KANSAS GEOLOGICAL SURVEY
OPEN-FILE REPORT 88-38

Geologic Implications of Waste Management in Kansas into the 21st Century

by

Ernest E. Angino

KANSAS GEOLOGICAL SURVEY
1930 Constant Avenue
University of Kansas
Lawrence, KS 66047

Geologic Implications of Waste Management in Kansas into the 21st Century

Kansas Geological Survey Open-file report 88-38

by

Ernest E. Angino
Department of Geology
University of Kansas
Lawrence, Kansas 66045

GEOLOGIC IMPLICATIONS OF WASTE MANAGEMENT IN KANSAS INTO THE 21ST CENTURY

Kansas Geological Survey Open-file report 88-38

by

Ernest E. Angino
Department of Geology
University of Kansas
Lawrence, Kansas 66045

Introduction

The issue of waste generation and waste management is one of the overriding concerns of modern society. We are a waste-generating society. Today, the average person in the United States produces 3.5 pounds of "just" trash per day. For the total U.S. population, this totals approximately 160 million tons of solid waste per year--almost twice the figure for 1960. Kansas is no exception. Our approximately 2,400,000 people contribute 1,533,000 tons of this total.

Proper waste disposal comes down to protecting the public health and the environment. No matter how we do that, however, waste material has to be disposed of and it has to go somewhere. Many studies have been conducted over the past several decades by public and private researchers and planners seeking a technologically feasible, economically justified, environmentally sound and politically acceptable approach to waste disposal.

Taken at face value, these four goals are individually, but not as a whole, compatible. Ultimately, there are only three places for society's waste materials to go: the air, the water, or the ground. It is with the last of these with which we will be concerned herein. When wastes of any kind are disposed of in or on the ground, geology can and will be a factor of concern. The wastes can and will react in some way with the surrounding medium: rocks, soils, water, and minerals. For this reason we must be concerned with the geological implications of waste management in Kansas.

Setting

From a geologic viewpoint, it is only a difference in degree of concern whether the waste is disposed of on the surface or in the subsurface. Chemical and physical reactions and interactions with the surrounding and enclosing medium and water will occur.

Interaction between wastes, rainfall, and surface water are obvious. It is, however, commonly forgotten that below the surface, two areas with different environmental conditions come to be part of the problem. The first is the so-called unconsolidated or unsaturated zone--that portion of the geologic section between the surface and the top of the water table. This is also called the vadose zone. The second area is that below the water table, the saturated zone. It is common (and easy) to ignore the fact that once below the water table all void space is filled with some type of fluid, fluid that reacts with any waste disposed in its environs. I will return to problems associated with this two-fold separation of the subsurface.

Regardless of whether waste is hazardous or non-hazardous and regardless of its disposal site (i.e., surface or subsurface), most waste will come in contact with water at some point in its history--unless a given waste is specifically isolated in some fashion from the environment. Consequently concern for the effect of waste on water quality is of paramount importance, especially in a state such as Kansas which is not overly endowed with water. The geological implications of waste management are different for different environmental and geologic settings. Considerable variation in geology exists across Kansas from the glaciated terrain in the northeast to the rolling Red Hills underlain by gypsum in the southwest. This geological variability needs to be evaluated and quantified into a solid foundation of base-line data.

All areas of the State generate solid wastes that will have to be handled and disposed of. It is customary to ignore or forget some types of waste produced constantly by society. Table 1 is a list of such wastes. All the waste materials listed can react with geologic materials at the point of disposal. However, to assess properly the geological implications of any waste being disposed of in any portion of the State, it will be necessary to understand fully the regional geology, distribution of water resources, and possible interactions between these and the waste parameters. In short, good, reliable base-line geologic data will be required. If this is to be accomplished properly, the State Geological Survey and other state agencies will have to be involved.

Some of the studies suggested in this report may already be underway or in the planning stage. Owing to time limitations, no attempt has been made to cross check with all the state agencies and groups concerned with water in the state. The important aspect is that there is enough for all to do and solving the problems that will arise in the future will require the cooperation of all parties. I leave to the respective parties concerned the responsibility for separating out possible studies already underway and those that fall under different agency charges.

Water

A review of the large literature pertaining to geologic interactions with waste materials clearly shows that water chemistry (and quality) is almost always affected by these interactions (e.g., Francis and Auerbach, 1983; Sanks and Asano, 1976; National Academy of Sciences, 1986). Contamination of water or loss of water quality is usually the most critical concern expressed in relation to waste disposal and management.

Several rational means exist to reduce the amount of waste that finally has to be buried. Clearly recycling, reuse, change of processes, and energy generation are important keys to solving the waste problem, but wastes are still generated. The issue is highlighted because of several facts commonly ignored in the emotionally charged discussions generated by the waste disposal problem. For example, as Melloan (1988) has noted, "paper . . . can only be recycled twice," incineration generates an ash, and limits exist as to how much demand exists for recycled glass, or recycled anything. Therefore, disposal has to be part of the solution and consequently waste in one form or another ends up in the ground where it can react with water.

Water quality is a tenuous term. It means different things to different people, depending on the anticipated use of the water. Quality can range from the near super-pure state required in nuclear reactors to subsurface brines that can be used as a source of base chemicals. With such a range, one thing badly needed is an updated series of maps of the state showing water quality distribution by aquifer. To be of value such maps would have to be at a scale to show sufficient detail for the person using the map to relate to it. A county map may be appropriate in some cases, but not in others. In some instances a regional map might suffice. Preferably, the map would be independent of political boundaries. One tied to a major drainage basin is worth consideration.

Knowing where water of good quality is located is an important first step in avoiding any action that can lead to its contamination. It is imperative that all known waste disposal sites of any kind be shown on these maps with some indication as to type, i.e., sanitary landfill, hazardous waste, fly ash, old municipal dump site, etc. This latter information is essential to alert one to locations of possible present or future contamination.

The exact location of waste disposal sites can be a problem if records have been lost or memories have become hazy. Many chemicals causing industrial wastes to be classified as hazardous are also present in municipal solid wastes (Table 2). Many cleaners, for example, have a chlorinated-hydrocarbon base. The areal extent of the disposal site is also of importance and should be shown on any maps produced. Consideration needs to be given to employing remote sensing with all of its present exactitude to locate abandoned surface-disposal sites. Knowledge of the location of these sites is important if future contamination is identified off site. It helps to know where any contamination source may be located. Analysis of imagery from known flood plain and upland sites could be helpful in locating older abandoned sites, their areal extent, and in assessing their potential hazard.

Of equal help and concern in understanding where future waste problems may arise is knowing the direction of ground-water movement within a specific drainage basin. It is important to delineate specifically (by boundary) known ground-water basins and aquifers in the state and to identify the detailed soil and geologic characteristics common to each, if any, and to highlight local differences. At present few maps with the appropriate geologic detail exist that provide this type of information. A hierarchy of drainage basins should be established and maps showing the geology, surface and ground-water quality generally available in the basin, quantity, direction of flow, and depth to the water table should be prepared. Such information is of extreme importance in the location of future waste-disposal sites and in understanding the possible direction of flow paths of any leachate plumes arising from existing waste disposal sites.

These maps can be prepared in an order reflecting the size of the cities involved. Many problems are likely to be most critical in the vicinity of the larger municipalities of the state. Concern for most waste is in proportion to the population of the city, town, or county that a particular waste site serves.

Similarly, maps identifying areas of existing or potential natural contamination or pollution are needed. Not all pollution is man-made. We need to document where natural environmental contamination exists. This is the only means by which we can identify the natural geochemical background of an area. Two examples can be given. One is the saline water intrusions in the Smoky Hill River channel, another could be the possible leaching of selenium from the Cretaceous Pierre shale (more specifically Sharon Springs Member) into existing water sources in western Kansas.

As society sets lower and lower limits for what is acceptable for different water uses, it will shortly come into conflict with the existing natural chemistry levels produced by normal weathering and runoff. It is necessary to deal with this geochemical likelihood as it is impractical to expect the laws of nature to be set aside specifically for Kansas. To know if contamination exists at low contaminant levels, we first have to know the base or background levels existent naturally.

An additional use of this type of map needs to be discussed. Under the proper circumstances, permanent disposal of hazardous wastes (in liquid or solidified form) in abandoned or unused underground subsurface mined-out areas is worthy of consideration, especially in subsurface openings such as abandoned salt mines, salt domes, old metal mines, coal mines, and deep quarries (U.S. Army Corps of Engineers, 1979; National Academy of Sciences, 1983).

