J. ENVIRONMENTAL SYSTEMS, Vol. 22(1) 27-35, 1992-93

RISK REDUCTION THROUGH REGULATORY CONTROL OF WASTE DISPOSAL FACILITY SITING*

F. G. WRIGHT

H. I. INYANG

V. B. MYERS

U.S. Environmental Protection Agency
Washington, D.C.

ABSTRACT

Structural failure of hazardous waste management facilities and consequent undesirable environmental and human health effects can result from natural and human-made hazards in sensitive environments. Potential hazards include catastrophic release of toxic materials into water, soil, and air; rapid and widespread transport of hazardous contaminants; and impracticable cleanup measures. Site-specific factors and facility type control the magnitude of the above-stated risks. Various approaches can be adopted to minimize potential facility damages and environmental degradation, including control of the facility's location and design conservatism. Since a host of economic and administrative factors are important to hazardous waste facility siting, the provision of incentives to facility planners to adopt good siting practices may enhance the implementation of siting plans that reduce risk. Several environments are assessed for their sensitivity to damages from hazardous waste installations. Measures of minimizing risk through location and design controls are discussed.

Within the 1984 Hazardous and Solid Waste Amendments (HSWA) to the Resource Conservation and Recovery Act (RCRA) (Public Law 98-616), codified at 42 U.S.C. §§6912, 6924(a), and 6924(o)(7), Section 3004(o)(7) requires the U.S. Environmental Protection Agency (EPA) to "specify criteria for the

---

*Opinions expressed in this article are those of the authors. They do not represent any current or future policy or regulations of the U.S. Environmental Protection Agency.

doi: 10.2190/2MTV-KFMV-XC19-R6K9
http://baywood.com

acceptable location of new and existing treatment, storage, and disposal facilities as necessary to protect human health and the environment." Some recent regulatory developments at EPA have addressed the control and location of hazardous waste treatment, storage, and disposal facilities (TSDFs), and associated aspects of design, construction, and operation in sensitive areas to minimize environmental risks. It has been recognized by EPA that risks can vary across facilities because they consist of different units (such as landfills, surface impoundments, waste piles, incinerators, and tanks), and across facility locations because they vary in geologic, hydrologic, climatic, and topographic characteristics. The overall goal of current and pending regulations is the long-term protection of human health and the environment from potential releases of hazardous substances from TSDFs in sensitive locations.

In 1981, EPA promulgated location standards in 40 Code of Federal Regulations (CFR) 264.18 (46 Federal Register 2802, Jan. 12, 1981) that restrict the location of hazardous waste TSDFs in three sensitive environmental settings, namely, fault zones; 100-year floodplains; and salt dome formations, salt bed formations, underground mines and caves. As originally written, these regulations prohibit the construction of new hazardous waste TSDFs within 61 meters (200 feet) of Holocene faults in some political jurisdictions of the western United States. Another requirement is that facilities located in 100-year floodplains "be designed, constructed, operated and maintained to prevent washout of any hazardous waste by a 100-year flood." The current rule allows variances to this requirement if the owner or operator can demonstrate that procedures are in effect to remove the wastes to safe locations before floodwaters can reach the facility, or that no adverse effects on human health or the environment will result if flooding and washout occur. There is also a RCRA statutory mandate that prohibits the placement of any non-containerized or bulk liquid hazardous waste in any salt dome formation, salt bed formation, underground mine, or cave.

There are impending modifications to the requirements described above. In response to the statutory mandate given in Section 3004(o)(7) of RCRA, there is an ongoing effort to expand the scope of these siting regulations within EPA. This mandate calls for an assessment of various categories of locations with respect to facility siting and the potential to harm human health or the environment. Such assessments are essential in the screening of sites and the development of control measures to guard against facility damage and consequent environmental degradation.

NATURE OF RISK

Under current EPA definitions, sensitive locations are those areas in which the risk of damage to facilities and consequent environmental degradation are elevated. Three general situations have been identified as being associated with elevated risk in such areas. These situations result in three different but related types of risk, namely, geological hazard susceptibility, ecosystem vulnerability, and remediation infeasibility. The remediation infeasibility aspect includes the risks of technical infeasibility and cost prohibitiveness. An assessment of ecosystem vulnerability and remediation infeasibility falls within the framework of consequence risk analysis. The three major categories of risk mentioned above are described in the following paragraphs.

