into ground water. In laboratory tests, when a free gasoline phase was in equilibrium with water, typical combined ethylbenzene and xylenes concentrations in water ranged from 1.08×10^4 to 2.39×10^4 µg/L, due to partitioning effects. Ethylbenzene has a moderate low K_{ow} value (3.15) and is biodegradable. Therefore, it is not expected to bioaccumulate. In laboratory tests, when a free gasoline phase was in equilibrium with water, typical combined ethylbenzene and xylenes

concentrations in water ranged from 1.08×10^4 to 2.39×10^4 µg/L.

X1.6.5 Naphthalenes:

X1.6.5.1 Toxicity Summary—In general, poisoning may occur by ingestion of large doses, inhalation, or skin adsorption of naphthalene. It can cause nausea, headache, diaphoresis, hematuria, fever, anemia, liver damage, vomiting, convulsions, and coma. Methylnaphthalenes are presumably less acutely toxic than naphthalene. Skin irritation and skin photosensitization are the only effects reported in man. Inhalation of the vapor may cause headache, confusion, nausea, and sometimes vomiting. The environmental concerns with naphthalenes are primarily attributed to effects on aquatic organisms. As a consequence, the EPA has not set any human health criteria for these materials (that is, there is no RfD or RfC, no drinking water MCL or MCLG or ambient water quality criteria). A risk assessment to define a RfD for these materials is presently under review by the EPA. Drinking water health advisories range from 20 µg/L (lifetime, adult) to 500 µg/L (one-day advisory for a child).⁶

X1.6.5.2 Physical/Chemical Parameter Summary: Naphthalene—Naphthalene has a relatively high Henry's law constant (1.15×10^{-3} m³-atm/mol) and, thus, has the capacity to volatilize rapidly under common above-ground environmental conditions. It has a moderate water solubility (3.10×10^4 µg/L) and $\log K_{ow}$ (3.11) and has the potential to leach to ground water. A moderate $\log K_{ow}$ value of 3.01 has been reported, but because naphthalene is very biodegradable, it is unlikely to bioconcentrate to a significant degree.

X1.6.5.3 Methylnaphthalenes—Henry's law constants (2.60×10^{-4} m³-atm/mol and 5.18×10^{-4} m³-atm/mol for 1- and 2-methylnaphthalene, respectively) suggest that these materials have the potential to volatilize under common above-ground environmental conditions. 1-Methylnaphthalene exhibits a water solubility similar to naphthalene (2.60×10^4 µg/L to 2.8×10^4 µg/L). However, solubility decreases with increasing alkylation (dimethylnaphthalenes: 2.0×10^3 µg/L to 1.1×10^4 µg/L, 1,4,5-trimethylnaphthalene: 2.0×10^3 µg/L). These materials are, therefore, expected to be slightly mobile to relatively immobile in soil (for example, $\log K_{oc}$ is in the range from 2.86 to 3.93 for 1- and 2-methylnaphthalenes). In aquatic systems, methylnaphthalenes may partition from the water column to

⁶ Office of Water, USEPA, Washington, DC

TABLE X1.5 Definitions of Important Toxicological Characteristics

Reference Dose—A reference dose is an estimate (with an uncertainty typically spanning an order of magnitude) of a daily exposure (mg/kg/day) to the general human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime of exposure.

Reference Concentration—A reference concentration is an estimate (with an uncertainty spanning perhaps an order of magnitude) of a continuous exposure to the human population (including sensitive subgroups) that is likely to be without appreciable deleterious effects during a lifetime.

Slope Factor—The slope of the dose-response curve in the low-dose region. When low-dose linearity cannot be assumed, the slope factor is the slope of the straight line from zero dose to the dose at 1 % excess risk. An upper bound on this slope is usually used instead of the slope itself. The units of the slope factor are usually expressed as (mg/kg/day)⁻¹.

Drinking Water MCLs and MCLGs—Maximum contaminant levels (MCLs) are drinking water standards established by the EPA that are protective of human health. However, these standards take into account the technological capability of attaining these standards. The EPA has, therefore, also established MCL goals (MCLGs) which are based only on the protection of human health. The MCL standards are often used as clean-up criteria.

Drinking Water Health Advisories—The Office of Drinking Water provides health advisories (HAs) as technical guidance for the protection of human health. They are not enforceable federal standards. The HAs are the concentration of a substance in drinking water estimated to have negligible deleterious effects in humans when ingested for specified time periods.

Water Quality Criteria—These criteria are not rules and they do not have regulatory impact. Rather, these criteria present scientific data and guidance of the environmental effects of pollutants which can be useful to derive regulatory requirements based on considerations of water quality impacts.

organic matter contained in sediments and suspended solids. Methylnaphthalenes have high $\log K_{ow}$ values (greater than 3.5) and have the potential to bioaccumulate. They do, however, exhibit a moderate degree of biodegradation, which typically decreases with increased alkylation.

X1.6.6 Three to Six-Ringed PHs—The most significant health effect for this class of compounds is their carcinogenicity, which is structure-dependent. Anthracene and phenanthrene have not been shown to cause cancer in laboratory animals. The available data does not prove pyrene to be carcinogenic to experimental animals. On the other hand, benzo[a]anthracene, benzo[a]pyrene, dibenz[a,h]anthracene, and 7,12-dimethylbenz[a]anthracene have been shown to be carcinogenic in laboratory animals. B(a)P and pyrene are discussed in X1.6.7 and X1.6.8 as representatives of carcinogenic and noncarcinogenic effects of this class.

X1.6.7 Benzo[a]pyrene (BaP)

X1.6.7.1 Toxicity Summary—Based on animal data, B(a)P has been classified as a probable human carcinogen (B2 carcinogen) by the USEPA. A range of oral slope factors from 4.5 to 11.7 (mg/kg/day) $^{-1}$ with a geometric mean of 7.3 (mg/kg/day) $^{-1}$ has been derived for B(a)P based on the observance of tumors of the forestomach and squamous cell carcinomas in mice. The data was considered less than optimal but acceptable (note that the carcinogenicity assessment for B(a)P may change in the near future pending the outcome of an on-going EPA review). The EPA has proposed a drinking water MCL at 0.2 $\mu\text{g/L}$ (based on the analytical detection limits). The MCLG for B(a)P is set at zero. In situations in which both aquatic life and water are consumed from a particular body of water, a recommended EPA water quality criterion is set at 2.8×10^{-3} $\mu\text{g/L}$. When only aquatic organisms are consumed, the criterion is 3.11×10^{-2} $\mu\text{g/L}$.

X1.6.7.2 Physical/Chemical Parameter Summary—When released to water, PAHs are not subject to rapid volatilization (Henry's law constants are on the order of 1.0×10^{-4} m 3 -atm/mol or less) under common environmental conditions. They have low aqueous solubility values and tend to sorb to soils and sediments and remain fixed in the environment. Three ring members of this group such as anthracene and phenanthrene have water solubilities on the order of 1000 $\mu\text{g/L}$. The water solubilities decrease substantially for larger molecules in the group, for example, benzo[a]pyrene has a water solubility of 1.2 $\mu\text{g/L}$. The $\log K_{ow}$ values for PAHs are on the order of 4.3 and greater, which suggests that PAHs will be expected to adsorb very strongly to soil. The PAHs with more than three rings generally have high $\log K_{ow}$ values (6.06 for benzo[a]pyrene), have poor biodegradability characteristics and may bioaccumulate.

X1.6.8 Pyrene:

X1.6.8.1 Toxicity Summary—Using data from animal studies, the USEPA has set an oral RfD for pyrene at 3×10^{-2} mg/kg/day. In converting a NOAEL from the animal study, in which the critical effects observed were kidney toxicity, an uncertainty factor of 3000 and a modifying factor of 1 were used. The EPA has assigned an overall low level of confidence in the RfD because although the study was well-designed, confidence in the supporting database is low. No drinking water MCLs or health advisories have been set. In situations in which both aquatic life and water are

consumed from a particular body of water, a recommended EPA water quality criterion is set at 2.8×10^{-3} $\mu\text{g/L}$. When only aquatic organisms are consumed, the criterion is 3.11×10^{-2} $\mu\text{g/L}$.

X1.6.8.2 Physical/Chemical Parameter Summary—Refer to X1.6.7.2 for BaP. Also see Table X1.2.

X1.6.9 MTBE:

X1.6.9.1 Toxicity Summary—Using data from animal studies, the USEPA has set an inhalation RfC for MTBE at 5 mg/m 3 . In converting a NOAEL from the animal study, in which the critical effects observed included increased liver and kidney weight and increased severity of spontaneous renal lesions (females), increased prostration (females) and swollen pericolar tissue, an uncertainty factor of 100 and a modifying factor of 1 were used. The EPA has assigned an overall medium level of confidence in the RfC because although the study was well-designed, some information on the chemistry was lacking. The confidence in the supporting database is medium to high. No drinking water MCLs or ambient water quality criteria have been set. However, a risk assessment, which may define a RfD for this material, is presently under review by EPA. Drinking water health advisories range from 40 $\mu\text{g/L}$ (lifetime, adult) to 3000 $\mu\text{g/L}$ (one-day advisory for a child).⁶

X1.6.9.2 Physical/Chemical Parameter Summary—The Henry's law constant for MTBE is estimated to be approximately 1.0×10^{-3} m 3 -atm/mol. It is, therefore, expected to have the potential to rapidly volatilize under common above-ground environmental conditions. It is very water soluble (water solubility is 4.8×10^7 $\mu\text{g/L}$), and with a relatively low capacity to sorb to soils (estimated $\log K_{ow} = 1.08$), MTBE will migrate at the same velocity as the water in which it is dissolved in the subsurface. The $\log K_{ow}$ value has been estimated to be between 1.06 and 1.30 , indicating MTBE's low bioaccumulative potential. It is expected to have a low potential to biodegrade, but no definitive studies are available.

X1.6.10 Lead:

X1.6.10.1 Toxicity Summary—(The following discussion is for inorganic lead—not the organic forms of lead (tetraethyllead, tetramethyllead) that were present in petroleum products.) A significant amount of toxicological information is available on the health effects of lead. Lead produces neurotoxic and behavioral effects particularly in children. However, the EPA believes that it is inappropriate to set an RfD for lead and its inorganic compounds because the agency believes that some of the effects may occur at such low concentrations as to suggest no threshold. The EPA has also determined that lead is a probable human carcinogen (classified as B2). The agency has chosen not to set a numeric slope factor at this time, however, because it is believed that standard procedures for doing so may not be appropriate for lead. At present, the EPA has set an MCLG of zero but has set no drinking water (MCL) or health advisories because of the observance of low-level effects, the overall Agency goal of reducing total lead exposure and because of its classification as a B2 carcinogen. An action of level of 15 $\mu\text{g/L}$ has been set for water distribution systems (standard at the tap). The recommended EPA water quality criterion for consumption of both aquatic life and water is set at 50 $\mu\text{g/L}$.

X 10.2 *Physical/Chemical Parameter Summary*—Organic lead additive compounds are volatile (estimated Henry's law constant for tetraethyl lead = 7.98×10^{-2} m³-atm/mol) and may also sorb to particulate matter in the air. Tetraethyl lead has an aqueous solubility of 800 µg/L and an estimated log K_{ow} of 3.69 and, therefore, should not be very mobile in the soil. It decomposes to inorganic lead in dilute aqueous solutions and in contact with other environmental media. In free product (gasoline) plumes, however, it may remain unchanged. Inorganic lead compounds tightly bind to most soils with minimal leaching under natural conditions. Aqueous solubility varies depending on the species involved. The soil's capacity to sorb lead is correlated with soil pH, cation exchange capacity, and organic matter. Lead does not appear to bioconcentrate significantly in fish but does in some shellfish, such as mussels. Lead is not biodegradable.

X1.7 *Discussion of Acceptable Risk (12)*—Beginning in the late 1970s and early 1980s, regulatory agencies in the United States and abroad frequently adopted a cancer risk criteria of one-in-one-million as a negligible (that is, of no concern) risk when fairly large populations might be exposed to a suspect carcinogen. Unfortunately, theoretical increased cancer risks of one-in-one-million are often incorrectly portrayed as serious public health risks. As recently discussed by Dr. Frank Young (13), the current commissioner of the Food and Drug Administration (FDA), this was not the intent of such estimates:

X1.7.1 In applying the de minimis concept and in setting other safety standards, the FDA has been guided by the figure of "one-in-one-million." Other Federal agencies have also used a one-in-one-million increased risk over a lifetime as a reasonable criterion for separating high-risk problems warranting agency attention from negligible risk problems that do not.

X1.7.2 The risk level of one-in-one-million is often misunderstood by the public and the media. It is not an actual risk, that is, we do not expect one out of every million people to get cancer if they drink decaffeinated coffee. Rather, it is a mathematical risk based on scientific assumptions used in risk assessment. The FDA uses a conservative estimate to ensure that the risk is not understated. We interpret animal test results conservatively, and we are extremely careful when we extrapolate risks to humans. When the FDA uses the risk level of one-in-one-million, it is confident that the risk to humans is virtually nonexistent.

X1.7.3 In short, a "one-in-one-million" cancer risk estimate, which is often tacitly assumed by some policy-makers to represent a trigger level for regulatory action, actually represents a level of risk that is so small as to be of negligible concern.

X1.7.4 Another misperception within the risk assessment arena is that all occupational and environmental regulations have as their goal a theoretical maximum cancer risk of 1 in 1 000 000. Travis, et al (14) recently conducted a retrospective examination of the level of risk that triggered regulatory action in 112 decisions. Three variables were considered: (1) individual risk (an upper-bound estimate of the probability at the highest exposure), (2) population risk (an upper-limit estimate of the number of additional incidences of cancer in the exposed population), and (3) population size. The

findings of Travis, et al (14) can be summarized as follows:

X1.7.4.1 Every chemical with an individual lifetime risk above 4×10^{-3} received regulation. Those with values below 1×10^{-6} remained unregulated.

X1.7.4.2 For small populations, regulatory action never resulted for individual risks below 1×10^{-4} .

X1.7.4.3 For potential effects resulting from exposures to the entire United States population, a risk level below 1×10^{-6} never triggered action; above 3×10^{-4} always triggered action.

X1.7.5 Rodricks, et al (15) also evaluated regulatory decisions and reached similar conclusions. In decisions relating to promulgation of National Emission Standards for Hazardous Air Pollutants (NESHAPS), the USEPA has found the maximum individual risks and total population risks from a number of radionuclide and benzene sources too low to be judged significant. Maximum individual risks were in the range from 3.6×10^{-5} to 1.0×10^{-3} . In view of the risks deemed insignificant by USEPA, Rodricks, et al (15) noted that 1×10^{-5} (1 in 100 000) appears to be in the range of what USEPA might consider an insignificant average lifetime risk, at least where aggregate population risk is no greater than a fraction of a cancer yearly.

X1.7.6 Recently, final revisions to the National Contingency Plan (16) have set the acceptable risk range between 10^{-4} and 10^{-6} at hazardous waste sites regulated under CERCLA. In the recently promulgated *Hazardous Waste Management System Toxicity Characteristics Revisions* (17), the USEPA has stated that:

"For drinking water contaminants, EPA sets a reference risk range for carcinogens at 10^{-6} excess individual cancer risk from lifetime exposure. Most regulatory actions in a variety of EPA programs have generally targeted this range using conservative models which are not likely to underestimate the risk."

X1.7.7 Interestingly, the USEPA has selected and promulgated a single risk level of 1 in 100 000 (1×10^{-5}) in the *Hazardous Waste Management System Toxicity Characteristics Revisions* (17). In their justification, the USEPA cited the following rationale:

The chosen risk level of 10^{-5} is at the midpoint of the reference risk range for carcinogens (10^{-4} to 10^{-6}) generally used to evaluate CERCLA actions. Furthermore, by setting the risk level at 10^{-5} for TC carcinogens, EPA believes that this is the highest risk level that is likely to be experienced, and most if not all risks will be below this level due to the generally conservative nature of the exposure scenario and the underlying health criteria. For these reasons, the Agency regards a 10^{-5} risk level for Group A, B, and C carcinogens as adequate to delineate, under the Toxicity Characteristics, wastes that clearly pose a hazard when mismanaged."

X1.7.8 When considering these limits it is interesting to note that many common human activities entail annual risks greatly in excess of one-in-one-million. These have been discussed by Grover Wrenn, former director of Federal Compliance and State Programs at OSHA, as follows:

X1.7.9 State regulatory agencies have not uniformly adopted a one-in-one-million (1×10^{-6}) risk criterion in making environmental and occupational decisions. The states of Virginia, Maryland, Minnesota, Ohio, and Wisconsin have employed or proposed to use the one-in-one hundred-thousand (1×10^{-5}) level of risk in their risk management decisions (18). The State of Maine Department of Human Services (DHS) uses a lifetime risk of one in one

hundred thousand as a reference for non-threshold (carcinogenic) effects in its risk management decisions regarding exposures to environmental contaminants (19). Similarly, a lifetime incremental cancer risk of one in one hundred thousand is used by the Commonwealth of Massachusetts as a cancer risk limit for exposures to substances in more than one medium at hazardous waste disposal sites (20). This risk limit represents the total cancer risk at the site associated with exposure to multiple chemicals in all contaminated media. The State of California has also established a level of risk of one in one hundred thousand for use in determining levels of chemicals and exposures that pose no significant risks of cancer under the Safe Drinking Water and Toxic Enforcement Act of 1986 (Proposition 65) (21). Workplace air standards developed by the Occupational Safety and Health Administration (OSHA) typically reflect theoretical risks of one in one thousand (1×10^{-3}) or greater (15).

X2. DEVELOPMENT OF RISK-BASED SCREENING LEVELS (RBSLs) APPEARING IN SAMPLE LOOK-UP TABLE X2.1

X2.1 Introduction:

X2.1.1 This appendix contains the equations and parameters used to construct the example "Look-Up" (Table X2.1). This table was prepared solely for the purpose of presenting an example Tier 1 matrix of RBSLs, and these values should not be viewed, or misused, as proposed remediation "standards." The reader should note that not all possible pathways have been considered and a number of assumptions concerning exposure scenarios and parameter values have been made. These should be reviewed for appropriateness before using the listed RBSLs as Tier 1 screening values.

X2.1.2 The approaches used to calculate RBSLs appearing in Table X2.1 are briefly discussed as follows for exposure to vapors, ground water, surficial soils, and subsurface soils by means of the following pathways:

X2.1.2.1 Inhalation of vapors.

X2.1.2.2 Ingestion of ground water.

X2.1.2.3 Inhalation of outdoor vapors originating from dissolved hydrocarbons in ground water.

X2.1.2.4 Inhalation of indoor vapors originating from dissolved hydrocarbons in ground water.

X2.1.2.5 Ingestion of surficial soil, inhalation of outdoor vapors and particulates emanating from surficial soils, and dermal absorption resulting from surficial soil contact with skin.

X2.1.2.6 Inhalation of outdoor vapors originating from hydrocarbons in subsurface soils.

X2.1.2.7 Inhalation of indoor vapors originating from subsurface hydrocarbons, and

X2.1.2.8 Ingestion of ground water impacted by leaching of dissolved hydrocarbons from subsurface soils.

X2.1.3 For the pathways considered, approaches used in this appendix are consistent with guidelines contained in Ref (26).

X2.1.4 The development presented as follows focuses only on human-health RBSLs for chronic (long-term) exposures.

X2.1.4.1 In the case of compounds that have been classi-

X1.7.10 Ultimately, the selection of an acceptable and de minimis risk level is a policy decision in which both costs and benefits of anticipated courses of action should be thoroughly evaluated. However, actuarial data and risk estimates of common human activities, regulatory precedents, and the relationship between the magnitude and variance of background and incremental risk estimates all provide compelling support for the adoption of the de minimis risk level of 1×10^{-6} for regulatory purposes.

X1.7.11 In summary, U.S. Federal and state regulatory agencies have adopted a one-in-one-million cancer risk as being of negligible concern in situations where large populations (for example, 200 million people) are involuntarily exposed to suspect carcinogens (for example, food additives). When smaller populations are exposed (for example, in occupational settings), theoretical cancer risks of up to 10^{-4} (1 in 10 000) have been considered acceptable.

fied as carcinogens, the RBSLs are based on the general equation:

$$\text{risk} = \text{average lifetime intake [mg/kg-day]} \times \text{potency factor [mg/kg-day]}^{-1}$$

where the intake depends on exposure parameters (ingestion rate, exposure duration, and so forth), the source concentration, and transport rates between the source and receptor. The potency factor is selected after reviewing a number of sources, including the USEPA Integrated Risk Information System (IRIS) (2) database, USEPA Health Effects Assessment Summary Tables (HEAST) (3), and peer-reviewed sources. The RBSL values appearing in Table X2.1 correspond to probabilities of adverse health effects ("risks") in the range from 10^{-6} to 10^{-4} resulting from the specified exposure. Note that this risk value does not reflect the probability for the specified exposure scenario to occur. Therefore, the actual potential risk to a population for these RBSLs is lower than the 10^{-6} to 10^{-4} range.

X2.1.4.2 In the case of compounds that have not been classified as carcinogens, the RBSLs are based on the general equation:

$$\text{hazard quotient} = \text{average intake [mg/kg-day]} / \text{reference dose [mg/kg-day]}$$

where the intake depends on exposure parameters (ingestion rate, exposure duration, and so forth), the source concentration, and transport rates between the source and receptor. The reference dose is selected after reviewing a number of sources, including the USEPA Integrated Risk Information System (IRIS) (2) database, USEPA Health Effects Assessment Summary Tables (HEAST) (3), and peer-reviewed sources. The RBSL values appearing in Table X2.1 correspond to hazard quotients of unity resulting from the specified exposure. Note that this hazard quotient value does not reflect the probability for the specified exposure scenario to occur. Therefore, the actual potential impact to a population for these RBSLs is lower than a hazard quotient of unity.

X2.1.5 Tables X2.2 through X2.7 summarize the equa-

TABLE X2.1 Example Tier 1 Risk-Based Screening Level (RBSL) Look-up Table^a

Note—This table is presented here only as an example set of Tier 1 RBSLs. It is not a list of proposed standards. The user should review all assumptions prior to using any values. Appendix X2 describes the basis of these values.

Exposure Pathway	Receptor Scenario	Target Level	Benzene	Ethylbenzene	Toluene	Xylenes (Mixed)	Napthalenes	Benz[a]Pyrene
Air								
Indoor air screening levels for inhalation exposure, $\mu\text{g}/\text{m}^3$	residential	cancer risk = $1\text{E-}06$ cancer risk = $1\text{E-}04$ chronic HQ = 1	3.92E-01 3.92E+01					1.86E-03 1.86E-01
	commercial/industrial	cancer risk = $1\text{E-}06$ cancer risk = $1\text{E-}04$ chronic HQ = 1	4.93E-01 4.93E-01	1.39E+03	5.56E+02	9.73E+03	1.95E+01	2.35E-03 2.35E-01
	residential	cancer risk = $1\text{E-}06$ cancer risk = $1\text{E-}04$ chronic HQ = 1	2.94E-01 2.94E-01	1.46E+03	5.84E+02	1.02E+04	2.04E-01	1.40E-03 1.40E-01
Outdoor air screening levels for inhalation exposure, $\mu\text{g}/\text{m}^3$	residential	cancer risk = $1\text{E-}06$ cancer risk = $1\text{E-}04$ chronic HQ = 1	2.94E-01 2.94E-01	1.04E+03	4.17E+02	7.30E+03	1.46E+01	
	commercial/industrial	cancer risk = $1\text{E-}06$ cancer risk = $1\text{E-}04$ chronic HQ = 1	4.93E-01 4.93E-01					2.35E-03 2.35E-01
				1.46E+03	5.84E+02	1.02E+04	2.04E+01	
OSHA TWA PEL, $\mu\text{g}/\text{m}^3$			3.20E+03	4.35E+05	7.53E+05	4.35E+06	5.00E+04	2.00E-02 ^a
Mean odor detection threshold, $\mu\text{g}/\text{m}^3$ ^b			1.95E+05		6.00E+03	8.70E+04	2.00E+02	
National indoor background concentration range, $\mu\text{g}/\text{m}^3$ ^c			3.25E-00 to 2.15E+01	2.20E+00 to 9.70E+00	9.60E-01 to 2.91E+01	4.85E-00 to 4.75E-01		
Soil								
Soil volatilization to outdoor air, mg/kg	residential	cancer risk = $1\text{E-}06$ cancer risk = $1\text{E-}04$ chronic HQ = 1	2.72E-01 2.73E+01					RES ^d RES
	commercial/industrial	cancer risk = $1\text{E-}06$ cancer risk = $1\text{E-}04$ chronic HQ = 1	4.57E-01 4.57E+01	RES	RES	RES	RES	RES RES
				RES	RES	RES	RES	
Soil-vapor intrusion from soil to buildings, mg/kg	residential	cancer risk = $1\text{E-}06$ cancer risk = $1\text{E-}04$ chronic HQ = 1	5.37E-03 5.37E-01					RES RES
	commercial/industrial	cancer risk = $1\text{E-}06$ cancer risk = $1\text{E-}04$ chronic HQ = 1	1.09E-02 1.09E+00	4.27E+02	2.06E+01	RES	4.07E+01	RES RES
				1.10E+03	5.45E+01	RES	1.07E+02	
Surface soil (0 to 3 ft) (0 to 0.9 m) ingestion/dermal/inhalation, mg/kg	residential	cancer risk = $1\text{E-}06$ cancer risk = $1\text{E-}04$ chronic HQ = 1	5.82E-00 5.82E+02					1.30E-01 1.30E-01
	commercial/industrial	cancer risk = $1\text{E-}06$ cancer risk = $1\text{E-}04$ chronic HQ = 1	1.00E-01 1.00E+03	7.83E+03	1.33E+04	1.45E+06	9.77E+02	3.04E-01 3.04E+01
				1.15E+04	1.87E+04	2.08E+05	1.90E+03	
Soil-leachate protect ground water ingestion target level, mg/kg	residential	MCLs cancer risk = $1\text{E-}06$ cancer risk = $1\text{E-}04$ chronic HQ = 1	2.93E-02 1.72E-02 1.72E+00	1.10E+02	1.77E+01	3.05E+02	N/A	9.42E+00 5.90E-01 RES
	commercial/industrial	cancer risk = $1\text{E-}06$ cancer risk = $1\text{E-}04$ chronic HQ = 1	5.78E-02 5.78E+00	5.75E+02	1.29E+02	RES	2.29E+01	1.85E+00 RES
				1.61E+03	3.61E+02	RES	6.42E+01	
Ground Water								
Ground water volatilization to outdoor air, mg/L	residential	cancer risk = $1\text{E-}06$ cancer risk = $1\text{E-}04$ chronic HQ = 1	1.10E+01 1.10E+03					>S ^e >S
	commercial/industrial	cancer risk = $1\text{E-}06$ cancer risk = $1\text{E-}04$ chronic HQ = 1	1.84E+01 >S	>S	>S	>S	>S	>S >S
				>S	>S	>S	>S	
Ground water ingestion, mg/L	residential	MCLs cancer risk = $1\text{E-}06$ cancer risk = $1\text{E-}04$ chronic HQ = 1	5.00E-03 2.94E-03 2.94E-01	7.00E-01	1.00E+00	1.00E+01	N/A	2.00E-04 1.17E-05 1.17E-03
	commercial/industrial	cancer risk = $1\text{E-}06$ cancer risk = $1\text{E-}04$ chronic HQ = 1	9.87E-03 9.87E-01	3.65E+00	7.30E+00	7.30E+01	1.46E-01	3.92E-05 >S
				1.02E+01	2.04E+01	>S	4.09E-01	
Ground water—vapor intrusion from ground water to buildings, mg/L	residential	cancer risk = $1\text{E-}06$ cancer risk = $1\text{E-}04$ chronic HQ = 1	2.38E-02 2.38E+00					>S >S
	commercial/industrial	cancer risk = $1\text{E-}06$ cancer risk = $1\text{E-}04$ chronic HQ = 1	7.39E-02 7.39E+00	7.75E+01	3.28E+01	>S	4.74E+00	>S >S
				>S	8.50E+01	>S	1.23E+01	

^a As benzene soluble coal tar pitch volatiles

^b See Ref (22)

^c See Refs (23–25)

^d RES—Selected risk level is not exceeded for pure compound present at any concentration

^e >S—Selected risk level is not exceeded for all possible dissolved levels (\leq pure component solubility)

tions and parameters used to prepare the example look-up Table X2.1. The basis for each of these equations is discussed in X2.2 through X2.10.

