RISK ASSESSMENT: TOOLS FOR REDUCING LIABILITY FROM UNDERGROUND STORAGE TANKS

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ABSTRACT: Although regulations are being implemented at federal, state, and local levels, many major oil companies have decided to do even more than is required by law to prevent leaks from underground storage tanks (USTs). On the other hand, regulatory agencies directing cleanup of contaminated sites may demand restoration that goes beyond reasonable concerns for protection of public health and the environment. These cross-currents indicate that simply complying with applicable codes and regulations may not be an adequate strategy for cost-effectively reducing the risks of handling light refined products. To control risks, it is important first to understand them. Risk assessment is useful before a leak occurs as well as after. Before the leak occurs, risk assessment requires estimates of the probability of release as well as the likely consequences (damages). Techniques are presented that can be used to managers of a large number of tanks or insurance underwriters to assess risks and prioritize risk reduction measures. Ultimately, these procedures could be used to determine an appropriate budget for tank upgrade programs.

After a leak, and armed with detailed site assessment data, relatively precise estimates of toxic risks are possible. More realistic risk estimates are possible for refined petroleum product losses than are possible at many hazardous waste sites because of the relatively homogeneous and predictable properties of refined products. Field-verified predictive techniques that can be used to support defensible risk estimates are reviewed. Cost-effective strategies for collecting data required to support risk assessment and remediation of contaminated sites are stressed.

Risks can be mitigated to generally acceptable levels at some sites even if contamination substantially exceeds federal maximum contaminant levels (MCLs). At other sites, remediation to lower levels would be advisable.

Tank owners are confronted by two circumstances where risk assessment techniques can be of value in managing the amount of resources dedicated to environmental concern. First, there are decisions involving the prevention of leaks. Federal regulations recently promulgated under Subtitle I of the Resource Conservation and Recovery Act and an increasing number of state and local regulations dictate construction and retrofit standards designed to prevent leaks or spills or to contain what does occur. Regulatory requirements, although well intended, may not be suitable in every case. In locations where the potential for environmental liability is very great, such as in the presence of vulnerable drinking water supplies, tank managers have frequently decided to go beyond regulatory requirements and provide additional leak control and/or detection systems. Risk assessment techniques can be extremely useful in identifying cases where such measures are prudent.

Second, risk assessment can be valuable in providing a reasoned basis for setting cleanup standards when a leak has already occurred. Generally speaking, there is a wide variation in the cleanup standards required by regulation and practice in various states. The standard that is set by regulatory agencies will vary to some extent, the available technologies and associated costs. In many situations, established risk assessment techniques can be used under existing regulations to arrive at reasonable and prudent standards that can be achieved economically while protecting human health and the environment.

To manage risks, it is important first to understand them. Risk assessment is useful before a loss occurs as well as after. Before a loss occurs, risk assessment requires estimates of this probability of release as well as the likely consequences (damages). After a leak, and armed with detailed site assessment data, relatively precise estimates of toxic risks are possible. This paper presents a variety of techniques that are available to support planning and risk management. For long-term planning and management, techniques will be presented that can be useful to managers of a large number of tanks, or insurance underwriters, to assess risks and prioritize risk reduction measures. Once a loss has occurred, cost-effective strategies for collecting data required to support remedial response planning will be stressed. Fate and transport and exposure assessment techniques will be presented.

As a preface to the paper, a general concept affecting risk assessment for losses of light refined petroleum products from underground storage tanks (USTs) must be introduced: More realistic and precise risk estimates are possible for this category of environmental risks than are possible for hazardous waste disposal sites. There are two primary reasons for this conclusion and one secondary reason:

• There is much less variability in the population of USTs than exists within the population of hazardous waste disposal sites. There are two primary reasons for this conclusion and one secondary reason:
  • There is much less variability in the population of USTs than exists within the population of hazardous waste disposal sites. As a result, the physical conditions of the release are more homogeneous and thus more readily predictable. Robust assessment procedures can be developed that apply to conditions at most sites.
  • The chemical and physical properties of the contaminants are also much more homogeneous than the wide variety of contaminants that may be present at hazardous waste sites. For example, all light refined products are lighter than water. In the case of unleaded gasoline, toxic risks can be assessed by focusing on a single contaminant—benzene. Although all refined products are not the same, and certainly any batch of gasoline is different from all other batches, nonetheless light refined products do share many similarities. These similarities permit the development of robust assessment procedures that apply to many releases.