Some areas are geologically prone to catastrophic events such as earthquakes, 100-year floods, landslides, subsidence, and volcanic eruptions. In these areas, the risk of environmental damage from hazardous waste facilities is tied to the occurrence of a single or combination of such events. From these initial events, a chain of events can be unleashed which could threaten the integrity of hazardous waste facilities. The probability of structural failure and consequent release of hazardous pollutants is dependent on a number of other conditional probabilities. An important part of stability analysis is the assessment of the probability that various components of a facility will fail, given the occurrence of a catastrophic event of a specified magnitude. These probabilistic analyses are necessary to assess the likelihood of the occurrence of a number of interrelated events, as exemplified by the potential of occurrence of an earthquake in the location of concern; the likelihood that the earthquake will be of a sufficient magnitude to cause failure of various components of the unit; and the likelihood that a damaging release will occur due to the failure of one or more components of the unit.

Ecosystem vulnerability risk is based on the undesirable consequences that could result from hazardous waste releases and management activities in certain locations. Among these types of sensitive locations are wetlands, permafrost regions, and areas of both vulnerable and highly valued ground-water resources. Natural processes in some of these locations can counteract minimal levels of contamination. However, contamination thresholds that may not be problematic in certain locations may have significant undesirable environmental effects in sensitive locations. These environments may not recover from such levels of degradation. Consequently, supplies of unpolluted drinking water, or the survival of fauna and flora supported by these environments would be threatened. Considering the utility of water supplies, the interdependence of plant and animal species, and the unique sequential order of the food chain, this situation can also threaten public health.

The last category of risk and sensitivity rests on the technical difficulties and high costs associated with remediation effort in certain environments. Locations that fall into this category are karst terrains, areas that have complex hydrogeology, and permafrost regions. Often in these locations, site characterization methods may not adequately delineate subsurface characteristics, such as boundaries of geohydrological zones that control contaminant fate and transport to the extent that is required to implement successful corrective action. In karst terranes or in fractured bedrock, ground water and contaminant flow may occur primarily through secondary porosity features such as solution holes and fractures. In these instances, estimation of flow quantities, directions, and rates may be very difficult to achieve, and may limit the success potential of remediation and ground-water monitoring schemes. Bedrock parameters which control flow such as fracture lengths, sizes and orientations may change by orders of magnitude within short distances. Furthermore, geomaterials are anisotropic and discontinuous in geologically complex areas, and would preclude the extrapolation of data obtained for specific points to others within the same area.

Ecological risk (ecorisk) assessment schemes usually address ecosystem vulnerability and remediation infeasibility. Therefore, ecorisk is covered under the risk categorization discussed above. The components of ecological risk assessment such as stressor characterization, ecologic characterization, exposure analyses and profiling, are described by U.S. EPA [1]. A relationship for analyzing risk characterization using these and other components is illustrated in Figure 1.