X2.2 Air—Inhalation of Vapors (Outdoors Indoors)—In this case chemical intake results from the inhalation of vapors. It is assumed that vapor concentrations remain constant over the duration of exposure, and all inhaled chemicals are absorbed. Equations appearing in Tables X2.2 and X2.3 for estimating RBSLs for vapor concentrations in the breathing zone follow guidance given in Ref (26). Should the calculated RBSL exceed the saturated vapor concentration for any individual component, ">P_{v,sat}" is entered in the table to indicate that the selected risk level or hazard quotient cannot be reached or exceeded for that compound

and the specified exposure scenario.

X2.3 Ground Water—Ingestion of Ground Water—In this case chemical intake results from ingestion of ground water. It is assumed that the dissolved hydrocarbon concentrations remain constant over the duration of exposure. Equations appearing in Tables X2.2 and X2.3 for estimating RBSLs for drinking water concentrations follow guidance given in Ref (26) for ingestion of chemicals in drinking water. Should the calculated RBSL exceed the pure component solubility for any individual component, ">S" is entered in the table to indicate that the selected risk level or hazard quotient cannot be reached or exceeded for that compound and the specified exposure scenario (unless free-phase product is mixed with the ingested water).

TABLE X2.2 Equations Used to Develop Example Tier 1 Risk-Based Screening Level (RBSLs) Appearing in "Look-Up" Table X2.1—Carcinogenic Effects^a

NOTE—See Tables X2.4 through X2.7 for definition of parameters.

Medium	Exposure Route	Risk-Based Screening Level (RBSL)
Air	inhalation ^b	$RBSL_{air} \left[\frac{\mu g}{m^3 \cdot air} \right] = \frac{TR \times BW \times AT_c \times 365 \frac{days}{years} \times 10^3 \frac{\mu g}{mg}}{SF_c \times IR_{air} \times EF \times ED}$
Ground water	ingestion (potable ground water supply only) ^b	$RBSL_w \left[\frac{mg}{L \cdot H_2O} \right] = \frac{TR \times BW \times AT_c \times 365 \frac{days}{years}}{SF_o \times IR_w \times EF \times ED}$
Ground water ^c	enclosed-space (indoor) vapor inhalation ^d	$RBSL_w \left[\frac{mg}{L \cdot H_2O} \right] = \frac{RBSL_{air} \left[\frac{\mu g}{m^3 \cdot air} \right]}{VF_{w-enc}} \times 10^{-3} \frac{mg}{\mu g}$
Ground water ^c	ambient (outdoor) vapor inhalation ^d	$RBSL_w \left[\frac{mg}{L \cdot H_2O} \right] = \frac{RBSL_{air} \left[\frac{\mu g}{m^3 \cdot air} \right]}{VF_{w-amb}} \times 10^{-3} \frac{mg}{\mu g}$
		$RBSL_s \left[\frac{\mu g}{kg \cdot soil} \right] =$
Surficial soil	ingestion of soil, inhalation of vapors and particulates, and dermal contact ^b	$\frac{TR \times BW \times AT_c \times 365 \frac{days}{years}}{EF \times ED \left[\left(SF_o \times 10^{-6} \frac{kg}{mg} \times (IR_{soil} \times RAF_o + SA \times M \times RAF_d) \right) + (SF_c \times IR_{air} \times (VF_{ss} + VF_d)) \right]}$
For surficial and excavated soils (0 to 1 m)		
Subsurface soil ^c	ambient (outdoor) vapor inhalation ^d	$RBSL_s \left[\frac{mg}{kg \cdot soil} \right] = \frac{RBSL_{air} \left[\frac{\mu g}{m^3 \cdot air} \right]}{VF_{s-amb}} \times 10^{-3} \frac{mg}{\mu g}$
Subsurface soil ^c	enclosed space (indoor) vapor inhalation ^d	$RBSL_s \left[\frac{mg}{kg \cdot soil} \right] = \frac{RBSL_{air} \left[\frac{\mu g}{m^3 \cdot air} \right]}{VF_{s-enc}} \times 10^{-3} \frac{mg}{\mu g}$
Subsurface soil ^c	leaching to ground water ^d	$RBSL_s \left[\frac{mg}{kg \cdot soil} \right] = \frac{RBSL_w \left[\frac{mg}{L \cdot H_2O} \right]}{LF_{sw}}$

^a Note that all RBSL values should be compared with thermodynamic partitioning limits, such as solubility levels, maximum vapor concentrations, and so forth. If a RBSL exceeds the relevant partitioning limit, this is an indication that the selected risk or hazard level will never be reached or exceeded for that chemical and the selected exposure scenario.

^b Screening levels for these media based on other considerations (for example, aesthetic, background levels, environmental resource protection, and so forth) can be derived with these equations by substituting the selected target level for RBSL_{air} or RBSL_w appearing in these equations.

^c These equations are based on Ref (26).

^d These equations simply define the "cross-media partitioning factors" VF_{ij} and LF_{sw}.

TABLE X2.3 Equations Used to Develop Example Tier 1 Risk-Based Screening Level (RBSLs) Appearing in "Look-Up" Table X2.1—Noncarcinogenic Effects^a

NOTE—See Tables X2.4 through X2.7 for all parameters.		Risk-Based Screening Level (RBSL)	
Medium	Exposure F		
Air	inhalation ^b	$RBSL_{air} \left[\frac{\mu g}{m^3 \cdot air} \right] = \frac{THO \times RID_1 \times BW \times AT_n \times 365 \frac{days}{years} \times 10^3 \frac{\mu g}{mg}}{IR_{air} \times EF \times ED}$	
Ground water	ingestion (potable ground water supply only) ^b	$RBSL_{gw} \left[\frac{mg}{L \cdot H_2O} \right] = \frac{THO \times RID_2 \times BW \times AT_n \times 365 \frac{days}{years}}{IR_{gw} \times EF \times ED}$	
Ground water ^c	enclosed-space (indoor) vapor inhalation ^d	$RBSL_{gw} \left[\frac{mg}{L \cdot H_2O} \right] = \frac{RBSL_{air} \left[\frac{\mu g}{m^3 \cdot air} \right]}{VF_{indoor}} \times 10^{-3} \frac{mg}{\mu g}$	
Ground water ^c	ambient (outdoor) vapor inhalation ^d	$RBSL_{gw} \left[\frac{mg}{L \cdot H_2O} \right] = \frac{RBSL_{air} \left[\frac{\mu g}{m^3 \cdot air} \right]}{VF_{outdoor}} \times 10^{-3} \frac{mg}{\mu g}$	
Surficial soil	ingestion of soil, inhalation of vapors and particulates, and dermal contact ^b	$RBSL_{soil} \left[\frac{mg}{kg \cdot soil} \right] = \frac{THO \times BW \times AT_n \times 365 \frac{days}{years}}{EF \times ED \left(\frac{10^{-6} \frac{kg}{mg} \times (IR_{soil} \times RAF_o + SA \times M \times RAF_d)}{RID_o} + \frac{(IR_{gw} \times (VF_{ss} + VF_d))}{RID_1} \right)}$	For surficial and excavated soils (0 to 1 m)
Subsurface soil ^c	ambient (outdoor) vapor inhalation ^d	$RBSL_{ss} \left[\frac{mg}{kg \cdot soil} \right] = \frac{RBSL_{air} \left[\frac{\mu g}{m^3 \cdot air} \right]}{VF_{subsoil}} \times 10^{-3} \frac{mg}{\mu g}$	
Subsurface soil ^c	enclosed space (indoor) vapor inhalation ^d	$RBSL_{ss} \left[\frac{mg}{kg \cdot soil} \right] = \frac{RBSL_{air} \left[\frac{\mu g}{m^3 \cdot air} \right]}{VF_{subsoil}} \times 10^{-3} \frac{mg}{\mu g}$	
Subsurface soil ^c	leaching to ground water ^d	$RBSL_{ss} \left[\frac{mg}{kg \cdot soil} \right] = \frac{RBSL_{gw} \left[\frac{mg}{L \cdot H_2O} \right]}{LF_{ss}}$	

^a Note that all RBSL values should be compared with thermodynamic partitioning limits, such as solubility levels, maximum vapor concentrations, and so forth. If a RBSL exceeds the relevant partitioning limit, this is an indication that the selected risk or hazard level will never be reached or exceeded for that chemical and the selected exposure scenario.

^b Screening levels for these media based on other considerations (for example, aesthetic, background levels, environmental resource protection, and so forth) can be derived with these equations by substituting the selected target level for $RBSL_{air}$ or $RBSL_{gw}$ appearing in these equations.

^c These equations are based on Ref (26).

^d These equations simply define the "cross-media partitioning factors," VF_{ss} and LF_{ss} .

X2.4 Ground Water—Inhalation of Outdoor Vapors

X2.4.1 In this case chemical intake is a result of inhalation of outdoor vapors which originate from dissolved hydrocarbons in ground water located some distance below ground surface. Here the goal is to determine the dissolved hydrocarbon RBSL that corresponds to the target RBSL for outdoor vapors in the breathing zone, as given in Tables X2.3 and X2.4. If the selected target vapor concentration is some value other than the RBSL for inhalation (that is, odor threshold or biological criterion), this value can be substituted for the $RBSL_{air}$ parameter appearing in the equations given in Tables X2.2 and X2.3.

X2.4.2 A conceptual model of the transport of chemicals

from ground water to ambient air is depicted in Fig. X2.1. For simplicity, the relationship between outdoor air and dissolved ground water concentrations is represented in Tables X2.2 and X2.3 by the "volatilization factor," $VF_{air/gw}$ [(mg/m³-air)/(mg/L-H₂O)], defined in Table X2.5. It is based on the following assumptions:

X2.4.2.1 A constant dissolved chemical concentration in ground water.

X2.4.2.2 Linear equilibrium partitioning between dissolved chemicals in ground water and chemical vapors at the ground water table.

X2.4.2.3 Steady-state vapor- and liquid-phase diffusion through the capillary fringe and vadose zones to ground

TABLE X2.4 Exposure Parameters Appearing in Tables X2.2 and X2.3

Parameters	Definitions Units	Residential	Commercial/Industrial
AT_c	averaging time for carcinogens years	70 years	70 years ^a
AT_n	averaging time for noncarcinogens years	30 years	25 years ^a
BW	adult body weight kg	70 kg	70 kg ^a
ED	exposure duration years	30 years	25 years ^a
EF	exposure frequency days/year	350 days/year	250 days/year ^a
iR_{soil}	soil ingestion rate mg/day	100 mg/day	50 mg/day ^a
$R_{in, indoor}$	daily indoor inhalation rate m ³ /day	15 m ³ /day	20 m ³ /day ^a
$R_{in, outdoor}$	daily outdoor inhalation rate m ³ /day	20 m ³ /day	20 m ³ /day ^a
R_w	daily water ingestion rate L/day	2 L/day	1 L/day ^a
LF_{soil}	leaching factor (mg/L-H ₂ O)/(mg/kg-soil)—see Table X2.5	chemical-specific	chemical-specific
M	soil to skin adherence factor (mg/cm ²)	0.5	0.5 ^a
RAF_o	dermal relative absorption factor volatiles, PAHs	0.5/0.05	0.5/0.05 ^a
RAF_o	oral relative absorption factor	1.0	1.0
RBSL	risk-based screening level for media: (mg/kg-soil, mg/L-H ₂ O, or μ g/m ³ -air)	chemical-, media-, and exposure route-specific	chemical-, media-, and exposure route-specific
RIC	inhalation chronic reference dose (mg/kg-day)	chemical-specific	chemical-specific
RIC_o	oral chronic reference dose (mg/kg-day)	chemical-specific	chemical-specific
SA	skin surface area cm ² /day	3160	3160 ^a
SF	inhalation cancer slope factor (mg/kg-day) ⁻¹	chemical-specific	chemical-specific
SF _o	oral cancer slope factor (mg/kg-day) ⁻¹	chemical-specific	chemical-specific
THQ	target hazard quotient for individual constituents unitless	1.0	1.0
TR	target excess individual lifetime cancer risk unitless	for example, 10 ⁻⁶ or 10 ⁻⁴	for example, 10 ⁻⁶ or 10 ⁻⁴
VF	volatilization factor, (mg/m ³ -air)/(mg/kg-soil) or (mg/m ³ -air)/(mg/L-H ₂ O)—see Table X2.5	chemical- and media-specific	chemical- and media-specific

^a See Ref (27).^a See Ref (28).

surface.

X2.4.2.4 No loss of chemical as it diffuses towards ground surface (that is, no biodegradation), and

X2.4.2.5 Steady well-mixed atmospheric dispersion of the emanating vapors within the breathing zone as modeled by a "box model" for air dispersion.

X2.4.3 Should the calculated $RBSL_{in}$ exceed the pure component solubility for any individual component, ">S" is entered in the table to indicate that the selected risk level or hazard quotient cannot be reached or exceeded for that compound and the specified exposure scenario.

X2.5 Ground Water—Inhalation of Enclosed-Space (Indoor) Vapors:

X2.5.1 In this case chemical intake results from the inhalation of vapors in enclosed spaces. The chemical vapors originate from dissolved hydrocarbons in ground water located some distance below ground surface. Here the goal is to determine the dissolved hydrocarbon RBSL that corresponds to the target RBSL for vapors in the breathing zone, as given in Tables X2.2 and X2.3. If the selected target vapor concentration is some value other than the RBSL for inhalation (that is, odor threshold or ecological criterion), this value can be substituted for the $RBSL_{air}$ parameter appearing in the equations given in Tables X2.2 and X2.3.

X2.5.2 A conceptual model for the transport of chemicals from ground water to indoor air is depicted in Fig. X2.2. For simplicity, the relationship between enclosed-space air and dissolved ground water concentrations is represented in Tables X2.2 and X2.3 by the "volatilization factor" VF_{wexp} [(mg/m³-air)/(mg/L-H₂O)] defined in Table X2.5. It is based on the following assumptions:

X2.5.2.1 A constant dissolved chemical concentration in ground water.

X2.5.2.2 Equilibrium partitioning between dissolved chemicals in ground water and chemical vapors at the ground water table.

X2.5.2.3 Steady-state vapor- and liquid-phase diffusion

through the capillary fringe, vadose zone, and foundation cracks.

X2.5.2.4 No loss of chemical as it diffuses towards ground surface (that is, no biodegradation), and

X2.5.2.5 Steady, well-mixed atmospheric dispersion of the emanating vapors within the enclosed space, where the convective transport into the building through foundation cracks or openings is negligible in comparison with diffusive transport.

X2.5.3 Should the calculated $RBSL_{in}$ exceed the pure component solubility for any individual component, ">S" is entered in the table to indicate that the selected risk level or hazard quotient cannot be reached or exceeded for that compound and the specified exposure scenario.

X2.6 Surficial Soils—Ingestion, Dermal Contact, and Vapor and Particulate Inhalation:

X2.6.1 In this case it is assumed that chemical intake results from a combination of intake routes, including: ingestion, dermal absorption, and inhalation of both particulates and vapors emanating from surficial soil.

X2.6.2 Equations used to estimate intake resulting from ingestion follow guidance given in Ref (26) for ingestion of chemicals in soil. For this route, it has been assumed that surficial soil chemical concentrations and intake rates remain constant over the exposure duration.

X2.6.3 Equations used to estimate intake resulting from dermal absorption follow guidance given in Ref (26) for dermal contact with chemicals in soil. For this route, it has been assumed that surficial soil chemical concentrations and absorption rates remain constant over the exposure duration.

X2.6.4 Equations used to estimate intake resulting from the inhalation of particulates follow guidance given in Ref (26) for inhalation of airborne chemicals. For this route, it has been assumed that surficial soil chemical concentrations, intake rates, and atmospheric particulate concentrations remain constant over the exposure duration.

X2.6.5 Equations used to estimate intake resulting from

the inhalation of airborne chemicals resulting from the volatilization of chemicals from surficial soils follow guidance given in Ref (26) for inhalation of airborne chemicals.

X2.6.6 A conceptual model for the volatilization of chemicals from surficial soils to outdoor air is depicted in Fig. X2.3. For simplicity, the relationship between outdoor air and surficial soil concentrations is represented in Tables

X2.2 and X2.3 by the "volatilization factor" $VF_{i,j}$, [(mg/m³-air)/(mg/kg-soil)] defined in Table X2.5. It is based on the following assumptions:

X2.6.6.1 Uniformly distributed chemical throughout the depth 0— d (cm) below ground surface,

X2.6.6.2 Linear equilibrium partitioning within the soil matrix between sorbed, dissolved, and vapor phases, where

TABLE X2.5 Volatilization Factors ($VF_{i,j}$), Leaching Factor ($LF_{i,j}$), and Effective Diffusion Coefficients ($D_{i,j}^{eff}$)

Symbol	Cross-Media Route (or Definition)	Equation
$VF_{w \rightarrow eo}$	Ground water \rightarrow enclosed-space vapors	$VF_{w \rightarrow eo} \left[\frac{(\text{mg}/\text{m}^3\text{-air})}{(\text{mg}/\text{L-H}_2\text{O})} \right] = \frac{H \left[\frac{D_{w \rightarrow eo}^{eff}/L_{GW}}{ER L_B} \right]}{1 + \left[\frac{D_{w \rightarrow eo}^{eff}/L_{GW}}{ER L_B} \right] + \left[\frac{D_{w \rightarrow eo}^{eff}/L_{GW}}{(D_{w \rightarrow eo}^{eff}/L_{GW})\eta} \right]} \times 10^3 \frac{\text{L}}{\text{m}^3}^a$
$VF_{w \rightarrow mo}$	Ground water \rightarrow ambient (outdoor) vapors	$VF_{w \rightarrow mo} \left[\frac{(\text{mg}/\text{m}^3\text{-air})}{(\text{mg}/\text{L-H}_2\text{O})} \right] = \frac{H}{1 + \left[\frac{U_{w \rightarrow mo}^{eff} L_{GW}}{WD_{w \rightarrow mo}^{eff}} \right]} \times 10^3 \frac{\text{L}}{\text{m}^3}^b$
VF_{ss}	Surficial soils \rightarrow ambient air (vapors)	$VF_{ss} \left[\frac{(\text{mg}/\text{m}^3\text{-air})}{(\text{mg}/\text{kg-soil})} \right] = \frac{2W\rho_s}{U_{ss}^{eff} \tau} \sqrt{\frac{D_{ss}^{eff} H}{\pi [\theta_{ws} + k_s \rho_s + H\theta_{ss}] \tau}} \times 10^3 \frac{\text{cm}^3\text{-kg}}{\text{m}^3\text{-g}}^c$ <p>or:</p> $VF_{ss} \left[\frac{(\text{mg}/\text{m}^3\text{-air})}{(\text{mg}/\text{kg-soil})} \right] = \frac{W\rho_s d}{U_{ss}^{eff} \tau} \times 10^3 \frac{\text{cm}^3\text{-kg}}{\text{m}^3\text{-g}}; \text{ whichever is less}^d$
VF_p	Surficial soils \rightarrow ambient air (particulates)	$VF_p \left[\frac{(\text{mg}/\text{m}^3\text{-air})}{(\text{mg}/\text{kg-soil})} \right] = \frac{P_s W}{U_{ss}^{eff} \tau} \times 10^3 \frac{\text{cm}^3\text{-kg}}{\text{m}^3\text{-g}}^e$
$VF_{ss \rightarrow mo}$	Subsurface soils \rightarrow ambient air	$VF_{ss \rightarrow mo} \left[\frac{(\text{mg}/\text{m}^3\text{-air})}{(\text{mg}/\text{kg-soil})} \right] = \frac{H\rho_s}{[\theta_{ws} + k_s \rho_s + H\theta_{ss}] \left(1 + \frac{U_{ss \rightarrow mo}^{eff} L_s}{D_{ss \rightarrow mo}^{eff} W} \right)} \times 10^3 \frac{\text{cm}^3\text{-kg}}{\text{m}^3\text{-g}}^f$
$VF_{ss \rightarrow eo}$	Subsurface soil \rightarrow enclosed-space vapors	$VF_{ss \rightarrow eo} \left[\frac{(\text{mg}/\text{m}^3\text{-air})}{(\text{mg}/\text{kg-soil})} \right] = \frac{H\rho_s}{[\theta_{ws} + k_s \rho_s + H\theta_{ss}]} \left[\frac{D_{ss \rightarrow eo}^{eff}/L_s}{ER L_B} \right] \times 10^3 \frac{\text{cm}^3\text{-kg}}{\text{m}^3\text{-g}}^g$
LF_{ss}	Subsurface soils \rightarrow ground water	$LF_{ss} \left[\frac{(\text{mg}/\text{L-H}_2\text{O})}{(\text{mg}/\text{kg-soil})} \right] = \frac{\rho_s}{[\theta_{ws} + k_s \rho_s + H\theta_{ss}] \left(1 + \frac{U_{ss \rightarrow gw}^{eff} L_s}{D_{ss \rightarrow gw}^{eff} W} \right)} \times 10^6 \frac{\text{cm}^3\text{-kg}}{\text{L-g}}^b$
D_{ss}^{eff}	Effective diffusion coefficient in soil based on vapor-phase concentration	$D_{ss}^{eff} \left[\frac{\text{cm}^2}{\text{s}} \right] = D_{ss}^{eff} \frac{\theta_{ss}^{3.33}}{\theta_{ss}^2} + D_{ss}^{eff} \frac{1}{H} \frac{\theta_{ss}^{3.33}}{\theta_{ss}^2}^a$
D_{crack}^{eff}	Effective diffusion coefficient through foundation cracks	$D_{crack}^{eff} \left[\frac{\text{cm}^2}{\text{s}} \right] = D_{crack}^{eff} \frac{\theta_{crack}^{3.33}}{\theta_{crack}^2} + D_{crack}^{eff} \frac{1}{H} \frac{\theta_{crack}^{3.33}}{\theta_{crack}^2}^a$
D_{ced}^{eff}	Effective diffusion coefficient through capillary fringe	$D_{ced}^{eff} \left[\frac{\text{cm}^2}{\text{s}} \right] = D_{ced}^{eff} \frac{\theta_{ced}^{3.33}}{\theta_{ced}^2} + D_{ced}^{eff} \frac{1}{H} \frac{\theta_{ced}^{3.33}}{\theta_{ced}^2}^a$
D_{ws}^{eff}	Effective diffusion coefficient between ground water and soil surface	$D_{ws}^{eff} \left[\frac{\text{cm}^2}{\text{s}} \right] = (h_{ced} + h_v) \left[\frac{h_{ced}}{D_{ced}^{eff}} + \frac{h_v}{D_{ss}^{eff}} \right]^{-1}^a$
C_{ss}^{sat}	Soil concentration at which dissolved pore-water and vapor phases become saturated	$C_{ss}^{sat} \left[\frac{\text{mg}}{\text{kg-soil}} \right] = \frac{S}{\theta_{ss}} \times [H\theta_{ss} + \theta_{ws} + k_s \rho_s] \times 10^6 \frac{\text{L-g}}{\text{cm}^3\text{-kg}}^f$

^a See Ref (29)

^b See Ref (30)

^c See Ref (31)

^d Based on mass balance

^e See Ref (32)

^f See Ref (33)

TABLE X2.6 Soil, Building, Surface, and Subsurface Parameters Used in Generating Example Tier 1 RBSLs

NOTE—See X2.10 for justification of parameter selection

Parameters	Definitions, Units	Residential	Commercial/Industrial
d	lower depth of surficial soil zone, cm	100 cm	100 cm
D^{air}	diffusion coefficient in air, cm^2/s	chemical-specific	chemical-specific
D^{water}	diffusion coefficient in water, cm^2/s	chemical-specific	chemical-specific
ER	enclosed-space air exchange rate, L/s	0.00014 s^{-1}	0.00023 s^{-1}
f_{oc}	fraction of organic carbon in soil, $\text{g-C}/\text{g-soil}$	0.01	0.01
H	henry's law constant, $(\text{cm}^3\text{-H}_2\text{O})/(\text{cm}^3\text{-air})$	chemical-specific	chemical-specific
$h_{c,soil}$	thickness of capillary fringe, cm	5 cm	5 cm
h_v	thickness of vadose zone, cm	295 cm	295 cm
I	infiltration rate of water through soil, cm/year	30 cm/year	30 cm/year
K_{oc}	carbon-water sorption coefficient, $\text{cm}^3\text{-H}_2\text{O}/\text{g-C}$	chemical-specific	chemical-specific
K_s	soil-water sorption coefficient, $\text{cm}^3\text{-H}_2\text{O}/\text{g-soil}$	$f_{oc} \times K_{oc}$	$f_{oc} \times K_{oc}$
L_B	enclosed-space volume/infiltration area ratio, cm	200 cm	300 cm
L_{cracks}	enclosed-space foundation or wall thickness, cm	15 cm	15 cm
L_{GW}	depth to ground water = $h_{c,soil} + h_v$, cm	300 cm	300 cm
L_S	depth to subsurface soil sources, cm	100 cm	100 cm
P_a	particulate emission rate, $\text{g}/\text{cm}^2\text{-s}$	6.9×10^{-14}	6.9×10^{-14}
S	pure component solubility in water, $\text{mg}/\text{L-H}_2\text{O}$	chemical-specific	chemical-specific
U_{air}	wind speed above ground surface in ambient mixing zone, cm/s	225 cm/s	225 cm/s
U_{GW}	ground water Darcy velocity, cm/year	2500 cm/year	2500 cm/year
W	width of source area parallel to wind, or ground water flow direction, cm	1500 cm	1500 cm
δ_{air}	ambient air mixing zone height, cm	200 cm	200 cm
δ_{GW}	ground water mixing zone thickness, cm	200 cm	200 cm
η	areal fraction of cracks in foundations/walls, $\text{cm}^2\text{-cracks}/\text{cm}^2\text{-total area}$	0.01 $\text{cm}^2\text{-cracks}/\text{cm}^2\text{-total area}$	0.01 $\text{cm}^2\text{-cracks}/\text{cm}^2\text{-total area}$
$\theta_{c,soil}$	volumetric air content in capillary fringe soils, $\text{cm}^3\text{-air}/\text{cm}^3\text{-soil}$	0.038 $\text{cm}^3\text{-air}/\text{cm}^3\text{-soil}$	0.38 $\text{cm}^3\text{-air}/\text{cm}^3\text{-soil}$
θ_{cracks}	volumetric air content in foundation/wall cracks, $\text{cm}^3\text{-air}/\text{cm}^3\text{-total volume}$	0.26 $\text{cm}^3\text{-air}/\text{cm}^3\text{-total volume}$	0.26 $\text{cm}^3\text{-air}/\text{cm}^3\text{-total volume}$
$\theta_{v,soil}$	volumetric air content in vadose zone soils, $\text{cm}^3\text{-air}/\text{cm}^3\text{-soil}$	0.26 $\text{cm}^3\text{-air}/\text{cm}^3\text{-soil}$	0.26 $\text{cm}^3\text{-air}/\text{cm}^3\text{-soil}$
θ_T	total soil porosity, $\text{cm}^3/\text{cm}^3\text{-soil}$	0.38 $\text{cm}^3/\text{cm}^3\text{-soil}$	0.38 $\text{cm}^3/\text{cm}^3\text{-soil}$
$\theta_{w,soil}$	volumetric water content in capillary fringe soils, $\text{cm}^3\text{-H}_2\text{O}/\text{cm}^3\text{-soil}$	0.342 $\text{cm}^3\text{-H}_2\text{O}/\text{cm}^3\text{-soil}$	0.342 $\text{cm}^3\text{-H}_2\text{O}/\text{cm}^3\text{-soil}$
$\theta_{w,cracks}$	volumetric water content in foundation/wall cracks, $\text{cm}^3\text{-H}_2\text{O}/\text{cm}^3\text{-total volume}$	0.12 $\text{cm}^3\text{-H}_2\text{O}/\text{cm}^3\text{-total volume}$	0.12 $\text{cm}^3\text{-H}_2\text{O}/\text{cm}^3\text{-total volume}$
$\theta_{v,soil}$	volumetric water content in vadose zone soils, $\text{cm}^3\text{-H}_2\text{O}/\text{cm}^3\text{-soil}$	0.12 $\text{cm}^3\text{-H}_2\text{O}/\text{cm}^3\text{-soil}$	0.12 $\text{cm}^3\text{-H}_2\text{O}/\text{cm}^3\text{-soil}$
ρ_s	soil bulk density, $\text{g-soil}/\text{cm}^3\text{-soil}$	1.7 g/cm^3	1.7 g/cm^3
τ	averaging time for vapor flux, s	$7.88 \times 10^8 \text{ s}$	$7.88 \times 10^8 \text{ s}$

the partitioning is a function of constant chemical- and soil-specific parameters.