Finally, the environmental contamination that results from the loss of a light refined product does not persist in the environment indefinitely. Tucker et al. showed that under a wide range of environmental settings characteristic of the state of Florida, significant levels of contamination do not persist in groundwater for more than 12 years if free-floating product is recovered expeditiously. Although contamination may persist somewhat longer in areas with less favorable hydrogeologic and climatic conditions, contamination is not expected to persist over several human generations. At most sites, some combi-
nation of an engineered remedial action and natural restoration processes can lead to aquifer restoration within 5 to 20 years. This is well within the planning horizons of local land use and water management plans.

Furthermore, the natural attenuation processes also act most effectively at the leading edge of a contaminated groundwater plume, controlling and limiting its maximum areal extent. Considering the clearly limited extent of contamination, in both space and time, it is possible to anticipate how land and water within a potentially contaminated area would actually be used for the duration of a contamination incident. These factors reduce the uncertainty of assessing the risks associated with hydrocarbon losses. Some of the factors discussed have been taken into account by insurers who offer pollution liability coverage for USTs.18

Assessing the risks posed by a population of tanks

The topics to be addressed in this section should be of interest to two audiences:

- Managers or engineers charged with managing a large number of USTs to ensure environmental compliance and cost minimization. In cost minimization, we include remedial costs and liability due to product losses.
- Insurance underwriters evaluating whether to write environment impairment liability (EIL) coverage to USTs, and establishing pricing strategies, including those that encourage risk reduction.

This paper will address the first audience, although many of the concepts are similar and apply to underwriters' concerns as well. The tank network manager typically must cope with resource limitations that dictate prioritization of risk reduction measures. A variety of options are available, including elimination of some tanks, though that option may hamper operational efficiency. The objective is to achieve the greatest risk reduction within cost constraints, that is, the most "bang for the buck." Let's begin with the most practical problem: how to do the most good with a fixed budget. To conclude this section, we will introduce additional techniques that can help define what the budget ought to be.

Risk is defined as the probability of an adverse outcome multiplied by the consequences if that outcome occurs. In this case, it is the probability of a product loss, \( P \), times the damages, \( D \), that may be expected from the loss:

\[
Risk = P \times D
\] (1)

The probability of a release from a UST or a cluster of several USTs is principally affected by the system's design, construction materials, installation procedures, and age. For systems subject to corrosion, the physicochemical properties of the backfill material, including its moisture content, are also important. The variety of release modes and basic engineering factors that can prevent, mitigate, or cause releases are addressed in reports from the U.S. Environmental Protection Agency (EPA)12, 13, 14, 15, 16 and the American Petroleum Institute (API).15, 16 A few interesting facts are apparent from these sources.

Most unprotected steel tanks will fail by corrosion within 20 years of installation. A significant percentage, however, will not. Through fortuitous, and largely unpredictable, combinations of ideal fabrication and installation, approximately one-fourth of all bare steel tanks corrode uniformly rather than locally (for example, at a weld). Such tanks may maintain their integrity for much longer than 20 years. If a bare steel tank has not failed by corrosion in 20 years, it probably will not for a long time.

Another important finding from the cited sources is that a lot of product losses result by noncorrosive mechanisms. These are dominated by mechanical damage during or shortly after installation, overfill, and pump and pluming joint failures. If one considers some of the less frequently encountered release mechanisms, such as vandalism and earthquakes, it should be recognized that the risk cannot be reduced to zero. There is an inherent risk in storage of petroleum products regardless of system design, installation, and operating procedures.

The aforementioned sources indicate that the probability of product loss can be reduced by retrofitting cathodic protection, or replacing aging bare steel tanks; and by overfill protection. The probability of loss is also less if recent precision test results indicate that the system is tight. For the purpose of deciding how to spend a fixed budget, however, a quantitative estimate of the probability of a loss is not critical. It is sufficient to prioritize tanks with a large number of risk factors, such as older bare steel tanks with overfill protection. The age at which heightened concern is warranted (usually 10 to 15 years) depends on the corrosivity of backfill materials and whether the tank is installed below the water table.

It is impossible to go into greater detail in this paper on the risk factors affecting probability of a release, so let's turn to methods for estimating the damages if a leak were to occur. Damages are readily separated into two parts: remediation costs and liability to claims by other parties. Both can be affected by the nature and magnitude of the loss, the environmental setting and political jurisdiction of the site, and monitoring systems. The probability of substantial claims by third parties is also correlated with nearby water use, buildings, underground utilities, population density, and critical habitats.

