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Effects From Past Solid Waste Disposal Practices

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This paper reviews documented environmental effects experience from the disposal of solid waste materials in the U. S. Selected case histories are discussed that illustrate waste migration and its actual or potential effects on human or environmental health. Principal conclusions resulting from this review were: solid waste materials do migrate beyond the geometric confines of the initial placement location; environmental effects have been experienced from disposal of municipal, agricultural, and toxic chemical wastes; and utilization of presently known science and engineering principles in siting and operating solid waste disposal facilities would make a significant improvement in the containment capability of shallow land disposal facilities.

Introduction and History

The objective of this paper is to review what has been learned by past migration and environmental effects experience in solid waste management. In constructing a brief history in 1976 of solid waste management, Wilson (*1*) concluded that no extensive history exists on this subject, that there is no tradition of scholarly research into solid waste treatment, and that only occasional articles provide documented insight into solid waste disposal experience. The need for collecting the existing documented experience to help develop land burial technology for solid wastes has never been greater.

Disposal methods for solid waste range from simple surface storage near the point of generation to systematic packaging, collection, transport, and placement in subsurface facilities. The need to deal with waste materials has been recognized for millenia, as is indicated by Biblical waste burial specifications (Deuteronomy 23:12-13). Over the ages, refuse piles have been of economic interest for such things as the presence of salt peter used in munitions manufacture, as materials for brickmaking, as soil amendments to enhance crop production, etc. (*1*, *2*). Analyses of waste disposal areas also yield reconstructed history via archaeological investigations.

Many of the principles and methods employed today in the field of solid waste management are not new but remain the same as at the turn of the century and earlier (*3*). The idea of organized collection and disposal is relatively new, beginning in the mid-nineteenth century. Bacteriological and epidemiological studies revealed that refuse dumped in city streets was the primary source of the plagues and epidemics which swept countries and continents. This finding resulted in the development of municipal refuse disposal schemes and operational practices, many of which persist to our time.

Before the 1900's, solid wastes were usually placed in open pits where they were frequently burned. Today, open dumping of solid wastes is still a common practice, especially in rural areas. Modern techniques for burying solid wastes have evolved and are known as "sanitary landfilling." A sanitary landfill is an engineered method of disposing of solid waste on land in a manner that protects the environment by spreading the waste in thin layers, compacting the layers, and covering them with soil. One of the first attempts to bury wastes by using techniques similar to what is now considered sanitary landfilling was made by the city of Champaign, Illinois, in 1904 (*4*). In 1930, the American Society of Civil Engineers published its first manual of practice for sanitary landfilling. Thus, the sanitary landfill, which is the cornerstone of modern burial practices, has been thought of as an environ-

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mentally sound means of refuse disposal for almost 50 years.

Despite the environmental advantages of sanitary landfilling over open dumping, and more than a half-century of experience with this disposal method, strict practice of sanitary landfilling is rare. In 1968, only 6% of municipal land disposal operations surveyed by the U. S. Public Health Service were considered adequate (5). This situation apparently had not improved much by 1976, when the U. S. EPA concluded: "... 90 percent of municipal and industrial solid wastes are disposed of on land in environmentally questionable ways. The results are potential public health problems, groundwater contamination by leachate, surface water pollution by runoff, air pollution from open burning, fires and explosions at dumps, and risks to ecological systems" (6).

Thus, while man has been burying solid wastes for thousands of years, technological advancements have been largely limited to development of sanitary landfilling in lieu of open dumping. The small percentage of landfills being operated in an environmentally sound manner suggests an emphasis on minimizing disposal costs rather than minimizing adverse environmental effects.

In 1969, 250,000,000 metric tons (250 Tg) of residential, commercial, and institutional solid waste were produced in the U. S. (1). If this waste has an average density of 300 kg/m^3, the annual quantity would fill 200 ha (2 km^2) of land to a height of 420 m. At present, there are approximately 18,500 disposal sites to handle this huge quantity of waste (6). Almost half our cities estimate that they will run out of known and available municipal waste disposal sites within a few years.

If wastes from mining and milling operations are ignored, an average of about 35 kg of solid waste per person per day were produced in the U. S. in 1970. The bulk of this waste is generated by the agricultural industry, although municipal and industrial wastes together amount to about 7 kg per person per day. Estimates for each waste type are shown in Table 1.

Table 1. U. S. production of solid wastes.

Waste type	Estimated rate of production,[a] kg/person/year
Agricultural	10,000
Municipal	1,300
Industrial	1,100
Nonradioactive hazardous	50
Low-level radioactive	<0.1

[a] Based on assumed population of 200 million (6–9).

