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Air Pathways from Hazardous Waste Sites

I. INTRODUCTION

This chapter addresses the potential for hazardous air emissions from environmental remediation sites. These emissions can occur at hazardous spill locations, at undisturbed remediation sites, and during cleanup of remediation sites under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) or the Superfund Amendments and Reauthorization Act (SARA). Air emissions may pose a potential health risk at these sites.

The US Environmental Protection Agency (EPA) developed the Hazard Ranking System (HRS) [1] to determine priorities among releases, or threatened releases, from remediation sites. The HRS applies the appropriate consideration of each of the following site-specific characteristics of such facilities:

- The quantity, toxicity, and concentrations of hazardous constituents that are present in such waste and a comparison with other wastes.
- The extent of, and potential for, release of such hazardous constituents to the environment.
- The degree of risk to human health and the environment posed by such constituents.

II. MULTIMEDIA TRANSPORT

Air contaminant releases from hazardous waste sites can occur from wastes placed aboveground or belowground. The following are categories of air contaminant releases:

- Fugitive dust resulting from:
  - Wind erosion of contaminated soils
  - Vehicle travel over contaminated roadways
- Volatilization release from:
  - Covered landfills (with and without gas generation)
  - Spills, leaks, and landforming
  - Lagoons

The EPA has detailed procedures for conducting air pathway analysis for Superfund applications [2]. Decision network charts are given for all expected situations.

Figures 19.1 and 19.2 present the decision networks that guide contaminant release screening analysis. Figure 19.1 deals with contaminants in or under the soil and Fig. 19.2 addresses aboveground wastes. Any release mechanisms evident at the site will require a further screening evaluation to determine the likely environmental fate of the contaminants involved.

III. CONTAMINANT FATE ANALYSIS

Simplified environmental fate estimation procedures are based on the predominant mechanisms of transport within each medium, and they generally disregard intermedia transfer or transformation processes. In general, they produce conservative estimates (i.e. reasonable upper bounds) for final ambient concentrations and the extent of hazardous substance migration. However, caution should be taken to avoid using inappropriate analytical methods that underestimate or overlook significant pathways that affect human health.

When more in-depth analysis of environmental fate is required, the analyst must select the modeling procedure that is most appropriate to the circumstances. In general, the more sophisticated models are more data, time, and resource intensive.

Figures 19.3 through 19.5 present the decision network for screening contaminant fate in air, surface water, ground water, and biota. Pathways must be further evaluated to determine the likelihood of population exposure.

A. Atmospheric Fate

The following numbered paragraphs refer to particular numbered boxes in Fig. 19.3:

1. The atmospheric fate of contaminants must be assessed whenever it is determined that significant gaseous or airborne particulate contaminants

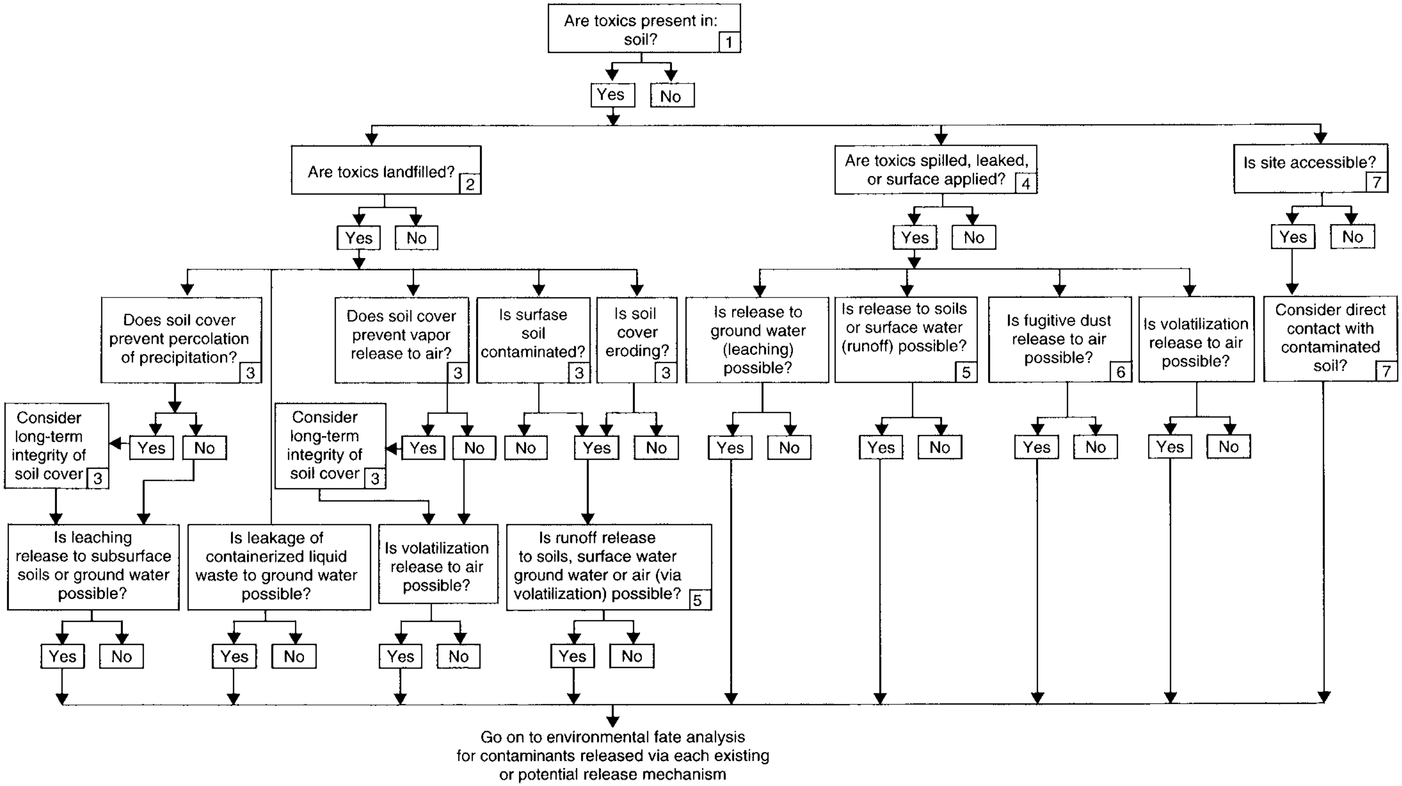

Fig. 19.1. Contaminant release decision network: contaminants in soil.

