

Exposure of Soil and Groundwater to Spills of Hazardous Materials Transported by Rail

A Geographic Information System Analysis

Pooja Anand and Christopher P. L. Barkan

The environmental impact of a hazardous material spill is a complex function of the material's physical and chemical characteristics and the local environmental conditions in which it is spilled. This study develops a geographical probability distribution for two important environmental parameters affecting this impact: soil type and groundwater depth. The paper assesses the probability of exposure of various soil types and groundwater depth regions to hazardous material spills from railroad tank car accidents. The State Soil Geographic database (STATSGO), a geographic information system (GIS) database from the U.S. Department of Agriculture, was used to analyze soils, and real-time groundwater data from the U.S. Geological Survey were used to analyze groundwater. The "rail2m" GIS database available from the Bureau of Transportation Statistics was used to conduct overlay analyses with the soil GIS data to obtain the probability of occurrence of various soil types under rail lines. The same method could not be used for groundwater exposure because no suitable GIS database for this parameter was available. Therefore, a nationwide probability distribution of the groundwater depth ranges was developed. The proportion of the three soil types under rail lines was 44.0% for sand, 51.2% for silt, and 4.0% for clay, the remainder being over surface water. The probability of occurrence of five groundwater depth regions was 16.4% for 5 to 15 ft, 12.6% for 15 to 25 ft, 23.3% for 25 to 75 ft, 12.0% for 75 to 125 ft, and 35.9% for greater than 125 ft. A matrix of the probability distribution of environmental scenarios was developed; it is suitable for use in conducting environmental risk assessments of railroad transportation of hazardous materials.

Each year a large volume of hazardous materials is transported by rail in the United States, the majority of it in railroad tank cars. In 2004, there were approximately 1.32 million tank car shipments in the United States and Canada (1). Although railroad-accident-caused spills of hazardous materials are uncommon events, they have the potential to affect humans and/or the environment adversely. Risk analysis techniques can be used to evaluate the likelihood and magnitude of these events. These techniques involve quantification of

the probability of an accident in which a hazardous materials car is derailed (2) and the conditional probability of release from a derailed tank car (3). Risk analysis also requires understanding the consequences of a spill. The outcome is affected by the properties of the spilled material and its impact on "receptors," that is, humans or environmental features that may be harmed by the material. There have been a number of studies of the acute risk to human health from rail transport of hazardous materials. Much less attention has been given to quantitative assessment of the potential impact on the environment.

The extent of environmental damage that will result from a spill varies depending on the characteristics of the location where it occurs. Barkan et al. (4) conducted a quantitative environmental risk analysis of hazardous material transport in railroad tank cars. In their analysis, the consequence term in the risk equation was based on empirical data from the railroads' environmental cleanup costs for hazardous material spills. Their analysis did not attempt to account for the possible effects of features of the environment in assessing the risk. Since then, the development of geographic information system (GIS) databases for rail lines and environmental features makes feasible more sophisticated analyses that take these characteristics into account.

The type of soil and the depth of groundwater are generally the two most important parameters affecting the difficulty and cost of environmental cleanup of a spill of hazardous materials (5). The combination of these features varies geographically and gives rise to a variety of possible environmental scenarios in which a spill may occur. Quantification of environmental risk requires an understanding of the likelihood of a spill occurring in these different conditions. Although prior studies of human health risk have accounted for population density along hazardous materials transportation routes, this is the first study that has quantified the exposure of environmental features.

This paper presents an exposure analysis of different soil types and groundwater depths along U.S. railroad lines and develops probabilistic estimates of their exposure to a potential hazardous material spill. This work is the first phase of a study addressing the environmental risk associated with rail transport of hazardous materials and focuses on their potential impact on soil and groundwater cleanup. Historically these cleanup areas have had the largest financial impact on railroads (4) and the science of modeling these effects has been extensively developed. More recently, natural resource damage, such as impact on surface water bodies, has emerged as an important additional factor affecting railroads' environmental risk, but it falls beyond the scope of this paper.

P. Anand, B-11B, and C. P. L. Barkan, 1201, Newmark Civil Engineering Laboratory, Railroad Engineering Program, Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign, 205 N. Mathews Avenue, Urbana, IL 61801.