Nature and magnitude of loss. It is impossible to predict in advance the type of loss that may occur. If it were possible, the tank manager would be able to prevent it. Some correlations with available information about the UST system may be anticipated, however.

Effective monitoring systems can reduce the loss. The losses that cause the most damage are slow leaks that go undetected for a long time, catastrophic losses due to tank rupture by mechanical damage, overfills, and spills are responded to quickly. The spread of contamination over a large area can be, and usually is, prevented. Slow leaks can go undetected for months, without effective leak detection. In the past, they were often discovered only by their symptoms of taste and odor after spreading over a large area. These conditions increase remediation costs and the probability of substantial claims by other parties. An effective monitoring system that detects such slow leaks within hours, a week, or a month, will be responded to by emptying the UST system. The total volume lost would thus be reduced substantially. Automatic, continuously operating leak detection systems have the potential to virtually eliminate slow leak losses. Reliability and down-time of such systems need to be accounted for. Inventory reconciliation and/or monthly sampling of monitor wells may also be expected to substantially reduce the volume lost by slow leaks, which, historically, have lasted for several months before detection.

Overfill protection. Overfill protection can reduce the number of losses significantly, but has relatively less effect on risk reduction. Historically, overfills have been a relatively frequent cause of losses, but overfill losses have below-average volume.10, 16 Response to overfills is relatively rapid, which further reduces the damages from this type of loss.

Environmental setting. Critical factors are depth to water, whether an uppermost water table aquifer is used for potable supplies locally, the permeability of unsaturated soils above the water table, and the rate of groundwater movement in the uppermost aquifer. These factors can be addressed using DRASTIC, a screening tool used by EPA to evaluate the vulnerability of groundwater systems to superficial contamination.

Political setting. States and/or local jurisdictions that tend to enforce stringent cleanup standards can affect remedial costs. Jurisdictions that frequently impose fines or other penalties can be a significant source of claims by other parties.

Monitoring systems. The importance of effective monitoring in reducing risk was discussed under "Nature and Magnitude of Loss." Rapid response is critical to avoiding claims by other parties and can also significantly reduce response and remediation costs for slow leaks. Monitoring systems do not substantially reduce damages from catastrophic fast leaks, which are readily detected and responded to regardless of the monitoring system in use.

Receptors. The tank network manager should prioritize sites for risk reduction measures based on the potential to cause harm, including the following risk factors:

- Nearest downgradient potable well
- Number of potable wells within a specific distance
- Nearest residential, commercial, or institutional structure
- Number of people who occupy such structures within a specific distance
- Proximity to underground utilities (buried cables, sewers, water mains)
• Proximity of critical habitats, such as protected wetlands, surface waters, endangered species habitats, and recreational fisheries. To decide the most effective way to spend a fixed budget, relative ranking of sites according to risk is sufficient. The riskiest sites are highlighted for risk reduction actions. UST removal versus upgrade can be evaluated in the context of the criticality of the installation to meet operational objectives of the facility. Absolute risk estimates are required to determine the most appropriate response—to determine what the budget ought to be. Absolute risk estimates may also be needed to underwrite insurance. The former problem is solved by a classic optimization or total cost minimization technique once the absolute economic risk is estimated. This absolute risk can be calculated by Equation 1, with

\[ P = P_n + P_c \]

Where:  
\( P_n \) = probability of loss by noncorrosive mechanisms  
\( P_c \) = probability of loss by corrosive failure.

Damages cover remedial costs and claims by others, including fines. A nominal estimate of remedial costs can be made considering the depth to groundwater, the transmissivity of the aquifer (affects pumping rate), the texture of soils in the unsaturated zone, and the political jurisdiction. The estimated remedial cost should be modified according to the anticipated response time based on the monitoring system in use at the facility.

Claims by others are expected to correlate with the number and severity of risk factors itemized earlier, and inversely with the response time of the monitoring system. This element of risk can be modified to consider such insurance-related issues as deductibles and maximum coverage per claim.

Through Equation 1, a variety of risk reduction measures can be evaluated: Tank removal, replacement and upgrade, overfill protection, and installation of more sophisticated monitoring equipment. Costs of these options can be compared with the risk reduction (in dollars) to determine the lowest cost plus risk strategy.