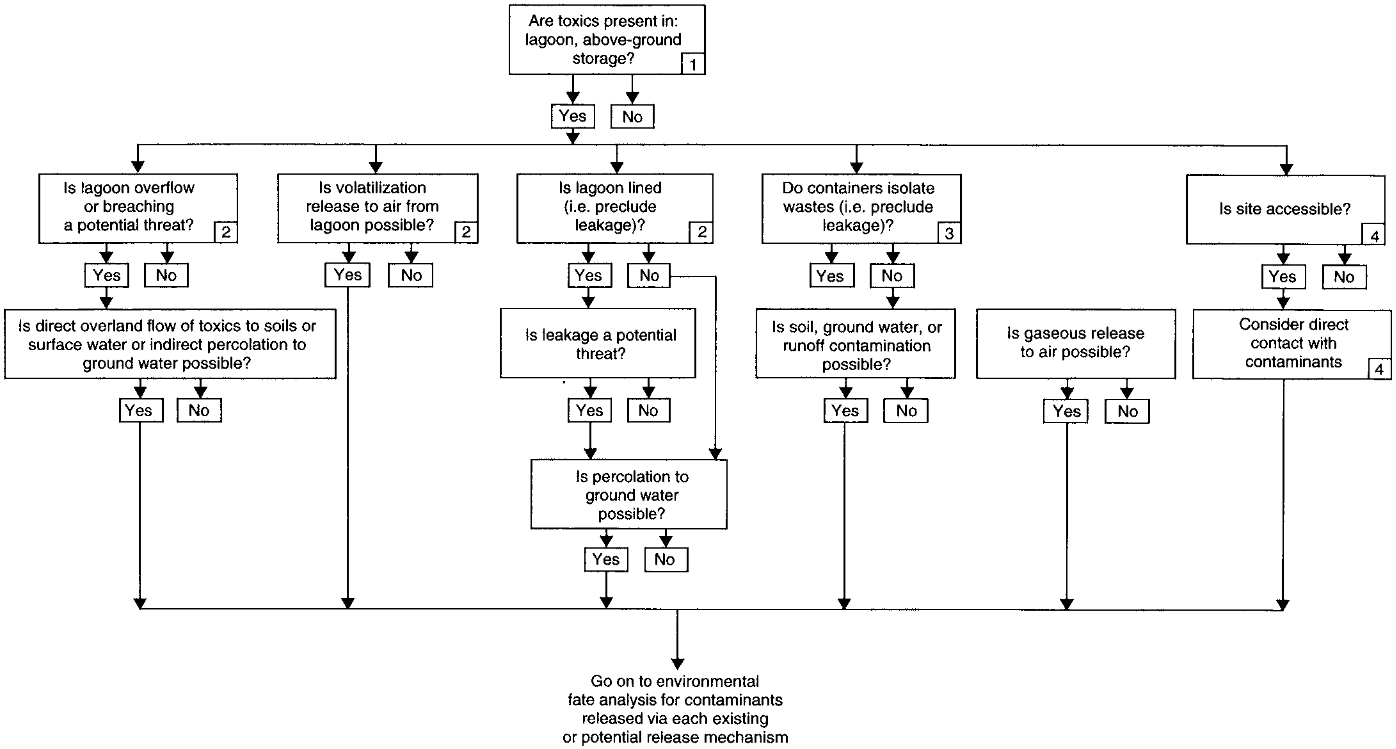

Fig. 19.2. Contaminant release decision network: contaminants above ground.

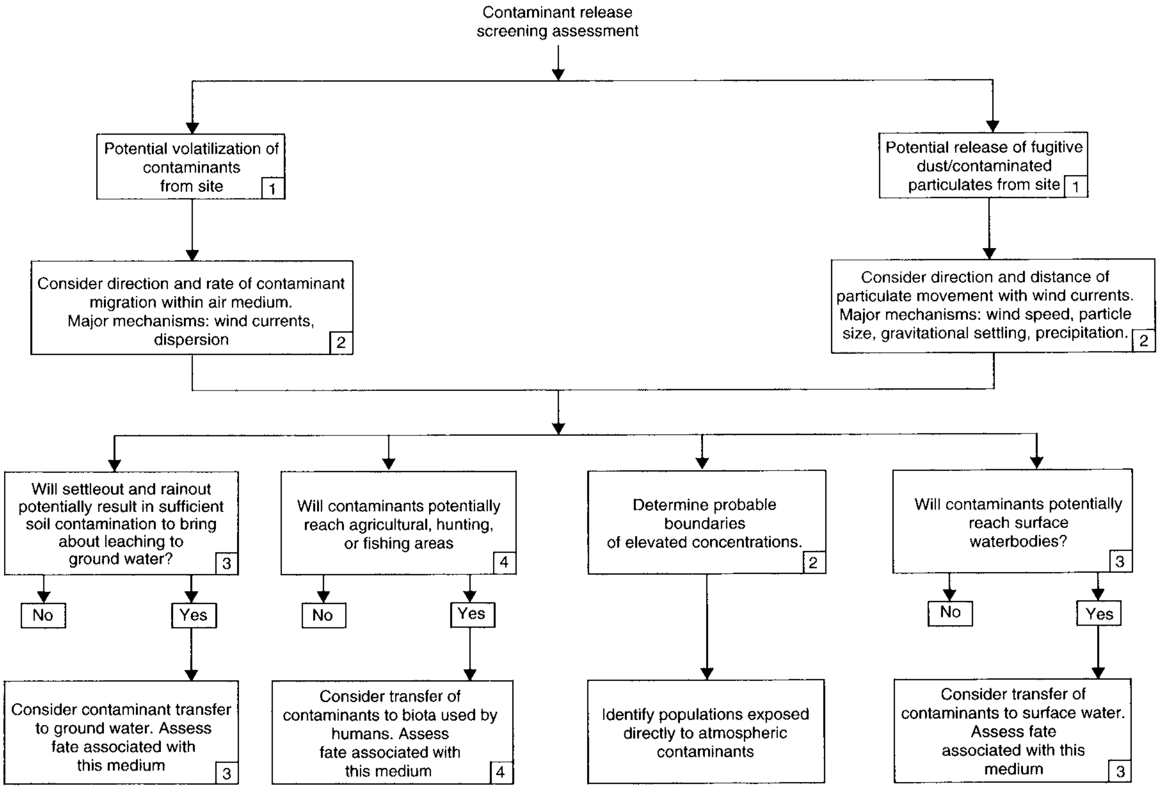

Fig. 19.3. Environmental fate screening assessment decision network: atmosphere.