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METHODOLOGY

The first step was to identify suitable databases regarding the geographic distribution of the variables of interest: soil type, groundwater depth, and rail line location. The next step was to generate a manageable set of environmental scenarios from the various possible combinations of soil type and groundwater depth. GIS data were available for rail lines and soil; therefore, spatial analysis was used to assess soil-type exposure in the vicinity of rail lines. However, suitable GIS data were not available for groundwater depth, so an alternative approach for this parameter had to be developed.

SOIL EXPOSURE ASSESSMENT

Soil type is an important environmental variable affecting the fate of a spilled material. The extent and pathway of a chemical’s movement during infiltration are a function of the properties of the soil, the chemical, and their interaction. Various soil characteristics, such as grain size, reactivity, and sorptive character, all affect the fate and transport of a spilled chemical in soil (6).

The State Soil Geographic database (STATSGO), from the Natural Resources Conservation Service (NRCS) website (7), contained the soil information required for this study. STATSGO is a GIS database organized on a state-by-state basis that has been compiled for regional or multistate level studies and planning. Each state in the database is divided into map units that represent individual smaller segments of land. The horizontal profile of each map unit is divided into sectors that are called components. Each map unit is composed of up to 21 components that are associated phases of soil series. A soil series is the lowest level in the U.S. system of soil taxonomy and the most homogenous with regard to its properties (8). Soil series differ from each other in their characteristics (9). Soil series are further divided into phases for the purpose of soil management (8, 9). The vertical section of a component is divided into layers from the top downward with at most six per component. Each layer has a set of 28 properties. This hierarchical structure is illustrated in Figure 1 for map unit “PA001” in Pennsylvania. The three primary tables in STATSGO are “mapunit,” “comp,” and “layer,” in a descending hierarchy.

Spatial information is available for a map unit as a whole but not for its individual components. However, nonspatial data or attribute information is defined for each component but not for the map unit as a whole. Therefore, a map unit is the smallest entity that can be visually represented. In order to link the attribute information to the spatial data, attribute data needed to be developed for the map unit from its components and layers. The comp table is a necessary link in the

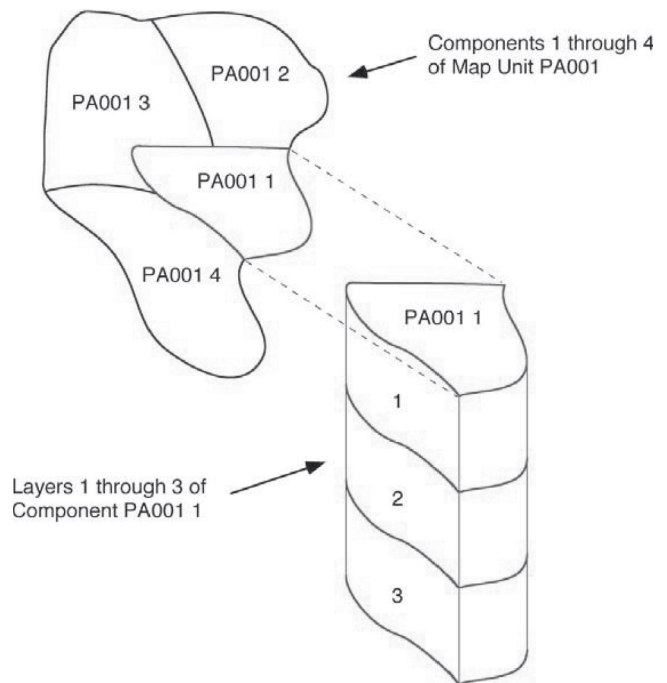


FIGURE 1 Components and layers for map unit PA001.

relational schema as it has the areal percentage of various components of a map unit, namely “compct.” This attribute is used as the weight for averaging any property across components for a map unit.

Soil types were divided into three categories—clay, silt, or sand—following the United States Department of Agriculture (USDA) textural triangle (10), in order to create a representative set of all nationwide soil types. This level of categorization was deemed suitable for purposes of hazardous material risk analysis and the attribute tables in STATSGO were searched for attributes that would permit this categorization.

The attributes “permh” and “perml” present in the layer table represent the highest and the lowest permissible values of permeability rate for a soil layer. Permeability rate (or infiltration rate) is often used to generalize soils into the three categories (Tables 1 and 2) (11, 12). However, minimum infiltration rate (perml) was chosen as the parameter for generalization because hydrology and soil textbooks (12) typically list the steady state at minimum infiltration rate.

