Allocating Hazardous Waste Sites
Most people agree that Superfund sites and other complex, multiparty, hazardous waste sites that pose risks to human health and the environment should be remediated. However, the process of apportioning cleanup costs is often disputed among the potentially responsible parties (PRPs). As the available state and federal funding for site cleanup has diminished, pressure has increased for PRP-funded cleanups. Allocating uncertain cleanup costs in a timely, equitable, and mutually acceptable manner among numerous PRPs with different connections to the site, especially given varying legal interpretations and limited data, creates a difficult dilemma. Costly and protracted litigation to determine cost shares is an increasingly unattractive option and provides a strong incentive for devising a fair, understandable, and efficient privately administered approach to allocating costs among PRPs. This article outlines such an approach.

The legal framework
At a typical hazardous waste site, several categories of PRPs often face liability: current and past site owners, current and past operators or lessees, waste generators whose wastes were released or disposed of at the site, and transporters who selected the disposal site and took the generator’s wastes to the site for treatment or disposal. Significant differences may exist within and among these classes of PRPs in terms of their contributions to and degree of responsibility for site conditions. Changes in site ownership and operations and disputes among identified PRPs often lead to disagreements over when the contamination occurred, whose wastes are present and most difficult to clean up, what volume or mass each party contributed, and which hazardous wastes actually drive cleanup costs.

As the cleanup price tag increases, PRPs often use various arguments to reduce their share of costs. For example, PRPs may claim that another PRP’s wastes are much more expensive or difficult to remediate, that their own wastes are in much smaller amounts or are less toxic than another PRP’s wastes, or that their own wastes have biodegraded.

Historically, judicial interpretations of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, or Superfund) and other federal and state environmental statutes based on various criteria have determined which parties were liable and what costs were recoverable. Relatively limited statutory guidance existed on how costs should be allocated among multiple PRPs. However, sophisticated analytical tools are now available and work within the legal framework. Thus, a brief overview of this legal framework provides a useful starting point.

The CERCLA statute and case law suggest that in an allocation proceeding among multiple PRPs, recoverable past costs consist of all costs of prior response actions that were necessary and consistent with the National Contingency Plan (NCP) (1), which is implementing regulations for CERCLA as detailed in the U.S. Code of Federal Regulations (CFR) 40 CFR 300 (2). Necessary response actions are those required by applicable state or federal statutes, regulations, and guidance and by site-specific agency orders or directives (1). Site or process improvement costs in which a party gains an econom-
ic benefit are not included. Response actions must also be consistent with the NCP. For example, specified procedures must be followed in selecting remedial actions, including the equivalent of a remedial investigation and feasibility study that defines the nature and extent of contamination, reviews potential remedial alternatives, and provides public review and comment on the proposed remedy.

In December, the U.S. Supreme Court issued a significant decision under CERCLA. According to Cooper Industries, Inc. v. Aviall Services, Inc. (543 U.S. ___, 125 S.Ct. 577 [2004]), private parties that undertake cleanups cannot sue another PRP for contribution under CERCLA §113 (f) (1), 42 USC 9613(f) (1), unless they first have either been sued by the government or settled with the government under CERCLA. This ruling is likely to limit the ability of PRPs to recover costs for voluntary cleanups of contaminated sites but is unlikely to affect allocation criteria or procedures in many cases.

The remedy must also meet the nine selection criteria set forth in 40 CFR 300.430(e)(9)(iii) (3), including overall protection of human health and the environment; compliance with federal and state applicable or relevant and appropriate requirements; both long- and short-term effectiveness of the cleanup as well as permanence of the remedy plan; reduced toxicity, mobility, or volume through treatment; implementability; cost; and state and community acceptance.

Parties will sometimes dispute whether another party’s past response actions were necessary or consistent with the NCP, claiming that the cleanup was inappropriate, failed to follow required procedures, or went beyond regulatory requirements. In such cases, a careful evaluation of the actions taken with regard to applicable regulations, statutes, and guidance is needed, along with an assessment of the technical appropriateness of the implemented cleanup.

According to Section 113 of CERCLA, Title 42, U.S. Code Section 9613, “In resolving contribution claims, the court may allocate response action costs among liable parties using such equitable factors as the court determines are appropriate” (4). This legal standard provides considerable latitude for a court to determine each party’s equitable share of the cleanup costs. Courts often consider the “Gore factors” (see box) to evaluate equitable factors (5, 6).