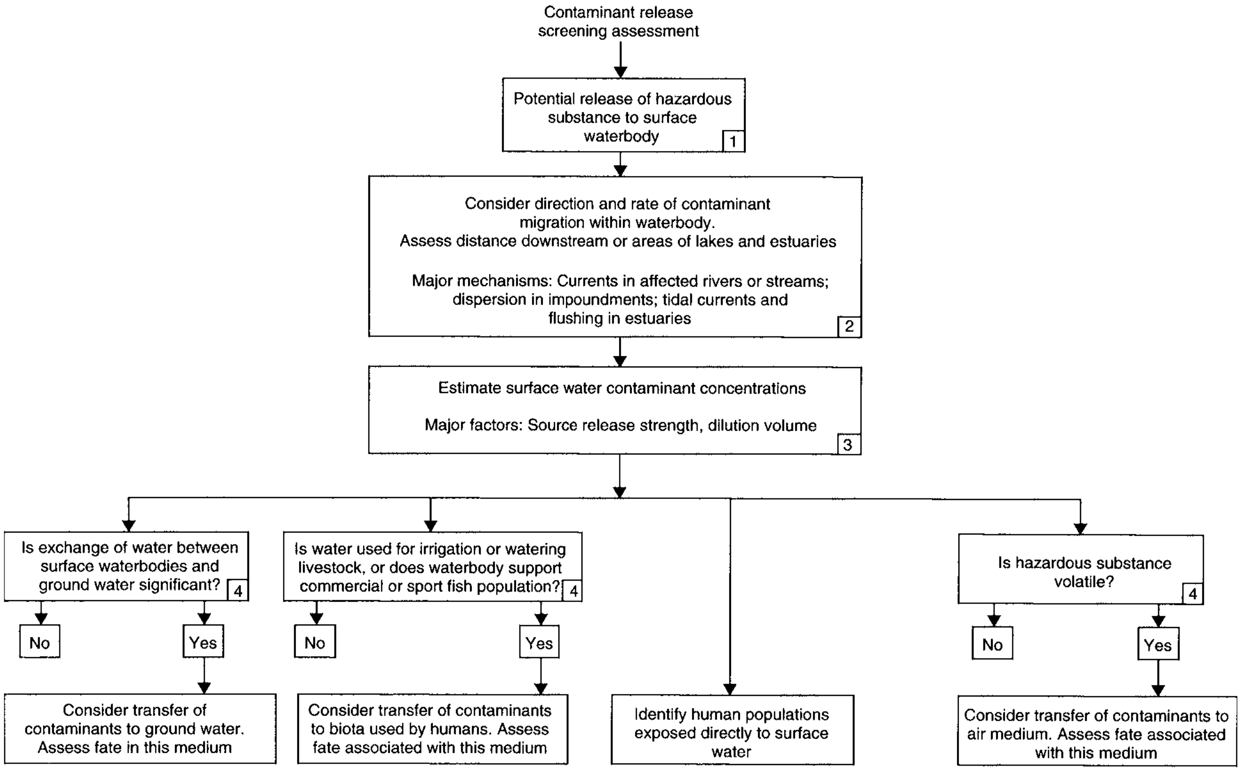

Fig. 19.4. Environmental fate screening assessment decision network: surface water.