These openings are scattered widely across Kansas and are present in many different rock types. In aggregate they total millions of cubic feet of unused space. This space can be an asset. What is needed is a detailed inventory of the availability of such space and the geologic conditions present at each site. Solid waste of many types properly contained will have to go somewhere. Hazardous wastes (as defined by Kansas Statutes) generated in Kansas now are shipped out of the state for disposal. At present there are no commercial hazardous-waste landfill sites in Kansas (KDHE, personal communication). At some time in the future, it is logical to assume that those states receiving our waste will stop providing this service. The state will then have to assume the responsibility of handling the hazardous wastes generated within its borders.

A careful assessment of the general geological conditions necessary to accept such wastes is needed. A careful hydrogeological review of the rock types and limits available to handle such waste is essential. Problems usually arise from lack of a proper geologic study and assessment prior to disposal at a site. When burying waste, hazardous or otherwise, one must critically examine the geology of the site, including the soil, faulting, rock types, their stability, water chemistry, mineralogy, and jointing.

Having pointed out the more general items of interest, it is necessary to consider the specifics. However, before doing this, it is also necessary to highlight some simple facts. The most obvious geological implications related to waste have to do with its interaction with water, its potential to reduce the growing-quality of land (through sewage sludge for land treatment, for example), and those rock-water chemical reactions that occur in the vadose zone before any contaminating solution reaches the ground-water table. We need to know the reactions that occur by interaction with agricultural chemicals or from leachate from any other waste "stored" on the surface, in the vadose zone, or in the saturated zone itself. Let us now return to a quick review of the geological specifics related to waste management.

The specific geologic information needed to assess properly the interaction between any waste disposed and the geology and hydrogeology of an area is extensive. Starting at the surface, we need to know in detail the local soil properties. A number of soil classification systems are used today. Unfortunately, most are not well suited to predicting the behavior of chemicals added to soil as a result of spills, leaks, or land disposal-operations (Dragun, 1988). Among the needed properties essential to predicting soil-chemical interactions are: soil size fraction (sand, gravel, clay, etc.), pH, percent organic matter, type of organic matter, clay-mineral content and dominant type, permeability, porosity, water content, and shale/clay ratios. Lessing (1980) breaks the information needed into seven major categories and I have added one (soils). These eight categories are:

1. Bed rock units
2. Surficial deposits
3. Structural features of bedrock and surface outcrops
4. Surface Drainage
5. Ground water
6. Geochemistry
7. Soils
8. Other geologic features of special significance

Within these eight categories are included specific details such as physical and chemical characteristics, 100-year-flood lines, water chemistry, water quality, solution features, etc. These are shown in more detail in Table 3 (modified from Lessing, 1980). Other factors of importance include climate and rainfall, including maximum known rainfall intensity in a given time, runoff characteristics, and infiltration rate.

Deep-Well Injection

The disposal of hazardous, and (rarely) non-hazardous wastes, by underground injection is a hotly debated topic. This report will not discuss the details and relative merits of this disposal technique. After all other means of reducing and disposing of certain wastes have been considered, it is clear that a certain small percentage of waste will remain that cannot be disposed of in a safe and satisfactory manner expect by subsurface (deep-well) injection. Public distrust of proposed scientific and technological solutions is currently a more difficult problem to overcome than geology-related problems; however, the wastes still must be disposed of. Many problems resulting from deep-well injection have arisen from the failure to understand (even ignore if you will) basic geologic and hydrologic principles. Wastes have been injected without regard to geochemical or geological suitability. I omit from this discussion of injection wells those handling the reinjection of oil field brines, which have their own problems. Suffice it to say that some wastes probably cannot be disposed of in a safe and satisfactory manner in any other way. This issue is reviewed and discussed in considerable detail in the National Academy of Sciences report, "Management of Hazardous Industrial Wastes" (1983).

The NAS report concluded that "subsurface injection is a technically acceptable method for hazardous liquid waste disposal or long-term isolation of toxic pollutants whereby the wastes are injected in deep subsurface aquifers that are of no or little value for other purposes . . . . The greatest concern is with the question of permanent isolation of the injected wastes from the biosphere." Many (perhaps hundreds) of abandoned injection sites may exist in the State; some undoubtedly are located improperly in relation to the local geology. If we are to be ready to anticipate future problem areas, it is necessary to map the location of as many of these abandoned injection wells as possible. Operating wells should obviously be shown on such a map, including oil-field brines injection systems. This concern for problem areas is important because we need to be alert for problems arising from past mistakes and alert to areas in which difficulties may arise in the future. All authorities should be knowledgeable immediately about potential problem sites.

To assess properly the effects of permanent disposal of liquid wastes, particularly those of extreme stability that may pose a potential long-term threat, better information and more research are urgently required in several areas. Paramount among those that can affect Kansas is the rate of fluid migration, level of isolation, and possible chemical reactions of specific liquid wastes with fluids in the deep stratigraphic basins of the state.

Prior to any waste being introduced into the subsurface, the short- and long-term migration rates and directions of migration of the fluids in potential subsurface disposal zones must be known. Migration may not occur at all; the deep waters may be stagnant. It is imperative to understand explicitly the heterogeneous chemical reactions that can occur between the natural brines and the surrounding country-rock now and over the time during which reaction and degradation will occur. It is important to determine which of the potential chemical reactions can occur spontaneously and to know the thermal conductivity and specific heat capacity (among others) of the rocks and fluids in potential disposal horizons. For many of these questions, answers are available when dealing with the most common sedimentary rocks, such as shale (Brookins, 1976), limestone and sandstone, but answers are lacking or imprecise for other rock types such as anhydrite, dolomite, granite, gabbro, and gneiss.

A major portion of the subsurface disposal of liquid wastes so far has occurred in sedimentary rocks and in sedimentary basins. If long-term disposal and isolation from potential ground-water sources is desired, the possibility of utilizing the crystalline rocks underlying the sedimentary basins in Kansas needs to be investigated. We know very little of the hydrologic, geologic, and geochemical conditions existing in the basement rocks of the state.

Given the proper hydrologic conditions (e.g. downward migration, high salinity, and subsurface brines compatible chemically with the stagnant waters or the liquid to be disposed of), the potential for such areas to accept liquid wastes for ultimate disposal has not been considered adequately. For many basins, the subsurface waters may be either moving deeper, moving very slowly, or may be stagnant. The latter physical situation is one that may be well-suited for permanent disposal of liquid wastes (Bredehoeft and Maini, 1981).

Having noted the above, how does this apply to Kansas? Earlier I noted that Kansas has in essence "copped out" of the hazardous waste disposal problem, by ignoring disposal. We simply don't have a serious problem because we ship our hazardous wastes out of the state for disposal. At some time in the future, perhaps before the year 2000, we may have that option taken away from us. In brief, we will have to dispose of Kansas-generated hazardous wastes in Kansas.

What are the subsurface hydrogeologic systems operating in the sedimentary (and/or basement) rocks of the Forest City, Salina, Hugoton, and Sedgwick basins? What is the direction of flow, rate of flow, and volume of flow of subsurface waters in them? What is the basic chemistry of the contained waters present in these basins as regards major and minor elements. Are there classes of wastes with which these waters are compatible? We know they are compatible with many brines produced along with petroleum in the State, but what of other chemical systems? The same questions need to be answered for basins in the underlying Precambrian rocks. Do we have enough information to model these flows adequately and meaningfully? What additional data are needed? Where necessary, these data should be collected and the models built.

Can these basins be used for disposal of wastes in any way? Pairing of a particular basin and the major communities in it in relation to industrial need and development may be a rational solution for some waste-disposal problems and an aid to economic development. The Kansas City, Kansas-Overland Park area and the Forest City Basin is an example; Wichita and the Sedgwick Basin is another.