The first three Gore factors require that a technical evaluation of site data and information be conducted before a defensible allocation can be made. These, as well as other technical considerations, are discussed in the remainder of this paper. Gore factors 4–6 are based on factual historical information about the PRPs’ involvement at the site. Other nontechnical factors that have been considered include the knowledge and/or acquiescence of the parties in the contaminating activities, the parties’ financial resources, the financial benefits each party derived from the contaminating activities, the state of mind of the parties, contracts between the parties bearing on the subject, traditional equitable defenses, and the relative culpability of the parties (7, 8).

The Gore factors

1. The ability of the parties to demonstrate that their contribution to a discharge, release, or disposal of a hazardous waste can be distinguished.
2. The amount of hazardous waste involved.
3. The degree of toxicity of the hazardous waste involved.
4. The degree of involvement by the parties in the generation, transportation, treatment, storage, or disposal of the hazardous waste.
5. The degree of care exercised by the parties with respect to the hazardous waste concerned, taking into account the characteristics of such hazardous waste.
6. The degree of cooperation by the parties with federal, state, or local officials to prevent any harm to the public health or the environment.

Under the analytical framework

In general, the recoverability of response action costs, including assessment and remediation, depends on when, why, and by whom such costs were incurred and may differ among governmental and private plaintiffs. Allocating costs is essentially a two-step process.

The first step in such disputes is to determine the total cost to assess and clean up the site. This requires a thorough understanding of the site, including use, storage, and disposal of hazardous waste; the vertical and horizontal extent of contamination; site cleanup goals; the area and volume of contaminated media requiring cleanup; applicable cleanup technologies; and the projected cleanup time frame and costs.

Published U.S. EPA guidance (9, 10) and industry resources (11, 12) can help in the projection of future costs, such as additional site assessment; remediation, including capital, operation, maintenance, and monitoring; permitting; agency oversight costs and regulatory compliance fees; and legal costs. In some cases, natural resource damage costs may also need to be considered, and the potential exposure associated with these claims depends on the value and damage to the lost natural resource. Superfund cleanup cost information is also available to help quantify future cleanup costs (13, 14).

Four methods for projecting future costs are described in the American Society for Testing and Materials (ASTM) cost estimation standard, ASTM E2137-01 (15), which is used as a guide in the environmental industry.

The “expected value” is derived from a decision tree or model of potential event outcomes and associated costs. The distribution of costs and the associated probabilities of each potential outcome are then used to calculate the expected value. A “most likely value” uses the costs for the scenario considered to be most likely to occur (i.e., the preferred or selected technology for cleanup). A “range of values” is used when the probabilities or rankings for various outcomes cannot be explicitly determined. The “known
minimum value” is used when “the outcome and cost uncertainties are so great that it is premature to estimate a range of values or a most likely value” (15).

Allowances for contingencies and uncertainties are included when cost estimates are developed. Cost databases assembled by industry, such as the Remedial Action Cost Engineering and Requirements (RACER) system (12), provide useful tools for estimating future cleanup costs. RACER is used as a cost-estimating tool by EPA, the Department of Defense (DOD), the Department of Energy, private-sector owners and operators, state regulators, and consultants. RACER is DOD-accredited. Alternatively, actual final (incurred) costs or costs determined by insurers or other entities that have assumed the liability for final cleanup can be used. Once the cost is established, an appropriate methodology must be implemented to allocate damages among PRPs.

The second step involves splitting up the cost among the responsible parties. Disputes among the parties in allocating cleanup costs frequently arise during litigation or lead to it. Technical experts are used in court and mediation to evaluate the technical basis that each party claims supports its perceived share of the costs. This often leads to a battle between experts supporting diametrically opposed positions. The trier-of-facts (generally a judge but sometimes a jury or an arbitrator) is then faced with the daunting challenge of sorting through complex science, site history, and factual information to rule on a dollar value or percentage that each party must contribute toward current or anticipated costs. In the face of such complex considerations, a simple approach such as the relative ownership or operational period by each of the PRPs at the site may be an attractive solution. However, a simple solution may not be the most appropriate or “equitable” decision. More technical factors may need to be considered.

Timing. Of course, the most favorable allocation of cost to a PRP is zero. This is justified, for example, if it is demonstrated that the chemical releases occurred before or after the PRP owned or operated the site, or when none of the generator’s waste was disposed of at the site or adversely impacted it.

Forensic tools to determine the source and timing of chemical releases have previously been described (16–18). For example, lead (19) or cesium (20) isotope data can sometimes provide information about the age of chemical release. Evaluating isoprenoids helps investigators to estimate the age of diesel releases (21–23). Information on documented releases, chemical handling, and storage and disposal practices must also be carefully evaluated.