The next step was to link this minimum infiltration rate information from the layer table to the spatial data to be able to create and display a soil type for each map unit. The relation between a map unit and its components and between a component and its layers was

TABLE 1 Generalization Based on Maximum Infiltration Rate (11)

Class	Maximum Infiltration Rate ^a	Soils Included	Generalization Adopted
Rapid	>7.5 cm/h	Sands, loamy sands, sandy loams	Sand
Moderate	0.5–7.5 cm/h	Fine sandy loam, silt loam, silty clay loam, sandy clay loam, loam, clay loam, sandy clay, and others	Silt
Slow	< 0.5 cm/h	Silty clay loam, silty clay, sandy clay, clay	Clay

^aCorresponds to the field “permh” in the STATSGO database.

TABLE 2 Generalization Based on Minimum Infiltration Rate (12)

Soils	Minimum Infiltration Rate ^a	Generalization Adopted
Sands	> 2 cm/h	Rapid ≥ coarse ≥ sand
Sandy and silty	1–2 cm/h	
Loams	0.5–1 cm/h	Moderate ≥ medium ≥ silt
Clayey soils	0.1–0.5 cm/h	
Sodic clayey	< 0.1 cm/h	Slow ≥ fine ≥ clay

^aCorresponds to the field “perml” in the STATSGO database.

one-to-many. But because the resolution of the spatial data was lower than that of the nonspatial data, this relation had to be converted from one-to-many to one-to-one so that a single soil type could be defined for each map unit. As discussed previously, a component can have up to six layers, each with a different minimum infiltration rate value. For purposes of analysis, it was necessary to assign a single infiltration rate value to a component. The options were to select one layer as representative for a component or to develop some type of weighted average across all layers of a component.

The effect of heterogeneity in the soil column is important in other environmental spill scenarios in which the source of a release is long-term leakage from an underground tank or piping (13), but it is less so in accident-caused spills of hazardous materials that are categorized as “instantaneous” releases. These spills invariably occur at the surface; consequently, the surface layer will often be the single most important soil attribute affecting the outcome of the spill. Therefore, in this analysis the first approach was used and it was assumed that the top layer of the soil was the most representative of the soil column. The comp table of all the states was joined with the corresponding layer table on the field MUIDSEQNUM (map unit identifier sequential number) such that only the first (topmost) layer was picked from the layer table for each component in the comp table. Thus a comp–layer join was obtained for the contiguous states.

As a result of the join, a minimum infiltration rate (perml) value was obtained for each component. In order to create a one-to-one relationship between a map unit and its components, a weighted average of minimum infiltration rate values was taken across all the components for each map unit in the comp–layer join, using the areal percent (comp_pct) values as the weighting factor for each component. This yielded a single averaged minimum infiltration rate value for each map unit. Based on this value a soil-type class was assigned to each map unit using the categorization scheme (Table 2). This resulted in the final table containing soil information for each map unit that could now be represented on the map. This new attribute table could be called the “map unit–comp–layer” join. This attribute table was joined with the spatial data for the 48 states on the field MUID (map unit identifier). The result of this was a single map of the 48 contiguous states showing the geographic distribution of sand, silt, and clay soils (Figure 2). About 1.3% of the area is surface water bodies (not shown in the figure).

Spatial Analysis of the Rail–Soil Overlay

The Bureau of Transportation Statistics maintains geographic databases of transportation facilities for the United States known as the

National Transportation Atlas Databases (NTAD). This contains GIS data from the Federal Railroad Administration for the U.S. railroad network. The database called “rail2m” from NTAD (version 2000) was used. The rail database also contains lines that are out of service but these were excluded from the analysis.

It would have been computationally intensive to conduct spatial analysis for all the states together. Therefore, to reduce the data sets to a workable size, 17 regional groups of states were formed. To further improve the efficiency of the GIS operations, sand, silt, and clay were handled separately for each group of states. The rail2m data set was added to the soil map for each group of states. Then, using the “clip” operation of ArcMAP, the portion of the rail network passing over each of the three types of soil was clipped. By summing up the clipped rail lengths over the 17 groups of states, for each of the three soil categories, the length of the rail network over sand, silt, and clay was obtained (Figure 3).