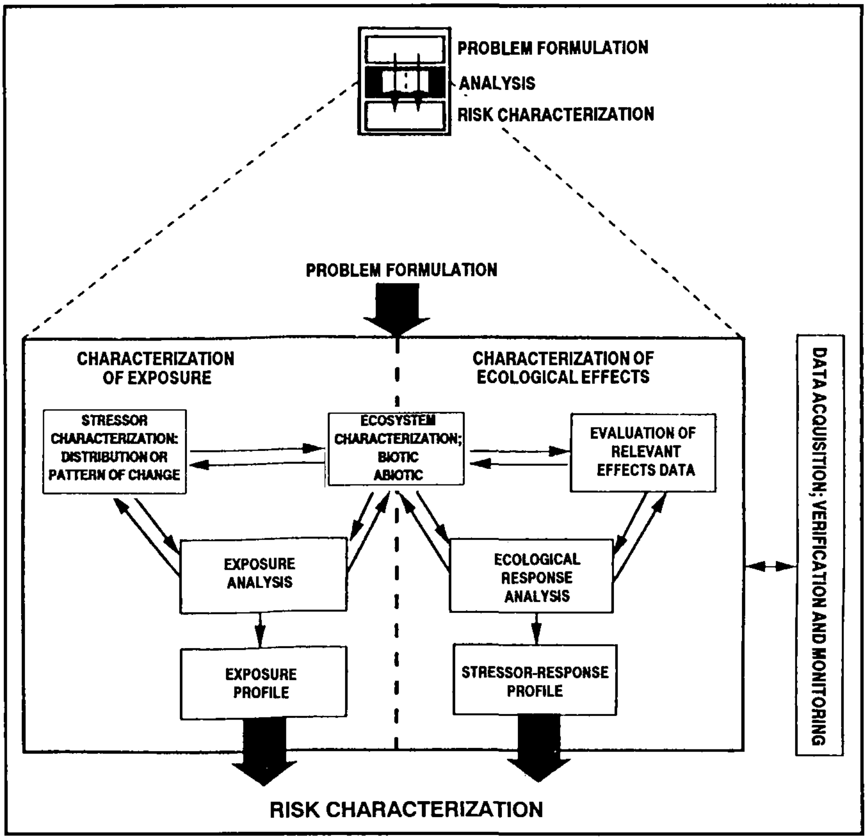

Figure 1. Analysis model for risk assessment [1].

ASSESSMENT OF VARIOUS SENSITIVE ENVIRONMENTS

The three components of overall risk are represented in various proportions in different locations that could be selected as sites for hazardous waste TSDFs. Various schemes have been developed for assessing risk components. These schemes range from simple qualitative to highly quantitative methods. Each method is rarely comprehensive. While some methods focus on the likelihood of the occurrence of an initiating event such as the failure of a liner as a result of a seismic event, other methods deal with the consequences of the release of hazardous materials into the ecosystem. Therefore, with respect to site selection for hazardous waste facilities, it may be necessary to use a combination of models that have different utilities. Furthermore, there are other socio-economic factors that need to be taken into consideration. Sometimes, these factors may not be easily quantified.

Regardless of the utility of any particular method, a qualitative or quantitative approach may be adopted in its development and use. Within quantitative methods, approaches may be deterministic or probabilistic. An example of a deterministic approach is the DRASTIC model [2]. This model addresses seven general factors which are significant with respect to the ground-water pollution potential of a site at which a release has occurred. The factors addressed in this additive model are the depths to ground water, recharge, type of aquifer medium, type of soil medium, topography, impact on the vadose zone, and aquifer conductivity. Various weights are assigned to these and other parameters that depend upon them. The magnitudes of these parameters are integrated into a single numerical index for characterizing the pollution potential of a site. Several additional analytical models have been developed to address the utility of various locations for waste facility siting. A document by the U.S. Nuclear Regulatory Commission furnishes descriptions of computer codes such as COOLEY, FE3DGW, USGS2D, and VTT for analyzing saturated flow conditions for potential hazardous waste facility sites [3]. While these codes are primarily deterministic, other codes exemplified by NUTRAN [4] are probabilistic.

Certain types of hazards to waste facilities correspond to particular geologic environments. A complete evaluation of the geologic susceptibility component of overall risk requires an analysis of the frequency and magnitude of occurrence of these hazards in the area of concern. In seismically active areas, hazards such as ground shaking, liquefaction, and surface faulting, can threaten the stability and structural integrity of hazardous waste facilities. In 100-year floodplains, waste management units can be damaged, submerged or washed out by periodic floods. If flooding occurs, there is increased potential for contamination of surface and ground-water resources. Other areas are inherently unstable. Examples of the latter are areas that are prone to volcanic eruptions, subsidence or sinkhole collapse, mass movement, and areas with loose or expansive foundation soils. In some cases, the instability of an area can be caused or exacerbated by human activities, such as underground mining, and oil and ground-water extraction. Hazardous waste units sited in these areas may suffer differential settlement, cracking, rupturing, and collapse of components. When a location is being considered as a possible site for a hazardous waste facility, the susceptibility of the site and hence, the facility to any of the geological hazards mentioned above depends on the proximity of that location to the known origin or region of the geological event or condition.