Distinguishability. Standardized laboratory methodologies allow the site investigator to distinguish the nature and identity of individual chemicals present in environmental media (24). Compounds sometimes can be linked to a specific PRP or can be eliminated from an association with a certain PRP. For example, lead from a historical release of leaded gasoline can be distinguished from methyl-tert-butyl ether (MTBE) originating from more recent gasoline formulations (25).

In some cases, records from disposal facilities on incoming waste may indicate the specific chemical wastes that a PRP sent to a site. Unique chemical markers may be present that are solely attributable to one PRP. Such markers could be priority pollutants or nontarget compounds that should be included in the site sampling and analysis plan or evaluated later with laboratory data. Constituent ratios and other forensic techniques sometimes allow the investigator to identify the origins of commingled chemicals. Costs can also be distinguished on the basis of activities at specific operable units and site locations. Further, costs can be assigned to individual PRPs for actions they have taken to remediate or remove particular wastes. These approaches may allow parties to distinguish chemicals released or generated by a specific PRP.

Toxicity. Numerous chemicals are listed as “hazardous substances” in 40 CFR 302.4 Table 302.4. Various chemical mixtures are considered to be hazardous wastes, pursuant to regulations (26) promulgated under the Resource Conservation and Recovery Act (27).

The degree of toxicity for noncarcinogens is reflected by their reference dose (RFD), defined as “an estimate of a daily exposure level to an agent for the human population, including sensitive subpopulations, that is likely to be without an appreciable risk of deleterious effects during a lifetime” (28). The degree of human toxicity for carcinogens is measured by their cancer slope factor (CSF), which is defined as “a plausible upper-bound estimate of the probability of a carcinogenic response per unit intake of a chemical over a lifetime” (28). Lower RFD values and higher CSF values reflect more potent noncarcinogens and carcinogens, respectively. Thus, the relative potency of chemical toxicants can be approximated with values published by EPA (29–31) and therefore can be considered in apportioning costs to PRPs, as shown in Figure 1 (see next page).

Remediation drivers. Risk-based cleanup standards or other potentially relevant regulatory standards (e.g., maximum contaminant levels for drinking water) often drive remedial requirements and costs. The ease or difficulty of assessment and remediation of chemicals is considered in assigning costs among PRPs. For example, although benzene is a known human carcinogen (32), it is typically biodegradable (33) and is often amenable to conventional and less costly treatment technologies, such as air sparging, soil vapor extraction (34), and nat-
ural attenuation. However, some herbicides, pesticides, and PCBs are typically more persistent and resistant to biodegradation and therefore usually require more costly remedial approaches. Thus, a smaller mass of recalcitrant or highly toxic chemicals can require a greater response action than a larger mass of less recalcitrant chemicals. Weighting costs toward PRPs that released chemicals that require more aggressive or costly cleanup technologies should therefore be considered.

**Mass.** Perhaps the most commonly used allocation factor is the mass or volume of waste material that each party sent to a site. Mass is the most useful factor when PRPs have sent known quantities of similar waste types, such as spent solvents or mixed solid waste, to one site (e.g., a landfill); however, accurate records are often lacking for these types of sites. Typically, at the majority of sites, the quantities of waste are unknown and must be estimated from soil and groundwater data (e.g., contaminant concentrations in various matrices). Various interpolation techniques are available to evaluate the volume of impacted media and the associated contaminant mass (35). The various contaminant phases (soil, vapor, and groundwater) and the equilibrium relationships between these phases must be carefully evaluated (36).

The extent of the contamination has traditionally been evaluated using 2-D or 3-D contour maps of concentration data. Such isoconcentration maps display the 2-D or 3-D spatial distribution of contamination and can be used to estimate the concentration between areas with measured values. Maps for small or simple field data sets can be hand-drawn. Large or complicated data sets require commercially available computer contouring programs, such as Surfer, Geosoft, or EVS, to estimate values between areas with observed values and to then calculate the total compound mass (37–39). Adequate spatial field data are needed to accomplish this task. Once calculated, the mass of a unique chemical (or chemicals) associated with a PRP can then be compared with those attributable to other PRPs. The calculated mass must also consider background concentrations, particularly for metals, and the mass attributable to the appearance of degradation products (e.g., tetrachloroethylene degrading to trichloroethylene).