Only about 4% as much hazardous industrial waste as municipal solid waste is produced. However, over 500 times as much hazardous industrial waste as low-level radioactive waste is produced. Production of hazardous industrial waste is expected to grow by more than 50% during the next decade (6). Pollution control residuals, e.g., flue gas desulfurization sludge, are expected to be produced at even faster rates.

Migration Experience and Effects at Solid Waste Disposal Locations

Well-documented case histories on the migration of disposed-of materials are limited. Those that are documented generally describe well-recognized environmental or public health damage. It is likely that there are many cases where migration has occurred but no highly visible damage has resulted. The converse is also likely true, that is, cases where disposal conditions have provided for containment. Very few of these latter experiences are to be found in the literature. A number of case histories have been selected to illustrate waste disposal site containment experience and effects.

Surface Disposal

As indicated earlier, surface accumulation of solid waste materials as a general practice has given way to subsurface disposal generally using sanitary landfill techniques. Notable exceptions to this trend are the mining and milling industries, where tailings are commonly piled on the surface. These piles are subject to wind and water redistribution limited only by natural or engineered stabilization systems.

Strip mining for coal or ore results in disturbed landscapes and accumulation of ash or process tailings. Surface ash disposal experience at large coal mining and utilization locations, such as the Four Corners Power Plant in New Mexico, has shown water and wind redistribution to be a readily observable phenomenon (10). Uranium mill tailings containing uranium series radionuclides and potentially toxic stable elements such as selenium, lead, cadmium, and molybdenum are mobilized by both air and surface water movement (11). Tailings have been used in constructing houses and other buildings. While both the surface-disposed coal ash and the mining and milling tailings are observed to migrate, no definite environmental or public health effects have been reported. The mere environmental presence of these materials is thought to be an undesirable effect by some.

Asbestos cement manufacturing waste piles are frequently located in high-density population areas (*12*). Approximately 1 million tons (900 Gg) of asbestos are used annually in the U. S. Asbestos cement products, such as pipe, wallboard, roof shingles, insulation, etc., account for 70% of the total usage. It has been estimated (*12*) that 5-10% of the material is dumped as scrap, of which 10% is fine dust and 90% coarse scrap. Substantial waste piles have grown over the years. The effect of such piles is difficult to assess, because of the 20-40 year latent period after the onset of exposure. Field tests at a plant in Denison, Texas, show that ambient levels of asbestos can be detected in the air for distances in excess of 10 km. A similar study (*13*) at Ambler, Pennsylvania, showed insignificant and infrequent asbestos emissions in the vicinity of the pile. This may be due to pile stabilization via vegetative cover.

Failure to cover materials placed at a disposal site can lead to problems such as the following two cases (*14*). In 1972, mercury-treated grain was found at the Wilson Creek dump in Grant County, Washington, by an unsuspecting farmer. He hauled it to his farm for livestock feed. The episode was discovered just before the farmer planned to utilize the grain. Three children in an Albuquerque, New Mexico, family became seriously ill, in 1970, after eating pork from a pig fed corn treated with a mercury compound. Local health officials found several bags of similarly treated corn in the community dump.

Subsurface Disposal

Theoretically, anytime the amount of water entering a burial area exceeds the field capacity of the deposited waste, leachate will be produced and discharged. Documented leachate plumes have developed around landfill operations in several parts of the country. In the following cases abandoned sand and gravel pits were occupied for municipal solid waste disposal. In 1933 at Sayville, Long Island, New York (*15*), waste was disposed from 6 m above grade to 9 m below grade. The groundwater table is located at a depth of 9 m. The leachate extends about 1.6 km down gradient, 50 m deep and up to 400 m in width contaminating about 4 million cubic meters of groundwater. Residential wells located in the contaminated zone were abandoned. A similar landfill at Rockford, Illinois (*16*), which was operated from 1946 to 1972, received municipal and industrial waste contaminated groundwater which flowed into a nearby river. Nine wells were contaminated and abandoned, including one for municipal water supply.

A municipal landfill at DuPage, Illinois, was operated from 1952 to 1966 (*17*). Waste was buried in trenches dug to a depth of 6 m at a site underlain by 3 to 6 m of sand overlying a 15 m thick layer of relatively impervious glacial clay, which in turn overlies dolomitic limestone that is a major aquifer in the area. The depth of the water table was initially 6 m. Piezometers installed through the disposal trenches and in the adjacent area indicate that with time, the groundwater level rose about 2 m above the base of the trenches. Leachate flows away from the trenches in all directions, although an estimated 90% of the flow is lateral through the upper layer of sand. Waste was buried at a distance from the creek varying between 12 to 800 m. Samples of groundwater recovered from the area indicate that pollutants have migrated 200 to 275 m down gradient from the site through the sand. Leachate has migrated only about 1.5 m downward into the glacial clay and has not affected the aquifer in the underlying bedrock. It was concluded that "apart from the springs along the side of the landfill, which could probably be considered no more than a local nuisance, this site has had little effect on the surrounding environment." Groundwater quality in the shallow sand has been degraded, but this water is not tapped by wells in the area. The 15 m thick stratum of glacial clay has been effective in preventing downward migration of leachate into the underlying major aquifer.