Consistent with the descriptions furnished for the components of ecological risk assessment, it may be difficult to remediate releases of contaminants in environments such as permafrost regions, wetlands, or other areas with complex hydrology. In these areas, contaminant releases can travel rapidly and disperse widely due to fluctuating water tables, freeze/thaw phenomenon or tidal influences to surface and ground water.

APPROACHES TO RISK REDUCTION

Three approaches can be adopted in reducing the risk of environmental pollution from releases of hazardous waste or hazardous constituents into sensitive environments. These approaches are selection of suitable sites, engineering design conservatism, and the adoption of engineering redundancy.

The first approach involves the selection of a location for the facility at which the probability of the occurrence of damaging events is minimal. The utility of this approach is that it is preventive rather than remedial. The extent to which an appropriate site can be selected for a hazardous waste facility is highly dependent upon adequate site characterization. In order to gain information about the general ground stability and hydrogeology of various regions, large-scale maps depicting the geographic distribution of various sensitive environments have been developed by federal agencies, private organizations, and researchers. For example, high risk seismic regions can be identified using bedrock acceleration zonation maps developed by USGS [5]. Similarly, karst regions can be generally identified using the karst distribution map of the United States developed by USGS [6] and geologic, topographic, or soil maps. Relatively new technologies such as Geographic Information Systems (GIS) and Global Positioning Systems (GPS) are beginning to be used for large-scale categorization of sites. On a more site-specific basis, geophysical techniques for characterizing the subsurface also exist. Some of these techniques have been employed in site exploration. For example, geophysical techniques have been employed in characterizing karst terranes as reported by Chamon and Dobereiner [7], Cooper and Ballard [8], Witten and King [9], and Handfelt and Attwooll [10]. Another common technique is the use of dye tracers as described by Mullen and Thorn [11].

In order to design stable hazardous waste management facilities, it is necessary to do additional site investigations to compliment information on the general site characteristics obtainable from the techniques described above. These site investigations which may include site reconnaissance and laboratory testing of geomaterial samples from the site, provide detailed data for use in the design of various facility components. Design also requires the testing of engineering materials for such parameters as strength, durability, and dimensions. Various philosophies should then be adopted to design TSDFs with reasonable factors of safety. In sensitive locations, the risk of damages from natural and manmade hazards that may not usually occur in most stable areas require the incorporation of higher factors of safety in design. Landfill and waste pile slopes may need to be kept at low angles to prevent vibration-induced sliding failures from seismic events. When placed underneath partly embedded structures in seismic zones, horizontal base isolators can minimize the instability that can result from excessive ground vibrations. Anchoring above-ground tanks can prevent them from being toppled and crushed during a flood. Increasing the flexibility of landfill or impoundment liners may provide an additional factor of safety against liner tear or cracking in areas susceptible to subsidence.

The redundancy approach involves the implementation of design measures which may not be directly associated with the design of the facility, but adds to the overall protection of the environment from hazards that may occur. For example, when a landfill is sited in a karst terrane or other regions with complex hydrogeology, it may be necessary to construct a slurry wall or grout curtain around the landfill. These ancillary structures serve the redundant purpose of containing contaminants that may be released from the landfill if a damaging event occurs. Similarly, installation of beneficial underground wells and grading of adjacent steep slopes can be performed to control potential landslides. The function of these ancillary structures is redundant in the sense that ordinarily, landfills are designed to reduce the potential for the escape of leachates. The inclusion of secondary containment basins in conjunction with thermal barriers underneath facilities in permafrost can mitigate releases of hazardous constituents and minimize the risk of thaw-induced consolidation and settlement of such facilities. The stability of soil profiles in floodplains can be improved through the implementation of soil stabilization measures such as heavy tamping, grouting, electrical stabilization, and chemical stabilization. To a large extent, some of these measures are also used as site improvement techniques for reducing the risk of soil liquefaction in seismically active areas.