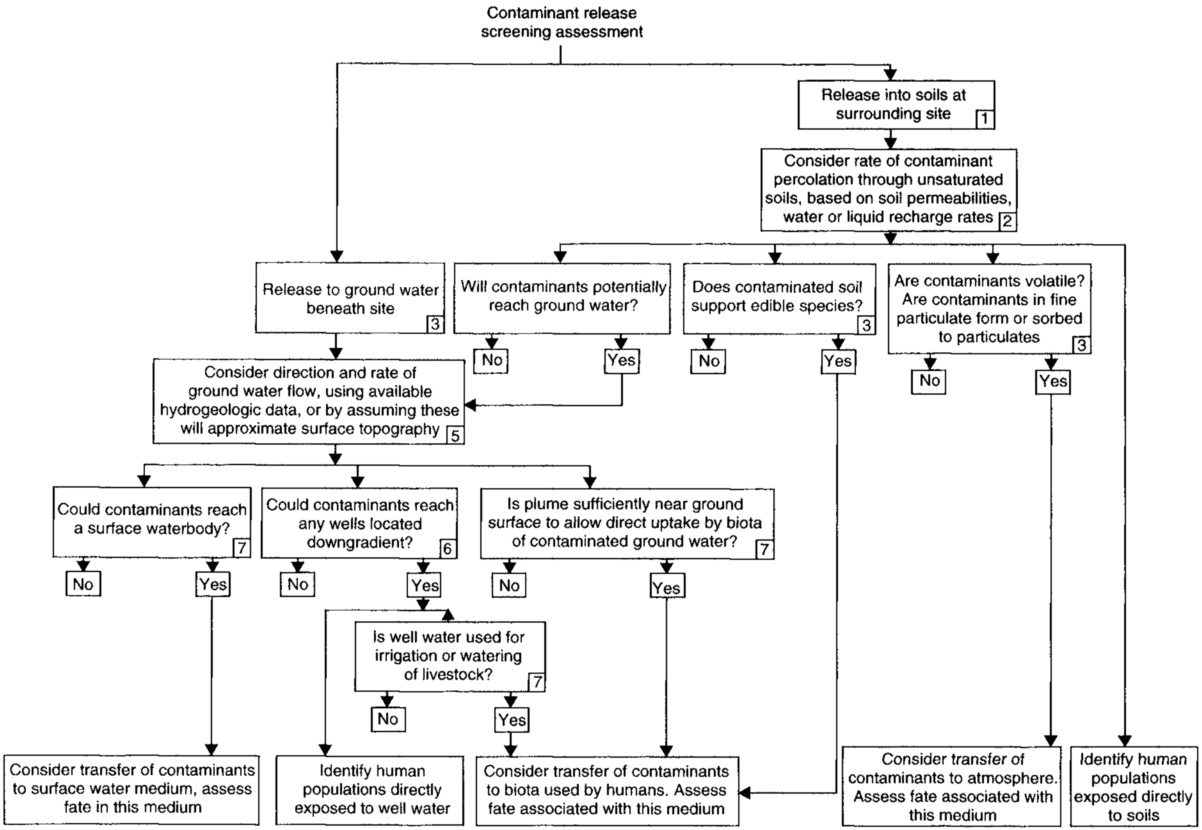

Fig. 19.5. Environmental fate screening assessment decision network: soils and ground water.

are released from the site. The atmospheric fate of contaminants released originally to other media, but eventually partitioned to the atmosphere beyond site boundaries, must also be assessed whenever this intermedia transfer is likely to be significant.

2. The predominant directions of contaminant movement will be determined by relative directional frequencies of wind over the site (as reflected in area-specific wind rose data). Atmospheric stability and wind speeds determine off-site areas affected by ambient concentrations of gaseous contaminants. Usually, high stability and low wind speed conditions result in higher atmospheric concentrations of gaseous contaminants close to the site. High stability and moderate wind speeds result in moderate concentrations over a larger downwind area. Low stability or high wind speed conditions cause greater dispersion and dilution of contaminants, resulting in lower concentrations over larger areas.

   For particulate contaminants (including those adsorbed to dust or soil particles), ambient concentrations in the atmosphere and areas affected by airborne contaminants are determined by wind speed and stability and also by particle size distribution. High winds result in greater dispersion and cause particles to remain airborne longer (which may also increase release rates). Low winds and high stability result in rapid settling of particles and in a more concentrated contaminant plume closer to the site. Larger particles settle rapidly, decreasing the atmospheric concentrations with distance from the site. Finer particles remain airborne longer, and their behavior more closely approximates that of gaseous contaminants, as described.

3. Settling and rainout are important mechanisms of contaminant transfer from the atmospheric media to both surface soils and surface waters. Rates of contaminant transfer caused by these mechanisms are difficult to assess qualitatively; however, they increase with increasing soil adsorption coefficients, solubility (for particulate contaminants or those adsorbed to particles), particle size, and precipitation frequency.

   Areas affected by significant atmospheric concentrations of contaminants exhibiting the foregoing physical and chemical properties should also be considered as potentially affected by contaminant rainout and settling to surface media. Contaminants dissolved in rainwater may percolate to ground water, run off or fall directly into surface waters, and adsorb to unsaturated soils. Contaminants settling to the surface through dry deposition may dissolve in or become suspended in surface waters or may be leached into unsaturated soils and ground water by subsequent rainfall. Dry deposition may also result in formation of a layer of relatively high contamination at the soil surface. When such intermedia transfers are likely, one should assess the fate of contaminants in the receiving media.

4. If areas identified as likely to receive significant atmospheric contaminant concentrations include areas supporting edible biota, the biouptake

of contaminants must be considered as a possible environmental fate pathway. Direct biouptake from the atmosphere is a potential fate mechanism for lipophilic contaminants. Biouptake from soil or water following transfer of contaminants to these media must also be considered as part of the screening assessments of these media.

B. Surface Water Fate

The following numbered paragraphs refer to particular numbered boxes in Fig. 19.4:

1. The aquatic fate of contaminants released from the CERCLA site as well as those transferred to surface water from other media beyond site boundaries must be considered.
2. Direction of contaminant movement is usually clear only for contaminants introduced into rivers and streams. Currents, thermal stratification or eddies, tidal pumping, and flushing in impoundments and estuaries render qualitative screening assessment of contaminant directional transport highly conjectural for these types of water bodies. In most cases, entire water bodies receiving contaminants must be considered potentially significant human exposure points. More in-depth analyses or survey data may subsequently identify contaminated and unaffected regions of these water bodies.
3. Similarly, contaminant concentrations in rivers or streams can be roughly assessed based on rate of contaminant introduction and dilution volumes. Estuary or impoundment concentration regimes are highly dependent on the transport mechanisms enumerated. Contaminants may be localized and remain concentrated or may disperse rapidly and become diluted to insignificant levels. The conservative approach is to conduct a more in-depth assessment and use model results or survey data as a basis for determining contaminant concentration levels.
4. Important intermedia transfer mechanisms that must be considered where significant surface water contamination is expected include transfers to ground water where hydrogeology of the area indicates significant surface water–ground water exchange, transfers to biota where waters contaminated with lipophilic substances support edible biotic species, and transfer to the atmosphere where surface water is contaminated by volatile substances. High temperatures, high surface area/volume ratios, high wind conditions, and turbulent stream flow also enhance volatilization rates.

   Contaminant transfer to bed sediments represents another significant transfer mechanism, especially in cases where contaminants are in the form of suspended solids or are dissolved hydrophobic substances that can become adsorbed by organic matter in bed sediments. For the purposes of this chapter, sediments and water are considered part of a single system because of their complex interassociation. Surface water–bed sediment transfer is reversible; bed sediments often act as temporary repositories for contaminants and gradually rerelease contaminants to surface waters. Sorbed or settled contaminants are frequently transported with bed sediment migration or flow. Transfer of sorbed contaminants to bottom-dwelling, edible biota represents a fate pathway potentially resulting in human exposure. Where this transfer mechanism appears likely, the biotic fate of contaminants should be assessed.