Knowing the geochemistry of these subsurface systems is important, as these basins may have to serve as disposal points sometime in the future if other states refuse to accept our hazardous wastes. What is the pH of these fluids, the total dissolved solid levels? What type of water is present in each basin ($CaCl_2$, $NaHCO_3$, etc.)? For certain organic wastes that resemble petroleum or petroleum-like products, deep-well injection may be the only or best means of disposal. As noted elsewhere in this report, fluids such as oils and gas (which many organic wastes resemble) have been chemically contained in subsurface geologic units for many millions of years at many locations in Kansas. The geology of these occurrences proves the presence of seals to fluid migration in the subsurface in many places. A good example is the Permian salt deposit that covers a large part of the state. One should be able to generate a computer-based land classification system for the State as a whole outlining the best areas for deep-well injection of specific waste types--if necessary. One such approach is that proposed on a smaller scale by Shiraji, et al. (1986).

Clearly a range of geological problems is associated with the disposal of wastes by deep-well injection. These concerns have been adequately outlined by Gordon and Bloom (1985), Mankin (1982), Warner and Lehr (1977), and several others. The geologic characteristics given in Table 4 could be codified and a weighing factor given to each. From such an approach a computer-derived system could be developed to weigh the merits of any site or region; that approach could also be used for any proposed disposal of wastes by subsurface-well injection. We need a vastly better understanding of the geochemistry of the subsurface environment, of the petrophysical and petrochemical properties of the rocks into which wastes are injected, of the potential migration pathways in these reservoirs, and of the waste, water, and rock interactions possible at the pressures, temperatures, and ionic strengths of the solutions involved. Additional information is available in the literature; however, deep-well injection of wastes, as noted earlier, should clearly be considered only as a last resort. Treatment technologies exist for many wastes that are now being injected.

Underground Disposal of Wastes

Can we dispose of certain liquid (or solid) wastes in cavities generated in the Permian salt beds of central and western Kansas? What is the extent and thickness of the salt units underlying western Kansas? Disposal in salt is a reasonable consideration for small volumes of solidified organic wastes. The very fact of the existence of the salt beds of Permian age indicates they have been essentially water free and water tight for over 200,000,000 years and clearly will be for millions of years more. What is the rate of solution along the retreating salt fronts? What is the exact location of the migrating front? Answers to these two geologic questions can be both reassuring and helpful in our utilizing the geologic properties of the salt beds themselves to our advantage in handling waste disposal problems. Such properties as water tightness, plasticity, high specific-heat capacity, inertness to organic materials, etc., are desirable under the proper set of circumstances.

Subsurface disposal of wastes in abandoned salt mines or subsurface cavities has been advocated widely and, in some instances, practiced (NAS, 1983). The essential question is not whether salt can be used as a receptacle for the disposal of waste, but whether other rock types (i.e., gypsum, anhydrite, tight, dry shales, etc.) are equally or more suitable for the disposal of specific wastes. This knowledge will become ever more critical and essential as the available disposal space around our major metropolitan areas becomes less and less available and as the attitude embraced in the NIMBY ("not in my backyard") syndrome spreads.

Those factors most important (NAS, 1983) in determining the best subsurface rock type and horizon for long-term containment of liquid or solid wastes should be clearly defined. Consideration and possible use of such geologic units should be part of any research program to solve problems related to the long-term disposal of wastes. However, the long-term integrity and safety of such in-state disposal horizons (as determined by geology, specific heat, dissolution rate, hydrologic containment, brine chemistry, aquifer flow rate, etc.) has not been considered adequately or evaluated properly basin-by-basin at specific near-surface locations in Kansas. A map outlining such areas on a broad regional (or county) scale would be extremely helpful in pointing out areas to avoid for disposal sites. A good example of this approach for sanitary landfills is given in Reppert and Lessing (1971).

As previously pointed out, a statewide inventory of the availability of subsurface space with a listing of special advantages and concerns of each site is needed. Concurrently, research needs to be initiated on the compatibility of wastes (liquid or solid) with the different types of subsurface brines and environmental conditions in the subsurface.

It is necessary to know possible reactions to be expected at temperatures of 50-200^{o}C, pHs in 4-9 range, brine chemistry of different ionic strengths, dissolved gases such as CO_2, CH_4, and H_2S, and pressures encountered in the different geologic basins of the state.

Such knowledge is critical, as some 10 billion gallons of hazardous waste are injected annually into wells in the U.S. (U.S. Water News, 1988). As in Kansas, a very high percentage of this waste (~95%) is injected to depths of 1000-5000 feet underground. What is the waste migration rate, in what direction is it moving, will it reach or is it likely to reach shallower subsurface drinking-water sources, and what products are generated by reactions between the wastes and the aquifer brines?

To evaluate these concerns, we need a detailed hydrogeologic model constructed for each of the major geologic basins in the state. We need to know the flow lines for hydraulic systems in each basin, the relation between surface water and shallow, moderate, and deep aquifers, recharge rates from surface, etc. The primary public concern (well-founded in my opinion) is the ultimate behavior of wastes (hazardous or not) disposed of in this manner.

Major Aquifers

Several major ground-water aquifers occur in Kansas. Among these are the Ogallala, Dakota, Equus Beds, Ireland sandstone, and those ground-water systems associated with the major rivers and valleys of the state: the Kansas, Republican, Big Blue, Arkansas, etc. All these aquifers are used as sources of industrial, municipal, recreational, domestic, or irrigation water and all are susceptible to pollution and contamination from several sources. Several smaller aquifers in addition to those listed above are even more susceptible to contamination.

Contamination, especially from toxic trace elements and organic compounds (especially agricultural chemicals), is insidious. It builds up slowly (DDT was a good example). Usually some indication or advance warning (wave front or plume front) is given of an impending problem. Clean up and remediation is both expensive and difficult and in some instances may not be possible. The key question arises when we ask, "Is the aquifer becoming contaminated?" To answer this, we must know the base-line chemistry of existing and potential major aquifers in the State, the seasonal range (if any) in chemistry, and the pH of the unit. Additionally, in the area of the aquifer we must know the depth to good-quality water.

A detailed compilation of the presence or absence of a wide range of parameters and contaminants in ground and surface water is needed. These data can then be used as the base line against which to compare the accumulation of the most widely used agricultural chemicals and other potential contaminants of concern, e.g. cadmium, lead, selenium, chromium, atrizine, etc., in the state's aquifers, reservoirs, and major river systems. Acquisition of these data is extremely critical and important; however, two major problems arise in conjunction with collecting the data. The first is cost. It is expensive; consequently collected data or the cost of acquiring such data should be shared among appropriate state agencies. The second major problem is more critical. The work is not exciting or flashy. Data collection is rarely considered important to support until the information is needed--then it is too late. In short, we need better base line-data on ground- and surface-water chemistry throughout the state.

A difficult area of research in which good baseline data are lacking in many areas is that of recharge. What is the annual recharge rate to the major subsurface aquifers in the state? Do we know enough about infiltration rates as a function of local geology to make a meaningful prediction of aquifer life, or to determine if a given aquifer will be able to meet future demands placed on it by industrial or population growth? I think not.

Another topic of concern is the rate of recharge by rivers to the aquifers underlying the alluvial valleys of the state. Putting the question another way, what is the safe rate of withdrawal of ground water from the major river valleys of the state? Do we have sufficient data to set meaningful withdrawal rates at different locations along river basins? Can these data be placed in a complete working model taking into consideration the rates of withdrawal, recharge, rainfall, infiltration, and surface flow? We need to have such an operating model for each major aquifers and river basin in the state. Past approaches to meeting this need have been very limited in scope in applicability.

For example, reliable information on the quantity and quality of water in the Dakota aquifer is scarce (McGovern, 1984). Present work in progress may help tp alleviate this problem. What is the recharge rate, if any, to units such as the Dakota from the overlying unconsolidated deposits and unconfined aquifers? What is the loss from the Ogallala to the Dakota and where and when is it occurring? These are critical data if use of the Dakota aquifer continues to expand. What is the thickness of each aquifer and what is the effect of this parameter on yield if it is variable over the extent of the aquifer? McGovern (1984) comments that "yields probably differ in relation to thickness of sandstone present and the degree of cementation. Sustained well yields may be dependent on the areal extent and interconnection of the principal sandstones" in the area. What are the ramifications that result from this? McGovern further comments that "water quality data from the Dakota aquifer are inadequate to provide any more than generalizations." The same comment can be made about other aquifers in the state.

Further comments on the Dakota are appropriate and illustrate the situation in several other aquifers. Dealy et al. (1984) point out that water in the Dakota is quite variable in quality. Total dissolved solids (TDS) range from 200-3300 mg/l. A detailed map is needed that outlines those areas where the water is of domestic (<500 mg/l), irrigation, (e.g. < 1200 mg/l), or industrial quality. Along with this it would be helpful to know the specific capacity, transmissivity, and storage coefficients, maximum yield, etc. for each area.