X2.6.6.3 Diffusion through the vadose zone,

X2.6.6.4 No loss of chemical as it diffuses towards ground surface (that is, no biodegradation), and

X2.6.6.5 Steady well-mixed atmospheric dispersion of the emanating vapors within the breathing zone as modeled by a "box model" for air dispersion.

X2.6.7 In the event that the time-averaged flux exceeds that which would occur if all chemical initially present in the surficial soil zone volatilized during the exposure period,

then the maximum factor is determined from a mass balance assuming that all chemical initially present in the surficial soil zone volatilizes during the exposure period.

X2.7 Subsurface Soils—Inhalation of Outdoor Vapors:

X2.7.1 In this case chemical intake is a result of inhalation of outdoor vapors which originate from hydrocarbons contained in subsurface soils located some distance below ground surface. Here the goal is to determine the RBSL for subsurface soils that corresponds to the target RBSL for outdoor vapors in the breathing zone, as given in X2.2. If the selected target vapor concentration is some value other than

TABLE X2.7 Chemical-Specific Properties Used in the Derivation Example Tier 1 RBSLs

Chemical	CAS Number	M_w , g/mol	H , $\text{L-H}_2\text{O}/\text{L-air}$	D^{air} , cm^2/s	D^{water} , cm^2/s	$\log(K_{oc})$, L/kg	$\log(K_{ow})$, L/kg
Benzene	71-43-2	78 ^A	0.22 ^A	0.093 ^A	1.1×10^{-9A}	1.58 ^A	2.13 ^A
Toluene	108-88-3	92 ^A	0.26 ^A	0.085 ^A	9.4×10^{-10D}	2.13 ^A	2.65 ^A
Ethyl benzene	100-41-4	106 ^A	0.32 ^A	0.076 ^A	8.5×10^{-10D}	1.98 ^A	3.13 ^A
Mixed xylenes	1330-20-7	106 ^A	0.29 ^A	0.072 ^D	8.5×10^{-10D}	2.38 ^A	3.26 ^A
Naphthalene	91-20-3	128 ^A	0.049 ^A	0.072 ^D	9.4×10^{-10A}	3.11 ^A	3.28 ^A
Benzo(a)pyrene	50-32-8	252 ^C	5.8×10^{-8B}	0.050 ^D	5.8×10^{-10D}	5.59 ^E	5.98 ^B
Chemical	CAS Number	SF_o , $\text{kg-day}/\text{mg}$	SF_i , $\text{kg-day}/\text{mg}$	RfD_o , $\text{mg}/\text{kg-day}$	RfD_i , $\text{mg}/\text{kg-day}$		
Benzene	71-43-2	0.029 ^F	0.029 ^F	...	...
Toluene	108-88-3	...	...	0.2 ^F	0.11 ^F		
Ethyl benzene	100-41-4	...	...	0.1 ^F	0.29 ^F		
Mixed xylenes	1330-20-7	...	...	2.0 ^F	2.0 ^F		
Naphthalene	91-20-3	...	...	0.004 ^G	...		
Benzo(a)pyrene	50-32-8	7.3 ^F	6.1 ^F	...	...

^A See Ref (34).

^B See Ref (35).

^C See Ref (7).

^D Diffusion coefficient calculated using the method of Fuller, Schettler, and Giddings, from Ref (11).

^E Calculated from K_{ow}/K_{oc} correlation: $\log(K_{oc}) = 0.937 \log(K_{ow}) - 0.006$, from Ref (11).

^F See Ref (2).

^G See Ref (3).

the RBSL for inhalation (that is, odor threshold or ecological criterion), this value can be substituted for the $RBSL_{air}$ parameter appearing in the equations given in Tables X2.2 and X2.3.

X2.7.2 A conceptual model for the transport of chemicals from subsurface soils to ambient air is depicted in Fig. X2.4. For simplicity, the relationship between outdoor air and soil concentrations is represented in Tables X2.2 and X2.3 by the "volatilization factor," VF_{amb} [(mg/m³-air)/(kg-soil)], defined in Table X2.5. It is based on the following assumptions:

X2.7.2.1 A constant chemical concentration in subsurface soils.

X2.7.2.2 Linear equilibrium partitioning within the soil matrix between sorbed, dissolved, and vapor phases, where the partitioning is a function of constant chemical- and soil-specific parameters.

X2.7.2.3 Steady-state vapor- and liquid-phase diffusion through the vadose zone to ground surface,

X2.7.2.4 No loss of chemical as it diffuses towards ground surface (that is, no biodegradation), and

X2.7.2.5 Steady well-mixed atmospheric dispersion of the emanating vapors within the breathing zone as modeled by a "box model" for air dispersion.

X2.7.3 Should the calculated $RBSL_s$ exceed the value for which the equilibrated vapor and dissolved pore-water phases become saturated, C_s^{sat} [mg/kg-soil] (see Table X2.5 for calculation of this value), "RES" is entered in the table to indicate that the selected risk level or hazard quotient cannot be reached or exceeded for that compound and the specified exposure scenario (even if free-phase product or precipitate is present in the soil).

X2.8 Subsurface Soils—Inhalation of Enclosed-Space (Indoor) Vapors:

X2.8.1 In this case chemical intake is a result of inhalation of enclosed-space vapors which originate from hydrocarbons contained in subsurface soils located some distance below ground surface. Here the goal is to determine the RBSL for subsurface soils that corresponds to the target RBSL for indoor vapors, as given in Tables X2.2 and X2.3. If the selected target vapor concentration is some value other than the RBSL for inhalation (that is, odor threshold or

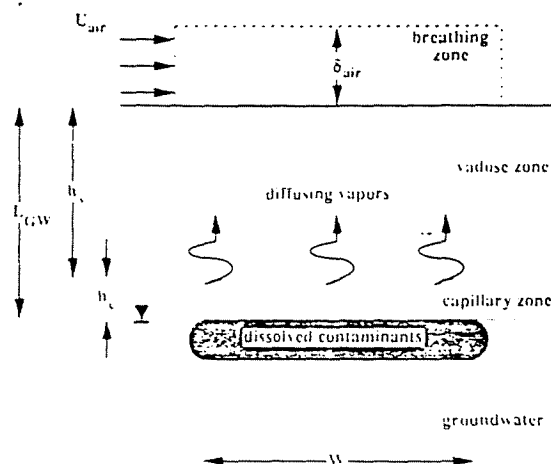


FIG. X2.1 Volatilization from Ground Water to Ambient Air

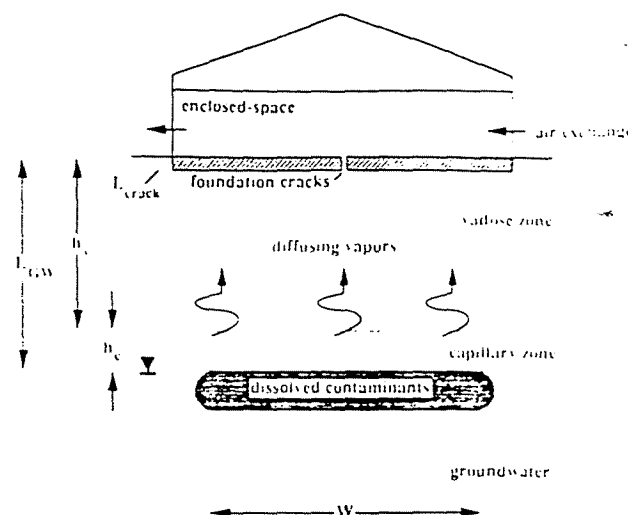


FIG. X2.2 Volatilization from Ground Water to Enclosed-Space Air

ecological criterion), this value can be substituted for the $RBSL_{air}$ parameter appearing in the equations given in Tables X2.2 and X2.3.

X2.8.2 A conceptual model for the transport of chemicals from subsurface soils to enclosed spaces is depicted in Fig. X2.5. For simplicity, the relationship between indoor air and soil concentrations is represented in Tables X2.2 and X2.3 by the "volatilization factor," VF_{esp} [(mg/m³-air)/(kg-soil)], defined in Table X2.5. It is based on the following assumptions:

X2.8.2.1 A constant chemical concentration in subsurface soils.

X2.8.2.2 Linear equilibrium partitioning within the soil matrix between sorbed, dissolved, and vapor phases, where the partitioning is a function of constant chemical- and soil-specific parameters.

X2.8.2.3 Steady-state vapor- and liquid-phase diffusion through the vadose zone and foundation cracks.

X2.8.2.4 No loss of chemical as it diffuses towards ground surface (that is, no biodegradation), and

X2.8.2.5 Well-mixed atmospheric dispersion of the emanating vapors within the enclosed space.

X2.8.3 Should the calculated $RBSL_s$ exceed the value C_s^{sat} [mg/kg-soil] for which the equilibrated vapor and dissolved pore-water phases become saturated (see Table X2.5 for calculation of this value), "RES" is entered in the table to indicate that the selected risk level or hazard

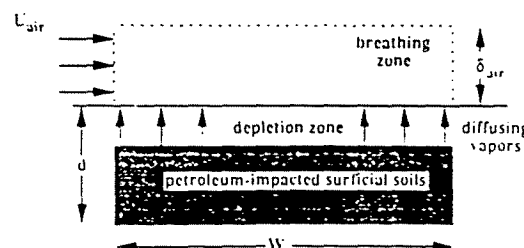


FIG. X2.3 Volatilization from Surficial Soils

quotient cannot be reached or exceeded for that compound and the specified exposure scenario (even if free-phase product or precipitate is present in the soil).

X2.9 Subsurface Soils—Leaching to Ground Water

X2.9.1 In this case chemical intake is a result of chemicals leaching from subsurface soils, followed by inhalation of enclosed-space vapors, inhalation of outdoor vapors, or ingestion of ground water as discussed in X2.1 through X2.3. Here the goal is to determine the RBSL for subsurface soils that corresponds to the target RBSLs for the inhalation or ingestion routes. If the selected target ground water concentration is some value other than an RBSL for ground water (that is, odor threshold or ecological criterion), this value can be substituted for the $RBSL_{gw}$ parameter appearing in the equations given in Tables X2.2 and X2.3.

X2.9.2 A conceptual model for the leaching of chemicals from subsurface soils to ground water is depicted in Fig. X2.6. For simplicity, the relationship between ground water and soil concentrations is represented in Tables X2.2 and X2.3 by the "leaching factor," LF_{sw} [(mg/L-H₂O)/(mg/kg-soil)], defined in Table X2.5. It is based on the following assumptions:

X2.9.2.1 A constant chemical concentration in subsurface soils.

X2.9.2.2 Linear equilibrium partitioning within the soil matrix between sorbed, dissolved, and vapor phases, where the partitioning is a function of constant chemical- and soil-specific parameters.

X2.9.2.3 Steady-state leaching from the vadose zone to ground water resulting from the constant leaching rate I [cm/s].

X2.9.2.4 No loss of chemical as it leaches towards ground water (that is, no biodegradation), and

X2.9.2.5 Steady well-mixed dispersion of the leachate within a ground water "mixing zone."

X2.9.3 Should the calculated RBSL_{so} exceed the value for which the equilibrated vapor and dissolved pore-water phases become saturated (see Table X2.5 for calculation of this value), "RES" is entered in the table to indicate that the selected risk level or hazard quotient cannot be reached or exceeded for that compound and the specified exposure scenario (even if free-phase product or precipitate is present in the soil).

X2.9.4 In some regulatory programs, "dilution attenuation factors" (DAFs) are currently being proposed based on

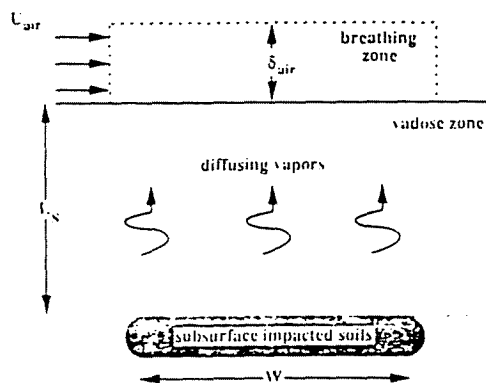


FIG. X2.4 Volatilization from Subsurface Soils to Ambient Air

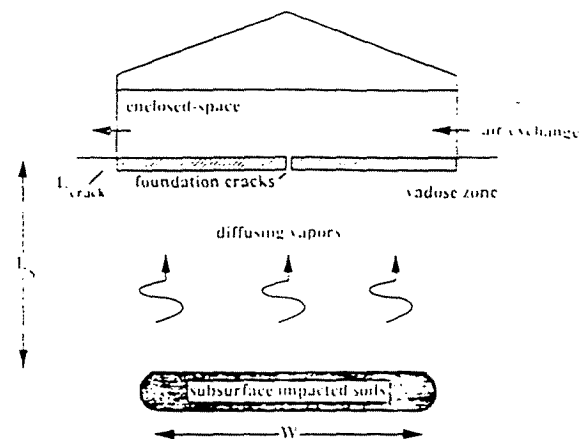


FIG. X2.5 Volatilization from Subsurface Soils to Enclosed-Space Air

fate and transport modeling results. A DAF is typically defined as the ratio of a target ground water concentration divided by the source leachate concentration, and is inherently very similar to the leachate factor, LF_{sw} , discussed here. The difference between these two terms is that LF_{sw} represents the ratio of the target ground water concentration divided by the source area soil concentration. Should a regulatory program already have a technically defensible DAF value, it can be equated to a leachate factor by the following expression:

$$LF_{sw} = \frac{DAF \times \rho_s}{[\theta_{sw} + k_d \rho_s + H\theta_{sw}]} \times 10^6$$

where the parameters are defined in Table X2.6.

X2.10 Parameter Values:

X2.10.1 Table X2.4 lists exposure parameters used to calculate the RBSLs appearing in sample Look-Up Table X2.1. All values given are based on adult exposures only. With the exception of the dermal exposure parameters (SA , M , and RAF_d), the values given are reasonable maximum exposure (RME) values presented in Ref (27) and are regarded as upper bound estimates for each individual exposure parameter.

X2.10.2 The skin surface area, $SA = 3160 \text{ cm}^2/\text{day}$, is based on the average surface area of the head, hands, and

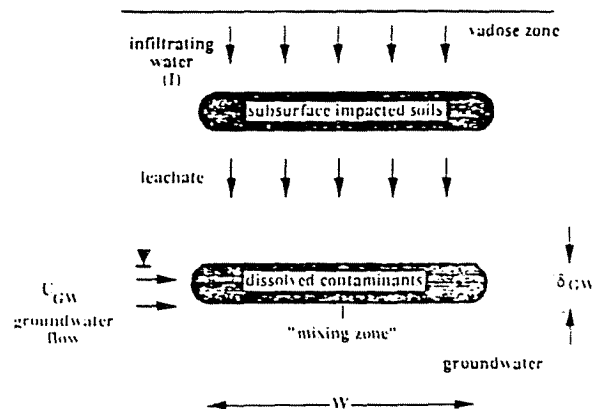


FIG. X2.6 Leaching from Subsurface Soils to Ground Water

forearms for adult males given in Ref (27). The soil-to-skin adherence factor, M [mg/cm^2], and dermal relative absorption factor, RAF_d [$\text{mg-absorbed}/\text{mg-applied}$], are based on guidance issued by Ref (28).

X2.10.3 Soil properties are based on typical values for sandy soils and are consistent with values given in Ref (30).

X2.10.4 Physical dimensions are consistent with the scale of typical underground fuel tank releases.

X2.10.5 Particulate emission rates were estimated by the approach presented by Cowherd, et al (32). It was assumed that the mode of the surficial soil size distribution was 2 mm, the erosion potential was unlimited, there was no vegetative cover, and the mean average annual wind speed was 4 m/s.

X2.10.6 The chemical-specific parameters used are de-

fined in Table X2.7.

X2.10.7 In this development, surficial soils are defined as those soils present within 1 m of ground surface. Subsurface soil RBSLs are based on assumed source depths of 1 m. Ground water is assumed to be located 3 m below ground surface.

X2.10.8 Once again, the reader is reminded that the parameter (and corresponding RBSL) values are presented here as examples only, and are not intended to be used as standards. At best, the parameters presented are reasonable values based on current information and professional judgment. The reader should review and verify all assumptions prior to using any of the example RBSLs as screening level values.

X3. USE OF PREDICTIVE MODELING IN THE RISK-BASED CORRECTIVE ACTION PROCESS

X3.1 Scope:

X3.1.1 Predictive modeling is a valuable tool that can provide information to the risk management process. In a RBCA, modeling is used to predict the location and concentration contaminants and to interpret, or extrapolate, site characterization data, historical monitoring data, and toxicological information. In addition, predictive modeling may be used in evaluation of remedial alternatives and in evaluating compliance targets in monitoring plans. This appendix discusses the following:

X3.1.1.1 Significance and use of predictive modeling in the RBCA process;

X3.1.1.2 Interpretation of predictive modeling results;

X3.1.1.3 Procedures for predictive migration models; and

X3.1.1.4 Procedures for exposure, risk, and dose-response assessment.

X3.1.2 This appendix is not intended to be all inclusive. Each predictive model is unique and may require additional procedures in its development and application. All such additional analyses should be documented in the RBCA process.

X3.2 Referenced Documents:

X3.2.1 ASTM Standards:

D 653 Terminology Relating to Soil, Rock, and Contained Fluids⁷

D 5447 Guide for Application of a Ground-Water Flow Model to a Site-Specific Problem^{*}

D 5490 Guide for Comparing Ground-Water Flow Model Simulations to Site-Specific Information^{*}

E 943 Terminology Relating to Biological Effects and Environmental Fate⁹

E 978 Practice for Evaluating Environmental Fate Models of Chemicals⁹

D 5609 Guide for Defining Boundary Conditions in Ground-Water Flow Modeling^{*}

D 5610 Guide for Defining Initial Conditions in Ground-Water Flow Modeling⁸

D 5611 Guide for Conducting a Sensitivity Analysis for a Ground-Water Flow Model Application⁸

X3.3 Terminology:

X3.3.1 *Definitions*—For definitions of terms used in this appendix, see Terminologies D 653 and E 943.

X3.3.2 Descriptions of Terms Specific to This Appendix:

X3.3.2.1 *analytical model*—a model that uses mathematical solutions to governing equations that are continuous in space and time and applicable to the flow and transport process.

X3.3.2.2 *application verification*—using the set of parameter values and boundary conditions from a calibrated model to approximate acceptably a second set of field data measured under similar conditions.

Discussion—Application verification is to be distinguished from code verification, which refers to software testing, comparison with analytical solutions, and comparison with other similar codes to demonstrate that the code represents its mathematical foundation.

X3.3.2.3 *boundary condition*—a mathematical expression of a state of the physical system that constrains the equations of the mathematical model.

X3.3.2.4 *calibration (model application)*—the process of refining the model representation of the fluid and media properties and boundary conditions to achieve a desired degree of correspondence between the model simulation and observations of the real system.

X3.3.2.5 *code validation*—the process of determining how well a modeling code's theoretical foundation and computer implementation describe actual system behavior in terms of the "degree of correlation" between calculated and independently observed cause-and-effect responses of the prototype fluid flow system (for example, research site or laboratory experiment) for which the code has been developed.

X3.3.2.6 *code verification*—the procedure aimed at establishing the completeness, consistency, correctness, and accuracy of modeling software with respect to its design criteria by evaluating the functionality and operational characteristics of the code and testing embedded algorithms and data transfers through execution of problems for which indepen-

⁷ Annual Book of ASTM Standards, Vol 04.08

⁸ Annual Book of ASTM Standards, Vol 04.09

⁹ Annual Book of ASTM Standards, Vol 11.04

dent benchmarks are available.

X3.3.2.7 *computer code (computer program)*—the assembly of numerical techniques, bookkeeping, and control language that represents the model from acceptance of input

data and instructions to delivery of output.

X3.3.2.8 *conceptual model*—an interpretation or working description of the characteristics and dynamics of the physical system.

