Managing subsurface property hazards: reactive soils and underground storage tanks

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Abstract

Fuels stored in underground tanks often contaminate urban soil and water. A geographic information system (GIS) mapped 1068 underground fuel tanks in Denton County, Texas, USA. Tank locations were compared with soil shrink–swell and corrosivity potentials. Higher percentages of reported leaking tanks were observed in expansive and corrosive soils. This study illustrates the utility of GIS for overlaying layers of data that affect underground tank integrity. Such overlays could find appropriate locations for new tanks, survey existing tanks for potential leak hazards, and assess hazards posed by leaking tanks based upon soil permeability.

Keywords: Reactive soils; Underground storage tanks; GIS

1. Introduction

Environmental liability is a growing concern for real estate managers. Numerous property owners have declared bankruptcy in the face of impending environmental cleanup costs. Annual insurance premiums for properties that pose environmental risks can exceed $10,000. Due to such high premiums, as well as concern over receiving just compensation in the event of a problem, many property owners do not carry environmental insurance. Inadequate insurance leaves landowners financially vulnerable. Land tenants that utilize hazardous chemicals are especially vulnerable to environmental lawsuits. Often these chemicals are stored onsite in large tanks. Many such tanks are buried beneath the land surface. This diminishes their perceived threat because they are not observed on a routine basis. Yet the proximity of these tanks to soil and groundwater poses substantial environmental risk.

Leaking underground storage tanks and associated piping are a major source of soil and groundwater contamination. They cause approximately 40% of all groundwater contamination in the US (LEAK, 1990).

Of the more than 19,000 documented leaking tanks in Texas, 6000 have impacted groundwater (Mace, Fisher, Welch & Parra, 1997). These tanks often contain petroleum products (such as gasoline and oil) and hazardous chemical substances (such as cleaning solvents and chemical waste). The US Environmental Protection Agency (EPA) regulates approximately 2 million underground storage tanks, but another 8 million are unregulated (Crawford, 1989; Hoffman, 1991). In 1990, the EPA estimated that nearly 30% of all underground storage tanks in the US had leaked (LEAK, 1990).

Most underground tanks are located in soil rather than bedrock. Shrink–swell and corrosion reactions that take place in soil can damage embedded structures such as storage tanks. Permeability influences the extent of soil and groundwater contaminated by a leaking underground tank. The objective of this study was to evaluate the spatial distribution of leaking underground tanks in Denton County, Texas in relation to potentially hazardous soil properties. Rationale for completing the study were: (1) to determine whether soils with a high capacity for shrink–swell or corrosion were associated with a higher percentage of leaking tanks (and therefore warrant more careful consideration when locating future tanks), and (2) to determine which leaking tanks posed the greatest potential environmental hazard based upon soil permeability.
2. Background

Corrosion, structural failure, and improper installation account for most of the leaks in underground storage tanks. Corrosion is an electrochemical process that weakens steel. Soil moisture, acidity, and electrical conductivity affect corrosion rates (NCSS, 1980). However, most tank failures, 60% according to the EPA, are due to structural failure or loose fittings (Leavenworth, 1987). Soils that shrink or swell with temporal moisture fluctuations stress underground tanks and piping, often leading to structural failure. Expansive clay deposits can exert pressures near 30 tons per square foot (Allen & Flanigan, 1986).

When tanks leak, soil permeability influences the potential rate and extent of subsurface contamination (EPA, 1987; ASTM, 1995). The ability of soil to transmit fluids is governed by such factors as texture and porosity (NCSS, 1980). Porosity is imparted by voids between individual grains, as well as cracks or tunnels in the soil. In general, fluids move faster through openings between larger particles (such as sand and gravel) than through openings between smaller particles (such as clay and silt).

In view of the environmental threat posed by underground tanks, the EPA requires that tank owners follow certain safety guidelines. First, tanks and piping must be installed according to industry codes. Second, tanks must be equipped with devices that prevent spills and overflows. Third, tanks must have cathodic (electrical) corrosion protection or protective linings (such as fiberglass and plastic). Finally, tanks and piping must be equipped with leak detection and containment devices. Detection devices include tightness testing, vadose zone monitoring, and groundwater monitoring. Containment devices include concrete vaults, double-walled tank systems, and lined excavation zones. Although these measures reduce tank leakage, failures still occur due to improper installation, faulty construction material, and unforeseen stresses exerted by vehicular traffic and expansive soil.