Proportion of the Three Soil Types Under Rail Lines

The proportion of the three soil categories under rail lines was calculated by comparing the length of rail lines on each soil category

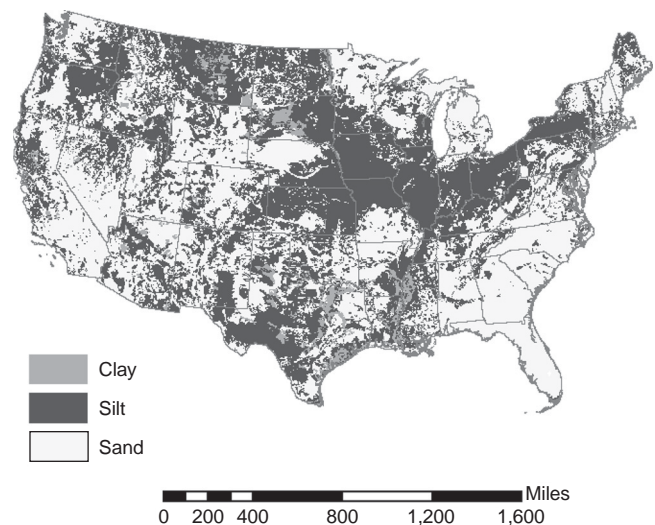


FIGURE 2 Three soil types in contiguous United States.

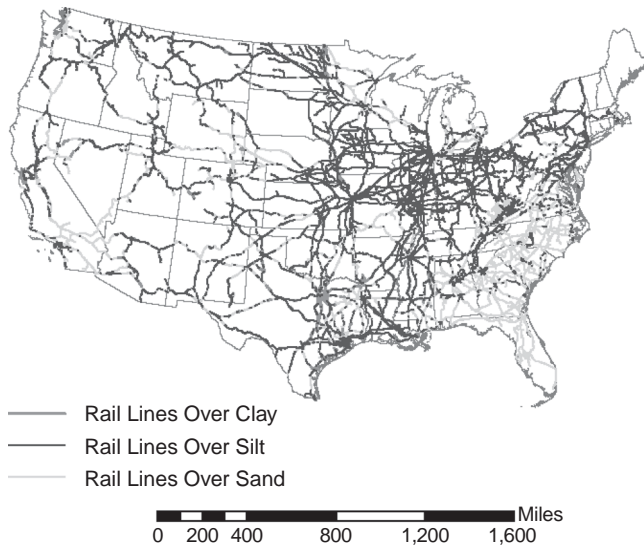


FIGURE 3 Three soil types under rail lines in contiguous United States.

with the total length of the rail network (Table 3). The total mileage of the U.S. rail network was calculated from the sum of lengths of all the records present in the original rail2m layer of the rail database. The proportions were calculated as follows:

$$P_{kl} = L_k / L \tag{1}$$

where

- P_{kl} = proportion of a soil type k , along rail lines;
- L_k = length of railroad on soil type k ; and
- L = total length of rail lines in the United States.

The possibility that some soil types might be more likely to be associated with rail lines than others was considered. For example, in order to minimize grade and construction expense, many rail lines were originally built adjacent to natural waterways. Thus one might expect a disproportionate exposure to sandy or silty soils that are characteristic of riverine areas. This assumption was investigated by comparing the proportion of rail mileage associated with each soil type to the overall areal percentage of each soil type in the contiguous United States (Tables 3 and 4). The proportions for the nationwide soil-type distribution (Table 4) were calculated as follows:

$$P_{kA} = A_k / A \tag{2}$$

where

- P_{kA} = proportion of a soil type k anywhere in the 48 contiguous states,
- A_k = area covered by soil type k , and
- A = total area covered by the three soil types and water.

Although there was evidence of slight heterogeneity, the difference was small and a chi-squared analysis showed that it was not significant ($\chi^2_{\text{observed}} = 1.45 < \chi^2_{3,0.05} = 7.81$). Thus the location of U.S. rail lines (taken as a whole) can be considered to be independent of soil type.

TABLE 3 Proportion of Three Soil Types Under Rail Lines

Soil Type k	Length of Rail Lines L_k (mi)	Proportion P_{kl}
Clay	4,012	0.040
Silt	50,873	0.512
Sand	43,705	0.440
Water	834	0.008
Total	99,424	

GROUNDWATER EXPOSURE ASSESSMENT

As mentioned previously, groundwater depth is the other important parameter affecting the risk of contamination of the groundwater table resulting from spills of hazardous materials. In the comp table of the STATSGO database, there are two attributes, “wtdeph” and “wtdepl,” which are defined as the maximum and minimum seasonal water table depths, respectively. Initially the intent was to use these fields to perform a GIS analysis analogous to the soil analysis. However, further investigation revealed that the maximum value for these attributes was 6 ft. According to NRCS, these values indicate the actual water table depth only if water was observed within the first 6 ft of the soil surface. Entries with a value of 6 ft actually indicated a groundwater depth lower than 6 ft or otherwise not observed. This information was unsuitable for this analysis and no other nationwide GIS database of groundwater depths was found. Consequently, an alternative approach had to be developed. The United States Geological Survey (USGS) has a data set that, although not exhaustive, is the most comprehensive nationwide data set available on groundwater depths.