TABLE X3.1 Example Screening Level Transport Models

Description	Mathematical Approximation	Parameters
Dissolved Phase Transport		
Maximum transport rate $u_{g,max}$ [cm/day] of dissolved plume	$u_{g,max} = \frac{K_p}{\rho_s R_c}$	$C(x)$ = dissolved hydrocarbon concentration along centerline ($x, y = 0, z = 0$) of dissolved plume [g/cm ³ -H ₂ O] C_{source} = dissolved hydrocarbon concentration in dissolved plume source area [g/cm ³ -H ₂ O] i = ground water gradient [cm/cm] K_s = saturated hydraulic conductivity [cm/day] k_s = sorption coefficient [(g-g-soil)/(g/cm ³ -H ₂ O)] L = distance downgradient [cm] R_c = retardation factor = $(1 + k_s \rho_s / \theta_s)$ S_w = source width (perpendicular to flow in the horizontal plane) [cm] S_o = source width (perpendicular to flow in the vertical plane) [cm] u = specific discharge [cm/day] $u_{g,max}$ = maximum transport rate of dissolved plume [cm/day] ^a x = distance along centerline from downgradient edge of dissolved plume source zone [cm] y = depth below water table [cm] z = lateral distance away from dissolved plume centerline [cm] α_x = longitudinal dispersivity [cm] $\approx 0.10 x$ α_y = transverse dispersivity [cm] $\approx \alpha_x / 3$ α_z = vertical dispersivity [cm] $\approx \alpha_x / 20$ λ = first-order degradation constant [d ⁻¹] θ_s = volumetric water content of saturated zone [cm ³ -H ₂ O/cm ³ -soil] ρ_s = soil bulk density [g-soil/cm ³ -soil] $\tau_{g,min}$ = minimum convective travel time of dissolved hydrocarbons to distance L [d] ^a $erf(\eta)$ = error function evaluated for value η C_{soil} = total soil hydrocarbon concentration [g/g-soil] $C_{v,eq}$ = equilibrium vapor concentration [g/cm ³ -vapor] ^a $C_{w,eq}$ = equilibrium dissolved concentration [g/cm ³ -H ₂ O] ^a D_{max} = maximum depth of immiscible phase penetration [cm] ^a H = Henry's Law Constant [(g/cm ³ -vapor)/(g/cm ³ -H ₂ O)] k_s = sorption coefficient [(g-g-soil)/(g/cm ³ -H ₂ O)] M_w = molecular weight [g/mol] P_v = vapor pressure of compound [atm] R = gas constant = 82 cm ³ -atm/mol-K R_{soil} = radial extent of hydrocarbon impact [cm] S_i = pure component solubility [g/cm ³ -H ₂ O] T = absolute temperature [K] V_{soil} = volume of hydrocarbon released [cm ³] x_i = mol fraction of component i θ_R = volumetric residual content of hydrocarbon under drainage conditions [cm ³ -hydrocarbon/cm ³ -soil] θ_w = volumetric content of soil pore water [cm ³ -H ₂ O/cm ³ -soil] θ_v = volumetric content of soil vapor [cm ³ -vapor/cm ³ -soil] τ = 3.1416 ρ_s = soil bulk density [g-soil/cm ³ -soil] (C_{soil}) = concentration at which immiscible phase forms in soil [g/g-soil] ^a D^{av} = pure component diffusion coefficient in air [cm ² /day] D^{ev} = effective diffusion coefficient for combined vapor and solute transport, expressed as a vapor phase diffusion coefficient (no immiscible hydrocarbon present outside of source area) [cm ² /day] ^a D^w = pure component diffusion coefficient in water [cm ² /day] H = Henry's Law Constant [(g/cm ³ -vapor)/(g/cm ³ -H ₂ O)] k_s = sorption coefficient [(g-g-soil)/(g/cm ³ -H ₂ O)] K_v = permeability to vapor flow [cm ²] L = distance [cm] R_v = porous media "retardation" factor (no immiscible hydrocarbon present outside of source area) S_i = pure component solubility [g/cm ³ -H ₂ O] $u_{v,max}$ = maximum convective transport rate of vapors [cm/day] ^a ∇P = vapor phase pressure gradient [g/cm ² -s ²] θ_w = volumetric content of soil pore water [cm ³ -H ₂ O/cm ³ -soil]
Minimum time $\tau_{g,min}$ [d] for leading edge of dissolved plume to travel distance L [cm]	$\tau_{g,min} = \frac{L}{u_{g,max}}$	
Steady-state attenuation [(g/cm ³ -H ₂ O)/(g/cm ³ -H ₂ O)] along the centerline ($x, y = 0, z = 0$) of a dissolved plume	$\frac{C(x)}{C_{source}} = \exp \left\{ \frac{x}{2\alpha_x} \left[1 - \sqrt{1 + \frac{4\lambda\tau_x}{u}} \right] \right\} \cdot \left(erf \left[\frac{S_w}{4\sqrt{\alpha_x x}} \right] \right) \left(erf \left[\frac{S_o}{4\sqrt{\alpha_z x}} \right] \right)$ where: $u = K_p / \theta_s$	
Immiscible Phase Transport: Maximum depth D_{max} [cm] of immiscible phase penetration Equilibrium Partitioning: Vapor Concentration: $C_{v,eq}$ [g/cm ³ -vapor] Maximum vapor concentration above dissolved hydrocarbons Maximum vapor concentration when immiscible hydrocarbon is present	$D_{max} = \frac{V_{soil}}{\theta_R R_{soil}^2}$ $C_{v,eq} = HC_{w,eq}$ $C_{v,eq} = \frac{x_i P_v M_w}{RT}$	
Maximum vapor concentrations in soil pores (no immiscible phase present)	$C_{v,eq} = \frac{HC_{soil} \rho_s}{[\theta_w + k_s \rho_s + H\theta_v]}$	
Dissolved Concentration: $C_{w,eq}$ [g/cm ³ -H ₂ O] Maximum dissolved concentration when immiscible hydrocarbon is present Maximum dissolved concentration in soil pores (no immiscible phase present) Equilibrium Partitioning: Soil Concentrations [g/g-soil]: Soil concentration $[C_{soil}]$ [g/g-soil] at which immiscible hydrocarbon phase forms in soil matrix	$C_{w,eq} = x_i S_i$ $C_{w,eq} = \frac{C_{soil} \rho_s}{[\theta_w + k_s \rho_s + H\theta_v]}$ $(C_{soil}) = \frac{S_i}{\rho_s} [\theta_w + k_s \rho_s + H\theta_v]$	
Vapor Phase Transport: Effective porous media diffusion coefficient D^{ev} [cm ² /day] for combined vapor and solute transport, expressed as a vapor phase diffusion coefficient (no immiscible hydrocarbon present outside of source area) Porous media "retardation" factor R_v (no immiscible hydrocarbon present outside of source area)	$D^{ev} = \frac{u_v^{3.33}}{\theta_v} D^{av} + \frac{1}{H} \frac{\theta_w^{3.33}}{\theta_v} D^w$ $R_v = \left[\frac{\theta_w}{H} + \frac{k_s \rho_s}{H} + u_v \right]$	

TABLE X3.1 Continued

Description	Mathematical Approximation	Parameters
Maximum convective transport rate $u_{v,max}$ [cm/day] of vapors	$u_{v,max} = \frac{1}{R_v} \frac{k_v}{\mu_v} \nabla P$	θ_v = volumetric content of soil vapor [cm ³ -vapor/cm ³ -soil] θ_r = total volumetric content of pore soil [cm ³ -oil matrix/cm ³ -soil] μ_v = vapor viscosity [g/cm ² -s] ρ_s = soil bulk density [g-soil/cm ³ -soil] $\tau_{c,min}$ = minimum time for vapors to travel a distance L [cm] by convection [day] ^A
Minimum time $\tau_{v,min}$ [d] for vapors to travel a distance L [cm] from source area by convection ^A	$\tau_{c,min} = \frac{L}{u_{v,max}}$	$\tau_{d,min}$ = minimum time for vapors to travel a distance L [cm] by diffusion [day] ^A
Minimum time $\tau_{v,min}$ [d] for vapors to travel a distance L [cm] from source area by diffusion	$\tau_{d,min} = \frac{L^2}{D^{eff} R_v}$	C_{soil} = total soil hydrocarbon concentration [g/g-soil] $C_{v,eq}$ = equilibrium vapor concentration [g/cm ³ -vapor] ^A d = distance below ground surface to top of hydrocarbon vapor source [cm] D^{eff} = effective diffusion coefficient for combined vapor and solute transport, expressed as a vapor phase diffusion coefficient (no immiscible hydrocarbon present outside of source area) [cm ² /day] ^A
Vapor Emissions from Subsurface Vapor Sources to Open Surfaces:		R_v = porous media "retardation" factor (no immiscible hydrocarbon present outside of source area) ^A $u_{v,max}$ = maximum convective transport rate $u_{v,max}$ of vapors [cm/day] ^A ρ_s = soil bulk density [g-soil/cm ³ -soil] τ = averaging time [s] A_B = total area of enclosed space exposed to vapor intrusion (area of foundation) [cm ²] A_{crack} = area of foundation through which vapors are transported (area of cracks, open seams, and so forth) [cm ²] C_{soil} = total soil hydrocarbon concentration [g/g-soil] $C_{v,eq}$ = equilibrium vapor concentration [g/cm ³ -vapor] ^A d = distance between foundation/walls and hydrocarbon vapor source [cm] D^{eff} = effective diffusion coefficient through soil for combined vapor and solute transport, expressed as a vapor phase diffusion coefficient (no immiscible hydrocarbon present outside of source area) [cm ² /day] ^A D^{crack} = effective diffusion coefficient through foundation cracks [cm ² /day] ^A L_{crack} = thickness of foundation/wall [cm] $M_{w,i}$ = molecular weight of i [g/mol] $M_{w,T}$ = average molecular weight of the hydrocarbon mixture [g/mol] P_i^* = vapor pressure of pure component i [atm] Q_B = volumetric flow rate of air within enclosed space [cm ³ /s] Q_{soil} = volumetric infiltration flow rate of soil gas into enclosed space [cm ³ /s] R = gas constant = 82 atm-cm ³ /mol-K R_v = porous media "retardation" factor ^A T = absolute temperature [K] x_i = mol fraction of component i θ_v = volumetric content of soil vapor [cm ³ -vapor/cm ³ -soil] ρ_s = soil bulk density [g-soil/cm ³ -soil] τ = 3.1416 τ = averaging time [s] $C_{w,eq}$ = equilibrium dissolved concentration in leachate source area [g/cm ³ -H ₂ O] ^A E_B = enclosed space air exchange rate [1/d] E_{max} = vapor emission rate into enclosed space [g/day] ^A F = vapor flux [g/cm ² -day] ^A i = ground water gradient [cm/cm] K_s = saturated hydraulic conductivity [cm/day] L = downwind length of vapor emissions source area [cm] M = ground water mixing zone thickness [cm] q_i = water infiltration rate [cm/day]
Maximum diffusive vapor flux F_{max} [g/cm ² -day] from subsurface vapor source located a distance d [cm] below ground surface (steady-state, constant source)	$F_{max} = D^{eff} \frac{C_{v,eq}}{d}$	
Maximum time-averaged diffusive vapor flux $\langle F_{max} \rangle$ [g/cm ² -day] from subsurface soils over period from time = 0 to time = τ , single-component immiscible phase present	$\langle F_{max} \rangle = \frac{\rho_s C_{soil}}{\tau} \left[\sqrt{d^2 + \frac{2C_{v,eq} D^{eff} \tau}{\rho_s C_{soil}}} - d \right]$	
Maximum combined convective and diffusive vapor flux F_{max} [g/cm ² -day] from subsurface vapor source located a distance d [cm] below ground surface	$F_{max} = R_v u_{v,max} C_{v,eq} - \frac{R_v u_{v,max} C_{v,eq}}{\left[1 - \exp\left(-\frac{R_v u_{v,max} d}{D^{eff}}\right) \right]}$	
Vapor Emissions from Surface Soils to Open Spaces:		
Maximum time-averaged diffusive vapor flux $\langle F_{max} \rangle$ [g/cm ² -day] from surface soils over period from time = 0 to time = τ , single-component immiscible phase present	$\langle F_{max} \rangle = \mu_s C_{soil} \sqrt{\frac{2C_{v,eq} D^{eff}}{\mu_s C_{soil} \tau}}$	
Maximum time-averaged diffusive vapor flux $\langle F_{max} \rangle$ [g/cm ² -day] from surface soils over period from time = 0 to time = τ , no immiscible phase present	$\langle F_{max} \rangle = 2\mu_s C_{soil} \sqrt{\frac{D^{eff}}{\pi R_v \tau}}$	
Maximum time-averaged diffusive vapor flux $\langle F_{max} \rangle$ [g/cm ² -day] from surface soils over period from time = 0 to time = τ , volatile components from relatively nonvolatile immiscible phase (for example, benzene from gasoline)	$\langle F_{max} \rangle = \frac{2D^{eff} \left(\frac{x_i P_i^* M_{w,i}}{RT} \right)}{\sqrt{\pi \tau} \frac{P_i^*}{P_v}}$ where $\tau = \frac{D^{eff}}{\mu_s \frac{RT(C_{soil} M_{w,i})}{P_i^*}}$	

X3.3.2.9 *ground water flow model*—application of a mathematical model to represent a site-specific ground water flow system.

X3.3.2.10 *mathematical model*—mathematical equations expressing the physical system and including simplifying assumptions. The representation of a physical system by mathematical expressions from which the behavior of the

system can be deduced with known accuracy.

X3.3.2.11 *migration model*—application of a mathematical model to represent a site-specific fluid flow system.

X3.3.2.12 *model*—an assembly of concepts in the form of mathematical equations that portray understanding of a natural phenomenon.

X3.3.2.13 *sensitivity (model application)*—the degree to

TABLE X3.1 Continued

Description	Mathematical Approximation	Parameters
Vapor Emissions to Enclosed Spaces Maximum vapor emission rate E_{max} [$g/cm^2 \cdot d$] to enclosed spaces from subsurface vapor sources located a distance d [cm] away from the enclosed spaces	$E_{max} = Q_B C_{w,eq} \left[\frac{D^{*n} A_B}{Q_B d^2} \exp\left(\frac{Q_{3D} - Q_{1D}}{Q_B C_{w,eq} A_{1D} + Q_B C_{w,eq} A_{2D} + Q_B C_{w,eq} A_{3D}}\right) \right. \\ \left. - \exp\left(\frac{Q_{3D} - Q_{1D}}{Q_B C_{w,eq} A_{1D} + Q_B C_{w,eq} A_{2D} + Q_B C_{w,eq} A_{3D}}\right) \right] \\ - \left[\frac{D^{*n} A_B}{Q_{1D} d^2} \exp\left(\frac{Q_{3D} - Q_{1D}}{Q_B C_{w,eq} A_{1D} + Q_B C_{w,eq} A_{2D} + Q_B C_{w,eq} A_{3D}}\right) \right]$	u_w = wind speed [cm/day] V_B = volume of enclosed space [cm^3] W = width of impacted soil zone [cm] h = height of breathing zone [cm]
Hydrocarbon Vapor Dispersion Ambient hydrocarbon vapor concentration resulting from area vapor source $C_{outdoor}$ [g/cm^3] Enclosed space vapor concentration C_{indoor} [g/cm^3]	$C_{outdoor} = \frac{FL}{u_w h}$ $C_{indoor} = \frac{E_{max}}{V_B E_B}$	
Leachate Transport Leaching impact on Ground Water Ground water source area concentration C_{source} [$g/cm^3 \cdot H_2O$] resulting from leaching through vadose zone hydrocarbon-impacted soils Ground water source area concentration C_{source} [$g/cm^3 \cdot H_2O$] resulting from hydrocarbon-impacted soils in direct contact with ground water	$C_{source} = C_{w,eq} \frac{q \cdot W}{(K_p M + q \cdot W)}$ $C_{source} = C_{w,eq}$	

^a Equation for this parameter given in this table.

TABLE X3.2 Reported Degradation Rates for Petroleum Hydrocarbons

Reference	Source of Data	Chemical Decay Rates (day ⁻¹ , [half-life days])							
		Benzene	Toluene	Ethyl-Benzene	Xylenes	O-Xylene	MTBE	Naphthalene	Benzo(a)Pyrene
Barker, et al. ^a	Borden Aquifer, Canada	0.007 [99]	0.011 [63]			0.014 [50]			
Kemblowski ^b	Eastern Florida Aquifer	0.0085 [82]							
Chiang, et al. ^c	Northern Michigan Aquifer	0.095 [7]							
Wilson, et al. ^d	Traverse City, MI Aquifer	0.007 to 0.024 [99] to [29]	0.067 [10]		0.004 to 0.014 [173] to [50]				
Howard, et al. ^e	Literature	0.0009 [730] to 0.069 [10]	0.025 [28] to 0.099 [7]	0.003 [228] to 0.116 [6]	0.0019 [365] to 0.0495 [14]		0.0019 [365] to 0.0866 [8]	0.0027 [258]	0.0007 [1058] to 0.0061 [114]

^a See Ref (36).

^b See Ref (37).

^c See Ref (38).

^d See Ref (39).

^e See Ref (40).

which the model result is affected by changes in a selected model input representing fluid and media properties and boundary conditions.

X3.3.2.14 *simulation*—in migration modeling, one complete execution of a fluid flow modeling computer program, including input and output.

DISCUSSION—for the purposes of this appendix, a simulation refers to an individual modeling run. However, simulation is sometimes also used broadly to refer to the process of modeling in general.

X3.4 Significance and Use:

X3.4.1 Predictive modeling is significant in many phases of RBCA, including the following:

X3.4.1.1 Determining the potential urgency of response based on estimated migration and attenuation rates of compounds of concern,

X3.4.1.2 Determining the extent of corrective action

based on estimated migration and attenuation rates of compounds of concern,

TABLE X3.3 Results of Exponential Regression for Concentration Versus Time^a

Site	Compound	k, % per day
Campbell, CA	benzene	1.20
	ethylbenzene	0.67
	xylene	1.12
Palo Alto, CA	benzene	0.42
	benzene	0.30
	PCE	0.46
Virginia Beach, VA	TCE	0.30
	benzene	0.42
	benzene	0.23
Montrose County, CO	benzene	0.16
Provo, UT	benzene	0.10
San Jose, CA	benzene	0.39
Chemical facility	toluene	0.34
	PCE	0.26
	TCE	0.26

^a Source: Ref (41).

X3.4.1.3 Establishing relationships between administered doses and adverse impacts to humans and sensitive environmental receptors, and

X3.4.1.4 Determining RBSLs concentrations in the absence of exposure.

X3.4.2 Examples of predictive modeling in the RBCA process include the following:

X3.4.2.1 The prediction of contaminant concentration distributions for future times based on historical trend data, as in the case of ground water transport modeling.

X3.4.2.2 The recommendation of sampling locations and sampling frequency based on current interpretation and future expectations of contaminant distributions, as in the design of ground water monitoring networks.

X3.4.2.3 The design of corrective action measures, as in the case of hydraulic control systems, and

X3.4.2.4 The calculation of site-specific exposure point concentrations based on assumed exposure scenarios, as in the case of direct exposure to surficial soils.

X3.4.3 Predictive modeling is not used in the RBCA process as a substitute for validation of site-specific data.

X3.5 Interpretation of Predictive Modeling Results:

X3.5.1 Predictive models are mathematical approximations of real processes, such as the movement of chemicals in the subsurface, the ingestion of chemicals contained in drinking water, and adverse impacts to human health and environmental resources resulting from significant exposures. One key step towards evaluating model results is to assess the accuracy and uncertainty, and to verify the model used.

X3.5.2 The accuracy of modeling-based predictions is evaluated using a post audit and is dependent upon a number of factors, including the following:

X3.5.2.1 The approximations used when describing the real system by mathematical expressions.

X3.5.2.2 The model setup, that is, the input parameters (for example, boundary conditions) used to generate the results, and

X3.5.2.3 The mathematical methods used to solve the governing equations (for example, user selection of numerical solution methods, expansion approximations, numerical parameters, and so forth).

X3.5.3 Predictive modeling results are always subject to some degree of uncertainty. It is important to quantify this uncertainty to properly interpret the results. Many times this is done with a sensitivity analysis in which the user identifies those parameters that most significantly influence the results. If most of all of the parameters do not produce "sensitivity," then the model may need to be reevaluated because it is possible that the key parameters are missing from the model.

X3.5.4 A postaudit may be performed to determine the accuracy of the predictions. While model calibration and verification demonstrate that the model accurately simulates past behavior of the system, the postaudit tests whether the model can predict future system behavior. Post audits are normally performed several years after the initial assessment and corrective action.

X3.5.5 In the RBCA process, "conservative" is an important criterion of predictive modeling. In the initial evaluation, Tier 1, the most conservative approach, is used, which provides a worst case scenario for potential exposure and

risk. Models that, because of their simplicity, neglect factors that yield conservative results are used. Input may include conservative values such as the USEPA RME values. When a more rigorous approach is warranted, such as in Tier 2 of the RBCA process, conservative values are often used, but in conjunction with a more reasonable case scenario. This level requires more specific information about the site and may involve the use of either simple or moderately complex mathematical models. It may involve the use of most likely exposure scenario (that is, USEPA MLE values). This information is used to set conservative corrective action objectives that are still regarded as overly protective. At some sites a comprehensive assessment is required (Tier 3) where SSTLs are determined using a site-specific transport and exposure model and, in some cases, parameter distributions. Tier 3 provides the most realistic evaluation of potential exposure and risk.

X3.6 Types of Predictive Migration and Risk Assessment Models:

X3.6.1 Predictive models typically used in the RBCA process can be grouped into two broad categories:

X3.6.1.1 Migration models, and

X3.6.1.2 Exposure, risk, and dose-response assessment models.

X3.6.2 The determination of Tier 1 RBSLs or Tiers 2 and 3 SSTLs generally involves the use of combinations of both types of models. A more detailed description of each type of model is given in X3.7 and X3.8.

X3.7 Procedures for Predictive Migration Models:

X3.7.1 Migration (fate and transport) models predict the movement of a petroleum release through soil, ground water, or air, or combination thereof, over time. Most models focus on specific phenomena (for example, ground water transport) and vary in complexity, depending on assumptions made during model development. In RBCA, simplistic screening-level migration models are utilized in Tiers 1 and 2, while more complex models are utilized in Tier 3.

X3.7.2 References to many simplistic models suitable for screening-level evaluations for a number of pathways relevant to hydrocarbon contaminant releases are listed in Table X3.1. Most of the screening-level migration models have a simple mathematical form and are based on multiple limiting assumptions rather than on actual phenomena. For example, a simple model is the use of estimated ground water flow velocity to assess the travel time between the leading edge of a dissolved hydrocarbon plume and a ground water well. The travel time is approximated by the following:

$$[\text{distance to well (ft)}/\text{flow velocity (ft/years)}] = \text{travel time (years)}$$

X3.7.2.1 In the case of a relatively light compound such as benzene dissolved in ground water, the flow velocity may best be equated with the ground water flow velocity. Heavier compounds such as naphthalene may be retarded so that a flow velocity lower than the ground water velocity may be used. If miscible liquids are present on the ground water surface, such as gasoline, the liquid flow velocity may actually exceed the ground water velocity.

X3.7.3 The use of more complex models is not precluded in the RBCA process; however, given limited data and assumptions that must be made, many complex numerical

models reduce to the analytical expressions given in Table X3.1.

X3.7.4 Migration Model Data Requirements—Predictive migration models require input of site-specific characteristics. Those most commonly required for various simplistic models include the following:

X3.7.4.1 Soil bulk density (for a typical soil: $\approx 1.7 \text{ g/cm}^3$).

X3.7.4.2 Total soil porosity (for a typical soil: $\approx 0.38 \text{ cm}^3/\text{cm}^3$).

X3.7.4.3 Soil moisture content can be conservatively estimated in many cases. It is approximately equal to the total soil porosity beneath the water table, and typically $>0.05 \text{ cm}^3\text{-H}_2\text{O}/\text{cm}^3\text{-soil}$ in the vadose zone; this can be a critical input parameter in the case of diffusion models and may require site-specific determination unless conservative values are used.

X3.7.4.4 Fraction organic matter in soil particles ($\approx 0.001 - 0.01$; sandy soil is often conservatively assumed); this can also be a critical parameter requiring site-specific determination unless conservative values are used.

X3.7.4.5 Hydraulic conductivity (generally site-specific determination required).

X3.7.4.6 Ground water gradient and flow direction (requires site-specific determination), and

X3.7.4.7 First-order decay-rate (generally requires site-specific calibration as models are very sensitive to this parameter); see Tables X3.2 and X3.3 and Ref (41) for a summary of measured values currently available from the literature. The data in Table X3.3 include retardation and dispersion as well as natural biodegradation in attenuation rates measured. However, sensitivity studies indicate that natural biodegradation is the dominant factor. The sensitivity studies use Ref (42). According to these sensitivity studies, an order of magnitude increase in natural biodegradation rate is 3.5 times as effective as an order of magnitude increase in retardation and 12 times as effective as an order of magnitude increase in dispersion in attenuating concentration over distance. Therefore, approximately 80 % of the attenuation shown in the Ref (41) data can be attributed to natural biodegradation.

X3.7.4.8 A similar analysis of the sensitivity of attenuation parameters for the vapor transport pathway also indicates that natural biodegradation is the predominant attenuation mechanism (43). Soil geology is not considered an attenuation mechanism directly, but is a stronger determinant of how far contamination travels than even natural biodegradation. Gasoline contamination does not travel very far in clay (less than 30 ft (9 m)) according to the vapor transport model (43).

X3.7.5 Depending on the models selected, other information may be required, such as meteorological information (wind speed, precipitation, temperature), soil particle size distributions, and nearby building characteristics.

X3.7.6 In most cases, measurements of the attenuation (decrease in concentrations) of compounds with distance away from the contaminant source area will be required to calibrate and verify the predictive capabilities of the selected models. The amount of data required varies depending on the following:

X3.7.6.1 The model code used.

X3.7.6.2 The model's sensitivity to changes in input parameters, and

X3.7.6.3 The contribution of the pathway of concern to the total incremental exposure and risk.

X3.7.7 Generally, site-specific physical and chemical properties for the most sensitive parameters are required for migration models to obtain accurate results. However, instead of site-specific data, conservative values selected from the literature may be used with appropriate caution.

3.7.8 Migration Modeling Procedure—The procedure for applying a migration model includes the following steps: definition of study objectives, development of a conceptual model, selection of a computer code or algorithm, construction of the model, calibration of the model and performance of sensitivity analysis, making predictive simulations, documentation of the modeling process, and performing a postaudit. These steps are generally followed in order; however, there is substantial overlap between steps, and previous steps are often revisited as new concepts are explored or as new data are obtained. The iterative modeling approach may also require the reconceptualization of the problem. The basic modeling steps are discussed as follows.

X3.7.8.1 Modeling Objectives—Modeling objectives must first be identified (that is, the questions to be answered by the model). The objectives aid in determining the level of detail and accuracy required in the model simulation. Complete and detailed objectives would ideally be specified prior to any modeling activities. Objectives may include interpreting site characterization and monitoring data, predicting future migration, determining corrective action requirements, or predicting the effect of proposed corrective action measures.

X3.7.8.2 Conceptual Model—A conceptual model of a subsurface contaminant release, such as a hydrocarbon release from an underground tank, is an interpretation or working description of the characteristics and dynamics of the physical system. The purpose of the conceptual model is to consolidate site and regional data into a set of assumptions and concepts that can be evaluated quantitatively. Development of the conceptual model requires the collection and analysis of physical data pertinent to the system under investigation.

(1) The conceptual model identifies and describes important aspects of the physical system, including the following: geologic and hydrologic framework; media type (for example, fractured or porous); physical and chemical processes; and hydraulic, climatic, and vapor properties. The conceptual model is described in more detail for ground water flow systems in Guide D 5447.

(2) Provide an analysis of data deficiencies and potential sources of error with the conceptual model. The conceptual model usually contains areas of uncertainty due to the lack of field data. Identify these areas and their significance to the conceptual model evaluated with respect to project objectives.

X3.7.8.3 Computer Code Selection—Computer code selection is the process of choosing the appropriate software algorithm, or other analysis technique, capable of simulating the characteristics of the physical system, as identified in the conceptual model. The types of codes generally used in the RBCA process are analytical and numerical models. The selected code should be appropriate to fit the available data

and meet the modeling objectives. The computer code must also be tested for the intended use and be well documented.

(1) Analytical models are generally based on assumptions of uniform properties and regular geometries. Advantages include quick setup and execution. Disadvantages include, in many cases, that analytical models are so simplistic that important aspects of a given system are neglected.

(2) Numerical models allow for more complex heterogeneous systems with distributed properties and irregular geometries. Advantages include the flexibility to simulate more complex physical systems and natural parameter variability. Disadvantages include that the approach is often very time-intensive and may require much more data and information to be collected.

(3) Other factors may also be considered in the decision-making process, such as the model analyst's experience and those described as follows for model construction process: factors such as dimensionality will determine the capabilities of the computer code required for the model.

X3.7.8.4 Model Construction—Model construction is the process of transforming the conceptual model into a mathematical form. The model typically consists of two parts, the data set and the computer code. The model construction process includes building the data set used by the computer code. Fundamental components of a migration model are dimensionality, discretization, boundary and initial conditions, contaminant, and media properties.