In some areas the Dakota aquifer is separated from the overlying Ogallala by a confining layer. These areas need to be mapped, because they will need to be developed as separate aquifers, in contrast to those areas where the two aquifers are in contact and/or hydraulic connection; they therefore must be considered as one. All of these points (Dealy et al., 1984) are applicable to aquifers elsewhere in the state, and are especially important in the western third of Kansas. Some of these data are available now. For example, see Leonard et al., 1984, and other papers in the conference report edited by Jorgensen and Signour (1984); however, few of the data are presented at map scales appropriate enough to be of practical value to irrigators, city engineers, or groundwater management districts. What is needed is a considerable expansion of this information with presentation of data in visual forms (maps) more practical than those in use at present. Why do we need these data? Simply put - if we do not know what is going on now in the major subsurface aquifers of the state, how are we going to be in a position to assess and understand future contamination and pollution problems that may developed in the areas of these aquifers?

Ground-water Quality

Ground-water quality (chemistry) results from the interaction of water with the rocks through which it moves and in which it is located. In short, it results from rock water interaction. Ground-water composition changes as the geochemistry of its environment changes. Both the movement and chemistry depend in some degree on the sorptive properties of surface and subsurface solids. The principal sorbents are hydrous iron and magnesium oxides, organic matter, and clay-mineral composition.

These three fractions play an important part in all rock-water interactions whether in the vadose zone or below the water table. When water contacts the solid phases in a rock, sediment, or soil, several processes take place. Table 5, taken from Hounslow (1983), summarizes these processes.

Key among these processes are the effects of the clay materials and organic matter. Over a large area of western Kansas we need to know the geologic effects on surface- and ground-water chemistry of irrigation run-off water, old and new landfills (e.g. county landfills), rainfall, and run-off from cattle lots, for example, as this water moves across and from the surface through the unconsolidated zone to the water table. As pointed out by Logan and Miller (1983), "A great threat to long-term water quality is the leaching of solid waste products to ground water." An example is the effect of nitrate. Nitrate (NO_3) leaching is a common problem when nitrate-containing wastes (e.g., sewage sludge or animal wastes) are applied or dispersed at rates exceeding the assimilative capacity of the surrounding or underlying soils and rock units. Of considerably more concern is the slow movement of low-level concentrations of some organic compounds to ground water. Owing to extensive crop fertilization and run-off from cattle "housing," the "nitrate problem" may cause considerable future degradation of ground water in Kansas. It deserves more attention. The questions noted above need examination, especially in relation to the major aquifers of the state, such as the Ogallala, Equus Beds, etc. For nitrate and many other compounds (especially the organic ones), the concentration in some waste materials is low, their analytical costs high, and our knowledge of their retention and stability in soil, unconsolidated sediments, and ground water is limited (Roberts et al., 1980).

Ground-water quality can also be severely reduced by interaction with a leachate plume migrating away from any waste-burial site. In attempting to determine whether a leachate plume will reach a particular ground-water source, we need to determine the complementary characteristics of soil, the unsaturated zone (vadose zone), and the aquifer. These factors determine and control the probability that any leachate will reach ground water (NAS, 1986).

Put another way, we need to know the locations of vulnerable aquifers. To approach this problem, we must know several key hydrologic variables that influence the potential for ground-water contamination. Among these are porosity, soil organic-matter content, soil pH, depth to aquifer, confinement geology of the aquifer, and the geologic characteristics of the recharge area of the aquifers. Of greatest interest are those areas of sandy soil and shallow water tables.

We should be in a position to use information on local geology to help develop data useful in pinpointing those areas where aquifers are particularly susceptible to contamination. Where western Kansas is underlain by the Ogallala and Dakota aquifers, we need to review continually the issue of irrigation efficiency and its potential for ground-water contamination. Understanding the interaction and extent of agricultural pollution is critical. Presently, our knowledge of the processes affecting ground-water quality is lacking, owing to an incomplete data base. It is essential to accumulate, as soon as possible, base-line data on water quality (chemistry) of the major, minor, and trace components of the subsurface aquifers in the state. Without this, it will be difficult to detect the early signs (the critical stage) of water-quality deterioration. The key to seeing trends of any type is base-line data. These data, in fact, should be accumulated and evaluated for each of the major ground-water basins and ground-water aquifers in the state.

We should also be alert in sensitive areas to the potential relations between land use (zoning control, present and future) and well-water quality. In brief, we need the ability to predict or identify at different locations the degree of vulnerability of a particular aquifer to contamination (NAS, 1986). What are the characteristics and boundaries of a given ground-water basin that can or will control contaminant flow? What are the flow patterns as opposed to flow rates? Aquifer volume, geologic setting, etc. must be assessed within the framework of future land use.

Taking an overview of these needs, it would be helpful to develop something that might be called a water supply and protection atlas by ground-water basin or aquifer for use by State and local governmental units, especially as it would apply to ground-water use and protection. A series of maps (overlaying if necessary) to delineate the following interactive parameters would be extremely useful in this regard.

1. A topographic and/or slope map, showing the sources of all public-water-supplies
2. A map showing potential sources of contamination, including surface and subsurface impoundments, hazardous-waste sites, landfills, auto junk yards, hydrocarbon-storage areas, salt-storage areas, and locations of permitted-discharges to surface- and ground-water.
3. An aquifer-information map, indicating depth to ground water, areas of equal potential (flow lines), and well-yield data.
4. A map showing all major drainage basins, major river systems, and their divides. In metropolitan areas more detailed maps could show small basins, flood potential around disposal sites, etc.

Such geologic information should be collected and presented to local governments to help in land-use planning and water-supply management. Additional information that could be indicated in areas near disposal sites are artificial recharge, run-off potential and direction of run off in relation to known disposal sites.

Ground-water Pollution

Water, it is important to remember, is one of the most active solvents known. Ground water in particular is occasionally ignored in long-term water-supply planning and management. This is not true for western Kansas, but is true for the eastern part of the state. One reason is the mistaken assumption that ground water cannot be easily evaluated in terms of availability, development, chemical quality, and economies of recovery (AIPG, 1985). However, modern information and hydrogeologic understanding along with improved analytical capability (both in modelling and chemical analyses) have made it easier to understand and plan protection measures again polluting activities.

Ground water is extremely important to the economy of Kansas. The water needs of about 63 percent of the State's population are provided by ground water (Jordan, 1987). Western Kansas has little surface water available in most areas; consequently, over time considerably more ground water is withdrawn than is recharged. Kansas was fifth in the nation in 1980 in relative production of ground water (in 10^6 gals/day). For all these major reasons and more, prevention of ground-water contamination from waste-disposal activities of any and all kinds should be the desired approach rather than depending on later cures and remediation.

The principal pollution sources of ground water in the U.S., in order, are given below. All are applicable in Kansas.

1. Industrial wastes
2. Municipal wastes
3. Agricultural chemicals
4. Septic systems-cesspool effluents
5. Leaking underground pipelines and flow
6. Animal waste
7. Acid mine drainage
8. Oil-field brines
9. Salt-water intrusion
10. Irrigation and storage tanks return

When precipitation is coupled with run-off, water saturates waste-disposal sites (landfills, sewage sludge, etc.), which in turn leads to chemical interaction with the wastes and finally to the generation of leachates. The chemistry of leachates is complex, but leachates cause the most problems. They can, and do, flow from the disposal sites in which they are generated into rivers, streams, and any underlying ground-water systems near the site. I take the position that all sanitary landfills will eventually be breached.

As a consequence, we badly need data in the vicinity of known and projected disposal sites, including information on the geologic interactions that can and do occur and on the relation of these sites to local drainage basins, the flow lines of local ground-water systems, and the potentiometric surface. A large amount of information is required to define properly the interaction of waste-disposal, geology, and the local environment.

The information required to make a proper analysis for water problems is given in Table 6. Those items of particular geologic importance are starred. Only those items listed under prediction and optimization analysis do not have a direct geological input. Even there, environmental factors have an element of geology involved.