Groundwater Database

USGS maintains information about groundwater levels in monitoring wells across the country that include springs, wells, test holes, drains, tunnels, and excavations (14). These groundwater levels are stored as discrete or continuous records of the water table depth. The discrete records represent previous measurements of water level at various points in time. Continuous records from some of the wells are relayed to the USGS offices and constitute what is called the “real-time groundwater data” (14). Each well is identified by a station number and the state where the well is located. Data on the depth of the water table below the surface, latitude and longitude,

TABLE 4 Proportion of Three Soil Types in the Contiguous United States

Soil Type k	Area A_k (square mi)	Proportion P_{kA}
Clay	108,067	0.036
Silt	1,379,329	0.457
Sand	1,490,226	0.494
Water	37,983	0.013
Total	3,015,605	

and other parameters are provided for each well. Although potentially useful for this analysis, the real-time groundwater database has some limitations, namely,

1. Presence of confined aquifers in the well data,
2. Changes in water depth due to seasonal variations, and
3. Geographic bias in the well distribution.

Several steps were taken to modify the database to reduce the impact of these limitations on this study.

Effect of Confined Aquifers

The groundwater level measurement for confined aquifers does not give a true value of the groundwater depth in that aquifer. In fact for some cases where the water level rises above the surface during measurement, the depth obtained is negative. The presence of the confined aquifers in the data set was potentially misleading with regard to the objectives of this analysis; therefore, it was necessary to remove them to minimize the bias they might introduce. The well site description has aquifer type as an attribute, but for most of the records this field is not recorded or populated. So, there was no way to completely segregate the real-time well data into confined and unconfined aquifers. For the purpose of this analysis, all the records for which the depth values were negative or nil were removed and the remaining records were assumed to represent unconfined aquifers. The net effect of including confined aquifers would be to underestimate average depth to groundwater.

Seasonal Variations in Groundwater Data

Groundwater levels can change seasonally, so the data were collected at two times of the year to determine whether this affected the estimated distribution of groundwater depths. Groundwater data were obtained in November 2002 and April 2003 and a cumulative frequency distribution of groundwater depths was created for both data sets. Slight differences were observed to a depth of about 100 ft but deeper than that the curves appeared nearly identical (5). A paired, two-tailed *t*-test analysis was conducted on the two data sets and no significant difference was found ($\alpha = 0.05$, $t_{\text{Observed}} = -0.028 > t_{40, 0.025} = -2.021$), so either data set could be used for further analysis. The more recent data were used and will be referred to as the "April data set."

Geographic Bias of Well Data

The objective was to assess the degree of exposure of various groundwater depth regions near railroads, but the well sites in the USGS database are not necessarily located near rail lines. Ideally wells would be randomly and independently distributed so that probability values calculated using this data set would be representative of the overall probability distribution of the groundwater depths in the United States. The latitude and longitude data for the 390 wells in the April data set were used to develop a map showing their location (Figure 4).

It was evident that there is a geographical bias in the distribution of the wells in the USGS database (e.g., Missouri and Pennsylvania have the highest density of wells followed by Texas, North Carolina, and California). Therefore, the data set needed to be modified to

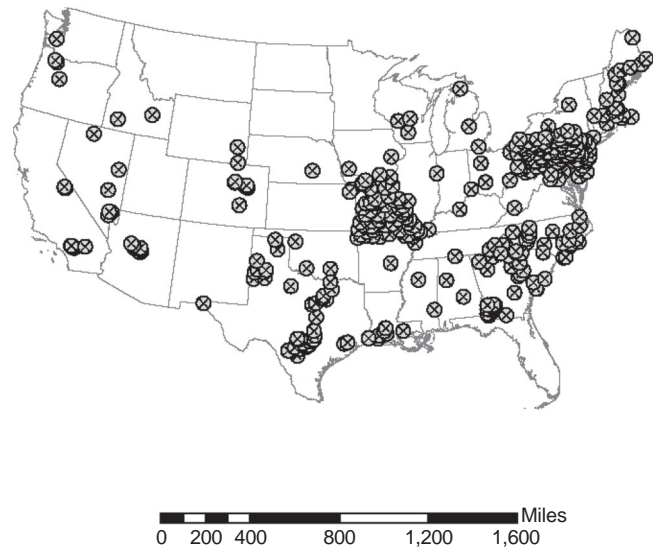


FIGURE 4 Plot of wells in contiguous United States, April 2003 data.