3. Study area

Denton County covers 958 square miles in north-central Texas, at the updip edge of the Gulf Coastal Plain (Fig. 1). The county has a population of approximately 80,000. Overall, the topography is nearly level to gently sloping, but moderately steep at local sandstone knobs. Denton County lies upon upper Cretaceous rock formations containing sandstone, shale, clay, limestone, and marl deposited in transitional and marine sedimentary environments (McGowen et al., 1991). Quaternary alluvial deposits, principally sand and clay, overlie the bedrock along stream valleys. Expansive soils have developed through weathering of clay-rich parent rocks in various parts of the county. Such soils have damaged house foundations and underground pipes in north-central Texas (Hudak, 1998; Hudak, Sadler & Hunter, 1998).

The climate of Denton County increases the potential hazard of expansive soils. The area has a temperate climate with hot dry summers and moderately wet springs and falls. Prolonged hot, dry periods with little or no rainfall followed by cool, wet periods provide an ideal environment for expansion (Keller, 1996). Dry soils swell when moistened and moist soils shrink when dried. Either process, shrinking or swelling, can damage structures buried in soil.

There are approximately 1100 underground storage tanks in Denton County, 117 of which have been reportedly leaking. The tanks are clustered in the urban areas of Denton (middle cluster in Fig. 2) and Lewisville (southeast cluster in Fig. 2) and also occupy smaller towns including Sanger, Pilot Point, and Lake Dallas. Most of the tanks in the study area belong to gasoline stations.

4. Methods

A list of all reported leaking petroleum storage tanks was acquired from the Texas Natural Resource Conservation Commission (TNRCC) in ASCII format. Records for Denton County were extracted from the database, reformatted into a D-Base IV file, and then geocoded and exported into an ArcView shapefile (ESRI, 1996). This procedure yielded a point map of leaking tanks.

A second data source, also from the TNRCC, listed all storage tanks (including those for which no leaks had been reported) located in Denton County. This hard-copy data included tank location, construction, and storage characteristics. Tank locations were referenced to a Denton County street map and assigned to soil units.
Soil properties (shrink–swell, corrosivity, and permeability) were retrieved from the States Soil Geographic Data (STATSGO). These properties were attached to a digitized coverage of soil units, acquired from the Denton County Soil Survey. The point coverage of leaking tanks was superimposed on polygon maps of each soil property. Each property was categorized (such as high, moderate, and low), and for each category, a percentage of leaking tanks was calculated.

A low shrink swell rating implies a potential volume change of less than 3% in an unconfined clod of soil as the moisture content increases from air dry to field capacity (NCSS, 1980). Moderate shrink–swell implies a 3–6% volume change, high shrink–swell corresponds with a 6–9% volume change, and a very high rating indicates a volume change in excess of 9%. A volume increase of only 3% is potentially dangerous to structures in soil (Brown, 1979).

Respectively, high, moderate, and low corrosivity potentials correspond to earth’s resistivity measurements of less than 2000 $\Omega$ cm$^{-3}$, 2000 to 5000 $\Omega$ cm$^{-3}$, and more than 5000 $\Omega$ cm$^{-3}$ (NCSS, 1980). High corrosivity potentials stem from clay constituents and a related tendency for moisture retention and electrical conduction.

5. Results and discussion

The 12 soil associations covering Denton County group into four shrink–swell, three corrosivity, and five permeability categories (Figs. 2–4). Polygons in Figs. 2–4 illustrate the importance of regional geology in controlling hazardous soil properties. For example, a marl (limey mud) rock formation underlies the western dark gray area in Fig. 2, the western dark gray area in Fig. 3, and the western light gray area in Fig. 4. This rock formation yields a clay rich soil with expansive minerals such as montmorillonite. The clay also imparts a high corrosivity and low permeability to the soil. In contrast, a formation containing sandstone, sand, and lesser amounts of clay underlies the light gray middle part of Fig. 2, the light gray middle of Fig. 3, and the medium gray middle of Fig. 4. This latter formation yields sandier soils having lower shrink–swell and corrosivity potentials, but higher permeability than the marl.