**Nonaqueous-phase liquids (NAPLs).** NAPLs are immiscible-phase organic compounds that exist as separate phases in the aquifer matrix. NAPLs are typically classified by their densities. Light NAPLs (LNAPLs) are less dense than water and include petroleum products such as gasoline and fuel oil. Dense NAPLs (DNAPLs) are denser than water and include most chlorinated solvents, PCBs, and waste produced from manufactured gas plants (40). Because the subsurface movement and distribution of both LNAPLs and DNAPLs are different from the movement and distribution of dissolved-phase contaminants, alternative methods are required to evaluate their migration potential, extent of impact, and mass. However, when NAPL mass is estimated, it is important to consider the difficulty of detecting DNAPLs (41) and the complexity of evaluating LNAPL mass (42).

**Facilitated transport.** Human activities can mobilize contaminants to great depths or distances, and this can potentially lead to increased site characterization and cleanup costs. Physical means, such as soil regrading or road construction, redistribute contamination to larger areas of impact. Some chemicals enhance transport beyond what is expected on the basis of Darcian flow and liquid/solid sorption equilibria. For example, at certain

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**FIGURE 1**

### Rankings of common carcinogens

The relative potency of chemical toxicants is considered in apportioning costs to potentially responsible parties. In this example, the cancer slope factor of several carcinogens is shown for (a) oral ingestion and (b) inhalation. Dioxin = 2,3,7,8-tetrachlorobenzodioxin; BaP = benzo[a]pyrene; VC = vinyl chloride; TCE = trichloroethylene; CT = carbon tetrachloride; 1,1,2-TCA = trichloroethane; PCE = tetrachloroethylene; MTBE = methyl-tert-butyl ether.

![Graph showing cancer slope factor for common carcinogens](image)
concentrations, surfactants enhance the aqueous solubilities of organic contaminants, which then travel farther and more quickly in the environment \((43, 44)\). High concentrations of organic compounds or solvents can also facilitate the transport of hydrophobic contaminants such as PCBs, DDT, di-oxins, and PAHs \((45)\). Because these contaminants are typically relatively immobile, such transport increases assessment and remediation costs. Facili-
tated transport is considered a weighting factor in allocating costs among PRPs.

**Biodegradability.** Biodegradable compounds typically require less costly cleanup technologies. However, they should still be considered in assigning costs among PRPs, because they can affect the properties or cleanup time of less biodegradable contaminants. For example, aerobically degradable contaminants can rapidly deplete oxygen in the subsurface; this results in anaerobic conditions that can limit the degra-
dation of the remaining contaminants. Alternatively, biodegradable compounds can promote co-metabol-
ic degradation of more recalcitrant compounds such as chlorinated solvents \((46)\). The toxicity and mass of resultant products should also be considered in al-
locating costs associated with parent biodegradable compounds.

**Ownership or operations period.** Although a PRP’s ownership or operations period at a site should be considered in apportioning cleanup costs, the result-
ing volume of chemicals released during such time frames and associated costs rarely follow a linear relationship with time. Variations over time in operations and in waste treatment, discharge, and removal practices must be carefully evaluated to understand their relative environmental impact. Also, from a le-
gal perspective, the Gore factors allow considerations such as the owners’ knowledge of or participation in the disposal activities and how they profited from them to be relevant equitable allocation factors.

### Putting it all together

Determining allocation factors and their relative weight is not trivial and requires technical experts and a consensus among all parties. As shown in the following equations, allocation factors are weighted by their relative importance to derive a cost allo-
cation model based on site-specific considerations.

\[
\text{Cost}_{\text{PRP}} = \frac{\sum_{i=1}^{n} \text{Fraction}_{\text{PRP}}}{\sum_{i=1}^{m} \text{Fraction}_{\text{PRP}}} \times \text{Total applicable cost} \quad (1)
\]

where \(\text{Cost}_{\text{PRP}}\) is the total recoverable cost allocated to PRP, \(n\) is the number of PRPs, and \(\text{Fraction}_{\text{PRP}}\) is the fraction allocated to each PRP according to the equation:

\[
\text{Fraction}_{\text{PRP}} = \frac{m}{\sum_{i=1}^{m} F_{m}} W_{m} \quad (2)
\]

where \(m\) is the allocation factor, \(F_{m}\) is the frac-
tion of \(m\) assigned to each PRP \((0-1)\), and \(W_{m}\) is the factor that weights \(m\) on the basis of relative importance.

\[
\text{Cost}_{\text{PRP}} \text{ is the total necessary site response action cost consistent with the NCP, which is assigned to each PRP or those associated with a specific operable unit, site feature (such as a storage tank or degreaser), or event (such as a time-critical removal action) unique to the PRP. The following cases provide specific examples.}