obtain a less biased probability distribution of groundwater ranges. Wells from each state were randomly selected by using the area of the state as the weighting factor, as follows:

$$N_{\text{state}} = N_{\text{total}} A_{\text{state}} / A_{\text{total}} \quad (3)$$

where

- N_{state} = total number of wells to be selected from a particular state,
- N_{total} = total number of wells in the April data set = 390,
- A_{state} = area of the state (square miles), and
- A_{total} = combined area of the 48 contiguous states (square miles).

By following this procedure it was possible to reduce the bias for those states for which the number of wells in the data set is greater than those that are required to be selected (e.g., Missouri and Pennsylvania). For the states for which the number of wells in the April data set is less than the number of wells to be selected, the bias could not be reduced (e.g., Illinois and New Mexico). This step reduced the number of wells from 390 to 166. These 166 data points formed the subset of the April 2003 data and are collectively referred to as the "adjusted data set." Although the bias could not be completely eliminated, it was assumed that the well sites in the adjusted data set were more representative of the depth to groundwater in the contiguous United States and that rail lines traverse groundwater depth regions randomly and independently, as we found for soil type. The adjusted data set was used to calculate the distribution of groundwater depth ranges.

Groundwater Ranges

The groundwater levels were categorized into five ranges (Table 5). These ranges were chosen somewhat arbitrarily to get five depth ranges, each with at least 10% of the wells. In order to determine whether the choice of ranges might affect the risk results that were being developed, a sensitivity analysis was conducted. The environmental risk analysis model was used to evaluate the effects of the assumption regarding the particular well-depth range categorization

TABLE 5 Probability of Occurrence of Five Groundwater Ranges

Groundwater Depth Range j (ft)	Number of Wells N_j	Probability P_j
>5 to ≤15	26	0.1635
>15 to ≤25	20	0.1258
>25 to ≤75	37	0.2327
>75 to ≤125	19	0.1195
>125	57	0.3585
Total	159	

scheme. The model was run by using four different well-depth categorization schemes and it was found that the choice of groundwater depths did not significantly affect the results (15).

Probability of Occurrence of Various Groundwater Ranges

The adjusted April data set was used to determine the probability values for groundwater ranges as follows:

$$P_j = N_j/N \tag{4}$$

where

- P_j = probability of occurrence of a groundwater region j , near rail lines;
- N_j = total number of wells in the groundwater depth range j ; and
- N = total number of wells in all the depth ranges considered.

Of the 166 wells in the adjusted data set, 159 fell in one or the other depth range; the remaining 7 wells had groundwater less than 5 ft deep. The probability values and the number of wells in a depth range are specified alongside the ranges in Table 5. Figure 5 shows

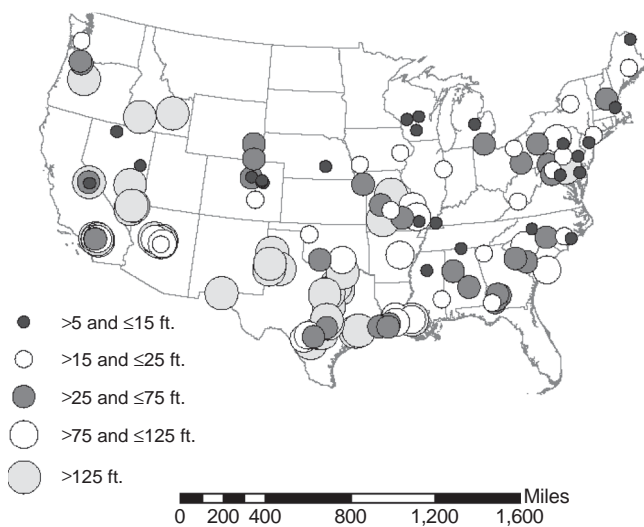


FIGURE 5 Distribution of wells in adjusted data set categorized by five groundwater depth ranges.

the geographical distribution of these wells based on their depth ranges. The next step was to obtain a matrix of the soil type and groundwater range combinations and develop probabilities for each environmental scenario.