There were no leaking tanks in the low shrink–swell or low corrosivity categories. The higher shrink–swell categories registered higher percentages of leaking tanks. Respectively, the very high, high, and moderate shrink–swell categories registered 15.0%, 11.7%, and 10.3% leaking tanks. A similar trend was apparent for corrosivity – a higher percentage of leaking tanks (11.7%) were located in the high corrosivity category than in the moderate category (10.3%).

In a relative sense, the percentages were consistent with classifications for shrink–swell or corrosivity. However, differences between observed and expected numbers of leaks in shrink–swell categories were not significantly different ($\chi^2$ statistic = 0.62 compared to critical value of 5.99 for $\alpha = 0.05$). Neither were differences between observed and expected numbers of leaks in corrosivity categories ($\chi^2$ statistic = 0.44 compared to critical value of 3.84 for $\alpha = 0.05$). Combinations of corrosivity and shrink–swell (moderate/moderate, high/moderate, high/high to very high) yielded a higher $\chi^2$ statistic (5.28), but it was still below the critical value (5.99) for $\alpha = 0.05$. These statistics suggest that shrin...
swell and corrosivity may affect tank integrity, but other factors (such as traffic loads, tank composition, and construction characteristics) also play important roles.

Fortunately, soils having high shrink–swell and corrosivity potential often have a low permeability. The high clay content of such soils impedes fluid transport. Maps compiled in the present study exemplify this trend. In general, soils in the higher permeability categories of Fig. 4 have relatively low shrink–swell and corrosivity potential (Figs. 2–4). The permeability overlay can be used to identify leaking tanks that may threaten nearby soil and groundwater. Tanks in the moderate and moderately rapid permeability categories overlie relatively permeable soil and warrant short-term corrective action planning.

Geographic Information Systems (GIS) are well suited to overlaying layers of data relevant to siting underground tanks (proactive mode), surveying existing tanks to determine where leak hazards exist (survey mode), and reacting to tanks that have already leaked (reactive mode). In a proactive mode, a GIS identifies potential tank sites posing the least hazard based upon soil properties. Such information could reduce the number of future tank releases in an area. The survey mode pertains to existing tanks that have not leaked but may leak in the future. In that mode, the GIS will
identify which tanks have the greatest likelihood of leaking due to structurally hazardous soils. Finally, in a reactive mode, the GIS will determine which leaking tanks pose the greatest threat to nearby soil and groundwater.

Limited resources (including time, money, regulatory oversight, and qualified professionals) warrant risk-based assessment of relative environmental hazard at existing and potentially hazardous release sites (ASTM, 1995). For example, a substantial deficit in the Texas Petroleum Storage Tank Remediation Fund prompted the Texas Water Commission to limit reimbursement to high priority sites posing a direct threat to groundwater contamination (TOMA, 1992). Gas station owners/operators contribute to this fund by paying annual tank fees (TNRCC, 1995).

In addition to hazardous soil properties, other variables relevant to siting and assessing underground storage tanks, that could be included in a GIS, include tank construction, proximity to nearby properties, presence of protective barriers and leak detection apparatus, depth to groundwater, and distance to lakes or wells. Ultimately, GIS could lead to more efficient underground tank planning, saving limited resources and mitigating environmental problems.

6. Conclusions

Soils affect the integrity of underground storage tanks. Data compiled in this study showed that expansive and corrosive soils registered higher percentages of leaking tanks than other soils. Land developers should consider these soil properties when locating new tanks. Such proactive planning could reduce the number of future leaks. In addition to finding new tank locations, GIS could be used to identify which existing tanks may be at the greatest risk of rupturing due to hazardous soils. GIS can also be deployed in a third, reactive-type mode. In a large city having dozens of leaking tanks, efforts to contain the leaks could be prioritized based upon potential environmental hazards. These hazards are controlled in part by such soil properties as permeability. GIS can quickly identify which tanks reside in the most permeable soils of a city or county. Potential beneficiaries of GIS, deployed in proactive, survey, or reactive modes for underground tanks, include property managers, planning departments, regulatory agencies, emergency management teams, lending institutions, and gasoline distributors.

References