**Case study 1: Multiple parties contaminating soil and groundwater.** For example, at an industrial site where various solvents were released by 2 PRPs \((n = 2)\) and 3 equally weighted allocation factors \((m = 3\) with \(W_{m} = 33\%\) for each allocation weighting fac-
tor) are present, such as timing, toxicity, and response drivers, the allocation is derived on the basis of 4 tech-
nical conclusions. First, the total recoverable costs for past and projected future response actions at the site equal $1 million. Second, PRP 1 owned or operated the site four times longer than PRP 2 did. Third, chemicals associated with PRP 1 are twice as toxic as those of PRP 2. Fourth, the chemicals that PRP 2 released required three times more effort to assess and/or remediate than those released by PRP 1. Therefore, according to equations 1 and 2:

\[
\begin{align*}
\text{PRP 1} &= 0.33 \times 0.80 \text{ (timing)} + 0.33 \times 0.67 \text{ (toxicity)} + 0.34 \times 0.25 \text{ (drivers)} \\
&= 57\% \text{ or } $570,000 \quad (3)
\end{align*}
\]

\[
\begin{align*}
\text{PRP 2} &= 0.33 \times 0.20 \text{ (timing)} + 0.33 \times 0.33 \text{ (toxicity)} + 0.34 \times 0.75 \text{ (drivers)} \\
&= 43\% \text{ or } $430,000 \quad (4)
\end{align*}
\]

PRP 1 would pay $570,000, and PRP 2 would be accountable for the remaining $430,000. If the allocation factors had been weighted differently, such as 10% for timing, 30% for toxicity, and 60% for response drivers, then the costs would reverse, and PRP 1 would owe $430,000 and PRP 2 would be allocated $570,000. A review of actual past rulings indicates a range in cost allocations between generators and operators when such factors were considered as the party’s recalcitrance, the source of cleanup funding, and whether the remedy was driven by chemicals attributed to the operator or generator \((47)\).

**Case study 2: Multiple parties contaminating river surface water and sediment.** Direct and in-
direct discharges from multiple facilities have polluted a river over the past 100 years. Hazardous substances reached the river via one or more of the following four discharge pathways: piping convey-
ances such as process piping, stormwater, and sewer; accidental spills; intentional dumping; and/or chemical transport via air, soil, and groundwater. The importance of each discharge pathway is scored considering the following factors: the relative weight of the discharge pathways, the frequency and duration of the discharge, the toxicity of the compounds discharged, and the reliability and quality of the information.

\[
\text{Discharge pathway score}_{i} = \text{Pathway weight}_{i} \times \text{Frequency & duration}_{i} \times \text{Toxicity}_{i} \times \text{Data quality}_{i} \quad (5)
\]
Each of these four factors is assigned a score of 1, 0.5, or 0 on the basis of its actual or potential adverse impact to the river and the data reliability. A total discharge score for the PRP is then computed by taking the sum of all applicable discharge pathway scores.

\[
\text{Total discharge score } \sum_{i} \text{discharge pathway scores}_i
\]

For example, reliable information indicates that a party frequently discharged toxic chemicals directly to a river via process piping. Further, a less toxic compound was accidentally spilled into the river once, but no records of intentional dumping or chemical transport were identified. The total discharge score for this PRP is the sum of the two complete discharge pathways.

Process piping discharge score = \(1 \times 1 \times 1 \times 1 = 1\)

Accidental spill discharge score = \(0.5 \times 0.5 \times 0.5 \times 1 = 0.125\)

Total discharge score = \(1 + 0.125 = 1.125\)

The costs allocated to this party would be based upon the party’s total discharge score relative to the sum of all discharge scores for all parties, as follows:

\[
\text{Percent allocation}_{\text{PRP}_i} = \left( \frac{\text{Total discharge score}_{\text{PRP}_i}}{\sum_{i} \text{Total discharge score}_{\text{PRP}_i}} \right) \times 100
\]

If the total discharge score for all parties is assumed to be equal to 20 and the total response actions costs are $10 million, then the allocation to PRP would be as follows:

Allocation to PRP = \((1.125/20) \times 100\) = 5.6% \times $10,000,000 = $560,000

These approaches can be used to evaluate whether a PRP contributed a de minimis (minor amounts of hazardous substances, in terms of volume, toxicity, or other hazardous effects, relative to other hazardous substances at a site) or a de micromis (a subset of de minimis in which waste volume is extremely small compared with a de minimis party’s volume) amount to site contamination. These allocation models can also be used to assign orphan shares—shares of responsibility attributable to PRPs who are insolvent or defunct—to viable PRPs. This objective approach enables PRPs to reach a consensus on the types, percentages, and weighting of the equitable factors that are considered in assigning response action costs and thus avoid lengthy, costly, and uncertain litigation.

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