C. Soil and Ground Water Fate

The following numbered paragraphs refer to particular numbered boxes in Fig. 19.5:

1. The fate of contaminants in the soil medium is assessed whenever the contaminant release atmospheric, or fate screening, assessment results show that significant contamination of soils is likely.
2. The most significant contaminant movement in soils is a function of liquid movement. Dry, soluble contaminants dissolved in precipitation, run-on, or human applied water will migrate through percolation into the soil. Migration rates are a function of net water recharge rates and contaminant solubility.
3. Important intermedia transfer mechanisms affecting soil contaminants include volatilization or re-suspension to the atmosphere and biouptake by plants and soil organisms. These, in turn, introduce contaminants into the food chain.

IV. MODELING

An extremely difficult task is the estimation of emissions from hazardous waste sites. Frequently, both the amounts of materials existing within the site and the compounds and mixtures that are represented are not known. Even if both of these pieces of information are reasonably well known, the conditions of the containers holding these chemicals are not initially known.

Hazardous materials may enter the air pathway by evaporation from leaking containers and release of these gases through fissures and spaces between soil particles. Another pathway may release hazardous substances to the air if they are water soluble. Then ground water passing leaking containers may carry substances to or near the surface, where they may be released to the air near the original source or at locations at significant distances.

A. Estimates of Long-Term Impact

If the foregoing problems of emissions estimation can be overcome, or if it is possible to make estimates of maximum possible and minimum possible emissions, then it is quite easy to make estimates of resulting long-term impact on the surrounding area. The representation of the emissions may be through consideration of an area source or area sources; or if vent pipes are releasing material or flaring the gases, point sources should be used.

A single finite line source method is used to simulate area sources in the long-term (seasons to years) model ISCLT (Industrial Source Complex Long Term model) [3]. Although this method has been criticized as frequently underestimating concentrations for receptors that are quite close to the area source (within two or three side lengths away), this model is usually used for these estimates. In addition to the long-term estimate of emission rate for each constituent to be modeled, the ISCLT model requires meteorological data in the form of a joint frequency distribution of three parameters: wind direction (in 16 classes), wind speed (in 6 classes), and Pasquill stability class (in 6 classes). As long as the emissions can be considered relatively constant over the period of simulation, the long-term estimates will represent mean concentrations over the period represented by the meteorological data.

B. Estimates of Short-Term Impact during Remediation

If it is necessary to consider short-term (hours or days) impact, the point, area, and line (PAL) air quality model [4] will do a superior simulation of the area sources and a similar simulation of any point sources as done by the ISCLT model. PAL also includes a version with deposition and settling algorithms (PAL-DS).

In addition to short-term emission estimates, normally for hourly periods, the meteorological data include hourly wind direction, wind speed, and Pasquill stability class. Although of secondary importance, the hourly data also include temperature (only important if buoyant plume rise needs to be calculated from any sources) and mixing height.

The short-term model can then be used to estimate resulting concentrations during specific periods or to estimate concentrations for suspected adverse meteorological conditions, so that changes can be incorporated in the remediation process if concentrations are expected to be higher than desirable.

V. ASSESSMENT OF A HAZARDOUS WASTE SITE

The contaminant cleanup process is shown in Fig. 19.6. The first step of a contaminant cleanup is a preliminary assessment (PA). During the PA of a site, readily available information about a site and its surrounding area are collected to "distinguish between sites that pose little or no threat to human health and the environment and sites that may pose a threat and require further investigation."[1] Any possible emergency response actions may also be

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[1] US EPA website (May 2003), http://www.epa.gov/superfund/whatissf/sfproces/pasi.htm.

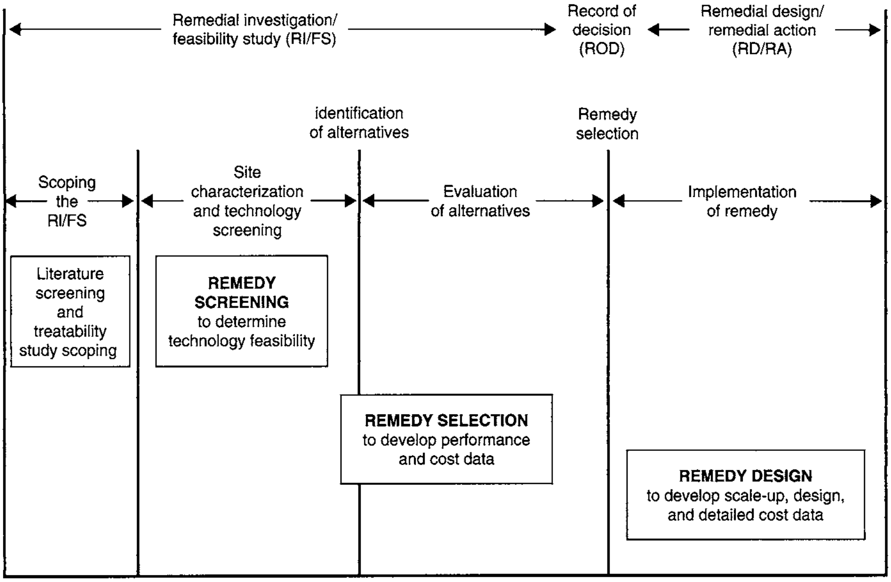

Fig. 19.6 Steps in a contaminated site cleanup, as mandated by Superfund. *Source*: US Environmental Protection Agency, 1992, Guide for Conducting Treatability Studies under CERCLA: Thermal Desorption, EPA/540/R-92/074 B.

identified. A site inspection or site investigation (SI) is performed if the preliminary assessment (PA), based on limited data, calls for one (that is why this step is often referred to as the PA/SI).[2]

In the US, certain hazardous waste sites are considered to be of sufficient concern to be "listed" on the National Priority List (NPL). The listing is actually a combination of the hazard (usually toxicity) of the contaminants found at the site and the likelihood that people or ecosystems will be exposed to these pollutants. Severely polluted sites and sites that contain very toxic compounds in measurable quantities are ranked higher than those with less toxic substances in lesser quantities.