**Risk assessment after a loss**

After a loss has occurred, risk assessment is an integral part of response planning. Risk assessment techniques similar to those applied for hazardous waste sites are generally appropriate. Florida and California, among other states, specifically identify risk assessment procedures as an integral element of the response planning process. The California Department of Health Services (CDHS) issued guidelines in 1986; Florida’s regulations are codified in Florida Administrative Code Section 17-70. Selected topics pertinent to petroleum losses are discussed below.

**Planning field data collection.** California’s site mitigation decision tree is an example of the integration of risk assessment considerations into the field data collection planning process. The author recommends the process outlined in Figure 1 at each decision point regarding additional data collection. Extreme assumptions (best case and worst case) should be adopted to fill all data gaps. Two risk estimates should be made based on the extreme assumptions, an upper and lower bound. If the upper bound estimate represents a risk acceptable to all parties, then additional data collection is not required. A no-action alternative would be viable. If the lower bound risk is unacceptable, then remediation should proceed. If the upper and lower bounds span the acceptable risk range, this analysis would imply significant uncertainty regarding the risks posed by contamination at the site, and additional data would be necessary to reduce the uncertainty in the risk estimate.

The step in Figure 1 labeled “Determine additional data requirements” involves a variety of considerations that cannot be developed in this paper. It is critical that additional data collection be designed to reduce the uncertainty in the risk estimate cost effectively.

**Selection of indicator chemicals.** One of the simplest features of risk assessment for subsurface losses of light refined products is the selection of indicator chemicals. Toxicity of unleaded gasoline is associated primarily with the benzene fraction and this simplifying concept has been applied to risk assessment by the Florida Petroleum Council and EPA. Tetraethyl lead and ethylene dibromide additives are significant contributors to toxicity and risk for some gasolines. Other aromatics, including toluene and xylene, can also contribute to taste and odor problems but are of relatively low toxicity when compared to benzene. Diesel fuels and light fuel oils generally contain polynuclear aromatic hydrocarbons (PNAs). The specific PNAs typically observed in significant concentrations in light refined products are two- and three-ring structures (such as naphthalene) usually considered to have lower toxicity than the heavier PNAs, which include benzo(a)pyrene. Nonetheless, these compounds are occasionally grouped and reported as total PNAs. When this approach is used, the lighter PNAs are usually attributed the same toxicity as benzo(a)pyrene, a procedure that probably overstates the risk.

**Fate and transport assessment.** The migration behavior of free product in the subsurface is quite complex and will not be described in detail here. If free product is encountered at a site, risks may be presumed to be unacceptable, and recovery of the product is usually warranted (Figure 1). Fate and transport assessment in support of risk assessment would generally focus on sites with residual contamination after free product has been recovered.

Residual hydrocarbons are petroleum products immobilized in soil/sediment pores by capillary action against the forces of gravity or hydraulic gradients. Theoretical prediction, or modeling, of the leaching, volatilization, biodegradation, and transport of the constituents of residual hydrocarbons is complicated and, for most purposes, can only be handled by computer simulation. There is a strong interaction between the unsaturated and saturated zones, since a major fraction of the residual hydrocarbons may be found near the fluctuating water table elevation. Recent research has focused on simulation of the biodegradation process because microbial action is apparently the dominant fate process ultimately restoring contaminated soils and groundwater.

Significant advances have been made recently in the development of computer models that address these complexities. Corapcioglu and Baehr and Baehr and Corapcioglu presented a model for the fate of an eight-component mixture analogous to gasoline in the unsaturated zone. Their model rigorously evaluates leaching, volatilization, and biodegradation and their effects on contaminant migration to ground-
water and weathering of the residual product. The model has not been validated and does not simulate fate in groundwater. Its extensive input and computational requirements qualify it as a research tool, unsuitable for routine site-specific application in its current state of development.

Borden and Bedient\textsuperscript{6,7} presented Bioplume II, an aquifer fate and transport model that emphasizes dissolved oxygen availability as the critical constraint on biodegradation. It simultaneously simulates dissolved hydrocarbons and oxygen in the aquifer, triggering rapid degradation at the boundaries of a plume where both constituents are optimal. Bioplume II has been field-validated at a site in Michigan. Bioplume II does not simulate the fate of residual hydrocarbons in the unsaturated zone. Its input requirements are generally consistent with data routinely available at contaminated sites, with the exception that aquifer dissolved oxygen is not routinely monitored.