A landfill at Austin, Texas, has had its poor performance documented (*4*). The site was opened before 1960 and closed in 1968. Waste was dumped in trenches 10 to 15 m deep, compacted moderately, and covered with soil at infrequent intervals. Trenches penetrate through gravel and marl and into the top of limestone.

Since abandonment, subsidence of the waste has created depressions of the surface of the fill. Rainwater ponds in these depressions and eventually seeps through the refuse. Flow of leachate is mostly lateral beneath the surface zone. Leachate emerges on the banks of a nearby creek. Although water quality in the creek is poor near the disposal site, downstream dilution renders the pollution a local problem. The greatest public health hazard probably occurs when the initial surge of a flash flood flushes standing pools of leachate from the area.

The case of groundwater pollution from an old pesticide dump, whose existence was not known to those who constructed a well and used groundwater some 38 years after the waste had been buried, has been documented (*18*). After a grasshopper infestation in Perham, Minnesota, in 1934, was brought under control, about 25 kg of unused pesticide containing lead and arsenic mixed with bran, sawdust, and molasses was buried in a shallow trench at the county fairgrounds. In 1971, a small parcel of land adjacent to the old arsenic disposal site was sold to a local construction firm, which constructed a maintenance building and shallow water well on the site in 1972. Soon after the building was placed in operation, 13 employees were stricken with a malady later diagnosed (after several weeks of uncertainty) to be arsenic poisoning. Subsequent investigation revealed the source of arsenic to be the 1934 burial ground, which was located only 15 m from the water well. Two of the 13 stricken were hospitalized and could not work for several months (*19*).

Contamination of an aquifer by industrial wastes occurred when in March 1971, an independent waste hauler disposed of an unspecified number of drums of chemical wastes (*20*). These wastes were primarily organic wash solvents, still bottoms, and residues from the manufacture of organic chemicals, plastics, and resins. Most of the drums were buried on private land leased by the waste hauler. The hauler told the lessor that he was in the drum salvaging business and empty drums would be stored there to allow accumulation of a large enough load to haul to ultimate purchasers.

A few months later, the owner of the property began to notice unusual odors emanating from the leased property and upon inspection found that there were thousands of drums, some of which had leaked.

The quantity of waste that entered the underlying soil is not known. About 10% of the 5000 buried drums that were subsequently excavated had leaked all or part of their contents. Although the quantity of waste entering the soil was relatively small, it polluted nearby wells.

Early in 1974, some of the residents living in the area noticed taste and odor problems with their well water. Analyses showed that groundwater, at least in the immediate vicinity of the site, was contaminated with toxic organic chemicals. The county board of health then passed an ordinance forbidding use of well water within the contaminated zone, permanently condemning 148 private wells, and ordering that they be plugged with concrete.

Another industrial waste case history (*20*) resulted in a variety of environmental damages caused by disposal of large quantities of toxic industrial waste. The problem started when, in 1974, three dead cattle were discovered on the property and the cause of death was found to be cyanide poisoning. Subsequent investigation showed that a 2 ha (20,000 m^2) area, which is part of a large tract set aside for a nuclear power plant, had been used as a disposal site for large quantities of hazardous industrial waste for several years. Apparently, the new owners did not know that the property had been used to bury toxic wastes. After the three dead cattle were found, a consultant was hired to survey the damage. The consultant found substantial damage to stream bottom organisms, downstream aquatic life, birds, grasses, trees, shrubs, nearby soils, and groundwater. For example, 2.5 km east of the site, concentrations of cyanide in groundwater were found to be 365 ppm; the current allowable limit for drinking water is 0.2 ppm.

Efforts are ongoing to monitor the quality of ground and surface waters to determine the long-range nature of the problem. Neither the quantity of waste buried at the site nor the amount leached into ground and surface waters is known.

An accident involving build-up and subsequent explosion of gases from a municipal solid waste disposal site has been documented. The incident occurred on September 27, 1969, in the arms vault of the supply room at the North Carolina National Guard Armory in Winston-Salem, North Carolina (*20*). Of the 25 guardsmen that were injured from the explosion, 3 died and 7 were disabled either partially or totally.