A public disclosure of the condition following contaminant treatment must be made. This final record of decision (ROD) indicates that the specific engineering remedy has been selected for the site. Like any other aspects of hazardous waste cleanup, this decision is subject to later contests (legal, scientific, or otherwise). Since public officials are not exempt from personal tort liabilities in their decisions, the ROD is usually made as a collective, agency decision based on past and ongoing contaminant measurements, and includes provisions for monitoring for years to come to ensure that the engineered systems continue to perform according to plan. The ROD must also

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[2] See the EPA publication Guidance for Performing Preliminary Assessments Under CERCLA, September 1991, PB92-963303, EPA 9345.0-01A) and the electronic scoring program "PA-Score" for additional information on how to conduct a PA.

ensure that a plan for operating and maintaining all systems is in place, including a plan for dealing with failures and other unexpected contingencies, such as improvements in measurement techniques that later identify previously undetected pollutants.

Scientists conduct exposure assessments to evaluate the kind and magnitude of exposure to contaminants. Such assessments are usually site specific for clearly identified contaminants of concern. For example, they may be conducted for an abandoned hazardous waste site or a planned industrial facility. For the former site, the list of contaminants of concern would be based on sampling and analysis of the various environmental compartments, while the latter would be based on the types of chemicals to be used or generated in the construction and operation of the industrial facility. Thus, the assessment considers sources of contaminants, pathways through which contaminants are moving or will be moving, and routes of exposure where the contaminants find their way to receptors (usually people, but also receptors in ecosystems, such as fish and wildlife). Table 19.1 includes some of the most important considerations in deciding on the quality of information needed to conduct an exposure assessment.

The necessary information to quantify is determined by both the characteristics of the contaminant and the route of exposure.

A. The Hazard Quotient

The hazard quotient (HQ) is the ratio of the potential exposure to a specific contaminant to the concentration at which no adverse effects are expected (known as the reference dose or RfD). The HQ is the ratio of a single contaminant exposure, over a specified time period, to a reference dose for that contaminant, derived from a similar exposure period:

$$\mathrm{HQ} = \frac{\mathrm{Exposure}}{\mathrm{RfD}} \tag{19.1}$$

If the calculated HQ is less than 1, no adverse health effects are expected to occur at these contaminant concentrations. If the calculated HQ is greater than 1, there is a likelihood that adverse action can occur at these concentrations. For example, the chromic acid (Cr^{6+}) mists dermal chronic RfD of $6.00 \times 10^{-3}\,\mathrm{mg\,kg^{-1}\,day^{-1}}$. If the actual dermal exposure of people living near a plant is calculated (e.g. by intake or lifetime average daily dose) to be $4.00 \times 10^{-3}\,\mathrm{mg\,kg^{-1}\,day^{-1}}$, the HQ is 2/3 or 0.67. Since this is less than 1, one would not expect people chronically exposed at this level to show adverse effects from skin contact. However, at this same chronic exposure, i.e. $4.00 \times 10^{-3}\,\mathrm{mg\,kg^{-1}\,day^{-1}}$, to hexavalent chromic acid mists via oral route, the RfD is $3.00 \times 10^{-3}\,\mathrm{mg\,kg^{-1}\,day^{-1}}$, meaning the HQ = 4/3 or 1.3. The value is greater than 1, so we cannot rule out adverse non-cancer effects.

The calculated HQ value cannot be translated into a probability that adverse health effects will occur (i.e. it is not actually a metric of risk). The

TABLE 19.1

Questions to Be Asked When Determining the Adequacy of Information Needed to Conduct Exposure Assessments

Compartment	Question
Soil	If humans have access to contaminated soils, can ranges of contamination be provided on the basis of land use (i.e. restricted access, road/driveway/parking lot access, garden use, agriculture and feedlot use, residential use, playground and park use, etc.)?
	Have the soil depths been specified? Do soil data represent surface soil data (≥3 in. in depth) or subsurface soil data (>3 in. in depth)? If soil depth is known, but does not meet surface or subsurface soil definitions, designate the data as *soil* and specify the depth (e.g. 0–6 in.). If the soil depth is unknown, the health assessor should designate the data as unspecified soil.
	Has soil been defined in the data? If not, the health assessor should assume soil includes any unconsolidated natural material or fill above bedrock that is not considered to be soil and excludes manmade materials such as slabs, pavements or driveways of asphalt, concrete, brick, rock, ash or gravel. A soil matrix may consist of pieces of each of these materials.
	Do soil data include uphill and downhill samples and upwind and downwind samples both on and off the site?
Sediment	Have the sediment samples been identified as grab samples or cores? Was the depth of the samples specified?
	Was the sampling program designed to collect sediment samples at regular intervals along a waterway or from depositional areas or both?
	Do the sediment data include results for upstream and downstream samples both on- and off-site?
	Has sediment been defined by the samplers? (To prevent confusion between sediment and soil, assume "sediment" is defined as any solid material, other than waste material or waste sludge that lies below a water surface, that has been naturally deposited in a waterway, water body, channel, ditch, wetland, or swale, or that lies on a bank, beach, or floodway land where solids are deposited.)
	Have any sediment removal activities (e.g. dredging, excavation, etc.) occurred that may have altered the degree of sediment contamination (leading to a false negative). This becomes important when the following occur: 1. Sediment contamination in fishable waters is used to justify sampling and analyses of edible biota. 2. Sediment data are used to justify additional downstream sampling, particularly at points of exposure and in areas not subject to past removal activities. 3. The significance of past exposure is assessed.
Surface water	Do surface-water data include results for samples both upstream and downstream of the site?
	Was information obtained on the number of surface-water samples taken at each station, as well as the frequency, duration, and dates of sampling?
Groundwater	Were groundwater samples collected in the aquifer of concern?
	Did sampling occur both up-gradient and down-gradient of the site and the site's groundwater contamination plume?
All	Did the sampling design include selected hot spot locations and points of possible exposure?

Source: Agency for Toxic Substances and Disease Registry, 2003, ATSDR Public Health Assessment Guidance Manual.

HQ is merely a benchmark that can be used to estimate the likelihood of risk.[3] It is not even likely to be proportional to the risk. So, an HQ >1 does not necessarily mean that adverse effects will occur.