Tucker \textit{et al.}\textsuperscript{24,25} presented the Underground Leak Transport Assessment (ULTRA) model, a comprehensive model of the fate and transport of benzene released with petroleum hydrocarbon losses. It addresses unsaturated and saturated zones as a coupled system. Oxygen availability is addressed by imposing an upper bound on the biodegradation rate, but the oxygen distribution is not resolved spatially as in Bioplume II.

In summary, the ULTRA concept includes the following:

- Water flows from the land surface through soils to the aquifer.
- The source of benzene is associated with residual hydrocarbons in the unsaturated soil zone immediately above the water table.
- Infiltrating rainwater dissolves benzene from the residual hydrocarbons and carries it to the aquifer.
- Benzene may also be released to the aquifer if the water table rises into the contaminated zone.
- Benzene concentrations in the source area decrease with time as leaching carries benzene to the aquifer, and natural mitigation by volatilization and biodegradation takes place.
- Benzene released to the aquifer is transported with the flowing groundwater and diluted by dispersion processes.
- Contaminated groundwater may be pumped out of the aquifer to simulate groundwater restoration actions.
- Benzene may be biodegraded within the aquifer or volatilized from the water table.

ULTRA was validated against field data from two leak sites in Florida, as indicated by a comparison of predicted and observed groundwater concentrations at one of the sites, shown as Figure 2. Similar results were observed at the second site. Concentrations predicted by ULTRA are expected to be reliable to within a factor of 5. These applications illustrate that natural mitigation processes acting in the subsurface are more effective than groundwater pumping and treatment systems in reducing benzene concentrations in the subsurface. This is illustrated by Figure 3, which shows the fate of subsurface benzene at one of the two sites.

ULTRA is a powerful predictive tool in support of risk assessment of petroleum-contaminated sites, particularly since it has been field-verified, and its input requirements are consistent with data routinely available at contaminated sites.

**Exposure assessment.** Exposure to toxic contaminants in the ground is virtually negligible in most situations. Exposure to groundwater contaminants occurs principally after the water is extracted by a well and used domestically. One exception to this rule occurs when free product or groundwater containing volatile contaminants migrates under a residence or other structure. If the water table is fairly close to the surface, vapors can diffuse through the unsaturated zone and accumulate in the confined air of the building.

Jury \textit{et al.}\textsuperscript{26} presented the theory of molecular diffusion of vapors through soils. The flux, \( F \) (mg/m\textsuperscript{2}/day) is given by:

\[
F = \frac{n_{a}^{0.3} D_{c} C_{a}}{n h}
\]

Where:  
- \( n_{a} \) = air-filled porosity of the soils  
- \( n \) = porosity of the soils  
- \( D_{c} \) = molecular diffusion coefficient of the contaminant in air (m\textsuperscript{2}/day)  
- \( C_{a} \) = concentration in the air phase at equilibrium with the free product or contaminated groundwater (mg/m\textsuperscript{3})  
- \( h \) = depth to product or water (m)

If free product contains 2 percent benzene, the concentration in air at equilibrium is 2 percent of the saturation vapor density of benzene or 8,740 mg/m\textsuperscript{3}. To evaluate vapor diffusion flux from contaminated groundwater, Henry's law applies, resulting in \( C_{a} (\text{mg/m}^{3}) = 0.235 C_{w} (\mu\text{g/L}), D_{c} = 0.90 \text{ m}^{2}/\text{day}. \) Thus,

\[
F = 7,850 \frac{n_{a}^{0.3} D_{c} C_{a}}{n h}
\]

**Figure 2.** Comparison of predicted and observed concentration of benzene in the recovery well—Vero Beach site

**Figure 3.** Model-predicted fate of subsurface benzene during 17 months after free-product recovery—Vero Beach site
where free product containing 2 percent benzene is present; and

\[ F = 0.212 \frac{N^{0.93} C_n}{n h} \]

where free product is not present.