The generation of leachate from a landfill is a complex process, depending not only on the characteristics of the landfilled wastes, but also on the (1) interaction of the waste with water percolating through the landfill, (2) operational variables such as waste placement in the landfill, (3) climatic conditions, (4) landfill design, and (5) potential for interaction of landfill waste and leachate with ground water. Leachate characteristics and the rate of leachate generation, however, are also dependent on the time and stage of landfill stabilization.

Geology plays a critical part in site selection for disposal on land. Key geologic factors that should be considered are often ignored or downgraded for economic or engineering reasons. Knowledge of topography, surface-water flow, flood potential, volume, chemistry, soils, local geology, ground-water flow and rate, slope characteristics of site, erosion, and slumping potential are of critical importance as landfilling is commonly limited to areas with a slope greater than 1 percent but less than 20 percent (Sittig, 1979). Relevant soil and vadose zone properties that are important and need evaluation are texture, structure, cover (soil) depth and quantity, permeability/transmissivity, pH, and cation-exchange capacity (CEC). Close attention must be paid to the permeability classes present in each area--from very rapid ($>1.4 \times 10^{-2}$ cm/sec) to very slow ($<4.2 \times 10^{-5}$ cm/s). Such data can be used to predict the time of site saturations and, when properly weighed, can be used as part of a system for disposal site selection (Angino and Jayaprakash, 1978).

We should be able to model the process of leachate generation from a municipal solid-waste landfill. Present models (so-called "wash-out models") are good or are used for mature landfills. We badly need models to predict products (leachate chemistry, volume, and rate) formed early in the life of a landfill. Early-life models are very important as the highest leachate strength (most contaminating solutions) tends to occur early; furthermore, the most severe conditions affecting the surrounding geology and environment are generated early.

Contamination of ground water from refuse leaching can occur: (1) when the landfill is located adjacent to or over an aquifer, (2) when a leachate is produced and it enters the aquifer, and (3) when a landfill is supersaturated with respect to soil moisture in comparison to the surrounding area. The overriding key to understanding what will happen is the hydrogeology of the site. As landfills have become more widely used, they are now likely to be the major or only means available for waste disposal and hence are most likely to contaminate local surface- or ground-water resources.

At different times and places and under proper circumstances, land-based disposal of solvents and solvent-contaminated wastes will be necessary. For every solid waste contaminated by solvents, there exists a concentration of solvents that is sufficiently low to allow disposal of waste in landfills without endangering human health or the environment (EIWMS, 1985). Preferentially, adoption of technology to reuse, recycle, destroy, detoxify, and minimize generation of hazardous waste is recommended. It must be recognized, however, that the ultimate disposal of solid wastes is to land and that solvent-bearing solid wastes will be generated and must be disposed of.

To handle solvent wastes intelligently, detailed hydrogeologic criteria are needed for site selection. It is necessary to know the local relationship between stratigraphy, lithology, geologic structure, fracture patterns (jointing), geomorphology, and ground-water and surface-water hydrology. Are there fractures in the underlying bedrock of the proposed site, what is the permeability of these units to any leachates generated, what is the depth to the water table beneath the disposal site and in the general vicinity? Additionally it is critical to know the ground-water travel time (flow velocity) from beneath the site to the nearest surface-water-body draining the area or to any aquifers in the area.

More specifically, one must fully characterize the ground-water hydrology and geochemistry of the waste site. The following characteristics should be established: hydraulic conductivity, porosity, permeability, transmissivity, density, leakance, potential for chemical adsorption, and attenuation by geologic materials. All these parameters need to be evaluated along with the quality and quantity of ground water in the area of the disposal site as well as the horizontal and vertical components of ground-water movement.

Further research needs to be done on the geochemistry and characteristics of leachates and hazardous chemicals in both the saturated and unsaturated zones, specifically the geochemistry of organic solvents in sand, shale, limestone, and clay materials.

Modelling studies on the fate of leachates and solvents in landfills and the saturated zone are needed, especially verification studies. The advection dispersion (A-D) model is the most widely used contaminant-transport model. The validity of the model has been established under laboratory conditions of constant-velocity and constant-dispersion coefficients. Verification of these models under real world, field conditions has been limited. Too many times existing models do not predict "real conditions" very accurately; consequently, field verification is a critical need.

We also should reexamine the specific conditions responsible for oil and gas entrapment in nature. As geologists we know that fluids such as oil and gas have been contained in geologic units for many millions of years at many locations. Examination of the geology of these occurrences can provide knowledge of those conditions prevalent where hydrocarbons have escaped to earth's surface and those locations where fluids were contained for long periods (tens of thousands or millions of years). These conditions hold the key to assuring the public of our ability to contain hydrocarbon wastes for much shorter times. The key is to compare and study these conditions to ascertain the ones that are controlling, such as permeability, pressure head, geology, etc.

Further detailed examination is needed of the factors controlling movement of pollutants in both the vadose zone and ground water. Contaminants move in aquifers by two predominant mechanisms: advection and hydrodynamic dispersion.

Hydrodynamic dispersion results in spreading the zone of contamination along the flow path of the ground water and leads to a reduction of contaminant concentration. In the worst case, it can spread a very toxic compound over a very wide area. What are some of the geochemical factors that control the mobility of these contaminants in ground water? As noted earlier these tend to be chemical speciation, oxidation-reduction potential, adsorption and adsorption reactions, ion exchange (controlled by clays dominantly) and chemical removal caused by Fe-Mn oxide coatings. What are the interactions of these parameters with the ground water? Naturally we want to have low-permeability materials with no aquifers below. This is, of course, usually a pipe dream.

Sewage Sludge

Repeated applications, for example, of metal-containing sewage sludge can have a drastic effect on soil levels of selected trace elements (such as cadmium, lead, and selenium), and lead to serious toxicity effects on plants. As Purvis (1988) states, "the land can even be made sterile." The process of contamination tends to be persistent. One cannot rely on leaching by rain water to restore metal-polluted soils to their original state because the exact cause of the metal immobilization is uncertain. Clearly some trace elements are adsorbed into clay-mineral lattices, some are absorbed onto clay surfaces, and some immobilized as refractory oxides. But what reactions are really going on? What are the oxidation-reduction reactions controlling these processes and what is the part played by organic matter? We simply do not know.

To make studies of this type useful in Kansas, we should examine the specific geochemical reactions controlled by major soil types in the vicinity of our larger cities where future wastes will have to be disposed of. Instrumentation and study of these reactions around existing landfills across the state is needed if we are to be able to predict or anticipate future problems around these landfills or in some future ones. Knowledge of "site specific" reactions is critical.

Composting

Composting, as a means of handling municipal wastes, is at present a popular alternative. At least 65 to 70 percent of the typical municipal solid-waste stream is compostable (Epstein and Williams, 1988). However, compost has minimal value as a fertilizer. Of real concern is the fact that trace levels of toxic heavy metals and toxic organics can be found in solid-waste composts. Interaction of these metals and organics with soil, rocks, and minerals is likely to occur and better geochemical knowledge of the reactions is essential if the technique is to have wide applicability and potential for Kansas Very likely it will, given the character of our wastes and our regional geology.

A trial composting-operation is currently underway in Dodge City (Epstein and Williams, 1988), and it is critical to examine in more detail the potential and actual geologic effects, if any, on the local ground-water system and on local geology. The Dodge City operation can, in fact, be extremely important as an example to the State in handling its waste-disposal problem. It should be incorporated into a detailed monitoring and testing scheme to evaluate effects on the geology and ground-water chemistry in the area in so far as possible. What are the geochemical reactions occurring between the composted material and vadose water, ground water, and local geology, etc.? What are the effects of this material on infiltration, surface and vadose zone permeability and porosity, and on water chemistry in general? What elements are leached most easily from the composted material? Clearly, there are both laboratory and field work studies that should be evaluated at an operating site. Studies of this type are critical as composting is clearly one of the popular paths to take in disposing of municipal wastes.

Modelling

One of the more important gaps in understanding the interaction between wastes and the geologic environment is our inability to evaluate a site's vulnerability to contamination in advance. We need an improved, practicable, and usable numerical rating-scheme for a site's acceptability as a disposal site. It is in this area that modelling can make a meaningful contribution to a preliminary understanding of what can happen after dumping. Aller et al. (1985) proposed setting up a numerical rating scheme, based on a model called DRASTIC. The letters stand for:

D = Depth to ground water
R = Recharge rate
A = Aquifer media
S = Soil media
T = Topography
I = Impact of vadose zone
C = Conductivity of aquifer

The DRASTIC model takes all these geologic parameters into consideration based on the information provided for each. It then assigns a combination of weights and a rating to each. Clearly, the limiting factor in its accuracy is the quality of the data provided for each parameter.