Non-cancer hazard estimates often have substantial uncertainties from a variety of sources. Scientific estimates of contaminant concentrations, exposures and risks, always incorporate assumptions to the application of available information and resources. Uncertainty analysis is the process used by scientists to characterize the just how good or bad the data are in making these estimates.

B. The Hazard Index

The HQ values are for individual contaminants. The hazard index (HI) is the sum of more than one HQ value to express the level of cumulative non-cancer hazard associated with inhalation of multiple pollutants (e.g. certain classes of compounds, such as solvents, pesticides, dioxins, fuels, etc.):

$$\mathrm{HI} = \sum_{1}^{n} \mathrm{HQ} \tag{19.2}$$

An HI can be developed for all pollutants measured, such as the 32 compounds measured in New Jersey as part of the National Air Toxics Assessment (Fig. 19.7). An HI can also be site specific. For example, if an environmental audit shows that only CCl_4 and Cr^{6+} were detected by sampling of soil. Recall that the previously calculated Cr^{6+} dermal HQ was 0.67. The dermal chronic RfD of CCl_4 is $4.55 \times 10^{-4}\,\mathrm{mg\,kg^{-1}\,day^{-1}}$. If the exposure is $1.00 \times 10^{-4}\,\mathrm{mg\,kg^{-1}\,day^{-1}}$, the HQ for chronic dermal exposure to tetrachloromethane is $1.00/4.55 = 0.22$.

Thus, the HI for this site is $0.67 + 0.22 = 0.89$. Since the HI is under 1, the non-cancer effect is not expected at these levels of exposure to the two compounds. However, if the chronic dermal exposure to CCl_4 had been $2.00 \times 10^{-4}\,\mathrm{mg\,kg^{-1}\,day^{-1}}$, the HQ for CCl_4 would have been 0.44, and the HI would have been calculated as $0.67 + 0.44 = 1.11$. This is a benchmark that indicates that the cumulative exposures to the two contaminants may lead to non-cancer effects.

C. Comprehensive Risk Communication

The amount of data and information regarding contaminant concentrations, exposure and effects can be overwhelming when presented to the public and clientele. Thus, these data must be reduced into meaningful formats. A recent example of how the information discussed in this and the previous chapters can be presented is that of the Ohio Environmental Protection

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[3] National Research Council, *Science and Judgment in Risk Assessment.* National Academy Press, Washington, DC, 1994.

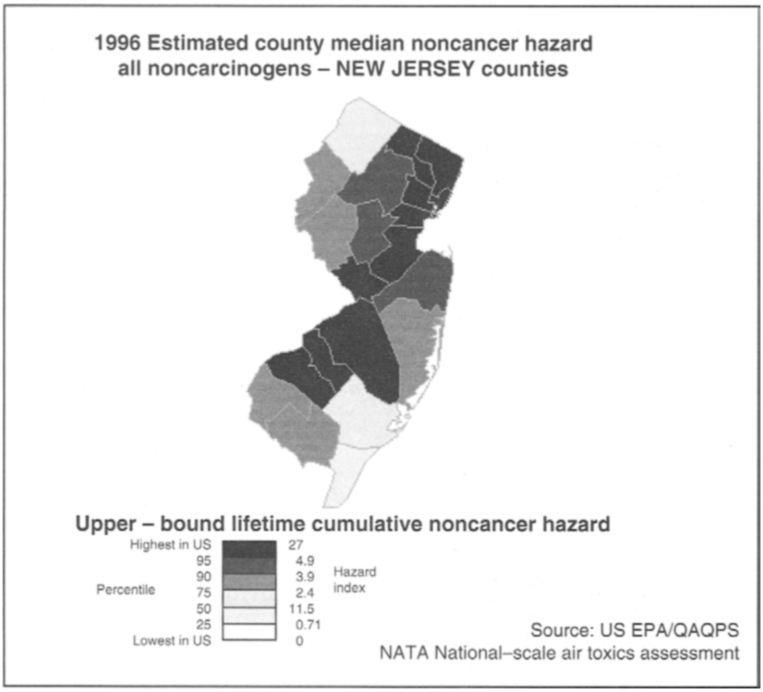

Fig. 19.7. Non-cancer hazard index for 32 air toxics included in the Clean Air Act, based on inhalation exposure data in New Jersey from political subdivisions. Estimates do not include indoor emissions and are based on exposure estimates for the median individual within each census tract, which EPA considers to be a "typical" exposure, meaning that individuals may have substantially higher or lower exposures based on their activities. *Source*: US Environmental Protection Agency, National Air Toxics Assessment.

Agency's Urban Air Toxic Monitoring Program,[4] that addresses potential risks in large urban areas with many industrial air pollution sources. Air quality samples were collected between 1989 and 1997 near a large industrial area in Cuyahoga County. The contaminant concentrations are typical of urban areas, the concentrations should be lower in the future. Pollution prevention activities by industry, vehicle emission tests by motorists and mandates in the Federal Clean Air Act will all help reduce toxics in the air. Samples were analyzed for volatile organic compounds (VOCs), heavy metals and polycyclic aromatic hydrocarbons (PAHs). The agency conducted a risk assessment based on both the cancer and non-cancer health risks, assuming that an individual is exposed constantly to the same concentration of the pollutant for a lifetime (i.e. exposure duration = total lifetime). The results of the cancer health risk assessment are provided in Table 19.2. Heavy metals contributed the majority of the cancer risk (about 66%).

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[4] Ohio Environmental Protection Agency, *News Release*, August 17, 1999.

TABLE 19.2

Cumulative Cancer Risk Based on Air Sampling in Cuyahoga County, Ohio, 1989–1997

Source of cancer risk	Total estimated risk
VOCs	0.515×10^{-4}
Heavy metals	1.21×10^{-4}
PAHs	0.123×10^{-4}
Total carcinogenic risk	1.85×10^{-4}

Source: Ohio Environmental Protection Agency (1999).