X3.7.8.5 Model Calibration—Calibration of a model is the process of adjusting input for which data are not available within reasonable ranges to obtain a match between observed and simulated values. The range over which model parameters and boundary conditions may be varied is determined by data presented in the conceptual model. In the case where parameters are well characterized by field measurements, the range over which that parameter is varied in the model should be consistent with the range observed in the field. The degree of fit between model simulations and field measurements can be quantified using statistical techniques.

(1) In practice, model calibration is frequently accomplished through trial-and-error adjustment of the model's input data to match field observations. The calibration process continues until the degree of correspondence between the simulation and the physical system is consistent with the objectives of the project.

(2) Calibration of a model is evaluated through analysis of residuals. A residual is the difference between the observed and simulated variable. Statistical tests and illustrations showing the distribution of residuals are described for ground water flow models in Guide D 5490.

(3) Calibration of a model to a single set of field measurements does not guarantee a unique solution. To minimize the likelihood of nonuniqueness, the model should be tested to a different set of boundary conditions or stresses. This process is referred to as application verification. If there is poor correspondence to a second set of field data, then additional calibration or data collection are required. Successful verification of an application results in a higher degree of confidence in model predictions. A calibrated but unverified model may still be used to perform predictive simulations when coupled with a sensitivity analysis.

X3.7.8.6 Sensitivity Analysis—Sensitivity analysis is a quantitative method of determining the effect of parameter variation on model results. Two purposes of a sensitivity analysis are (1) to quantify the uncertainty in the calibrated model caused by uncertainty in the estimates of parameters, stresses, and boundary conditions, and (2) to identify the model inputs that have the most influence on model calibration and predictions.

(1) Sensitivity of a model parameter is often expressed as the relative rate of change of a selected model calculation during calibration with respect to that parameter. If a small change in the input parameter or boundary condition causes a significant change in the output, the model is sensitive to that parameter or boundary condition.

(2) Whether a given change in the model calibration is considered significant or insignificant is a matter of judgment. However, changes in the model's conclusions are usually able to be characterized objectively. For example, if a model is used to determine whether a contaminant is captured by a potable supply well, then the computed concentration is either detectable or not at the location. If, for some value of the input that is being varied, the model's conclusions are changed but the change in model calibration is insignificant, then the model results may be invalid because, over the range of that parameter in which the model can be considered calibrated, the conclusions of the model change. More information regarding conducting a sensitivity analysis for a ground water flow model application is presented in Guide D 5611.

X3.7.8.7 Model Predictions—Once these steps have been conducted, the model is used to satisfy the modeling objectives. Predictive simulations should be documented with appropriate illustrations, as necessary, in the model report.

X3.8 Procedures for Risk, Exposure, and Dose-Response Assessment Models:

X3.8.1 "Exposure models" are used to estimate the chemical uptake, or dose, while "risk assessment models" are used to relate human health or ecological impacts to the uptake of a chemical. Risk and exposure assessment models are often combined to calculate a target exposure point concentration of a compound in air, water, or soil.

X3.8.1.1 In the case of compounds that have been classified as carcinogens, exposure and risk assessment models are generally linked by the expression:

$$\text{risk} = \text{average lifetime intake [mg/kg-day]} \times \text{slope factor [mg/kg-day]}^{-1}$$

where the intake depends on exposure parameters (ingestion rate, exposure duration, and so forth) and the concentration at point-of-exposure. The slope factor (sometimes called the "potency factor") is itself based on a model and set of underlying assumptions, which are discussed as follows.

X3.8.1.2 In the case of compounds that have not been classified as carcinogens, exposure and risk assessment models are generally linked by the expression:

$$\text{hazard quotient} = \frac{\text{average intake [mg/kg-day]}}{\text{reference dose [mg/kg-day]}}$$

where the intake depends on exposure parameters (ingestion rate, exposure duration, and so forth) and the concentration at point-of-exposure. The reference dose is itself based on a

model and set of underlying assumptions, which are discussed as follows.

X3.8.2 Toxicity Assessment: Dose-Response Models—Toxicity assessments use dose-estimates of a "safe dose" or toxic level based on animal studies. In some instances, human epidemiological information is available on a chemical. Toxicologists generally make two assumptions about the effects of risk agents at the low concentrations typical of environmental exposures:

X3.8.2.1 Thresholds exist for most biological effects; in other words, for noncarcinogenic, nongenetic toxic effects, there are doses below which no adverse effects are observed in a population of exposed individuals, and

X3.8.2.2 No thresholds exist for genetic damage or incremental carcinogenic effects. Any level of exposure to the genotoxic or carcinogenic risk agent corresponds to some non-zero increase in the likelihood of inducing genotoxic or incremental carcinogenic effects.

X3.8.3 The first assumption is widely accepted in the scientific community and is supported by empirical evidence. The threshold value for a chemical is often called the NOAEL. Scientists usually estimate NOAELs from animal studies. An important value that typically results from a NOAEL or LOAEL value is the RfD. A reference dose is an estimate (with an uncertainty typically spanning an order of magnitude) of a daily exposure (mg/kg/day) to the general human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime of exposure. The RfD value is derived from the NOAEL or LOAEL by application of uncertainty factors (UF) that reflect various types of data used to estimate RfDs and an additional modifying factor (MF), which is based on a professional judgment of the quality of the entire database of the chemical. The oral RfD, for example, is calculated from the following equation:

$$RfD = \frac{NOAEL}{(UF \times MF)}$$

X3.8.4 The second assumption regarding no threshold effects for genotoxic or carcinogenic agents is more controversial but has been adopted by the USEPA. For genotoxic and carcinogenic agents, extrapolations from high experimental doses to low doses of environmental significance require the use of mathematical models to generate low dose-response curves. It should be noted that although the EPA uses the linear multi-state model to describe incremental carcinogenic effect, there is no general agreement in the scientific community that this is the appropriate model to use.

X3.8.5 The critical factor determined from the dose-response curve is the slope factor (SF), which is the slope of the dose-response curve in the low-dose region. The units of the slope factor are expressed as (mg/kg-day)⁻¹ and relate a given environmental intake to the risk of additional incidence of cancer above background.

X3.8.6 The RfD or SF values are generally obtained from a standard set of reference tables (for example, Ref (2) or Ref (3)). It is important to note that the information in IRIS has typically only been peer-reviewed within the EPA and may not always have support from the external scientific community. Whereas the information in IRIS has been subject to

agency-wide data quality review, the information in the HEAST tables has not. The user is expected to consult the original assessment documents to appreciate the strengths and limitations of the data in HEAST. Thus, care should be exercised in using the values in HEAST. Some state and local agencies have toxicity factors they have derived themselves or preferences for factors to use if neither IRIS nor HEAST lists a value. Values for a range of hydrocarbons typical of interest are presented in Table X3.1.

X3.8.7 It is important to note that in extrapolating the information obtained in animal studies to humans, a number of conservative assumptions are made.

X3.8.7.1 For noncarcinogens, an arbitrary system of default safety and uncertainty factors, as discussed (in multiples of ten), is used to convert observations, in animals to estimates in humans.

X3.8.7.2 For carcinogens, some of the most important assumptions include: (1) the results of the most sensitive animal study are used to extrapolate to humans, (2) in general, chemicals with any incremental carcinogenic activity in animals are assumed to be potential human carcinogens, and (3) no threshold exists for carcinogens.

X3.8.8 The uncertainty in the RfD and SF values are often neglected in deference to single point values which are then typically summarized in databases such as IRIS and HEAST and assumptions described are risk management policy decisions made by the USEPA. These assumptions are not explicitly defined and further obscure the conservatism in the safe dose estimate. Thus, care must be exercised in interpreting results which have as a basis these conservative toxicity evaluations.

X3.8.9 Exposure Assessment Modeling—The goal of exposure assessment modeling is to estimate the chemical uptake that occurs when a receptor is exposed to compounds present in their environment. In principal, the process for developing and using migration models presented in X3.7 is directly applicable to exposure assessment modeling. In this case the user:

X3.8.9.1 Develops a conceptual model by identifying significant exposure pathways and receptors,

X3.8.9.2 Selects a model to describe the contact rate and subsequent uptake of the chemical(s),

X3.8.9.3 Performs a sensitivity analysis to identify critical parameters,

X3.8.9.4 Selects appropriate exposure parameters (breathing rates, and so forth),

X3.8.9.5 Generates estimates of exposure and uptake, and

X3.8.9.6 Assesses the uncertainty in the estimates.

X3.8.10 There are differences between the process outlined in X3.7 and that which can be practically applied to exposure assessment modeling. For example, with the exception of exposures and impacts to environmental resources, it is difficult to calibrate exposure assessment models unless very expensive epidemiological studies are conducted.

X3.8.11 Typically, the models used to estimate uptake are simplistic algebraic expressions, such as those contained in Ref (27). Application of these equations is illustrated in Appendix X2.

X3.8.12 In many cases, exposure parameter values are available in Ref (27), but other more recent information is also available in peer-reviewed publications, and all sources

should be carefully reviewed. While point values are often selected for simplicity, statistical distributions for many of the exposure parameters are readily available for Tier 3 analyses.

X3.8.13 It is common for USEPA RME values to be used in exposure assessment calculation, as is done for the example Tier 1 Look-Up Table discussed in Appendix X2. The RME value is generally defined as a statistical upper limit of available data (generally 85 to 90 % of all values are less than the RME value). Therefore, by consistently selecting and multiplying conservative RME values the user models a scenario that is very improbable and always more

conservative than the "true" RME exposure scenario. Thus, great care must be exercised, when using combinations of these default values in risk assessments, to avoid a gross overestimation of exposure for a specific site.

X3.9 *Report*—The purpose of the model report is to communicate findings, to document the procedures and assumptions inherent in the study, and to provide detailed information for peer review. The report should be a complete document allowing reviewers and decision makers to formulate their own opinion as to the credibility of the model. The report should describe all aspects of the modeling study outlined in this appendix.

X4. INSTITUTIONAL CONTROLS

X4.1 *Introduction*:

X4.1.1 The purpose of this appendix is to provide a review of generally used institutional controls. For purposes of this appendix, "institutional controls" are those controls that can be used by responsible parties and regulatory agencies in remedial programs where, as a part of the program, certain concentrations of the chemical(s) of concern will remain on site in soil or ground water, or both. Referenced in this appendix are examples of programs from California, Connecticut, Illinois, Indiana, Iowa, Massachusetts, Michigan, Missouri, and New Jersey. In addition, federal programs, such as Superfund settlements and RCRA closure plans have used the following techniques described for some years as a mechanism to ensure that exposure to remaining concentrations of chemical(s) of concern is reduced to the degree necessary.

X4.1.2 The types of institutional controls discussed in this appendix are as follows:

X4.1.2.1 Deed restrictions, or restrictive covenants.

X4.1.2.2 Use restrictions (including well restriction areas).

X4.1.2.3 Access controls.

X4.1.2.4 Notice, including record notice, actual notice, and notice to government authorities.

X4.1.2.5 Registry act requirements.

X4.1.2.6 Transfer act requirements, and

X4.1.2.7 Contractual obligations.

X4.1.3 Institutional controls for environmental remedial programs vary in both form and content. Agencies and landowners can invoke various authorities and enforcement mechanisms, both public and private, to implement any one or a combination of the controls. For example, a state could adopt a statutory mandate (see X4.2) requiring the use of deed restrictions (see X4.3) as a way of enforcing use restrictions (see X4.4) and posting signage (a type of access control, see X4.5). Thus, the institutional controls listed as follows are often used as overlapping strategies, and this blurs the distinctions between them.

X4.2 *Statutory Mandates*—Some states' emergency response programs mandate post-remediation institutional controls and impose civil penalties for noncompliance. The schemes vary from state to state, but all impose obligations on landowners to use one or more institutional controls listed in this appendix.

X4.3 *Deed Restrictions*

X4.3.1 Deed restrictions place limits and conditions on the use and conveyance of land. They serve two purposes: (1) informing prospective owners and tenants of the environmental status of the property and (2) ensuring long-term compliance with the institutional controls that are necessary to maintain the integrity of the remedial action over time. Restraining the way someone can use their land runs counter to the basic assumptions of real estate law, so certain legal rules must be satisfied in order to make a deed restriction binding and enforceable.

X4.3.2 There are four requirements for a promise in a deed restriction (also called a "restrictive covenant") to be held against current and subsequent landowners: (1) a writing, (2) intention by both original parties that particular restrictions be placed on the land in perpetuity, (3) "privity of estate," and (4) that the restrictions "touch and concern the land."

X4.3.2.1 The first requirement is that of a writing. It is a rule of law that conveyances of land must be documented in a writing. The same rule holds for deed restrictions affecting land. Ideally, a deed restriction used as an institutional control would be written down with particularity and then recorded in the local land records office, in much the same fashion as the documentation and recordation of a sale of land. Parties may also encounter the requirement that the deed restriction be executed "under seal," a legal formality that has been abandoned in most states.

X4.3.2.2 The second requirement is that the deed restriction should precisely reflect what the parties' intentions are in regard to the scope and the duration of the restrictions. Explicitly stating in the deed restriction that the parties intend the restriction to "run with the land" (that is, last forever and bind subsequent owners) is strongly recommended.

X4.3.2.3 The third requirement, privity of estate, arises from a concern that only persons with a certain relationship to the land should be able to enforce a deed restriction. Normally, deed restrictions are promises between the buyer and the seller or between neighbors; therefore, the state or a third party may not enforce a deed restriction. However, even in states that require privity of estate, this concern is addressed if the landowner took the land with knowledge that the restrictions existed and might be enforced by these third parties. Thus, it is also strongly recommended that the deed

restriction explicitly state that the state environmental authority may enforce the restriction. Recording of the deed restriction serves as notice to anyone who later purchases or acquires an interest in the land. Therefore, privity of estate should not be a barrier to state enforcement of the deed restriction if the proper steps are taken.

X4.3.2.4 Finally, a deed restriction is only enforceable if the promise "touches and concerns the land." A rough rule of thumb to decide this point is whether the landowner's legal interest in the land is decreased in value due to the deed restriction. If the land is devalued in this way, then the restriction could be said to "touch and concern the land." Note that the focus of the inquiry is on the land itself; promises that are personal in nature and merely concern human activities that happen to take place on the land are least likely to be enforceable. Thus, any deed restriction used as an institutional control should be written so that it centers on the land and the use of the land.

X4.3.3 Due to the potential enforcement hurdles encountered by a governmental agency in enforcing a deed restriction, it may be appropriate for an individual state to seek statutory and regulatory amendments to ensure that such authority exists in regard to all deed restrictions for environmental purposes.

X4.3.4 Remedies for noncompliance with deed restrictions comes in two forms: (1) persons or agencies may sue to obtain a court order (injunction) requiring compliance or (2) if the state statute allows for it, the state's attorney general can seek enforcement of civil penalties, such as fines, for noncompliance.

X4.3.5 A state program can require a landowner to continue monitoring activities and to allow state environmental officials access to the site to monitor compliance with institutional controls. These arrangements may have to be put in a deed restriction in order to run with the land from owner to owner, but responsible parties can also be required to sign a contract making these promises. Of course, almost every state has authority to issue administrative orders to accomplish some or all of these arrangements.

X4.3.6 The preceding arrangements can also set out procedures that will be followed if some emergency requires that the remediation site be disturbed. If, for example, underground utility lines must be repaired, the landowner would follow this protocol for handling the soil and alerting the state authority.

X4.4 *Use Restrictions:*

X4.4.1 Use restrictions are usually the heart of what is in a deed restriction. Use restrictions describe appropriate and inappropriate uses of the property in an effort to perpetuate the benefits of the remedial action and ensure property use that is consistent with the applicable cleanup standard. Such techniques also prohibit any person from making any use of the site in a manner that creates an unacceptable risk of human or environmental exposure to the residual concentrations of chemical(s) of concern.

X4.4.2 Use restrictions address uses that may disturb a containment cap or any unremediated soils under the surface or below a building. A prohibition on drinking on-site (or off-site by means of well restriction areas discussed as follows) ground water may also be appropriate.

X4.4.3 As an example, a program may allow a restriction

of record to include one or more of the following.

X4.4.3.1 Restriction on property use:

X4.4.3.2 Conditioning the change of use from nonresidential on compliance with all applicable cleanup standards for a residential property;

X4.4.3.3 Restricting access; or

X4.4.3.4 Restricting disturbance of department-approved remedial effects.

X4.4.4 Well restriction areas can be a form of institutional control by providing notice of the existence of chemical(s) of concern in ground water, and by prohibiting or conditioning the construction of wells in that area.

X4.4.4.1 This technique preserves the integrity of any ground water remedial action by prohibiting or conditioning the placement and use of any or all types of wells within the area.

X4.4.4.2 Well restrictions of this nature would be subject to agency approval and public notice, and may include the restriction on constructing or locating any wells within a particular designated area. Notice of the well restriction is recorded on the land records and with various health officials and municipal officials. The restrictions can only be released upon a showing that the concentrations of the chemical(s) of concern in the well restriction area is remediated in accordance with state standards.

X4.5 *Access Controls:*

X4.5.1 Another subset of institutional controls is the control of access to any particular site. The state uses the following criteria to determine the appropriate level and means of access control:

X4.5.1.1 Whether the site is located in a residential or mixed use neighborhood;

X4.5.1.2 Proximity to sensitive land-use areas including day-care centers, playgrounds, and schools; and

X4.5.1.3 Whether the site is frequently traversed by neighbors.

X4.5.2 Access can be controlled by any of the following: fencing and gates, security, or postings or warnings.

X4.6 *Notice*—Regulations of this type generally provide notice of specific location of chemical(s) of concern on the site, and disclose any restrictions on access, use, and development of part or all of the contaminated site to preserve the integrity of the remedial action.

X4.6.2 *Record Notice:*

X4.6.2.1 Some states require that sites having releases of hazardous waste file a notice on the land records providing to any subsequent purchaser of the property information regarding the past or current activities on the site.

X4.6.2.2 The record notice requirement may be broad; the program may require any property subject to a response action to obtain a professional opinion and then prepare and record a Grant of Environmental Restriction that is supported by that opinion.

X4.6.2.3 The record notice requirement can be ancillary to a transfer act (see X4.8), in which case recording of an environmental statement is only required in conjunction with a land transaction.

X4.6.3 *Actual Notice:*

X4.6.3.1 States may require direct notice of environmental information to other parties to a land transaction.

These laws protect potential buyers and tenants, and they also help ensure that use restrictions and other institutional controls are perpetuated.

X4.6.3.2 Actual notice of an environmental defect or failure to provide notice may give a party the right to cancel the transaction and result in civil penalties. For example, landlords and sellers who do not give notice as required by the state may be liable for actual damages plus fines. Nonresidential tenants who fail to notify landowners of suspected or actual hazardous substance releases can have their leases canceled and are subject to fines.

X4.6.4 *Notice to Government Authorities*—Parties to a land transaction may also be required to file the environmental statement with various environmental authorities. Notice to the government may be required before the transaction takes place.

X4.7 *Registry Act Requirements:*

X4.7.1 Some states have registry act programs that provide for the maintenance of a registry of hazardous waste disposal sites and the restriction of the use and transfer of listed sites.

X4.7.2 A typical registry act provides that the state environmental agency establish and maintain a registry of all real property which has been used for hazardous substance disposal either illegally or before regulation of hazardous waste disposal began in that state.

X4.7.3 The state agency is responsible for investigating potential sites for inclusion on the registry. The registry includes the location of the site and a listing of the hazardous wastes on the property, and may also include a classification of the level of health or environmental danger presented by the conditions on the property. The state agency may be required to perform detailed inspections of the site to determine its priority relative to other registered sites.

X4.7.4 Owners of sites proposed for inclusion on the registry have rights of hearing and appeal, and owners of sites on the registry have rights to modify or terminate their listing. In some cases, the owner of a site proposed for inclusion on the registry may obtain the withdrawal of the proposed registration by entering into a consent agreement with the state. Such a consent agreement establishes a timetable and responsibility for remedial action.

X4.7.5 When a site appears on the state registry, the owner must comply with regulatory requirements in regard to use and transfer of the site. The use of a site listed on the registry may not be changed without permission of the state agency. In negotiations for a conveyance of a registered site, the owner may be obligated to disclose the registration early in the process, and permission of the state agency may be required to convey a registered property. Under other schemes, permission to convey is not required, but the seller must notify the state agency of the transaction.

X4.7.6 Finally, registry acts require that the listing of a property on a hazardous materials site registry be recorded in the records of the appropriate locality so that the registration will appear in the chain of title.

X4.8 *Transfer Act Requirements:*

X4.8.1 Some states have transfer act programs that require full evaluation of all environmental issues before or after the transfer occurs. It may be that within such program, institutional controls can be established by way of consent

order, administrative order, or some other technique that establishes implementation and continued responsibility for institutional controls.

X4.8.2 A typical transfer act imposes obligations and confers rights on parties to a land transaction arising out of the environmental status of the property to be conveyed. Transfer acts impose information obligations on the seller or lessor of a property (see X4.6.3). That party must disclose general information about strict liability for cleanup costs as well as property-specific information, such as presence of hazardous substances, permitting requirements and status, releases, and enforcement actions and variances.

X4.8.3 Compliance with transfer act obligations in the manner prescribed is crucial for ensuring a successful conveyance. Sometimes the transfer act operates to render a transaction voidable before the transfer occurs. Failure to give notice in the required form and within the time period required or the revelation of an environmental violation or unremediated condition will relieve the transferee and the lender of any obligation to close the transaction, even if a contract has already been executed. Moreover, violation of the transfer act can be the basis for a lawsuit to recover consequential damages.

X4.9 *Contractual Obligations:*

X4.9.1 One system for ensuring the future restriction on use of a site, or the obligation to remediate a site, is to require private parties to restrict use by contract. While this method is often negotiated among private parties, it will be difficult, if not impossible, to institutionalize some control over that process without interfering with the abilities and rights of private parties to freely negotiate these liabilities.

X4.9.2 Another avenue is for the landowner or responsible party to obligate itself to the state by contract. The state may require a contractual commitment from the party to provide long-term monitoring of the site, use restrictions, and means of continued funding for remediation.

X4.10 *Continued Financial Responsibility*—Another aspect of institutional controls is the establishment of financial mechanisms by which a responsible party ensures continued funding of remediation measures and assurance to the satisfaction of the state.

X4.11 *References:*

X4.11.1 The following references serve as examples and are current as of the fourth quarter of 1993:

X4.11.1.1 *References for Deed Restrictions:*

- 24 New Jersey Regulations 400 (1992) (New Jersey Administration Code § 7.26D-8.2 (e) (2))
- 24 New Jersey Regulations 400-02 (1992) (New Jersey Administration Code §§ 7.26D-8.1-8.4)
- 24 New Jersey Regulations 401 (1992) (New Jersey Administration Code § 7.26D Appendix A, Model Document, Declaration of Environmental Restrictions and Grant of Easement, Item 8)
- Illinois Responsible Property Transfer Act § 7(c) (1985)
- Massachusetts Regulations Code Title _____ § 40.1071 (2) (1) & (k)
- Massachusetts Regulations Code, Title _____ § 40.1071(4)
- Michigan Administration Code 299.5719 (3) (e) (1990)
- Michigan Rules 299.5719 (2), (3) (d)

X4.11.1.2 *References for Use Restrictions:*

- 24 New Jersey Regulations 400 (New Jersey Administration Code § 7.26D-8.2 (d))
- Michigan Administration Code 299.5719 (3) (a), (b), (g)
- New Jersey Regulation 7.26D-8.4

X4.11.1.3 *References for Access Controls:*

Iowa Administration Code r. 334.121(b)
Michigan Rule 299.5719(3)(f)
New Jersey Regulations § 26D-8.2

X4.11.1.4 References for Notice:

California Health and Safety Code § 25359.7 (1981)
Illinois Responsible Property Transfer Act (1985)
Indiana Code §§ 13-7-22.5-1-22 (1989) ("Indiana Environmental Hazardous Disclosure and Responsible Party Transfer Law")
Massachusetts Regulations Code Title _____ §§ 40.107-1090 (1993)
Michigan Rule 299.5719(3)(e)

X4.11.1.5 References for Registry Act Requirements:

Iowa Code Ann. §§ 455B.426-455B.432, 455B.411 (1990)
Missouri Code Regulations Title 10, §§ 25-10.010, 25-3.250 (1993)

X4.11.1.6 References for Transfer Act Requirements:

Connecticut General Stat. §22a-134 et seq.
Illinois Responsible Property Transfer Act (1985)
Indiana Code §§ 13-7-22.5-1-22 (1989) ("Indiana Environmental Hazardous Disclosure and Responsible Party Transfer Law")
New Jersey Senate Bill No. 1070, the Industrial Site Recovery Act, amending the environmental cleanup Responsibility Act, N.J.S.A. 13-13 et seq.
New Jersey Spill Compensation and Control Act, N.J.S.A. 17:27 et seq.

X4.11.1.7 Reference for Contractual Obligations:

Michigan Rule 299.5719(2)

X4.11.1.8 Reference for Continued Financial Responsibility:

Michigan Rule 299.5719(2)

X5. EXAMPLE APPLICATIONS OF RISK-BASED CORRECTIVE ACTION

X5.1 Introduction—The following examples illustrate the use of RBCA at petroleum release sites. The examples are hypothetical and have been simplified in order to illustrate that RBCA leads to reasonable and protective decisions; nevertheless, they do reflect conditions commonly encountered in practice.

X5.2 Example 1—Corrective Action Based on Tier 1 Risk-Based Screening Levels:

X5.2.1 Scenario—A release from the underground storage tank (UST), piping, and dispenser system at a service station is discovered during a real estate divestment assessment. It is known that there are petroleum-impacted surficial soils in the area of the tank fill ports; however, the extent to which the soils are impacted is unknown. In the past, both gasoline and diesel have been sold at the facility. The new owner plans to continue operating the service station facility.

X5.2.2 Site Assessment—The responsible party completes an initial site assessment focussed on potential source areas (for example, tanks, lines, dispensers) and receptors. Based on historical knowledge that gasoline and diesel have been dispensed at this facility, chemical analyses of soil and ground water are limited to benzene, toluene, ethylbenzene, xylenes, and naphthalene. Site assessment results are summarized as follows:

X5.2.2.1 Field screening instruments and laboratory analyses indicate that the extent of petroleum-impacted soils is confined to the vicinity of the fill ports for the tanks. A tank and line test reveals no leaks; therefore, evidence suggests that soils are impacted due to spills and overfills associated with filling the storage tank.

X5.2.2.2 The current tanks and piping were installed five years ago.

X5.2.2.3 The concrete driveway is highly fractured.