Two more simple models were proposed to the State of Kansas by Angino and Jayaprakash (1978) and Flores and Angino (1978) in the KDHE 208 study titled, "Water Quality Effects Associated with Residual Waste Planning." A fundamental problem limiting the usefulness of complex simulation models is how chemical processes that occur at the interstitial level of porous media are represented on a field scale. According to NAS, (1987) insufficient field data are available on the behavior of most chemicals in geologic media to test the available simulation models properly. The major problem is a lack of knowledge of what really happens in the vadose zone and in ground-water systems themselves. The subsurface ground-water environment is highly complex when compared to surface waters. For example, media-specific criteria for many contaminants are completely lacking; moreover, in many models multiple contaminants are commonly treated as having effects that are additive rather than multiplicative.

None of the methods available addresses the issue of quality control of the techniques (solute-transport models) used to estimate contaminant transport or movement. Furthermore, as noted in NAS, 1987, p. 140, "There is no model that will adequately describe all ground water quality problems because the assumptions and simplifications generally associated with models do not adequately mimic all the processes that influence the movement and behavior of the water and/or the chemicals of interest." This concern is primarily directed toward models for predicting movement and fate of chemicals in ground water. As noted, "..this is especially true for those cases in which water miscible organic solvents may enhance the mobility of selected organic chemicals in which immiscible solvents exist and in which chemical movement occurs in fractured rock and well structured soils."

Ground-water modelling is a valuable tool that aids site selection, conceptualization, and the evaluation of various remedial alternatives. Modelling *ground water flow* is generally performed with confidence. Unfortunately, as noted above, that confidence is not justified when models are applied to organic transport. Having made these comments, what conclusions of geologic interest can we draw from them?

The first and most important is what can be called "site truth." Many modelers have got to get out of the computer room and go back to the field in an attempt to relate some of the models to reality. They need to become better informed about field parameters around and within a site and how site-specific and chemical-specific data can interact.

As noted, the mechanics and a physical-chemical understanding of solute-transport data are two-pronged. They are site specific (hydrologic units, porosity, intrinsic permeability, hydrodynamic dispersion, etc.) and chemical specific (solubility, wettability, volatilization, biodegradability, chemical- water interaction, etc.) We need to enhance our understanding of these and other related parameters to improve the predictive capacities of existing models before we develop new ones.

It is important to repeat the quotation (NAS, 1987) made earlier - "There is no model that will accurately describe all ground water quality problems because the assumptions and simplifications generally associated with models do not accurately mimic all processes that influence movement and behavior of water and/or the chemicals of interest."

Surface Water

We have not discussed the pollution-potential to surface-water resources in the state. The potential exists, of course, but the greatest danger is to ground water. The geological aspects are the same in both instances. What is needed is an accurate count and a location map of all dumps and sanitary landfills--old and unused as well as operating. All public-water-supply intakes, rivers, etc. should be indicated on location maps. We would then be in a position to see immediately the relation between water quality and possible sources of pollution and hence be in a position to anticipate possible trouble spots or areas. Comparing these maps with watershed maps, we could see potential pollution situations and perhaps head them off.

As we continue to express concern about the EPA list of toxic inorganics and organics, we must analyze selected river waters and water supplies for those trace elements and compounds of concern to ascertain whether they may be of natural origin. Among these are PO_4, NO_3, and Se. We need to be especially alert to those elements or compounds that have increased solubility at pHs above 7. Given the geology of Kansas, an interest in reactions occurring at a pH range of 7-9 should be of concern. Detection of surface-water contamination is in many ways easier than ground water. A spill is easy to see; it is visible and its movement to a small creek, stream, or river is noticed. Ground-water contamination is not nearly so apparent.

For surface water, we also need a better understanding of the mineralogical composition of the suspended load in a given stream. The greatest control on the chemistry of surface water is the relative clay-mineral content of the suspended material. The ratio of montmorillonite to kaolinite or other clay minerals is critical.

We need to understand better the geochemical reactions possible between organic and inorganic compounds in solution and the suspended load. These reactions are controlled by several factors. Among the most critical are water pH, mineralogy of suspended load, size fractions, COD, BOD, temperature, dissolved-O_2 content, percent organic material, and the oxygen-reaeration coefficient under various levels of flow. A tabulation and assessment of these values for any stream or river in the state used as a source of drinking water would advance our understanding of the meaning of the levels of many of the compounds for which analyses are now required under the 1986 amendments to Safe Drinking Water Act of 1974.

For the major fresh-water aquifers of the state, it is essential to know the recharge rate, the volume of recharge, and the location of any surface or shallow dumps or landfills in the recharge area. Surface water, either by bank seepage from rivers or percolation of surface water through the vadose zone in the recharge area, can contribute to the degradation of ground water. The latter activity is a serious possibility in the High Plains areas overlying the Ogallala aquifer, especially if ponding occurred at some disposal sites. Such contamination by recharge is also possible in river valleys or along valley walls of a valley aquifer.

A review of the literature suggests two possible major sources of surface-water contamination in Kansas are feed lots of all sizes (they can contribute to an increase of Cl and NO_3 in surface and/or ground water and overuse or improper use of agricultural chemicals). Some contamination of surface and ground water from both of these sources has occurred in the past and the potential exists for future contamination. In my view maps showing the location of all feed lots or all potential areas of contamination would help pinpoint possible sources of future problems. Soil maps showing agricultural areas with particularly sandy or porous soils overlying zones of any major ground-water aquifer could help in pinpointing areas of particular concern. Other similar examples could be given. The key of course, is to know the location of all sites of potential contamination, and to compare these areas to the known geology (soil types, rock types, jointing pattern, fracture pattern, geomorphology, slope maps, etc.). Having this type of information for the general area surrounding the major cities and towns of each county or regional area of the state is essential if future disposal of waste is not to impact surface or ground water near populated areas.

Lastly, (as controversial as it may be) from a scientific sense it is important to know what areas of the state are best suited geologically to contain any crucial waste for which disposal is critical. It is appropriate that those areas with the proper hydrology, geologic conditions (such as salt beds), and other characteristics be located now and properly investigated as a prelude to future disposal problems before they arrive.

Conclusions

One of the overriding concerns of modern society is waste disposal - what to do with waste and how to manage it. The irreducible wastes of society have to go into the air, water, or ground. When the wastes are disposed of in the ground, they react in some way with the local geology (rocks, minerals, water, soil). Consequently, geological implications related to waste disposal and management exist and must be considered.

Most wastes (hazardous or not) come in contact with water at some point, unless specifically isolated in some fashion from the environment. For this reason, concern for the effect of waste on water quality is of considerable importance to a state such as Kansas. The geological implications of waste management are different for different environmental and geologic settings. To handle this problem it is essential to know and have several things. Key among these are:

1. The location of all known waste-disposal sites in the State, with some indication of the type of waste contained.
2. Information indicating the direction and rate of ground-water movement within all major drainage and sedimentary basins of the state.
3. Maps highlighting the above information, along with other maps indicating depth to the water table, location of water of specific quality and quantity, and areas of potential natural pollution.
4. A much improved data bank of the base or background levels of water quality in various aquifers and surface waters across the state.
5. An inventory of underground space (volume) available for disposal of hazardous waste (by rock type) in the state.
6. A much more detailed understanding of the geologic factors affecting waste disposal.
7. A detailed geologic and hydrogeologic understanding of the Ogallala, Dakota, and other major aquifers of the State.
8. A better understanding of the potential effects of sewage sludge and composting on ground- and surface-water quality.
9. Improved ground-water models that are meaningful and bear a reasonable resemblance to the actual physical and chemical states existing in those areas for which the models are prepared.
10. Lastly a more detailed understanding of those geological factors that can interact with wastes and affect the surface water quality of the state's streams and rivers.

The list of conclusions indicates there is much to be done and learned about the geologic implications of waste management in Kansas. The most important message indicated by this assessment is the one that says "let us get on with the task before it overwhelms us" and we are reduced to proposing patchwork solutions to difficult and critical waste and water problems. .

REFERENCES

Aller, L., Bennett, T., Lehr, J., and Petty, R., 1985, DRASTIC: A Standardized System for Evaluating Groundwater Pollution Potential Using Hydrogeologic Settings: Wash. D.C. EPA Office Research and Development.