Each category in the table shows the cumulative risks from exposure to all compounds detected under a specific contaminant class. The US EPA has defined acceptable exposure risks for individual compounds to range from 10^{-6} to 10^{-4}. Also, it is quite possible that one or a few contaminants are contributing the lion's share of risk to each contaminant class. For example, a particularly carcinogenic PAH, like benzo(a)pyrene or dibenz(a,h)anthracene (each with a inhalation cancer slope factor of 3.10), could account for most of the risk, even if its concentrations are about the same as other PAHs. In fact, this appears to be the case when looking at the individual chemical species listed in Table 19.3 that were used to derive the risks. Likewise, the VOC cancer risk was largely determined by the concentrations of benzene, while the heavy metals, although largely influenced by Cr^{6+}, were more evenly affected by arsenic and cadmium.

The cancer risk calculations are based on the unit risk estimate (URE), which is the upper-bound excess lifetime cancer risk that may result from continuous exposure to an agent at a defined concentration. For inhalation this concentration is $1\,\mu g\,m^{-3}$ in air. For example, if the URE = 1.5×10^{-6} per $\mu g\,m^{-3}$, then 1.5 excess tumors are expected to develop per million population being exposed daily for a lifetime to 1 μg of the contaminant per cubic meter of air.

The cancer risk reported for each individual contaminant is below the level designated by federal health agencies as acceptable, and falls with the range of risks expected for large cities, with their numerous sources of toxic air contaminants (i.e. the so-called "urban soup").

The non-cancer hazard index calculations are provided in Table 19.4. Non-carcinogenic health effects include developmental, reproductive or cardiovascular health problems. Any total HI number below 100% is generally regarded as a safe level of exposure.

As was the case for cancer risk, a few compounds can drive the non-cancer hazard index. For example, the case above, 3-chloropropene and tetrachloromethane (account for an HI of 0.53, while all the other measured VOCs account for only 0.10. And, these two compounds account for almost 82% of the total non-carcinogenic risk estimates.

TABLE 19.3

Individual Chemical Species Used to Calculate Cancer Risks shown in Table 19.2

Compound	Carcinogenic unit risk $(\mu g\,m^{-3})^{-1}$	Source	Average concentration $(\mu g\,m^{-3})$	Carcinogenic risk
VOCs				
Methyl Chloride	1.8 E-06	HEAST	0.68	1.22 E-06
Dichloromethane	4.7 E-07	IRIS	2.06	9.70 E-07
Trichloromethane	2.3 E-05	IRIS	0.27	6.29 E-06
Benzene	8.3 E-06	IRIS	3.91	3.25 E-05
Carbon tetrachloride	1.5 E-05	IRIS	0.55	8.30 E-06
Trichloroethene	1.7 E-06	HEAST	0.55	9.42 E-07
Tetrachloroethene	9.5 E-07	HEAST	1.07	1.02 E-06
Styrene	5.7 E-07	HEAST	0.49	2.81 E-07
Sum				*5.15 E-05*
Heavy metals				
Arsenic	4.30 E-03	IRIS	0.00271	1.17 E-05
Cadmium	1.80 E-03	IRIS	0.00765	1.38 E-05
Chromium(total)[a]	1.20 E-02	IRIS	0.00800	9.60 E-05
Sum				*1.21 E-04*
PAHs				
Benzo(a)pyrene[b]	2.10 E-03	1	0.006	1.26 E-06
Benzo(a)anthracene	2.10 E-04	0.1	0.0048	1.01 E-06
Benzo(b)fluoranthene	2.10 E-04	0.1	0.0023	4.83 E-07
Benzo(k)fluoranthene	2.10 E-04	0.1	0.0007	1.47 E-07
Chrysene	2.10 E-05	0.01	0.0047	9.87 E-08
Dibenz(a,h)anthracene	2.10 E-03	1	0.0041	8.61 E-06
Indeno[1,2,3-cd]pyrene	2.10 E-03	0.1	0.0031	6.51 E-07
Sum				*1.23 E-05*
Total carcinogenic risk				*1.85 E-04*

[a] Estimation based on the slope factor of chromium (VI).
[b] Estimation based on the slope factor of oral route.
Source: Ohio Environmental Protection Agency, 1999, Cleveland Air Toxics Study Report.

TABLE 19.4

Cumulative Hazard Index Based on Air Sampling in Cuyahoga County, Ohio, 1989–1997

Source of non-carcinogenic risk	Hazard index (HI)
VOCs	0.63
Heavy metals	0.008
PAHs	0.012
Total non-carcinogenic risk	0.65

Source: Ohio Environmental Protection Agency (1999).

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1. Federal Register, Part II, Environmental Protection Agency, 40 CFR Part 300, *Hazard Ranking System: Final Rule*, Vol. 55, No. 241, December 14, 1990.
2. *Procedures for Conducting Air Pathway Analysis for Superfund Applications, Vol. I, Application of Air Pathway Analyses for Superfund Activities*, EPA-450/1-89-001, July 1989.
3. US EPA, *User's Guide for the Industrial Source Complex (ISC2) Dispersion Models*. EPA-450/4-92-008a (Vol. I—User Instructions), EPA-450/4-92-008b (Vol. II—Description of Model Algorithms), EPA-450/4-92-008c (Vol. III—Guide for Programmers). US Environmental Protection Agency, Research Triangle Park, NC, 1992.
4. Petersen, W. B., and Rumsey, E. D., *User's Guide for PAL 2.0—A Gaussian Plume Algorithm for Point, Area, and Line Sources*, EPA/600/8-87/009. US Environmental Protection Agency, Research Triangle Park, NC, 1987 (NTIS Accession No. PB87-168 787).

SUGGESTED READING

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QUESTIONS

1. How would the release of a volatile gas from contaminated soil be affected by the soil temperature?
2. The EPA Hazardous Ranking System computes a numerical score for hazardous waste. If the score exceeds a predetermined value, the waste site is placed on the NPL for Superfund cleanup. Discuss the pros and cons of such a ranking system.
3. Describe a possible situation in which an air contaminant is controlled but the control system used transfers the contaminant problem to another medium, such as water or soil.
4. Explain the differences between a hazard quotient, hazard index, and cumulative cancer risk.