SOIL-GROUNDWATER MATRIX

The three soil types and five groundwater ranges were combined to give 15 soil-groundwater combinations or scenarios. If soil type and groundwater depth were independent, the probabilities of occurrence of these scenarios could be obtained by multiplying the probability for the corresponding soil type (Table 3) with the probability for the corresponding groundwater range (Table 5). To check the validity of this assumption, the 166 wells were plotted on the soil map (Figure 2) using their latitude and longitude attributes. Using this overlay (Figure 6), it was possible to count the number of wells in each category of groundwater depth range over each soil-type category (Table 6).

A chi-squared analysis of the data in Table 6 indicated that soil and groundwater distributions are independent at $\alpha = 0.025$ but not at $\alpha = 0.05$ ($\chi^2_{8,0.05} = 15.5 < \chi^2_{\text{Observed}} = 17.14 < \chi^2_{8,0.025} = 17.54$), indicating a weak dependence between the two parameters. Therefore, the probability of occurrence of the 15 scenarios was estimated by comparing the number of wells on a soil type in a groundwater depth range with the total number of wells (i.e., 159), using the values in Table 6. The proportions are calculated as follows:

$$P_{jk} = N_{jk}/N_T \tag{5}$$

where

- P_{jk} = probability of occurrence of an environmental scenario with groundwater region j and soil type k , along rail lines;
- N_{jk} = total number of wells in the groundwater depth range j over soil type k ; and
- N_T = total number of wells in all the environmental scenarios considered.

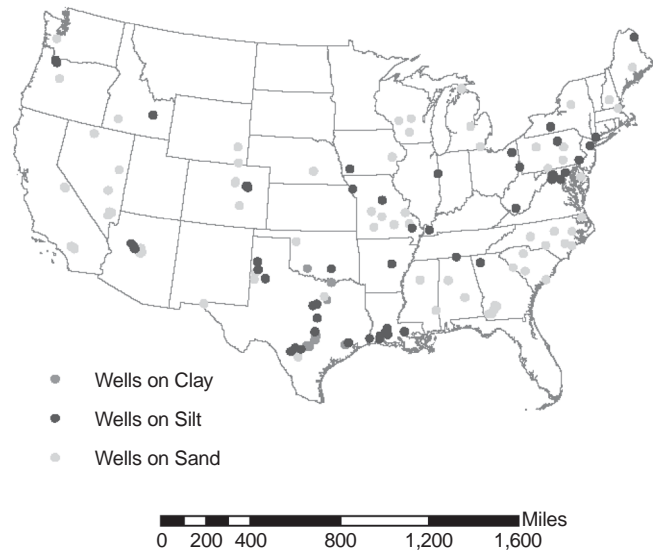


FIGURE 6 Distribution of wells in adjusted data set in three soil regions.

TABLE 6 Number of Wells over Each Soil Type in Each Groundwater Depth Range

Depth to Groundwater (ft)	Clay	Silt	Sand	Total
>5 to ≤15	0	11	15	26
>15 to ≤25	0	7	13	20
>25 to ≤75	4	9	24	37
>75 to ≤125	0	12	7	19
>125	8	19	30	57
Total	12	58	89	159

Table 7 represents the nationwide estimate for the probability of occurrence of the 15 environmental scenarios generated in this study.

DISCUSSION

From the probability distribution of soil types, it was found that silts are the most common soils under rail lines (Table 3), whereas sands are the most common nationwide (Table 4); however, this difference was not significant. Among the groundwater depths, water tables deeper than 125 ft are the most frequent and water tables in the range 75 to 125 feet are the least frequent (Table 5). From the joint distribution of soil type and groundwater ranges (Tables 6 and 7), it is evident that the most frequent scenario was the presence of sand on regions with groundwater depth greater than 125 ft. Clays and silt were also most common in areas with groundwater tables deeper than 125 ft. A chi-squared test of the soil-type distribution near rail lines and the groundwater depth distribution showed that the two parameters were not independent. The residuals suggested that silts were positively associated with water tables 75 to 125 ft in depth, whereas clays appear to be positively associated with water depths greater than 125 ft, and negatively associated with water tables less than 25 ft.