X5.2.2.4 No other sources are present.

X5.2.2.5 The site is underlain by layers of fine to silty sands.

X5.2.2.6 Ground water, which is first encountered at 32 ft (9.7 m) below ground surface, is not impacted.

X5.2.2.7 Maximum depth at which hydrocarbons are detected is 13 ft (3.9 m). Maximum detected soil concentrations are as follows:

Compound	Depth Below Ground Surface, ft (m)	Concentration, mg/kg
Benzene	8 (2.4)	10
Ethylbenzene	4 (1.2)	4
Toluene	6.5 (1.9)	55

Xylenes	35 (10)	58
Naphthalene	2 (0.6)	17

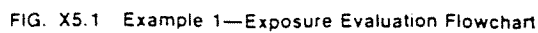
X5.2.2.8 A receptor survey indicates that two domestic water wells are located within 900 ft (273.6 m) of the source area. One well is located 500 ft (152.4 m) hydraulically down-gradient from the impacted soil zone, the other well is hydraulically up-gradient. Both wells produce water from the first encountered ground water zone.

X5.2.3 Site Classification and Initial Response Action—Based on classification scenarios given in Table 1, this site is classified as a Class 3 site because conditions are such that, at worst, it is a long-term threat to human health and environmental resources. The appropriate initial response is to evaluate the need for a ground water monitoring program. At most, this would consist of a single well located immediately down-gradient of the impacted petroleum soils. The responsible party recommends deferring the decision to install a ground water monitoring system until the Tier 1 evaluation is complete, and justifies this recommendation based on no detected ground water impact, the limited extent of impacted soils, and the separation between impacted soils and first-encountered ground water. The regulatory agency concurs with this decision.

X5.2.4 Development of Tier 1 Look-Up Table of Risk-Based Screening Level (RBSL)—Assumptions used to derive example Tier 1 RBSL Look-Up Table X2.1 in Appendix X2 are reviewed and presumed valid for this site. A comparison of RBSLs for both pathways of concern indicates that RBSLs associated with the leaching pathway are the most restrictive of the two. As this aquifer is currently being used as a drinking water supply, RBSL values based on meeting drinking water MCLs are selected. In the case of naphthalene, for which there is no MCL, the RBSL value corresponding to a residential scenario and a hazard quotient of unity is used.

X5.2.5 Exposure Pathway Evaluation—Based on current and projected future use, the only two potential complete exposure pathways at this site are: (1) the inhalation of ambient vapors by on-site workers, or (2) the leaching to ground water, ground water transport to the down-gradient drinking-water well, and ingestion of ground water (see Fig. X5.1).

X5.2.6 Comparison of Site Conditions With Tier 1 RBSLs—Based on the data given in X5.2.3.7 and the RBSLs given in Look-Up Table X2.1 in Appendix X2, exceedences of Tier 1 RBSLs are noted only for benzene and toluene.



X5.2.7 *Evaluation of Tier 1 Results*—The responsible party decides to devise a corrective action plan to meet Tier 1 standards after considering the following factors:

X5.2.7.1 The shallow aquifer is not yet affected.

X5.2.7.2 Quick (relative to rate of chemical migration) removal of the source will eliminate the need for ground water monitoring.

X5.2.7.3 The new owner plans to install new tanks within six months.

X5.2.7.4 Limited excavation of soils to meet Tier 1 criteria could be performed quickly and inexpensively when the tanks are removed, relative to the cost of proceeding to a Tier 2 analysis.

X5.2.7.5 An excavation proposal will facilitate the real estate deal.

X5.2.8 *Tier 1 Remedial Action Evaluation*—Excavate all impacted soils with concentrations above the Tier 1 RBSLs when the current tanks are replaced. Subsequently resurface the area with new concrete pavement to reduce future infiltration and leaching potential through any remaining impacted soils. It is agreed that ground water monitoring is not necessary and the governing regulatory agency agrees to issue a No Further Action and Closure letter following implementation of the corrective action plan.

X5.3 *Example 2—RBCA Based on Tier 2 Evaluation:*

X5.3.1 *Scenario*—During the installation of new double-contained product transfer lines, petroleum-impacted soils are discovered in the vicinity of a gasoline dispenser at a service station located close to downtown Metropolis. In the past, both gasoline and diesel have been sold at this facility, which has been operating as a service station for more than twenty years.

X5.3.2 *Site Assessment*—The owner completes an initial site assessment focussed on potential source areas (for example, tanks, lines, dispensers) and receptors. Based on historical knowledge that gasoline and diesel have been dispensed at this facility, chemical analyses of soil and ground water are limited to benzene, toluene, ethylbenzene, xylenes, and naphthalene. Results of the site investigation are as follows:

X5.3.2.1 The extent of petroleum-impacted soils is confined to the vicinity of the tanks and dispensers. A recent tank and line test revealed no leaks; therefore, evidence suggests that the releases occurred sometime in the past.

X5.3.2.2 The current tanks, lines, and dispensers were installed three years ago.

X5.3.2.3 The asphalt driveway is competent and not cracked.

X5.3.2.4 Another service station is located hydraulically down gradient, diagonally across the intersection.

X5.3.2.5 The site is underlain by silty sands with a few thin discontinuous clay layers.

X5.3.2.6 Ground water, which is first encountered at 32 ft (9.7 m) below ground surface, is impacted, with highest dissolved concentrations observed beneath the suspected source areas. Dissolved concentrations decrease in all directions away from the source areas, and ground water samples taken hydraulically down gradient from a well located in the center divider of the street (about 100 ft (30.4 m) from the source area) do not contain any detectable levels of dissolved hydrocarbons.

X5.3.2.7 Ground water flow gradient is very shallow and ground water flow velocities are at most tens of feet per year.

X5.3.2.8 Ground water yield from this aquifer is estimated to be in excess of 5 gal/min (18.9 L/min), and total dissolved solids levels are less than 700 mg/L. Based on this information, this aquifer is considered to be a potential drinking water supply.

X5.3.2.9 A shallow soil gas survey indicates that no detectable levels of hydrocarbon vapors are found in the utility easement running along the southern border of the property, or in soils surrounding the service station kiosk.

X5.3.2.10 Impacted soils extend down to the first encountered ground water. Maximum concentrations detected in soil and ground water are as follows:

Compound	Soil, mg/kg	Ground water, mg/L
Benzene	20	2
Ethylbenzene	4	0.5
Toluene	120	5
Xylenes	100	5.0
Naphthalene	2	0.05

X5.3.2.11 A receptor survey indicates that no domestic water wells are located within one-half mile of the site; however, there is an older residential neighborhood located 1200 ft (365.7 m) hydraulically down gradient of the site. Land use in the immediate vicinity is light commercial (for example, strip malls). The site is bordered by two streets and a strip mall parking lot.

X5.3.3 *Site Classification and Initial Response Action*—Based on classification scenarios given in Table 1, this site is classified as a Class 3 site because conditions are such that, at worst, it is a long-term threat to human health and environmental resources. The appropriate initial response is to evaluate the need for a ground water monitoring program. The owner proposes that the ground water monitoring well located hydraulically down gradient in the street divider be used as a sentinel well, and be sampled yearly. The regulatory agency concurs, provided that the well be sampled every six months.

X5.3.4 *Development of Tier 1 Look-Up Table of Risk-Based Screening Level (RBSL) Selection*—Assumptions used to derive example Tier 1 RBSL Look-Up Table X2.1 in Appendix X2 are reviewed and presumed valid for this site. Due to the very low probability of the exposure pathway actually being completed in the future, MCLs are not used and the site owner is able to negotiate Tier 1 RBSLs based on a 10^{-5} risk to human health for carcinogens and hazard quotients equal to unity for the noncarcinogens (based on ground water ingestion).

X5.3.5 *Exposure Pathway Evaluation*—Based on current and projected future use, and the soil gas survey results, there are no potential complete exposure pathways at this site. The down gradient residential neighborhood is connected to a public water supply system, and there is no local use of the impacted aquifer. However, being concerned about future uncontrolled use of the aquifer, the regulatory agency requests that the owner evaluate the ground water transport to residential drinking water ingestion pathway, recognizing that there is a low potential for this to occur (see Fig. X5.2).

X5.3.6 *Comparison of Site Conditions With Tier 1 RBSLs*—Based on the data given in X5.3.2.10 and the RBSLs given in example Look-Up Table X2.1 in Appendix X2.

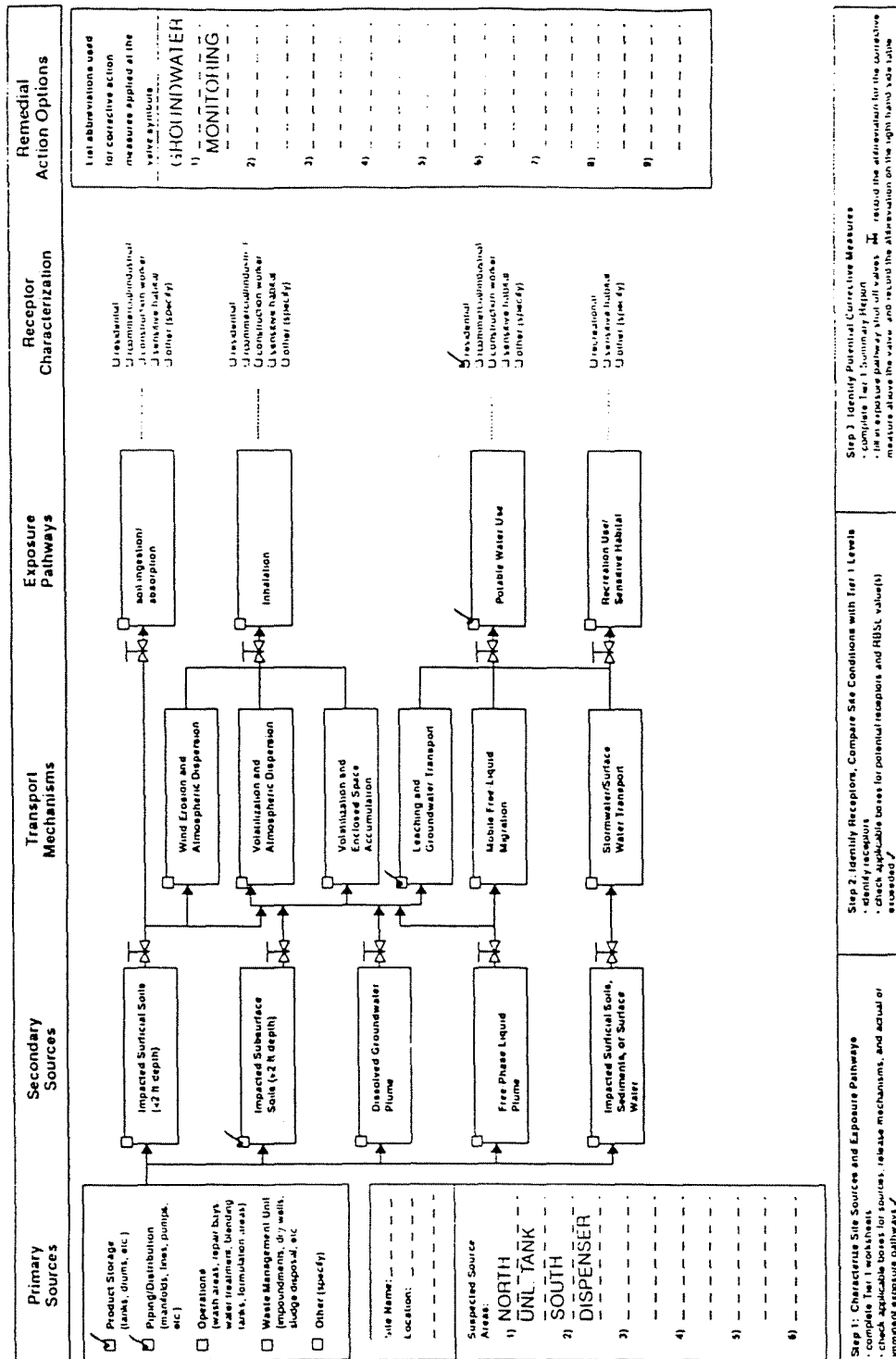


FIG. X5.2 Example 2—Exposure Evaluation Flowchart

exceedences of Tier 1 soil and ground water RBSLs are noted only for benzene.

X5.3.7 Evaluation of Tier 1 Results—The responsible party decides to proceed to a Tier 2 evaluation for benzene and the pathway of concern, rather than devise a corrective action plan to meet Tier 1 standards after considering the following factors:

X5.3.7.1 The shallow aquifer is impacted, but the dissolved plume appears to be stable and ground water movement is very slow.

X5.3.7.2 Excavation of soils to meet Tier 1 criteria would be expensive, due to the depth of impacted soils. Excavation would shut down the facility, and require all tanks and new lines to be removed and reinstalled.

X5.3.7.3 Costs for application of other conventional treatment methods, such as vapor extraction and pump and treat, are estimated to exceed \$300 000 over the life of the remediation, and

X5.3.7.4 A tier 2 analysis for this site is estimated to require minimal additional data, and is anticipated to result in equally protective, but less costly corrective action.

X5.3.8 Tier 2 Evaluation—The owner collects additional ground water monitoring data and verifies that:

X5.3.8.1 No mobile free-phase product is present.

X5.3.8.2 The dissolved plume is stable and ground water concentrations appear to be decreasing with time.

X5.3.8.3 Extent of the dissolved plume is limited to within 50 ft (15.2 m) of the property boundaries.

X5.3.8.4 Dissolved oxygen concentrations are higher outside of the dissolved plume, indicating some level of aerobic biodegradation.

X5.3.8.5 Ground water movement is less than 50 ft/year (15.2 m), and

X5.3.8.6 Simple ground water transport modeling indicates that observations are consistent with expectations for the site conditions.

X5.3.9 Remedial Action Evaluation—Based on the demonstration of dissolved plume attenuation with distance, the owner negotiates a corrective action plan based on the following: (1) compliance with the Tier 1 RBSLs at the monitoring well located in the street center divider, provided that deed restrictions are enacted to prevent the use of ground water within that zone until dissolved levels decrease below drinking water MCLs, (2) deed restrictions are enacted to ensure that site land use will not change significantly, (3) continued sampling of the sentinel/compliance ground water monitoring well on a yearly basis, (4) should levels exceed Tier 1 RBSLs at that point for any time in the future, the corrective action plan will have to be revised, and (5) closure will be granted if dissolved conditions remain stable or decrease for the next two years.

X5.4 Example 3—RBCA With Emergency Response and In Situ Remediation:

X5.4.1 Scenario—A 5 000-gal (18 925-L) release of super unleaded gasoline occurs from a single-walled tank after repeated manual gaging with a gage stick. Soils are sandy at this site, ground water is shallow, and free-product is observed in a nearby monitoring well within 24 h. The site is located next to an apartment building that has a basement where coin-operated washers and dryers are located for use by the tenants.

X5.4.2 Site Assessment—In this case the initial site assessment is conducted rapidly and is focussed towards identifying if immediately hazardous conditions exist. It is known from local geological assessments that the first encountered ground water is not potable, as it is only about 2 ft (0.6 m) thick and is perched on a clay aquitard. Ground water monitoring wells in the area (from previous assessment work) are periodically inspected for the appearance of floating product, and vapor concentrations in the on-site utility corridors are analyzed with an explosimeter. While this flurry of activity begins, a tenant of the apartment building next door informs the station operator that her laundry room/basement has a strong gasoline odor. Explosimeter readings indicate vapor concentrations are still lower than explosive levels, but the investigation team notes that "strong gasoline odors" are present.

X5.4.3 Site Classification and Initial Response Action—This limited information is sufficient to classify this site as a Class 2 site (strong potential for conditions to escalate to immediately hazardous conditions in the short term), based on the observed vapor concentrations, size of the release, and geological conditions. The initial response implemented is as follows:

X5.4.3.1 Periodic monitoring of the apartment basement begins to ensure that levels do not increase to the point where evacuation is necessary (either due to explosion or acute health effects). In addition, the fire marshal is notified and building tenants are informed of the activities at the site, potential hazards, and abatement measures being implemented.

X5.4.3.2 A free-product recovery/hydraulic control system is installed to prevent further migration of the mobile liquid gasoline, and

X5.4.3.3 A subsurface vapor extraction system is installed to prevent vapor intrusion to the building.

X5.4.4 Development of Tier 1 Look-Up Table of Risk-Based Screening Level (RBSL) Selection—Assumptions used to derive example Tier 1 RBSL Look-Up Table X2.1 in Appendix X2 are reviewed and presumed valid for this site. Target soil and ground water concentrations are determined based on the vapor intrusion scenario. After considering health-based, OSHA PEL, national ambient background, and aesthetic vapor concentrations, target soil levels are based on achieving a 10^{-4} chronic inhalation risk for benzene, and hazard quotients of unity for all other compounds. The agency agrees to base compliance on the volatile monoaromatic compounds in gasoline (benzene, toluene, xylenes, and ethylbenzene), but reserves the right to alter the target levels if aesthetic effects persist in the building basement at the negotiated levels.

X5.4.5 Exposure Pathway Evaluation—Given that: (1) there is a very low potential for ground water usage, (2) a 20-ft (6.1-m) thick aquitard separates the upper perched water from any potential drinking water supplies, and (3) the close proximity of the apartment building, the owner proposes focusing on the vapor intrusion—residential inhalation scenario (see Fig. X5.3). The agency concurs, but in order to eliminate potential ground water users as receptors of concern, requests that a down-gradient piezometer be installed in the lower aquifer. The owner concurs.

X5.4.6 Comparison of Site Conditions With Tier 1

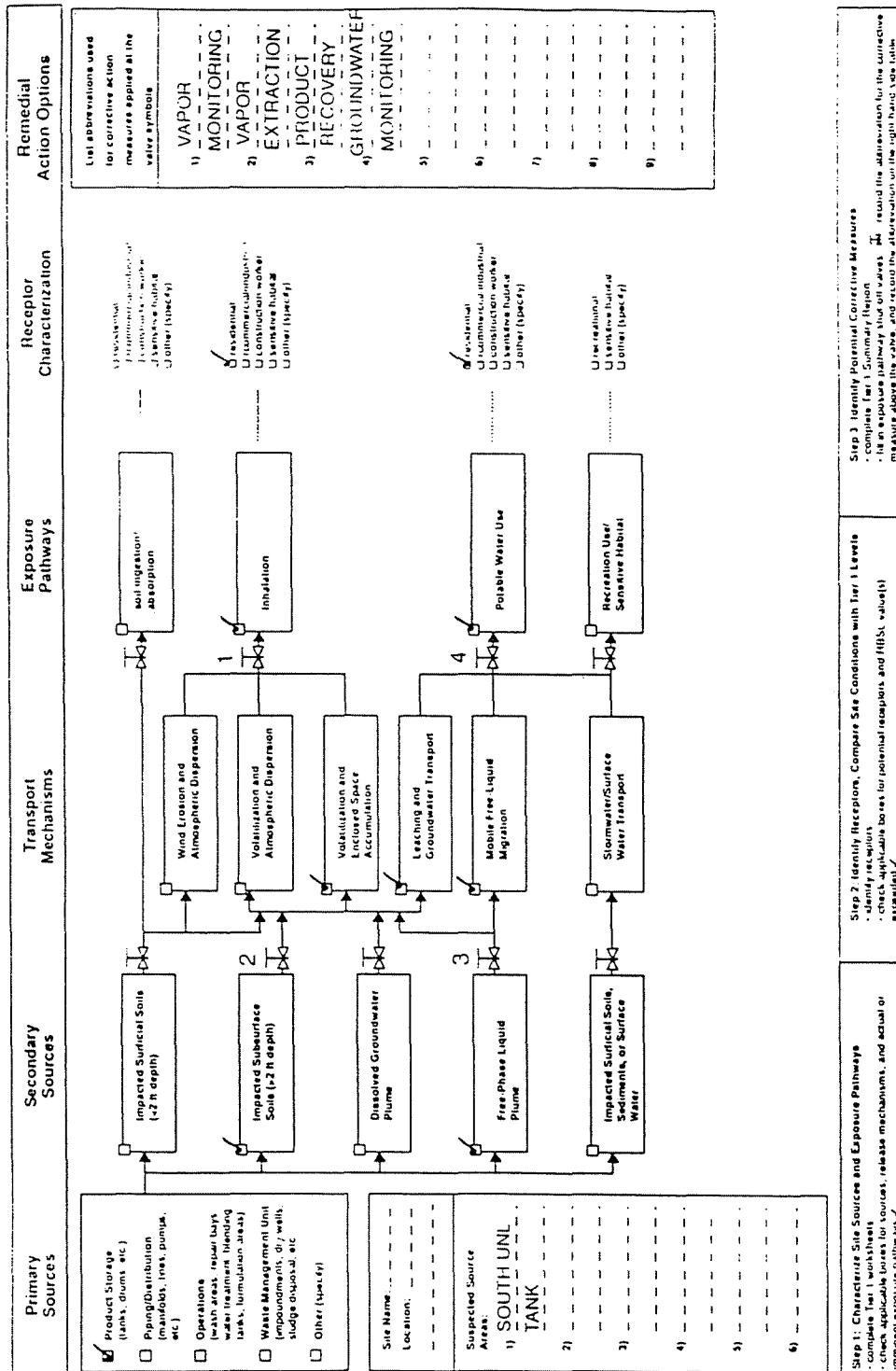


FIG. X5.3 Example 3—Exposure Evaluation Flowchart

RBSLs—While a complete initial site investigation has yet to be conducted, all parties agree that currently the RBSLs are likely to be exceeded.

X5.4.7 Evaluation of Tier 1 Results—The owner decides to implement an interim corrective action plan based on Tier 1 RBSLs, but reserves the right to propose a Tier 2 evaluation in the future.

X5.4.8 Tier 1 Remedial Action Evaluation—The owner proposes expanding the vapor extraction system to remediate source area soils. In addition he proposes continuing to operate the free-product recovery/hydraulic control system until product recovery ceases. Monitoring of the piezometer placed in the lower aquifer will continue, as well as periodic monitoring of the apartment building basement. Additional assessments will be conducted to ensure that building vapors are not the result of other sources. After some period of operation, when hydrocarbon removal rates decline, a soil and ground water assessment plan will be instituted to collect data to support a Tier 2 evaluation.

X5.5 Example 4—RBCA Based on Use of a Tier 2 Table Evaluation—In circumstances where site-specific data are similar among several sites, a table of Tier 2 SSTL values can be created. The following example uses such a table.

X5.5.1 Scenario—Petroleum-impacted ground water is discovered in monitoring wells at a former service station. The underground tanks and piping were removed, and the site is now occupied by an auto repair shop.

X5.5.2 Site Assessment—The responsible party completes an initial site assessment to determine the extent of hydrocarbon-impacted soil and ground water. Because gasoline was the only fuel dispensed at the site, the assessment focussed on benzene, toluene, ethylene benzene, and xylenes (BTEX) as the chemicals of concern. Site assessment results are summarized as follows:

X5.5.2.1 The area of hydrocarbon-impacted soil is approximately 18 000 ft² (1672 m²) and the depth of soil impaction is less than 5 ft (1.5 m); The plume is off site,

X5.5.2.2 The site is covered by asphalt or concrete,

X5.5.2.3 The site is underlain by clay,

X5.5.2.4 Hydrocarbon-impacted perched ground water is encountered at 1 to 3 ft (0.3 to 0.9 m) below grade. This water is non-potable. The first potable aquifer is located over

100 ft (30 m) below grade and is not impacted. There is no free product.

X5.5.2.5 Maximum detected concentrations are, as follows:

Compound	Soil, mg/kg	Ground water, mg/L
Benzene	39	1.8
Toluene	15	4.0
Ethylbenzene	12	0.5
Xylenes	140	9.0

X5.5.2.6 Ground water velocity is 0.008 ft/day (0.0024 m/day) based on slug tests and ground water elevation survey and assumed soil porosity of 50 %.

X5.5.2.7 A receptor survey indicates that the nearest down gradient water well is greater than 1.0 mile (1.6 km) away and the nearest surface water body is 0.5 miles (0.8 km). The distance to the nearest sensitive habitat is greater than 1.0 mile; however, there is a forest preserve frequented by day hikers and picnickers next to the site. The nearest home is 1000 ft (305 m) away. The commercial building on site is 25 ft (7.6 m) from the area of hydrocarbon-impacted soil.

X5.5.3 Site Classification and Initial Response Action—Based on the classification scenarios given in Table 1, this site is classified as a Class 4 site, with no demonstrable long-term threat to human health, safety, or sensitive environmental receptors, because the hydrocarbon-impacted soils are covered by asphalt or concrete and cannot be contacted, only non-potable perched water with no existing local use is impacted, and there is no potential for explosive levels or concentrations that could cause acute effects in nearby buildings. The appropriate initial response is to evaluate the need for a ground water monitoring program.

X5.5.4 Development of Tier 1 Look-Up Table of Risked-Based Screening Level (RBSL)—The assumptions used to derive the example Tier 1 RBSL Look-Up Table are presumed valid for this site.

X5.5.5 Exposure Pathway Evaluation—The complete pathways are ground water and soil volatilization to enclosed spaces and to ambient air, and direct exposure to impacted soil or ground water by construction workers. A comparison of RBSLs for these pathways of concern indicates that

TABLE X5.1 Example 1—Site Classification and Initial Response Actions

Criteria and Prescribed Scenarios	Example Initial Response Actions
<p>3. Long-term (>2 years) threat to human health, safety, or sensitive environmental receptors</p> <ul style="list-style-type: none"> Subsurface soils (>3 ft (0.9 m) BGS) are significantly impacted, and the depth between impacted soils and the first potable aquifer is less than 50 ft (15 m). Ground water is impacted, and potable water supply wells producing from the impacted interval are located >2 years ground water travel time from the dissolved plume. Ground water is impacted, and non-potable water supply wells producing from the impacted interval are located >2 years ground water travel time from the dissolved plume. Ground water is impacted, and non-potable water supply wells that do not produce from the impacted interval are located within the known extent of chemical(s) of concern. Impacted surface water, storm water, or ground water discharges within 1500 ft (457 m) of a sensitive habitat or surface water body used for human drinking water or contact recreation. Shallow contaminated surface soils are open to public access, and dwellings, parks, playgrounds, day-care centers, schools, or similar-use facilities are more than 500 ft (152 m) of those soils. 	<p>Notify appropriate authorities, property owners, and potentially affected parties, and evaluate the need to</p> <ul style="list-style-type: none"> Monitor ground water and determine the potential for future migration of the chemical(s) of concern to the aquifer. Monitor the dissolved plume and evaluate the potential for natural attenuation and the need for hydraulic control. Identify water usage of well, assess the effect of potential impact, monitor the dissolved plume, and evaluate whether natural attenuation or hydraulic control are appropriate control measures. Monitor the dissolved plume, determine the potential for vertical migration, notify the user, and determine if any impact is likely. Investigate current impact on sensitive habitat or surface water body, restrict access to area of discharge (if necessary), and evaluate the need for containment/control measures. Restrict access to impact soils.