CONCLUSION

In this article, the technical issues that are relevant to the location of hazardous waste TSDFs in sensitive environments have been discussed. These issues include categorization of various types of hazards, analyses of associated types of risk, and engineering mitigation measures.

It is recognized that socio-economic and political factors may influence the implementation of some of the measures discussed above in certain locales. State and local authorities maintain jurisdiction over siting issues in their respective geographic regions. Some of the approaches adopted by these authorities to promote good siting practices for hazardous waste facilities include provision of siting incentives, community involvement, and regulatory restrictions. Most commonly, the last approach involves the specification of setback distances within which facilities would not be permitted. A siting program is more likely to be successful if an integrated approach is adopted using a balance of factors. A framework should be developed that incorporates the technical issues discussed in this article and the socio-political factors for us in making sound siting decisions.

The United Nations designated the decade of the 1990s as the International Decade for Natural Disaster Reduction (IDNDR). One of the stated goals of associated programs is the reduction of fatalities, human suffering, environmental damage, and economic losses caused by natural hazards. Most of the technical issues discussed above also have relevance to this goal because they pertain to redemptive control of TSDF location and related design and operating factors which directly cause or significantly contribute to releases of hazardous constituents. Such actions can diminish avoidable adverse consequences.

REFERENCES

1. U.S. EPA, *Framework for Ecological Risk Assessment,* United States Environmental Protection Agency, Washington, D.C., EPA/630/R-92/001, 1992.
2. U.S. EPA, *DRASTIC: A Standardized System for Evaluating Ground-Water Pollution Potential Using Hydrogeologic Settings,* Robert S. Kerr Environmental Research Laboratory, U.S. Environmental Protection Agency, Ada, Oklahoma, 1985.
3. U.S. NRC, *A Summary of Repository Siting Models,* Office of Nuclear Material Safety and Safeguards, United States Nuclear Regulatory Commission, Washington, D.C., NUREG/CR-2782, 1982.
4. B. Ross, C. M. Koplik, M. S. Guiffre, S. P. Hodgin, and J. J. Duffy, NUTRAN: A Computer Model of Long-Term Hazards from Waste Repositories, *The Analytic Sciences Corporation Report UCRL-15150,* 1979.
5. U.S.G.S., *Map of Horizontal Acceleration, A, in Rock with 90 Percent Probability of Not Being Exceeded in 250 Years,* United States Geological Survey, Reston, Virginia, 1988.
6. U.S.G.S., *Engineering Aspects of Karst,* United States Geological Survey, Reston, Virginia, 1984.
7. N. Chamon and L. Dobereiner, An Example of the Use of Geophysical Methods for the Investigation of a Cavern in Sandstones, *Bulletin of the International Association of Engineering Geology, 38,* pp. 37-43, 1988.

8. S. S. Cooper and F. F. Ballard, Geophysical Exploration for Cavity Detection in Karst Terrain, in *Geotechnical Aspects of Karst Terrains, Geotechnical Special Publication No. 14*, American Society of Civil Engineers, New York, pp. 25-39, 1988.
9. A. J. Witten and W. C. King, Acoustic Imaging of Subsurface Features, American Society of Civil Engineers, New York, *Journal of Environmental Engineering, 116*, pp. 166-181, 1990.
10. L. D. Handfelt and W. J. Attwooll, Exploration of Karst Conditions in Central Florida, in *Geotechnical Aspects of Karst Terrains, Geotechnical Special Publication No. 14*, American Society of Civil Engineers, New York, pp. 40-52, 1988.
11. B. Mullen and R. Thorn, *Groundwater Tracing and Water Quality in the Vicinity of a Landfill in County Monaghan, Ireland*, proceedings of the 21st Congress of the International Association of Hydrogeologists, Guilin, China, pp. 910-915, 1988.

Direct reprint requests to:

Hilary I. Inyang
Senior Geoenvironmental Engineer (IPA)
U.S. Environmental Protection Agency (OS-5303W)
401 M Street, S.W.
Washington, D.C. 20460