The finding that the distribution of soil types beneath rail lines and the overall distribution of soil types in the 48 contiguous states are not significantly different indicates that nationwide studies of rail transportation risk can assume these to be independent, thus simplifying the analysis. This result also suggests that the same would be true for studies of truck transportation risk because the highway network is denser than the rail network, and thus even less likely to differ. It might also hold true for the pipeline network, but a specific

TABLE 7 Probability of Occurrence of 15 Soil–Groundwater Combination Scenarios

Depth to Groundwater (ft)	Clay	Silt	Sand	Total
>5 to ≤15	0.000	0.069	0.094	0.164
>15 to ≤25	0.000	0.044	0.082	0.126
>25 to ≤75	0.025	0.057	0.151	0.233
>75 to ≤125	0.000	0.075	0.044	0.119
>125	0.050	0.119	0.189	0.358
Total	0.075	0.365	0.560	1.000

investigation would be appropriate if there is evidence of a more geographic bias in the location of pipelines compared with rail or highway routes. However, for smaller scale, route, or product-specific analyses, a GIS analysis using the methodology described here would be necessary to account for local variations in soil-type distribution. Suitable portions of the nationwide database developed for soil types in this study could be used (Figure 2) or higher-resolution route-specific data, if necessary.

A nationwide GIS analysis of groundwater depths in the proximity of rail lines analogous to the soil-type analysis was not possible because of the lack of a suitable database. Consequently the distribution of groundwater depths was estimated based on a sample of USGS real-time groundwater wells.

The results presented in this paper are the first attempt to develop a nationwide estimate of the probability distribution of the exposure of two of the most important elements affecting the risk to the environment from railroad spills of hazardous materials, soil type, and depth to groundwater. The probability distributions for the different environmental scenarios developed in this paper can be used as a basis for estimating this aspect of environmental risk due to rail transportation of hazardous materials (15, 16). The distributions developed in this paper can also be applied to other environmental risk studies with the caveat that the limitations and the assumptions underlying their development are properly considered and accounted for.

FUTURE RESEARCH

The results presented in this paper could be further refined, particularly if better data were available. One example of this is the assumption regarding soil types beneath rail lines. The uppermost soil layer was selected as representative of soil characteristics below. This assumption is probably reasonable for nationwide estimates of risk because it is likely that deviations from this assumption will average out when one considers the entire rail network. The assumption that surface soil is a satisfactory predictor of deeper soil types could be evaluated with more work using the data in the layer table of the STATSGO database. This step would be more important for route-specific risk analyses.

The inadequacy of the GIS database on groundwater depth is probably the greatest limitation to a more refined estimate of the nationwide distribution of this parameter. In the absence of such data, there is little that can be done. However, one option would be to use the buffering capability of GIS software to determine the number of real-time groundwater wells within some predetermined distance from rail lines. The distribution of wells inside the buffer would be counted for each of the five depth ranges and the distribution of groundwater depths could be compared with the overall distribution to determine whether there is any difference. Confidence that the overall distribution was adequately representative would increase if the difference were small. However, the relatively small number of wells in the USGS real-time database is likely to be a constraint in this effort. A larger number of data points could be obtained using the wells with discrete groundwater measurements rather than the continuously monitored wells (14). The longer the time span considered, the greater the number of observations will be. However, use of these data would also introduce uncertainty regarding how accurately the resultant distribution represents current conditions. To avoid this complication, a recent sample from the continuous, real-time data was used. An investigation into the long-term, temporal stability of the distribution

of groundwater depths developed using the discrete database would improve understanding of this parameter.

Finally, the actual routings of hazardous materials shipments over the rail network were not taken into account. Most likely this will not have a serious impact on the results because there is no reason to believe that the distribution of environmental features along rail lines with hazardous materials traffic is substantially different than the rail network as a whole. The finding that the nationwide percentage of soil types is not different than what occurs beneath the rail network further corroborates the likely validity of this assumption. To evaluate this assumption further, an analysis could be conducted in which the actual volume of hazardous materials were flowed for each segment in the rail network and accounted for in the exposure assessment. Presently this is not easily done because of the limitations of the rail2m data set. This data set contains limited information on the gross tonnage on each link, but contains no details on the makeup of the traffic. Thus, a more complicated analysis would be needed in which a rail network model was used in conjunction with traffic flow data to determine likely routings of hazardous materials across the rail network.

Although the last point above is a potential question for nationwide assessments of risk, it is less of a problem for many likely practitioners trying to conduct specific risk analyses. Railroads and chemical shippers interested in addressing environmental risk from particular hazardous materials traffic will generally be in a position to know the traffic makeup over a particular route so they can simply incorporate such data into an analysis that employs the methodology and findings described in this paper.

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