TABLE X5.2 Example 2—Site Classification and Initial Response Actions

Criteria and Prescribed Scenarios		Example Initial Response Actions	
3	Long-term (>2 years) threat to human health, safety, or sensitive environmental receptors	Notify appropriate authorities, property owners, and potentially affected parties and evaluate the need to	
	<ul style="list-style-type: none"> Subsurface soils (>3 ft (0.9 m) BGS) are significantly impacted, and the depth between impacted soils and the first potable aquifer is less than 50 ft (15 m) Ground water is impacted, and potable water supply wells producing from the impacted interval are located >2 years ground water travel time from the dissolved plume. Ground water is impacted, and non-potable water supply wells producing from the impacted interval are located >2 years ground water travel time from the dissolved plume. Ground water is impacted, and non-potable water supply wells that do not produce from the impacted interval are located within the known extent of chemical(s) of concern. Impacted surface water, storm water, or ground water discharges within 1500 ft (457 m) of a sensitive habitat or surface water body used for human drinking water or contact recreation. Shallow contaminated surface soils are open to public access, and dwellings, parks, playgrounds, day-care centers, schools, or similar-use facilities are more than 500 ft (152 m) of those soils 	<ul style="list-style-type: none"> Monitor ground water and determine the potential for future contaminant migration to the aquifer Monitor the dissolved plume and evaluate the potential for natural attenuation and the need for hydraulic control Identify water usage of well, assess the effect of potential impact, monitor the dissolved plume, and evaluate whether natural attenuation or hydraulic control are appropriate control measures Monitor the dissolved plume, determine the potential for vertical migration, notify the user, and determine if any impact is likely Investigate current impact on sensitive habitat or surface water body, restrict access to area of discharge (if necessary), and evaluate the need for containment/control measures. Restrict access to impact soils. 	

TABLE X5.3 Example 3—Site Classification and Initial Response Actions

Criteria and Prescribed Scenarios		Example Initial Response Actions	
2	Short-term (0 to 2 years) threat to human health, safety, or sensitive environmental receptors	Notify appropriate authorities, property owners, and potentially affected parties, and evaluate the need to	
	<ul style="list-style-type: none"> There is potential for explosive levels, or concentrations of vapors that could cause acute effects, to accumulate in a residence or other building. Shallow contaminated surface soils are open to public access, and dwellings, parks, playgrounds, day-care centers, schools, or similar use facilities are within 500 ft (152 m) of those soils. A non-potable water supply well is impacted or immediately threatened Ground water is impacted, and a public or domestic water supply well producing from the impacted aquifer is located within two-years projected ground water travel distance down gradient of the known extent of chemical(s) of concern Ground water is impacted, and a public or domestic water supply well producing from a different interval is located within the known extent of chemicals of concern Impacted surface water, storm water, or ground water discharges within 500 ft (152 m) of a sensitive habitat or surface water body used for human drinking water or contact recreation. 	<ul style="list-style-type: none"> Assess the potential for vapor migration (through monitoring/modeling) and remove source (if necessary), or install vapor migration barrier. Remove soils, cover soils, or restrict access. Notify owner/user and evaluate the need to install point-of-use water treatment, hydraulic control, or alternate water supply. Institute monitoring and then evaluate if natural attenuation is sufficient, or if hydraulic control is required. Monitor ground water well quality and evaluate if control is necessary to prevent vertical migration to the supply well. Institute containment measures, restrict access to areas near discharge, and evaluate the magnitude and impact of the discharge. 	

RBSLs associated with soil volatilization to an enclosed space are the most restrictive RBSLs.

X5.5.6 Comparison of Site Conditions with Tier 1 RBSLs—Based on the data given in X5.5.2 and the RBSLs given in Table X2.1, exceedances of Tier 1 RBSLs are noted for benzene in soil and ground water and toluene for ground water.

X5.5.7 Evaluation of Tier 1 Results—The responsible party decided to proceed to a Tier 2 evaluation for the pathways of concern rather than develop a corrective action plan for the following reasons:

X5.5.7.1 Only shallow perched water is impacted, and the dissolved plume is moving very slowly in tight clay.

X5.5.7.2 Excavation of soils to meet Tier 1 criteria would be expensive and would disrupt activities of the on-site business. Off-site excavation would be impractical and may not be able to clean up ground water to Tier 1 criteria.

X5.5.7.3 Other conventional treatment methods, such as pump and treat and vapor extraction, would be relatively ineffective in the heavy clay, and

X5.5.7.4 A Tier 2 evaluation for this site requires no

additional data and is expected to be an equally protective but less costly corrective action.

X5.5.8 Development of a Tier 2 Table of Site-Specific Target Levels (SSTLs)—The Tier 2 table is similar to the Tier 1 Look-Up Table with the exception that SSTLs for the pathways of concern are presented as functions of both the distance from the source to the receptor and the soil type.

X5.5.8.1 For the pathways considered, approaches for the Tier 2 table are consistent with guidelines contained in Ref (26).

X5.5.8.2 The equations, assumptions, and parameters used to construct the Tier 1 Look-Up Table and Tier 2 table are similar, except as noted as follows:

(1) **Ground Water: Ingestion of Ground Water**—A one-dimensional analytical mass balance equation with attenuation mechanisms of retardation, dispersivity, and first-order biological decay (in sandy soil only) was applied in conjunction with the equations in Tables X2.2 and X2.3 to calculate SSTLs. The analytical model is limited to steady-state conditions and longitudinal dispersion. The analytical solution to the mass balance equation is presented in Ref (44).

TABLE X5.4 Example Tier 2 Site-Specific Target Level (SSTL) Table—Soil and Ground Water

	Exposure Pathway	Receptor Scenario	Distance to Source, ft. (m)	SSTLs at Source Sandy Soil Natural Biodegradation Carcinogenic Risk = 1×10^{-5} , HQ = 1				SSTLs at Source Clay Soil, No Natural Biodegradation Carcinogenic Risk = 1×10^{-5} , HQ = 1			
				Benzene	Ethylbenzene	Toluene	Xylene	Benzene	Ethylbenzene	Toluene	Xylene
Soil	Soil vapor intrusion from soil to buildings	residential	10 (3)	0.052	18	11	450	1.7	570	300	9500
			25 (7.6)	0.47	160	160	1.7 ^a	65	11 ^a	10 ^a	RES ^b
		commercial/industrial	100 (30)	3.1 ^a	RES	RES	RES	RES	RES	RES	RES
			10 (3)	0.13	39	24	980	4.3	1200	550	2.0 ^a
	Surficial soil ingestion and dermal	residential	25 (7.6)	1.2	340	340	3.6 ^a	950	24 ^a	22.5 ^a	RES
			100 (30)	8.0 ^a	RES	RES	RES	RES	RES	RES	RES
		commercial/industrial		22	5100	5400	280	22	5100	5400	280
				120	9600	1.7 ^a	1500	117	9600	1.7 ^a	1500
	Soil leachate to protect ground water ingestion target level	residential	0 (0)	0.17	47	130	2200	0.17	47	130	2200
			100 (30)	0.32	88	250	4200	0.20	130	760	RES
		commercial/industrial	500 (152)	4.0	1200	6300	RES	RES	RES	RES	RES
			0 (0)	0.58	130	350	6200	0.58	130	350	6200
Ground Water	Ground water ingestion	residential	100 (30)	1.1	250	670	1.2 ^a	0.70	380	2100	RES
			500 (152)	13	3300	1.75 ^a	RES	RES	RES	RES	RES
		commercial/industrial	0	0.029	3.6	7.3	73	0.029	3.6	7.3	73
			100	0.054	6.8	14	140	0.035	10	43	>S ^c
	Ground water vapor intrusion from ground water to buildings	residential	500	0.68	90	350	>S	>S	>S	>S	>S
			0	0.099	10	20	200	0.099	10	20	200
		commercial/industrial	100	0.185	19	38	>S	0.12	29	120	>S
			500	2.3	250	>S	>S	>S	>S	>S	>S
	Ground water vapor intrusion from ground water to buildings	residential	10	0.11	32	17	510	5.0	>S	>S	>S
			25	0.72	210	160	>S	1200	>S	>S	>S
		commercial/industrial	100	>S	>S	>S	>S	>S	>S	>S	>S
			10	0.28	70	36	>S	13	>S	>S	>S
	industrial	25	1.9	>S	350	>S	>S	>S	>S	>S	
		100	>S	>S	>S	>S	>S	>S	>S	>S	

^a Weight percent.^b RES—Selected risk level is not exceeded for pure compound present at any concentration.^c >S—Selected risk level is not exceeded for all possible dissolved levels.

(2) *Ground Water: Inhalation of Outdoor Vapors*—This pathway was not considered because exposure concentrations were very low.

(3) *Ground Water: Inhalation of Enclosed-Space (Indoor) Vapors*—A one-dimensional mass balance equation following Jury, et al (31) has been used to model vapor transport (43). This model was used in conjunction with the equations in Table X2.2 and X2.3 to calculate SSTLs. The model includes concentration attenuation between the source and the building by partitioning into immobile pore water, adsorption onto soil, and biological degradation (in sandy soil only).

(4) *Subsurface Soils: Inhalation of Outdoor Vapors*—This pathway was not considered because exposure concentrations were very low.

(5) *Subsurface Soils: Inhalation of Enclosed-Space (Indoor) Vapors*—The SSTLs were calculated using the Jury model (31) as discussed in Paragraph (3) of X5.5.8.2.

(6) *Subsurface Soils: Leaching to Ground Water*—The SSTLs were calculated using the one-dimensional mass-balance equation described in Paragraph (1) of X5.5.8.2, in conjunction with the leachate factor, LF_{SIL} , as discussed in X2.9.4.1.

(7) All exposure parameter values listed in Table X2.4, soil, building surface, and subsurface parameter values listed in Table X2.6, and chemical-specific properties listed in Table X2.7 have not been changed.

(8) First-order decay rates in sandy soil were assumed to be 0.2 % per day for all BTEX compounds. These rates are considered conservative. Chiang, et al (38) determined that a

DO of 2.0 mg/L is required for rapid and complete biodegradation of benzene. Chiang, et al (38) measured a biodegradation rate of 0.95 % per day, and Barker, et al (36) measured a biodegradation rate of 0.6 % per day for benzene. In general, published biodegradation rates range from 0.6 to 1.25 % per day. Chiang, et al (38) also determined that biodegradation rates may be slower and incomplete at DO concentrations below 2.0 mg/L. This is a conservative value since aerobic biodegradation continues at DO concentrations as low as 0.7 mg/L (44).

(9) Clay properties are as follows:

Total soil porosity, cm ³ /cm ³	0.05
Volumetric water content, cm ³ /cm ³	0.40
Ground water Darcy velocity, cm/s	25

X5.5.8.3 Assumptions used to derive the example Tier 2 SSTL table are reviewed and presumed valid for this site. Due to the very conservative assumptions used to calculate exposure and the small number of people potentially exposed, the Tier 2 SSTLs are based on a 10^{-5} risk to human health for carcinogens and hazard quotients equal to unity for noncarcinogens.

X5.5.9 *Comparison of Site Conditions with Tier 2 Table SSTLs*—Based on the data given in X5.5.2 and the SSTLs given in the example table, no exceedances of Tier 2 soil or ground water SSTLs are noted.

X5.5.10 *Tier 2 Remedial Action Evaluation*—Based on the fact that Tier 2 soil or ground water SSTLs are not exceeded, the responsible party negotiates a corrective action plan based on the following:

X5.5.10.1 Annual compliance monitoring of ground

water at down gradient monitoring wells will be performed to demonstrate decreasing concentrations.

X5.5.10.2 Should levels exceed Tier 2 SSTLs at any of these monitoring points at any future time, the corrective

action plan will be reevaluated, and

X5.5.10.3 Closure will be granted if dissolved concentrations remain stable or decrease for the next two years.

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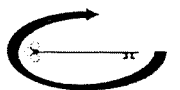
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APPENDIX B

Steven Winter Associates Report



RISK-BASED SCREENING LEVELS

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1.0 INTRODUCTION

BENCHMARK Environmental Engineering & Science, PLLC (BEES) requested that Steven Winter Associates, Inc. (SWA) complete an ASTM E1739-95 Tier 1 screening evaluation for six polycyclic aromatic hydrocarbons (PAHs), assuming a commercial/industrial exposure and considering both 10^{-4} and 10^{-6} cancer risk scenarios. The PAHs consist of benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, chrysene, and dibenzo(a,h)anthracene.

Specific worker exposure pathways to be evaluated included exposure to soils and soil vapors (ingestion, dermal contact, inhalation) via utility/foundation work; and exposure to vapors entering buildings (from subsurface soils) via cracks in the floor slab.

In addition, information related to cyanide cleanup levels for soil was also requested.

2.0 METHOD

From ASTM E1739-95, Tables X2.2 and X2.3, the following equations were selected to develop the Tier 1 risk-based screening levels (RBSLs):

EQUATION	MEDIUM	EXPOSURE ROUTE
5	Surficial soil	Ingestion of soil, inhalation of vapors and particulates, and dermal contact
7	Subsurface soil	Enclosed space (indoor) vapor inhalation

The equations are as follows:

EQUATION 5 (Carcinogenic Effects):

Surficial soil: ingestion of soil, inhalation of vapors and particulates, and dermal contact:

$$RBSL_s \left[\frac{mg}{kg - soil} \right] = \frac{TR \times BW \times AT_c \times 365 \frac{days}{year}}{EF \times ED \left[\left(SF_o \times 10^{-6} \frac{kg}{mg} \times (IR_{soil} \times RAF_o + SA \times M \times RAF_d) \right) + \left(SF_i \times IR_{air} \times (VF_s + VF_p) \right) \right]}$$

EQUATION 5 (Non-Carcinogenic Effects):

Surficial soil: ingestion of soil, inhalation of vapors and particulates, and dermal contact:

$$RBSL_s \left[\frac{mg}{kg - soil} \right] = \frac{THQ \times BW \times AT_n \times 365 \frac{days}{year}}{EF \times ED \frac{\left(10^{-6} \frac{kg}{mg} \times (IR_{soil} \times RAF_o + SA \times M \times RAF_d) \right)}{RfD_o} + \frac{(IR_{air} \times (VF_{ss} + VF_p))}{RfD_i}}$$

EQUATION 7 (Carcinogenic Effects):

Subsurface soil: ambient space (indoor) vapor inhalation:

$$RBSL_s \left[\frac{mg}{kg - soil} \right] = \frac{RBSL_{air} \left[\frac{\mu g}{m^3 - air} \right]}{VF_{seep}} \times 10^{-3} \frac{mg}{\mu g}$$

EQUATION 7 (Non-Carcinogenic Effects):

Subsurface soil: ambient space (indoor) vapor inhalation

$$RBSL_s \left[\frac{mg}{kg - soil} \right] = \frac{RBSL_{air} \left[\frac{\mu g}{m^3 - air} \right]}{VF_{seep}} \times 10^{-3} \frac{mg}{\mu g}$$

The terms in these equations include:

AT _c	averaging time for carcinogens, years
AT _n	averaging time for noncarcinogens, years
BW	adult body weight, kg
ED	exposure duration, years
EF	exposure frequency, days/years
IR _{air}	daily inhalation rate, m ³ /day
IR _{soil}	soil ingestion rate, mg/day
M	soil to skin adherence factor, mg/cm ²
RAF _d	dermal relative absorption factor, PAHs
RAF _o	oral relative absorption factor

RBSL _{air}	risk-based screening level for air, (mg/m ³ -air)
RBSL _s	risk-based screening level for soil, (mg/kg-soil)
RfD _i	inhalation chronic reference dose, (mg/kg-day)
RfD _o	oral chronic reference dose, (mg/kg-day)
SA	skin surface area, (cm ² /day)
SF _i	inhalation cancer slope factor, (mg/kg-day) ⁻¹
SF _o	oral cancer slope factor, (mg/kg-day) ⁻¹
THQ	target hazard quotient for individual constituents, unitless
TR	target excess individual lifetime cancer risk, unitless
VF _p	volatilization factor, surficial soil to ambient air (particulates)
VF _{scsp}	volatilization factor, subsurface soil to ambient air (vapors)
VF _{ss}	volatilization factor, subsurface soil to enclosed space vapors

No modification was made to the values listed by ASTM for commercial/industrial exposure and various soil, building, surface and subsurface parameters, from Tables X2.4 and X2.6 in the standard. For the chemical-specific parameters, values were generally selected from USEPA and NYSDEC/NYSDOH sources. The selected chemical-specific values are identified in Table 1. For one of the parameters (i.e., the carbon-water sorption coefficient) two different values were obtained. Calculations using these values were computed separately, so that the most conservative (lowest) RBSL could be identified.

<p align="center">TABLE 1</p> <p align="center">CHEMICAL-SPECIFIC VALUES</p>			
PARAMETER	DEFINITION	VALUE	SOURCE
RfD_i	Inhalation chronic reference dose, mg/kg-day	3E-02	NYSDOH Division of Environmental Health, Bureau of Toxic Substances Assessment. In absence of values for the 6 PAHs, the RfD_o for pyrene is used.
RfD_o	Oral chronic reference dose, mg/kg-day	3E-02	NYSDOH Division of Environmental Health, Bureau of Toxic Substances Assessment. In absence of values for the 6 PAHs, the RfD_o for pyrene is used.
SF_i	Inhalation cancer slope factor (mg/kg/day)⁻¹	For benzo(a) pyrene, 2.1 (mg/kg/day)⁻¹, based on a unit risk of 6E-4/μg/m³. Weighting factors for 5 other PAHs as follows: benzo(a)anthracene: 0.1; benzo(b)fluoranthene: 0.1; benzo(k)fluoranthene: 0.01; chrysene: 0.01; and dibenz(a,h)anthracene: 1.0.	NYSDOH Division of Environmental Health, Bureau of Toxic Substances Assessment.
SF_o	Oral cancer slope factor (mg/kg/day)⁻¹	For benzo(a)pyrene, 7.3. Weighting factors for the other 5 PAHs: benzo(a)anthracene: 0.1; benzo(b)fluoranthene: 0.1; benzo(k)fluoranthene: 0.01; chrysene: 0.01; and dibenz(a,h)anthracene: 1.0.	EPA's Integrated Risk Information System database. EPA's Provisional Guidance for Quantitative Risk Assessment of Polycyclic Aromatic Hydrocarbons for relative potency, with the exception of the weighting factor for chrysene. The value for chrysene is provided by the NYSDOH Division of Environmental Health, Bureau of Toxic Substances Assessment.

TABLE 1			
CHEMICAL-SPECIFIC VALUES			
PARAMETER	DEFINITION	VALUE	SOURCE
H	Henry's law constant (cm ³ -H ₂ O)/(cm ³ -air)	benzo(a)anthracene: 3.35E-06 benzo(a)pyrene: 1.13E-06 benzo(b)fluoranthene: 1.11E-04 benzo(k)fluoranthene: 8.29E-07 chrysene: 9.46E-05 dibenz(a,h)anthracene: 1.47E-08	USEPA Soil Screening Guidance Technical Manual, Table 36.
k_{oc}	Carbon-water sorption coefficient, cm ³ -H ₂ O/g-C	benzo(a)anthracene: 1,380,000 benzo(a)pyrene: 5,500,000 benzo(b)fluoranthene: 550,000 benzo(k)fluoranthene: 550,000 chrysene: 200,000 dibenz(a,h)anthracene: 33,000,000	NYS TAGM 4046, Appendix A, Table 1.
k_{oc} (Alternate)	Carbon-water sorption coefficient, cm ³ -H ₂ O/g-C	benzo(a)anthracene: 3.98E+05 benzo(a)pyrene: 1.02E+06 benzo(b)fluoranthene: 1.23E+06 benzo(k)fluoranthene: 1.23E+06 chrysene: 3.98E+05 dibenz(a,h)anthracene: 3.80E+06	USEPA Soil Screening Guidance Technical Manual, Table 39.
D^{air}	Diffusion coefficient in air, cm ² /s	benzo(a)anthracene: 5.10E-02 benzo(a)pyrene: 4.3E-02 benzo(b)fluoranthene: 2.26E-02 benzo(k)fluoranthene: 2.26E-02 chrysene: 2.48E-02 dibenz(a,h)anthracene: 2.02E-02	USEPA Soil Screening Guidance Technical Manual, Table 37.
D^{wet}	Diffusion coefficient in water, cm ² /s	benzo(a)anthracene: 9.00E-06 benzo(a)pyrene: 9.00E-06 benzo(b)fluoranthene: 5.56E-06 benzo(k)fluoranthene: 5.56E-06 chrysene: 6.21E-06 dibenz(a,h)anthracene: 5.18 E-06	USEPA Soil Screening Guidance Technical Manual, Table 37.
D^{wet} (Alternate)	Diffusion coefficient in water, cm ² /s	benzo(a)anthracene: 6.07 E-06 benzo(a)pyrene: 5.71E-06 benzo(b)fluoranthene: 5.72 E-06 benzo(k)fluoranthene: 5.71 E-06 chrysene: 6.29 E-06 dibenz(a,h)anthracene: 5.39 E-06	Wilke-Chang technique, as published in Perry's Chemical Engineer's Handbook, sixth ed., calculated by BEES.

3.0 RESULTS

The results of the PAH analysis are presented in Table 2. The computer spreadsheets used to derive these values are contained in Appendix A.

TABLE 2						
RISK-BASED SCREENING LEVELS FOR COMMERCIAL/INDUSTRIAL EXPOSURE BASED ON ASTM E 1739 TIER 1						
	Soil (mg/kg)			Subsurface Soil (mg/kg)		
	(1)	(2)	(3)	(1)	(2)	(3)
Benzo(a) anthracene	3.04	304	23,800	>S	>S	>S
Benzo(a)pyrene	0.304	30.4	23,800	>S	>S	>S
Benzo(b)fluoranthene	3.04	304	23,800	>S	>S	>S
Benzo(k)fluoranthene	30.4	3,040	23,800	>S	>S	>S
Chrysene	30.4	3,040	23,800	>S	>S	>S
Dibenzo(a,h) anthracene	0.304	30.4	23,800	>S	>S	>S

(1) = Carcinogenic effects: 1 in One Million Risk (TR = 1.00 E-06)

(2) = Carcinogenic effects: 1 in Ten Thousand Risk (TR = 1.00 E-04)

(3) = Non-Carcinogenic Effects

>S = Selected risk level is not exceeded for all possible dissolved levels.

4.0 DISCUSSION

There are a number of simplifying assumptions in the Tier 1 method, and in our approach. For example, while it is unlikely that a utility worker would be exposed to contaminants in an excavation for 250 days/year for 25 years, these are the default assumptions.

In addition, ASTM recommends that the user input values from USEPA's current IRIS and HEAST tables for the slope factors (SF) and reference doses (RfD). HEAST refers the reader to IRIS for the six PAHs, and IRIS has only one value listed - an oral slope factor (SF_o) for benzo(a)pyrene; "no data" or "not available" is listed for the others, i.e.:

TABLE 3				
TOXICITY VALUES AVAILABLE FROM HEAST/IRIS				
POLYCYCLIC AROMATIC HYDROCARBON (PAH)	SF _o	SF _i	RfD _o	RfD _i
Benzo(a)anthracene	NA	NA	ND	ND
Benzo(a)pyrene	7.3	NA	ND	ND
Benzo(b)fluoranthene	NA	NA	ND	ND
Benzo(k)fluoranthene	NA	NA	ND	ND
Chrysene	NA	NA	ND	ND
Dibenzo(a,h) anthracene	NA	NA	ND	ND

NA = Not Available

ND = No Data

In the absence of values from IRIS and HEAST, we adopted NYSDOH's approach, which is to use a weighting scheme relative to benzo(a)pyrene for the other five PAHs and to adapt the oral slope factor to the inhalation route. We also applied NYSDOH's approach for RfDs, i.e., used the lowest available reference dose for any of the PAHs listed by IRIS, that for pyrene.

It is our understanding that NYSDEC will be revising TAGM 4046 for benzo(a)pyrene based on the same slope factor presented in this report, and weight other PAHs the same way, to be consistent with NYSDOH's current policy.

5.0 CYANIDE CLEANUP LEVELS

The NYSDOH Division of Environmental Health, Bureau of Toxic Substances Assessment was queried in regard to typical cleanup levels for cyanide in soil. Their approach is "case by case", using realistic or standard assumptions for exposure (e.g., assumptions such as those used in ASTM's Tier 1 screening for petroleum releases). Cyanide is not classifiable as a human carcinogen, and so values are set based on USEPA's non-cancer reference dose for oral exposure (2E-02 mg/kg-day).

In USEPA's **Soil Screening Guidance Technical Manual** (Appendix A), a generic soil screening level of 1,600 mg/kg is cited for amenable cyanide. Additionally, USEPA Region IX has preliminary remediation goals for free cyanide, of 1,100 mg/kg in residential soil and 21,400 mg/kg in industrial soil. Appendix B contains copies of the references from which these values are taken.

6.0 REFERENCES

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McGaughy, Robert E., USEPA Office of Research and Development, (202) 564-3244. Discussion 8/25/98 on PAHs and technical guidance for oral and inhalation slope factors. Address: 8623D USEPA Headquarters, 401 M Street, S.W., Washington, DC 20460.

National Toxicology Program, **Polycyclic Aromatic Hydrocarbons, 15 Listings in Report on Carcinogens** eighth edition. National Institutes of Health. Accessed via <http://ehis.niehs.nih.gov/roc/eighth/chemicals/pah.pdf>

NYSDEC Technical and Administrative Guidance Memorandum, **Determination of Soil Cleanup Objectives and Cleanup Levels (TAGM 4046)**. New York State Department of Environmental Conservation Memorandum to Regional Hazardous Waste Remediation Engineers, Bureau Directors and Section Chiefs, from Michael J. O'Toole, Jr., Director, Div. of Hazardous Waste Remediation, dated January 24, 1994. HWR-94-4046.

U.S. Environmental Protection Agency, **Integrated Risk Information System (IRIS) database**, accessed August 21, 1998 at <http://www.epa.gov/ngispgm3/iris/subst/> for polycyclic aromatic hydrocarbons.