American Institute Professional Geologists, 1984, Hazardous Waste--Issues and Answers 1984: AIPG, Arvada, Colo., 25 p.

American Institute Professional Geologists, 1985, Ground Water--Issues and Answers: AIPG, Arvada, Colo., 24 p.

Angino, E. E. and Jayaprakash, G., 1978, *in*: Ground Water Quality Effects Associated with Residual Waste Planning: "208" Report to the Kansas Dept. of Health and Environment, Chap. 3, 26 pp.

Bredehoeft, J. D. and Maini, T., 1981, Strategy for Radioactive Waste Disposal in Crystalline Rock: Science, v. 213, pp. 293-296.

Brookins, D. G., 1976, Shale as a repository for radioactive waste--the evidence from Oklahoma: Environmental Geology, v. 1, pp. 255-259.

Dealy, M. T., Kume, J., and Jenkins, E. D., 1984, Hydrogeology and Development of the Dakota Aquifer in Southwest Kansas *in*: Geohydrology of the Dakota Aquifer, ed. by D. G. Jorgensen and D. C. Signour: National Water Well Assoc., Worthington, Ohio, pp. 209-220.

Dragun, J., 1988, The Fate of Hazardous Materials in Soil, Parts 1, 2: Hazardous Materials Control. V. 1, pp. 31-78, Part I. V. 1, pp. 41-65, Part 2.

Environmental Institute for Waste Management Studies, 1985, Disposal of Solvents and Solvent-Contaminated Wastes to Land--a Position Paper: University of Alabama, Tuscaloosa, Alabama, 47 pp.

Epstein, E. and Williams, T., 1988, Solid Waste Composting Gains New Credence: Solid Waste and Power, v. 2, pp. 24-30.

Everett, L. G., Wilson, L. G., and Hoylman, E. W., 1984, Vadose Zone Monitoring for Hazardous Waste Sites: Noyes Data Corp., Park Ridge, New Jersey, 356 p.

Flores, R. and Angino, E. E., 1978, Predicting the Pollution Potential of Leachates from Hazardous Waste Sites on Ground Water Quality *in*: Ground Water Quality Effects Associated with Residual Water Planning: "208" Report to the Kansas Dept. Health and Environment. Chap. 6, 59 pp.

Francis, C. W. and Auerbach, S. I., 1983, Environment and Solid Wastes: Butterworths, Boston, 498 p.

Gordon, W. and Bloom, J., 1985, Limits to Underground Injection as a Hazardous Waste Disposal Method: Hazardous Waste and Hazardous Materials, v. 2, pp. 411-452.

Hounslow, A. W., 1983, Geochemistry and Subsurface Characterization Related to the Transport and Fate of Inorganic Contaminants *in*: Environment and Solid Wastes, C. W. Francis and S. I. Auerbach: Butterworth, London, pp. 149-160.

Jordan, P. R., 1987, National Water Summary--Kansas: U. S. Geol. Survey, WSP 2300, pp. 237-244.

Jorgensen, D. G. and Signor, D. C., 1984, Geohydrology of the Dakota Aquifer: National Water Well Association, Worthington, Ohio, 247 p.

Kehew, A. E., 1988, General Geology for Engineers: Prentice-Hall, Englewood Cliffs, New Jersey, p. 292.

Krag, B. L., 1985, Hazardous Wastes and their Management: Hazardous Waste and Hazardous Materials, v. 2, pp. 251-308.

Leonard, R. B., Signor, D. C., Jorgensen, D. G., and Helgesen, J. O., 1984, Geohydrology and Hydrochemistry of the Dakota Aquifer, Central United States *in*: Geohydrology of the Dakota Aquifer, Ed. by D. G. Jorgensen and D. C. Signour: National Water Well Assoc., Worthington, Ohio, pp. 229-237.

Lessing, P., 1980, Guideline for Geological Investigations of Hazardous Waste Disposal Sites: West Virg. Geol and Econ. Survey, Circular C-17, 8 pp.

Logan, T. J. and Miller, R. H., 1983, Responsible Long-Term Use of Agricultural and Urban Land for Solid Waste-Disposal, Chp. 21 *in*: Environment and Solid Wastes, C. W. Francis and S. I. Auerbach Eds: Butterworth, Boston.

Mankin, C. J., 1982, "Appendix D: Geological Considerations of Deep Well Injection of Liquid Industrial Wastes." Geological Aspects of Industrial Waste Disposal, Summary of a Workshop: U.S. Nat. Res. Council, Wash. DC.

Matheson, M. C. and Cadwallader, M. W., 1988, Geomembranes for Municipal Solid Waste Landfills: Public Works v. 119, pp 80-81.

McGovern, H. E., 1984, Overview of Dakota Aquifer in Kansas *in* Geohydrology of the Dakota Aquifer, Ed. by D. G. Jorgensen and D. C. Signour: National Water Well Assoc., Worthington, Ohio, pp. 58-61.

Melloan, G., 1988, Waste Disposal and the "Environmental Evangelists": Wall Street Jour., July 26, 1988, p. 27.

National Academy of Science, 1983, Management of Hazardous Industrial Wastes, Research and Development Needs: National Academy Press, Washington, D.C., 76 p.

__________, 1986a, Ground Water Quality Protection - State and Local Strategies: National Academy Press, Washington, D. C., 309 p.

__________,1986b, Pesticides and Ground Water Quality: National Academy Press, Washington, D. C., 124 p.

__________, 1987, National Water Monitoring and Assessment: National Academy Press, Washington, D. C., 110 p.

__________, 1988, Hazardous Waste Site Management: Water Quality Issues: National Academy Press, Washington, D. C., 212 p.

Purvis, D., 1986, Long-term Effects of Application of Sewage Sludge to Soil on Composition of Herbage with Respect to Potentially Toxic Elements: Environ. Geochem. and Health, v. 8, pp 11-13.

Reed, S. C. and Crites, R. W., 1984, Handbook of Land Treatment Systems for Industrial and Municipal Wastes: Noyes Data Corp. Park Ridge, New Jersey, 427 p.

Reppert, R. S. and Lessig, P., 1971, Sanitary Landfill Sites in Southwestern West Virginia: West Virg. Geol. and Econ. Survey, Env. Geol. Bull. No. 3, 15 p.

Roberts, P. V., McCarty, P. L., Reinhard, M., and Schreiner, J., 1980, Organic-contaminant behavior during ground water recharge: JWPCF, v. 52, pp. 161-172.

Robertson, J. M., Toussaint, C. R., and Josque, M. A., 1974, Organic compounds entering ground water from a landfill: EPA-660/2-74-077, U.S. Environmental Protection Agency.

Sanks, R. L. and Asano, T., 1976, Land Treatment and Disposal of Municipal and Industrial Wastewater, D. L. Warner *in*: Hydrogeological Aspects of Land Application of Wastewater: Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan, pp. 133-146.

Shiraji, M. A., Peterson, S. A., Lowrie, L., and Hart J. W., 1986, Computer Based Land Classification for Management of Hazardous Waste: Hazardous Waste and Hazardous Materials, v. 3, pp. 77-100.

Sittig, M., 1979, Landfill Disposal of Hazardous Wastes and Sludges: Noyes Data Corp. Park Ridge, New Jersey, 365 p.

Vogl, E. G. and Angino, E. E., 1985, Chemical Effects of Selected Trace Metals from Landfill Leachates on Ground Water Quality: Hazardous Waste and Hazardous Materials, v. 2, pp. 159-175.

Warner, D. L. and Lehr, J. H., 1977, An Introduction to the Technology of Subsurface Wastewater Injection: EPA/600/Z-77-240, pp. 293-295.

Williams, N. D., Pohland, F. G., McGowan, K. C., and Saunders, F. M., 1987, Simulation of Leachate Generation from Municipal Solid Waste; Project Summary: EPA/600/S2-87/059, 4 p.

U.S. Army Corps of Engineers, 1979, Survey of Solidification/Stabilization Technology for Hazardous Industrial Wastes: Report No. EPA-600/2-79-056, Vicksburg, Miss.