The source of the problem was a nearby municipal waste landfill which was opened in 1949. The armory was constructed on grade, with no subsurface ventilation system, within 10 m of the waste disposal site. Soils beneath the area are sandy. Operation of the municipal solid waste disposal site, while perhaps not in strict accordance with current standards for sanitary landfills, was equivalent to or better than operation of its contemporaries.

Prior to the accident, there were several indications that a problem existed. In the summer of 1965, a welder working on part of a storm drainage system near the armory was burned slightly in a flash fire. In November of the same year, a fireman working near one of the street drains dropped a lighted match into a man hole and was burned slightly when gas in the sewer exploded. In December 1965, a flash fire occurred while downspouting was welded on the armory's roof drain system that was connected to an underground drainage system extending into the solid waste landfill. In 1966, an inspector found methane in the storm drains. Soon thereafter, a blower was installed to vent methane from the storm drains.

On September 26, 1969, the day before the explosion, officials investigated the occurrence of gas odors from the arms storage vault of the armory supply room. No source of gas, defective piping, or other causes were noted. Arrangements were made to have the fire department check the vault with portable gas detection equipment the following week. The explosion occurred the morning following the inspection.

Investigations following the explosion indicated that the explosion occurred when someone lit a match in the arms storage vault. Analyses of soils around and beneath the armory after the explosion indicated that gases were present at explosive concentrations. A sampling program verified that combustible gas from the landfill had migrated beneath the armory, presenting a continuous hazard of gas accumulation and explosion.

The U. S. EPA (*20*) documents environmental damage to cattle in about 250 km^2 in Louisiana, caused by burial of hexachlorobenzene (HCB), a persistent, water-soluble, fat-soluble organic compound present in some industrial wastes. Its long-term persistence allows volatilization to occur. Although not acutely toxic, continued low-dose exposure to HCB by ingestion or inhalation causes bioaccumulation and chronic damage to the liver and enzymatic functions.

In December 1972, a routine analysis of beef fat showed 1.5 ppm of HCB. Until that time, HCB was rarely found; the observed concentration of HCB exceeded the U. S. Department of Agriculture guideline of 0.3 ppm then in effect. Other cattle were then sampled and similarly high concentrations of HCB were found.

An investigation determined that HCB waste derived from the manufacture of perchloroethylene and carbon tetrachloride was being placed in landfills. Concentrations of HCB as high as 5000 ppm were found in soil at the disposal sites; it was later learned that HCB-contaminated wastes were being employed as cover because they were effective at keeping birds away.

The specific mechanism of bioaccumulation of HCB in cattle has not been determined. The most likely pathway was volatilization of HCB from wastes buried at shallow depth and subsequent bioaccumulation in cattle grazing in the area. Damages included destruction of 27 head of cattle.

In 1959, officials of Kane County, Illinois, requested the State of Illinois to evaluate a proposed landfill site in Aurora near the Fox River (*21*). The State Geological Survey advised against the use of the site, concluding that "pollution of presently used groundwater aquifers can occur from the proposed landfill" since the site has only a thin layer of soil over a creviced bedrock aquifer. The county in turn would not approve the site. Despite this opposition, the city purchased and annexed the land in 1961. The city used the site as an open dump from 1961 to late 1965. A trench was dug to bedrock and filled with waste. Runoff collected in the trench and saturated and leached the waste.

Within two months, unfiltered leachate migrated from the site and polluted seven residential wells between the landfill and the Fox River in exactly the manner predicted. The wells contained strong, black, odorous leachate and were totally unusable. The leachate damaged sinks, faucets, and other plumbing fixtures.

In another case an area located 24 km east of Denver, was declared surplus and given to Denver as a landfill site (*14*). As of July 1972, the site was accepting all but highly radioactive wastes and keeping only informal records of quantities delivered.

Short-lived radioactive wastes from a nearby medical school and a hospital are also accepted at this site. These wastes are apparently well protected but are dumped directly into the disposal ponds rather than being buried separately.

A complaint was received that some cattle had died as the result of ingesting material washed downstream from this site. Authorities felt that this occurred because of runoff caused by an overflow of the disposal ponds into a nearby creek after a heavy rainstorm. Laboratory tests indicated the presence of cyanide in water ponded downstream from the site. Significant amounts of cyanide were discharged into pits at the disposal site.