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APPENDIX A

COMPUTER SPREADSHEETS

	W	P _a	d	U _{air}	d _{air}	T	VF _{ss}
Benzo(a)anthracene	1500	1.7	100	225	200	7.88E+08	7.19E-06
Benzo(a)pyrene	1500	1.7	100	225	200	7.88E+08	7.19E-06
Benzo(b)fluoranthene	1500	1.7	100	225	200	7.88E+08	7.19E-06
Benzo(k)fluoranthene	1500	1.7	100	225	200	7.88E+08	7.19E-06
Chrysene	1500	1.7	100	225	200	7.88E+08	7.19E-06
Dibenzo(a,h)anthracene	1500	1.7	100	225	200	7.88E+08	7.19E-06

	W	P _a	U _{air}	d _{air}	DS ^{eff}	H	x	0 _{ws}	K _s	Alt. K _s	P _a	0 _{as}	T	VF _{ss}	Alt. VF _{ss}
Benzo(a)anthracene	1500	1.7	225	200	0.0199498	3.35E-06	3.1416	0.12	13800	3980	1.7	0.26	7.88E+08	3.84E-09	7.16E-09
Benzo(a)pyrene	1500	1.7	225	200	0.05070014	1.13E-06	3.1416	0.12	55000	10200	1.7	0.26	7.88E+08	1.78E-09	4.14E-09
Benzo(b)fluoranthene	1500	1.7	225	200	0.00206136	1.11E-04	3.1416	0.12	5500	12300	1.7	0.26	7.88E+08	1.13E-08	7.53E-09
Benzo(k)fluoranthene	1500	1.7	225	200	0.04163181	8.29E-07	3.1416	0.12	5500	12300	1.7	0.26	7.88E+08	4.38E-09	2.93E-09
Chrysene	1500	1.7	225	200	0.00232551	9.46E-05	3.1416	0.12	2000	3980	1.7	0.26	7.88E+08	1.83E-08	1.30E-08
Dibenzo(a,h)anthracene	1500	1.7	225	200	2.09626161	1.47E-08	3.1416	0.12	330000	38000	1.7	0.26	7.88E+08	5.34E-10	1.57E-09

	D ^{air}	0 _{as}	0 _T	D ^{vat}	Alt. D ^{vat}	H	0 _{ws}	DS ^{eff}	Alt. DS ^{eff}	VF _{ss}	Alt. VF _{ss}
Benzo(a)anthracene	5.10E-02	0.26	0.38	9.00E-06	6.07E-06	3.35E-06	0.12	0.0199498	0.0147424	4.3859E-11	3.24119E-11
Benzo(a)pyrene	0.043	0.26	0.38	9.00E-06	5.71E-06	1.13E-06	0.12	0.0507001	0.0334048	9.431E-12	6.21476E-12
Benzo(b)fluoranthene	2.26E-02	0.26	0.38	5.56E-06	5.72E-06	1.11E-04	0.12	0.0020614	0.0020697	3.7682E-10	3.78349E-10
Benzo(k)fluoranthene	2.26E-02	0.26	0.38	5.56E-06	5.71E-06	8.29E-07	0.12	0.0416318	0.0427235	5.6817E-11	5.83063E-11
Chrysene	2.48E-02	0.26	0.38	6.21E-06	6.29E-06	9.46E-05	0.12	0.0023255	0.0023307	9.8629E-10	9.98496E-10
Dibenzo(a,h)anthracene	2.02E-02	0.26	0.38	5.18E-06	5.39E-06	1.47E-08	0.12	2.0962616	2.1791958	8.3006E-13	8.62266E-13

	P _e	W	U _{air}	d _{air}	VF _p
Benzo(a)anthracene	6.90E-14	1500	225	200	2.30E-12
Benzo(a)pyrene	6.90E-14	1500	225	200	2.30E-12
Benzo(b)fluoranthene	6.90E-14	1500	225	200	2.30E-12
Benzo(k)fluoranthene	6.90E-14	1500	225	200	2.30E-12
Chrysene	6.90E-14	1500	225	200	2.30E-12
Dibenzo(a,h)anthracene	6.90E-14	1500	225	200	2.30E-12

	H	0 _T	ER	L _B	Dcrack ^{eff}	Alt. Dcrack ^{eff}	0 _{acrack}	0 _{wcrack}	Lcrack
Benzo(a)anthracene	3.35E-06	0.38	0.00023	300	0.0199498	0.01474238	0.26	0.12	15
Benzo(a)pyrene	1.13E-06	0.38	0.00023	300	0.05070014	0.03340484	0.26	0.12	15
Benzo(b)fluoranthene	1.11E-04	0.38	0.00023	300	0.00206136	0.00206974	0.26	0.12	15
Benzo(k)fluoranthene	8.29E-07	0.38	0.00023	300	0.04163181	0.04272345	0.26	0.12	15
Chrysene	9.46E-05	0.38	0.00023	300	0.00232551	0.00233066	0.26	0.12	15
Dibenzo(a,h)anthracene	1.47E-08	0.38	0.00023	300	2.09626161	2.17919578	0.26	0.12	15

LTV Steel - Development of Risk - Based Screening Levels for PAH - Contaminated Areas

Carcinogenic Effects : 1 in Ten Thousand Risk (TR = 1.00E-04)

	TR	BW	AT _c	EF	ED	SF ₀	IR _{SOIL}	RAF ₀	SA	M	RAF _d	SF ₁	IR _{AIR}	VF _{SS}	Alt. VF _{SS}	VF _P	RBSL _{AIR}
Benzo(a)anthracene	1.00E-04	70	70	250	25	0.73	50	1	3160	0.5	0.05	0.21	20	3.84E-09	7.16E-09	2.30E-12	6.81E+00
Benzo(a)pyrene	1.00E-04	70	70	250	25	7.3	50	1	3160	0.5	0.05	2.1	20	1.78E-09	4.14E-09	2.30E-12	6.81E-01
Benzo(b)fluoranthene	1.00E-04	70	70	250	25	0.73	50	1	3160	0.5	0.05	0.21	20	1.13E-08	7.53E-09	2.30E-12	6.81E+00
Benzo(k)fluoranthene	1.00E-04	70	70	250	25	0.073	50	1	3160	0.5	0.05	0.021	20	4.38E-09	2.93E-09	2.30E-12	6.81E+01
Chrysene	1.00E-04	70	70	250	25	0.073	50	1	3160	0.5	0.05	0.021	20	1.83E-08	1.30E-08	2.30E-12	6.81E+01
Dibenzo(a,h)anthracene	1.00E-04	70	70	250	25	7.3	50	1	3160	0.5	0.05	2.1	20	5.34E-10	1.57E-09	2.30E-12	6.81E-01

	I		II	
	RBSL _s	Alt. RBSL _s	RBSL _{ss}	Alt. RBSL _{ss}
Benzo(a)anthracene	3.04E+02	3.04E+02	1.55E+08	2.10E+08
Benzo(a)pyrene	3.04E+01	3.04E+01	7.22E+07	1.10E+08
Benzo(b)fluoranthene	3.04E+02	3.04E+02	1.81E+07	1.80E+07
Benzo(k)fluoranthene	3.04E+03	3.04E+03	1.20E+09	1.17E+09
Chrysene	3.04E+03	3.04E+03	6.84E+07	6.82E+07
Dibenzo(a,h)anthracene	3.04E+01	3.04E+01	8.21E+08	7.90E+08

I. Concentration in Soil in mg/kg

Ingestion of soil, inhalation of vapors and particulates, and dermal contact. The alternate value uses a different carbon-water sorption coefficient. See equation #5 on ASTM Table X2.2

II. Concentration in Subsurface Soil in mg/kg

Inhalation of vapor in enclosed space. The alternate value uses a different diffusion coefficient in water. See equation #7 on ASTM Table X2.2

LTV Steel - Development of Risk - Based Screening Levels for PAH - Contaminated Areas

Carcinogenic Effects : 1 in One Million Risk (TR = 1.00E-06)

	TR	BW	AT _c	EF	ED	SF ₀	IR _{SOIL}	RAF ₀	SA	M	RAF _d	SF ₁	IR _{AIR}	VF _{SS}	Alt. VF _{SS}	VF _P	RBSL _{AIR}
Benzo(a)anthracene	1.00E-06	70	70	250	25	0.73	50	1	3160	0.5	0.05	0.21	20	3.84E-09	7.16E-09	2.30E-12	6.81E-02
Benzo(a)pyrene	1.00E-06	70	70	250	25	7.3	50	1	3160	0.5	0.05	2.1	20	1.78E-09	4.14E-09	2.30E-12	6.81E-03
Benzo(b)fluoranthene	1.00E-06	70	70	250	25	0.73	50	1	3160	0.5	0.05	0.21	20	1.13E-08	7.53E-09	2.30E-12	6.81E-02
Benzo(k)fluoranthene	1.00E-06	70	70	250	25	0.073	50	1	3160	0.5	0.05	0.021	20	4.38E-09	2.93E-09	2.30E-12	6.81E-01
Chrysene	1.00E-06	70	70	250	25	0.073	50	1	3160	0.5	0.05	0.021	20	1.83E-08	1.30E-08	2.30E-12	6.81E-01
Dibenzo(a,h)anthracene	1.00E-06	70	70	250	25	7.3	50	1	3160	0.5	0.05	2.1	20	5.34E-10	1.57E-09	2.30E-12	6.81E-03

	I		II	
	RBSL _s	Alt. RBSL _s	RBSL _{ss}	Alt. RBSL _{ss}
Benzo(a)anthracene	3.04E+00	3.04E+00	1.55E+06	2.10E+06
Benzo(a)pyrene	3.04E-01	3.04E-01	7.22E+05	1.10E+06
Benzo(b)fluoranthene	3.04E+00	3.04E+00	1.81E+05	1.80E+05
Benzo(k)fluoranthene	3.04E+01	3.04E+01	1.20E+07	1.17E+07
Chrysene	3.04E+01	3.04E+01	6.84E+05	6.82E+05
Dibenzo(a,h)anthracene	3.04E-01	3.04E-01	8.21E+06	7.90E+06

I. Concentration in Soil in mg/kg

Ingestion of soil, inhalation of vapors and particulates, and dermal contact. The alternate value uses a different carbon-water sorption coefficient. See equation #5 on ASTM Table X2.2

II. Concentration in Subsurface Soil in mg/kg

Inhalation of vapor in enclosed space. The alternate value uses a different diffusion coefficient in water. See equation #7 on ASTM Table X2.2

LTV Steel - Development of Risk - Based Screening Levels for PAH - Contaminated Areas

Non-Carcinogenic Effects

	THQ	RfD ₁	RfD ₀	BW	ATn	EF	ED	IR _{SOIL}	RAF ₀	SA	M	RAF _d	IR _{AIR}	VF _{SS}	Alt. VF _{SS}	VF _P	RBSL _{AIR}
Benzo(a)anthracene	1.00E+00	3.00E-02	3.00E-02	70	25	250	25	50	1	3160	0.5	0.05	20	3.84E-09	7.16E-09	2.30E-12	1.53E+02
Benzo(a)pyrene	1.00E+00	3.00E-02	3.00E-02	70	25	250	25	50	1	3160	0.5	0.05	20	1.78E-09	4.14E-09	2.30E-12	1.53E+02
Benzo(b)fluoranthene	1.00E+00	3.00E-02	3.00E-02	70	25	250	25	50	1	3160	0.5	0.05	20	1.13E-08	7.53E-09	2.30E-12	1.53E+02
Benzo(k)fluoranthene	1.00E+00	3.00E-02	3.00E-02	70	25	250	25	50	1	3160	0.5	0.05	20	4.38E-09	2.93E-09	2.30E-12	1.53E+02
Chrysene	1.00E+00	3.00E-02	3.00E-02	70	25	250	25	50	1	3160	0.5	0.05	20	1.83E-08	1.30E-08	2.30E-12	1.53E+02
Dibenzo(a,h)anthracene	1.00E+00	3.00E-02	3.00E-02	70	25	250	25	50	1	3160	0.5	0.05	20	5.34E-10	1.57E-09	2.30E-12	1.53E+02

I		II	
RBSL _S	Alt. RBSL _S	RBSL _{SS}	Alt. RBSL _{SS}
Benzo(a)anthracene	2.38E+04	2.38E+04	3.50E+09
Benzo(a)pyrene	2.38E+04	2.38E+04	1.63E+10
Benzo(b)fluoranthene	2.38E+04	2.38E+04	4.07E+08
Benzo(k)fluoranthene	2.38E+04	2.38E+04	2.70E+09
Chrysene	2.38E+04	2.38E+04	1.54E+08
Dibenzo(a,h)anthracene	2.38E+04	2.38E+04	1.85E+11

I. Concentration in Soil in mg/kg

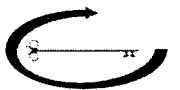
Ingestion of soil, inhalation of vapors and particulates, and dermal contact. The alternate value uses a different carbon-water sorption coefficient. See equation #5 on ASTM Table X2.2

II. Concentration in Subsurface Soil in mg/kg

Inhalation of vapor in enclosed space. The alternate value uses a different diffusion coefficient in water. See equation #7 on ASTM Table X2.2

APPENDIX C

Subarea K and L Test Pit Logs for October 1998

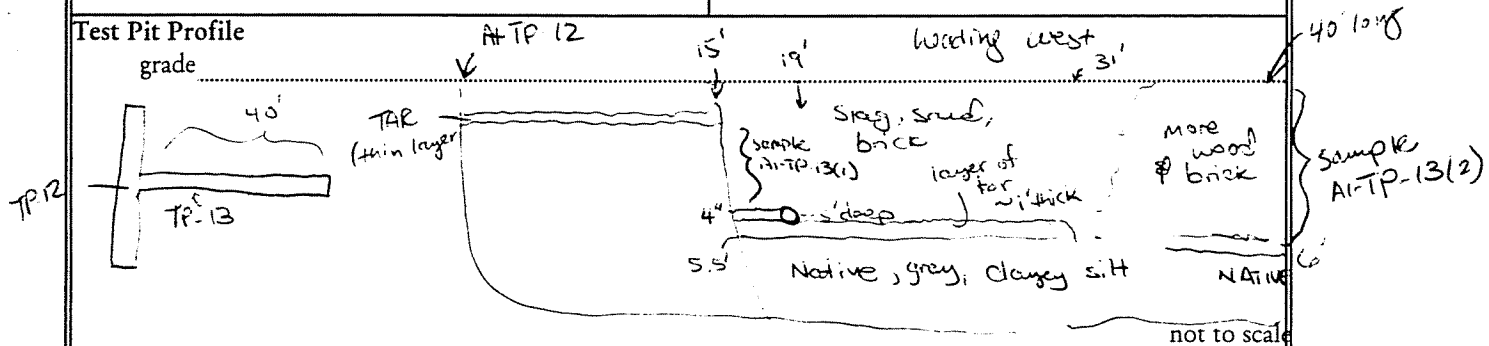


FIELD TEST PIT LOG

[illegible]

FIELD TEST PIT LOG

Test Pit No.: <u>AI-TP-13</u>	Project: <u>A-1 Invert. of Sidewalk</u>
Location: <u>Ave. 1, near gate, W. of TP-12</u>	Project No: <u>0002-003-100</u>
Date: <u>10/6/98</u>	Logged By: <u>DMA</u>
Excavation Method: <u>L 932</u>	

[illegible]

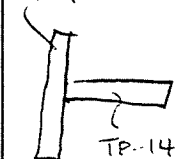
FIELD TEST PIT LOG

Test Pit No.: A1-TP-14	Project: LTV Steel - Area 1
Location: North of TP-10	Project No: 0002-003-100
Date: 10/2/98	Logged By: JINA
Excavation Method: Liebherr 932	

Test Pit Profile

grade

TP-10



Hit Building foundation ~ 3' N of int. w/

Building foundation - ~ 3' ~~deep~~ below grade
no tar

not to scale

[illegible]

FIELD TEST PIT LOG

Test Pit No.: <u>A TP-15</u>	Project: <u>LTV Steel Plant Subarea 6 Invest.</u>
Location: <u>East of TP-12</u>	Project No: <u>0002-003-100</u>
Date: <u>10/6/98</u>	Logged By: <u>JML</u>
Excavation Method: <u>Liabherr 932</u>	

Test Pit Profile

grade

TP-12

0.5-

10-15'

TP-12

118

Pict 13 of AI-TP 15(1)

37

46

1

Water @ 5.5' deep

Braunich tan sind

Hard
not
able to
dig

TAE

72

2. 1/2

37

U. S. S. S. R.

(۱) کراچی

78-1500

— i c i

- Sample to S'

AI-TP-15
(2)

not to scale

[illegible]

FIELD TEST PIT LOG

[illegible]

FIELD TEST PIT LOG

Test Pit No.: <u>AI-TP-17</u>	Project: <u>LIU Steel - Area 1 Inv. of S</u>
Location: <u>at AI-TP-2</u>	Project No: <u>0002 - 003 - 100</u>
Date: <u>10/6/98</u>	Logged By: <u>JWJ</u>
Excavation Method: <u>Liebherr 932</u>	

Test Pit Profile

grade

p: 0 47.7 ppm

NOAH

5046

Gravel, brown
Sand & 100m, dry

Foundation :

2.5'

Water
Sleeping in
at 40°

DK gray-black, sand, gravel
w/ oily product, strong odor

layer
of tar.
over native
below

Gray native silty
clay.

Mottled

AI-TP-17 (1)

AI-TP-17(2)

not to scale

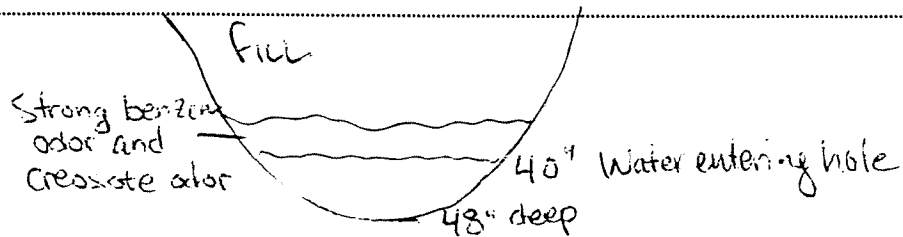
Depth bgs	Soil Description	Samples-- Depth	Comments include Water entering pit w/depth
	Test pit 41' West of TP-17		
	Same as TP-17		
	Fill	2'	
			oily, tar product
			Water seeping in @ 40"
	Test pit 89' West of TP-17		
	Same as TP-17		
	Fill	2'	
			oily, tar product
			Water seeping in @ 40"

FIELD TEST PIT LOG

Test Pit No.: <u>AI-TP-18</u>	Project: <u>LTV Plant Site Subarea L Invest.</u>
Location: <u>Upgradient of AI-P-2, 130' W of</u>	Project No: <u>0002-08-100</u>
Date: <u>10/6/98</u> <u>AI-TP-17</u>	Logged By: <u>JMA</u>
Excavation Method: <u>Liebherr 932</u>	

Test Pit Profile

grade.



not to scale

[illegible]

FIELD TEST PIT LOG

Test Pit No.: <u>AI-TP-19</u>	Project: <u>LTV Steel Subarea Invest</u>
Location: <u>Upgrad. of AI-P-2, 116' W of TP-17</u>	Project No: <u>0002-003-100</u>
Date: <u>10/6/98</u>	Logged By: <u>JWA</u>
Excavation Method: <u>Whebbert 932</u>	

Test Pit Profile

grade.

Pict. 14 -
inside of TP

Pict 15 -
of tar that
comes from pit

orange, brown sand, dry

28 ft

tarry material

Water entering pit @ 40"

Same

Sample A1-TP-19

not to scale

[illegible]

FIELD TEST PIT LOG

[illegible]

FIELD TEST PIT LOG

[illegible]

FIELD TEST PIT LOG

[illegible]

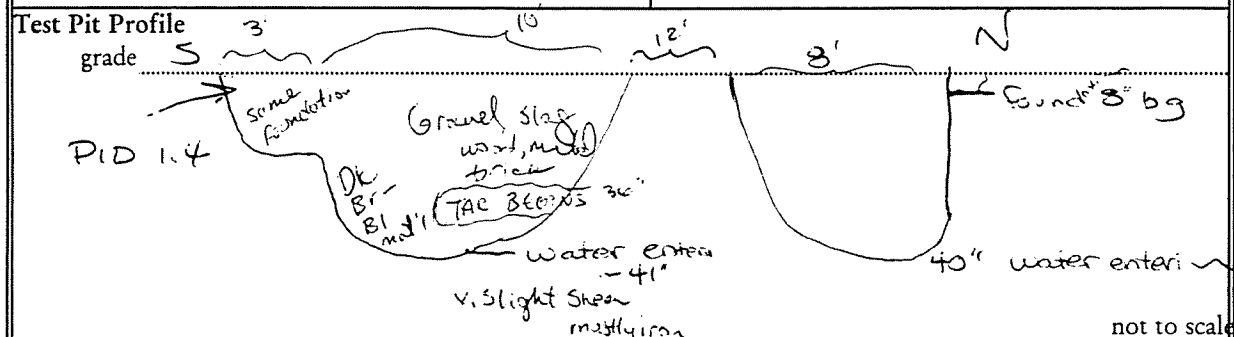
Sample to 4!

AI-TP-22

took one
jar of
white
mat'l
for pth

FIELD TEST PIT LOG

Test Pit No.: <u>A1-TP 23</u>	Project: <u>LTV Plant Site Area 1 Inv.</u>
Location: <u>Approx 10' E of TP-17</u>	Project No: <u>0002-003-100</u>
Date: <u>10/6/98</u>	Logged By: <u>JMS</u>
Excavation Method: <u>Liebherr 932</u>	

[illegible]

2.00

[illegible]

[illegible][illegible]

FIELD TEST PIT LOG

Test Pit No.: <u>AI-TP-26</u>	Project: <u>LTV Steel, Amer. Inv. of S. J. Park</u>
Location: <u>~ 25' W of AI-TP-24</u>	Project No: <u>0002-003-100</u>
Date: <u>10/16/98</u>	Logged By: <u>SMA</u>
Excavation Method: <u>Liebherr 932</u>	

Test Pit Profile

grade

Brown sandy silt
dry, appears clean

Coarse gravel, 2-3" w/
trace - little silt mixed in,
all coarse w/ product

6.5' water entering test pit

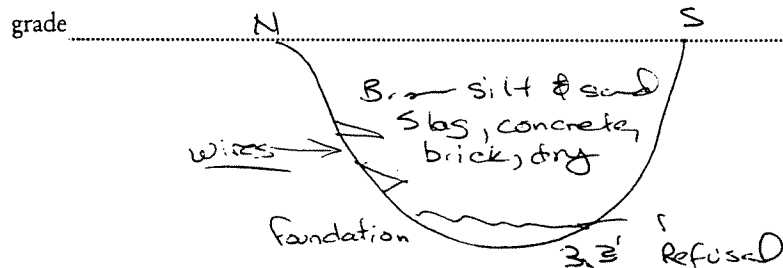
not to scale

[illegible]

FIELD TEST PIT LOG

Test Pit No.: AI-TP-27	Project: CIV Steel AI Inv of Subarea
Location: 50' S of AI-TP-26 (100' SW of 22)	Project No: 0002-203-100
Date: 10/6/98	Logged By: JMA
Excavation Method: Liebherr 932	

Test Pit Profile



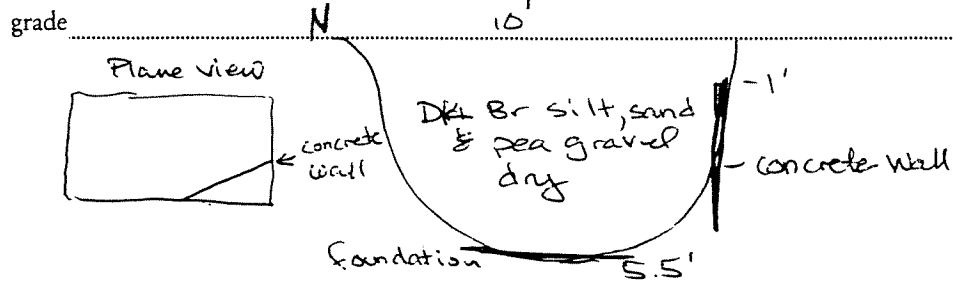
not to scale

[illegible]

FIELD TEST PIT LOG

Test Pit No.: <u>AI - TP - 28</u>	Project: <u>LTV Steel AI Inv. of Subarea K</u>
Location: <u>26' E of K2 blun K2 & TP28</u>	Project No: <u>0002-003-100</u>
Date: <u>10/16/98</u>	Logged By: <u>JMA</u>
Excavation Method: <u>Liebherr 932</u>	

Test Pit Profile



not to scale

[illegible]

FIELD TEST PIT LOG

Test Pit No.: <u>AI-TP-29</u>	Project: <u>LTV Steel AI Inv. of Sbarrae</u>
Location: _____	Project No: <u>0002-003-100</u>
Date: <u>10/16/98</u>	Logged By: <u>Jiva</u>
Excavation Method: <u>Liebherr 932</u>	

Test Pit Profile

grade

TP-26
TP-30 } 40'
TP-29

refused at
1.5', too hard to dig
w/ backhoe

not to scale

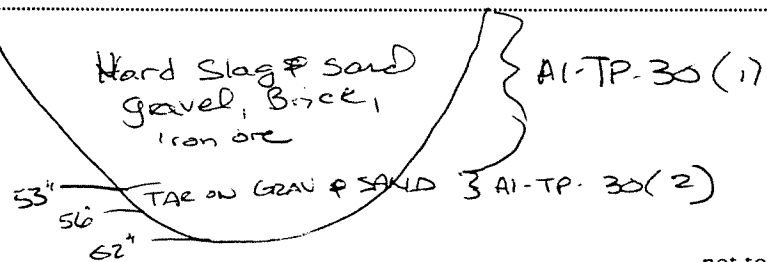
[illegible]

FIELD TEST PIT LOG

Test Pit No.: <u>AI-TP-30</u>	Project: <u>LV Plant A.i. inv. of Sabarea k</u>
Location: <u>Sec AI-TP-29</u>	Project No: <u>0002-003-100</u>
Date: <u>10/6/98</u>	Logged By: <u>JMA</u>
Excavation Method: <u>Liebherr 932</u>	

Test Pit Profile

grade



not to scale

[illegible]

FIELD TEST PIT LOG

Test Pit No.: <u>AI-TP-31</u>	Project: <u>LTV Area 1 Inv of Surface</u>
Location: <u>20'</u>	Project No: <u>0002-003-100</u>
Date: <u>10/6/98</u>	Logged By: <u>JNA</u>
Excavation Method: <u>Liebharr 932</u>	

Test Pit Profile

grade **N**

Sample
AI-TP-31

not to scale

[illegible]