U. S. Water News, 1988, Halstead, Kansas, Feb., p. 7.

TABLE 1

A Partial List of General Types of Solid Waste

1. Municipal solid waste (trash, glass, paper, food wastes, etc.)
2. Sewage sludge
3. Sludge from water treatment facilities
4. Industrial wastes
    a. Liquid and solid
    b. Hazardous and non-hazardous
5. Fly ash primarily from coal-fired power plants
6. Incineration ash
7. Low and high-level radioactive waste
8. Hospital and infectious wastes

TABLE 2

Organic Solvents in Household Cleaning Products
(Taken from Survey by Matheson, Michael C. and Cadwallender, Mark W. (1988), Geomembranes for Municipal Solid Waste Landfills, p. 80-81. Public works, v. 119, no. 6 (May).

Solvent	Product(s)
Orthodichlorobenzene	Drain degreaser
Paradichlorobenzene	Drain degreaser
Toilet bowl deodorizer	
1,1,1 Trichloroethane	Septic tank drain field cleaner
Drain opener	
Oven cleaner (aerosol)	
Cleaning fluid	
Furniture polish	
Trichloroethylene	Cleaning fluid
Perchloroethylene	Laundry degreaser
Home and auto parts cleaner	
"Aliphatic, aromatic"	Septic tank drain field cleaner
Laundry degreaser	
Cleaning fluid	
Engine degreaser	
Car wash	
"Petroleum distillates"	Septic tank drain field cleaner
Drain opener	
Oil and grease dissolver	
Garage degreaser	
Cleaning fluid	
Engine degreaser	
Spray cleaner	
Floor cleaner	
Furniture polish	
Spot remover	
Methylene chloride	Oven cleaner
Graffiti remover	
Brush cleaner	
"Harmful organics"	Floor stripper and cleaner
"Chlorinated solvents"	Laundry degreaser

TABLE 3

Major Geologic Criteria Effecting Waste Disposal
modified from Lessing (1980)

1. Bedrock Units
    a. Rock type (lithological and formation).
    b. Age and correlation with recognized formations.
    c. Dimensional characteristics, such as thickness and extent.
    d. Distribution and surface expression of bedrock units.
    e. Physical and chemical characteristics.
    f. Distribution and extent of the weathered zone.
    g. Response of bedrock materials to natural processes.
    h. Geohydrology of the bedrock units.

2. Surficial Deposits
    a. Regional and local setting.
    b. Identification of material types.
    c. Dimensional characteristics, such as thickness and extent.
    d. Surface expression and relation to present topography.
    e. Physical and chemical characteristics
    f. Distribution and extent of altered zones.
    g. Response of surficial materials to natural processes.
    h. Geohydrology of the surficial units.

3. Structural Features of Bedrock and Surficial Units
    a. Occurrence, location, and distribution.
    b. Dimensional characteristics
    c. Orientation and changes in orientation.
    d. Special effects of the bedrock.
    e. Local seismo-tectonic environment (seismic history).
    f. Faults (location, magnitude, association with fault systems, etc.).
    g. Fracture and joint systems.
    h. Solution features.
    i. Active and abandoned quarry and mine locations.
    j. Subsidence features and potential for future subsidence.

4. Surface Drainage
    a. Distribution and occurrence.
    b. Relations to local topography (drainage density and flood plains).
    c. Relations to geological features.
    d. Source and permanence.
    e. Variations in amounts of flows (discharge).
    f. Evidence of earlier occurrence of water at localities now dry.
    g. Estimated flood peaks and flows (including probable maximum flood or 100-year flood.
    h. Water quality, constant or variable.
    i. Use of surface waters.

5. Ground Water
    a. Distribution and occurrence (confined and unconfined).
    b. Hydraulic gradients (flow directions and rates).
    c. Recharge and discharge areas for aquifers.
    d. Relations to topography.
    e. Relations to geological units and structure.
    f. Seasonal variations.
    g. Water quality.
    h. Use of ground water, location and number of wells.
    i. Water-table elevation, including perched water tables.
    j. Water-well yield, drawdown, specific capacity, depth, pumping rates, etc.

6. Features of Special Significance
    a. Accelerated erosion and/or deposition in vicinity.
    b. Subsidence or settlement (including hydrocompaction and piping).
    c. Soil creep.
    d. Slump and slide masses in bedrock and surficial deposits.
    e. Deposits related to geologically recent flooding.
    f. Rockfall areas.
    g. Subsidence over or near underground mines, quarries, or naturally created voids.
    h. Seismic hazards.
    i. Expansive solid and rock properties.
    j. Porosity and especially permeability of all units.
    k. Geomorphic processes.
    l. Potential mineral resources and past and present mining activities.
    m. Nature, amount, and availability of cover material.

7. Geochemistry
    a. Detailed mineralogical, physical, and chemical studies of selected clay minerals to determine their suitability for or compatibility with various pollutants (organic and/or inorganic).
    b. Determine the chemical-physical relations between the clay minerals and the specific wastes to be disposed of by conducting laboratory studies coupled with in-situ observations. Physical and chemical parameters to consider include pH, Eh, ion-exchange capacities, precipitation products, ionic strength of solutions for both the clay minerals and the types of pollutant.
    c. Conduct frequent field inspections, such as soil sampling, to ensure maintenance of a closed system between the waste-disposal site and the surrounding area, and to verify any assumptions and interpretations in the original suitability studies.

8. Soils
    a. Clay type.
    b. Sand-clay ratio.
    c. Organic-matter content.
    d. Soil type (classification).
    e. Soil pH.
    f. Ion exchange reactions possible.

TABLE 4

Necessary Site Characteristics for Deep Well Injection

1. The geologic/hydrologic environment.
2. Structural geology.
3. The physical and chemical properties of the formation rocks, and
4. The chemical characteristics of the subsurface fluids.

If these parameters can be reasonably determined, a potential injection formation must then be evaluated for suitability. A suitable formation meets the following criteria

1. It should have no value as a resource - for example, as a source of drinking water, hydrocarbons, or geothermal energy;
2. It must have sufficient porosity and volume to accept the anticipated volume of liquids;
3. It should be sealed above and below by formations with sufficient strength, thickness and low permeability to prevent migration of the waste from the disposal zone; and
4. It should be located in an area with little seismic activity, to minimize both the risk of earthquake damage to the well and the triggering of seismic events.
5. It should be compatible with the wastes to be injected to prevent any adverse impact to the containment zone that would allow wastes to escape.

TABLE 5

Processes of Rock-Water Interaction

1. The water dissolves certain of the solid constituents that move into the ground-water system. Under normal conditions, this process determines ground-water quality.

2. Insoluble materials such as clay and colloidal sesquioxides may be formed by the chemical alteration of existing minerals. This process characteristically occurs in but is not necessarily restricted to the soil. These secondary materials often have high sorptive capacities and greatly influence the movement of pollutants in the subsurface.

3. Materials may be removed from the aqueous phase by several processes. If the water is saturated with a particular component, or if the geochemical environment changes, new minerals may be precipitated in the pore spaces of the existing rock, soil, or sediment. Another process involves the sorption of inorganic ions or dissolved organic matter onto an existing solid phase. If this is an ion-exchange reaction, other ions will be released to the liquid phase.

4. Materials may be added to the liquid phase by desorption reactions. These reactions will often occur when a geochemical barrier is breached. In addition to determining the degree of sorption that occurs, the geochemical parameters determine, to a large extent, the stability of the sorbent itself.

(From Hounslow, 1983)

TABLE 6

Information Required for Ground-Water Problem Analysis and Decision-Making

* Hydrogeologic maps showing extent and boundaries of all aquifers and non-water-bearing rocks.
* Topographic map showing surface-water bodies and landforms.
* Water-table, bedrock-configuration, and saturated-thickness maps.
* Transmissivity maps showing aquifers and boundaries.
* Relation of saturated thickness to transmissivity.
* Hydraulic connection of streams to aquifers.
* Type and extent of recharge areas (irrigated areas, recharge basins, recharge wells, natural recharge areas).
* Surface-water diversions.
* Ground-water pumpage (distribution in time and space).
* Precipitation.
* Areal distribution of water quality in aquifer.
* Streamflow quality (distribution in time and space).
* Geochemical and hydraulic relations of rocks, natural water, and artificially introduced water or waste liquids.
* Water-level-change maps and hydrographs.
* Streamflow, including gain and loss measurements.
* History of pumping rates and distribution of pumpage.

Economic information on water supply and demand.
Legal and administrative rules.
Environmental factors.
Other social considerations