The steady-state concentration in the structure can be calculated by a simple ventilation model, that is

\[ N = 20 \text{ day}^{-1} \text{ and } h = 3 \text{ m}, \]

for a clean sand. Loams are intermediate and average 0.03. 23

0.0135 mg/m³ (lifetime cancer risk of 10⁻⁴). The risk level of 10⁻⁴ may be appropriate since the exposure is not expected to persist for

70 years. This concentration should be contrasted with the average indoor benzene concentration of 0.0258 mg/m³ reported from 353 homes by Sample and Gilbert. 2

Typical values of \((n^{0.93}/n)\) range from \(5 \times 10^{-5}\) for clay soils to 0.15 for a clean sand. Loams are intermediate and average 0.03. 35

Following EPA risk assessment guidelines, \(C_i\) should not exceed 0.0135 mg/m³ (lifet ime cancer risk of 10⁻⁴). The risk level of 10⁻⁴ may be appropriate since the exposure is not expected to persist for 70 years. This concentration should be contrasted with the average indoor benzene concentration of 0.0258 mg/m³ reported from 353 homes by Sample and Gilbert. 2

Applying reasonable values for a detached one-story residence of \(N = 20 \text{ day}^{-1}\) and \(h = 3 \text{ m}, \)

\[ C_i = \frac{F}{N h} \]

The results of calculations based on these formulae and data are presented in Table 1, which shows the maximum concentration of benzene in groundwater to avoid indoor air concentrations exceeding 0.0135 mg/m³. Air diffusion through clay soils is so slow that even if there were floating product under the building, it would not result in unacceptable air concentrations. On the other hand, in loamy or sandy soils, unacceptable exposures could occur by contaminated groundwater transport under buildings, regardless of the source of potable water for the residents.

Assuming that contaminated groundwater is used domestically, a variety of exposure pathways are possible. Recent research indicates that inhalation exposures in the home may well exceed direct ingestion of tap water where volatile contaminants are concerned. Direct ingestion of unboiled tap water is a relatively small source of exposure for most people. 4 The International Commission for Radiological Protection (ICRP) 36 recommends assuming 0.1 to 0.2 L/day of direct tap water ingestion. In several studies discussed by Andelmann, 4 intake of tap water by adults (including beverages such as coffee and tea) ranged from 0.96 to 1.3 L/day. A portion of this intake is associated with beverages prepared from boiled water, which tends to drive off volatiles such as benzene. It is clear that we do not ingest the amount of benzene contained in 2 L of water per day. There is good reason to believe, however, that we would inhale that much benzene from the release to indoor air of volatiles from the much larger volume of water used in a house every day. Results, such as those reported by Andelmann 4 support an assumption that domestic use of water results in exposure to the volatile contaminants contained in 2 to 4 L of water per day. Most of the exposure is by inhalation. As a result, provision of bottled water for drinking and cooking does not substantially reduce exposure if contaminated water is still used for bathing and sanitary purposes in the home.

A final exposure pathway of interest is the use of well water to irrigate vegetable crops such as are commonly grown in back yard gardens. Briggs, et al. 8, 9 presented a method for estimating plant uptake from irrigation water. Their results indicate that the concentration of benzene in plant tissues, on a wet weight basis (Cp, µg/kg), would be about equal to the concentration in irrigation water, given in µg/L. If back yard gardeners consume an average 0.1 kg of home-grown produce per day their exposure would be:

\[ \text{Exposure (µg/day)} = 1 \times \frac{(C_p)}{(kg \text{ of produce})} \times (0.1 \text{ kg/day}) = 0.1 C_p (µg/L) \]

Based on the discussion of exposure to indoor water uses, at the Federal maximum contaminant level (MCL) of 5 µg/L people are exposed to about 10 to 20 µg of benzene per day. A similar exposure would occur if well water were used to irrigate the back yard vegetable garden and the concentration was approximately 100 µg/L. If this exposure persisted for 15 years, the incremental individual cancer risk would be approximately 10⁻⁶.

To summarize this discussion of exposure pathways, it was found that even where local groundwater is not used for domestic purposes, exposures to subsurface hydrocarbons can occur by volatilization from the water table or use of well water to irrigate vegetable gardens. Site-specific assessment would always be required to evaluate exposures. If a loss occurred far from any occupied buildings, groundwater contamination may pose negligible risk. In many populated areas with shallow water tables, however, groundwater contamination exceeding approximately 100 µg/L benzene could pose an unacceptable risk regardless of the source of tap water.

### Conclusions

The applicability and utility of a wide range of risk assessment procedures to manage the risks posed by subsurface losses of light refined petroleum products have been illustrated. Anyone charged with the responsibility of managing UST facilities to avoid environmental liabilities should be aware of the variety of ways that risk assessment can support rational planning and decision-making.

### References