Radioactively contaminated solid wastes generated by the nuclear industry are handled primarily at five U. S. locations operated by government contractors and at six U. S. locations operated by commercial concerns licensed by the government (*22*). The migration of radionuclides in extremely low concentrations from some of these facilities has been the subject of considerable attention in recent years (*23, 24*). Although no environmental damage has been noted, a good deal of attention has been given the measurable presence of these materials beyond the confines of their original disposition. Due to the built-in radiation emission identifier, radionuclides are detected in environmental media at mass levels very much smaller than is possible for stable elements.

In comparing the containment records of municipal landfills, industrial chemical earthen burial facilities, and shallow land radioactive waste burial sites, some observers (*25, 26*) have noted that management of radioactively contaminated waste is neither unique nor unusual from a containment point of view.

Biological systems are capable of removing solid waste materials from one location to another. One example (*27*) is the jackrabbit, which was responsible for the dispersal of radioactive salts from radioactive waste disposal trenches on the Hanford Reservation in the state of Washington.

Generation of sludge containing high concentrations of removed pollutants from air and water discharge streams is increasing and will be a potential containment problem in solid waste management (*28*). Another area of increasing sludge distribution is the use of digested sewage sludge as a fertilizer and soil amendment (*29*). These solid wastes may carry metal toxicants and some virus burden. Land reclamation activities are apt to increase the attractiveness of using sludge. Proper waste management procedures to control the spread of unwanted materials will require development.

Observations

The case histories described in the preceding sections represent a selection of the published records of disposal site field performance. Undoubtedly, there are many uninvestigated and unpublished accounts of material movement at waste disposal sites, and many uninvestigated cases where there are no significant adverse environmental impacts to report. Based on this review, the following observations seem reasonable. There are few documented histories of good burial site field performance. This probably indicates a lack of investigation of sites where there has been no apparent environmental damage. Burial of municipal solid wastes in abandoned sand and gravel pits is a common practice. Pollution of groundwater or surface water is likely to result. In cases where a thick layer of relatively impervious clay separates the buried waste from an underlying aquifer, there is likely to be little, if any, short-term pollution of the aquifer. Toxic chemical wastes may pollute groundwater supplies, surface waters, and surface environs even though large quantities of waste do not migrate from the site. The waste may be so toxic and concentrated that relatively minor leaching can lead to problems. An old toxic waste fill, whose existence is unknown to a new property owner, may pollute groundwater that is used by the unsuspecting owner. Gases arising from decomposition of cellulosic solid waste can kill vegetation and pose an explosion hazard. Some toxic wastes are volatile. After they are buried, they may migrate through the soil and pollute groundwater, soil, vegetation, and grazing animals. Much of the environmental damage reported in these case histories resulted from lack of environmental engineering knowledge or application on the part of the waste disposers.

Conclusions

A range of opinions and conclusions may be found in the literature on the current status of solid waste management. Some of these are summarized below.

"Solid waste processing and disposal practices are grossly inadequate for today's needs" (*30*).

"Of the approximately 100 in-ground solid-waste disposal sites currently in operation in the Texas Coastal Zone, only 20 percent are geologically and hydrologically secure sites. Clearly, geologic and hydrologic criteria have not been used in the selection of most existing sites. The Texas Coastal Zone is not unique . . . immediate economic considerations outweigh fundamental hydrologic suitability in site selection" (*31*).

A survey made of cut and cover municipal landfills during 1968-69 showed that 59 percent had problems with fires, 9 percent polluted the groundwater, 17 percent had trouble with vermin, 37 percent had drainage problems, and 12 percent experienced gas, odor, or settlement problems (*32*).

"The nature and extent of hazardous waste treatment and disposal methods is based on economic rather than pollution control considerations" (*33*).

"The disposal of wastes on land is essentially unregulated except in the case of radioactive wastes" (*34*).

". . . of all the environmental problems plaguing our society, those associated with shallow subsurface waste disposal are relatively simple and could be solved inexpensively. Considering the number of such disposal facilities in existence, there have been relatively few documented cases of groundwater pollution, and those could probably have been avoided if present-day technology had been applied" (*35*).

"Many land disposal sites are leaching heavy metals, biological contaminants, and other pollutants into the groundwater, on which we are becoming increasingly dependent for drinking water. EPA studies show that thousands of acres of landfills containing municipal and industrial solid wastes are major potential sources of groundwater contamination, and that industrial storage and disposal lagoons, pits, and basins are leaking millions of gallons of potentially hazardous substances into the groundwater each year. Our concerns are compounded by the fact that subsurface migration is generally an extremely slow process. Thus, we may not yet know the long-term health, economic, and ecological consequences of the huge quantities of municipal and industrial solid wastes we have dumped upon the land in past decades" (*6*).

Some general conclusions regarding the experience and effects of solid waste management documented to 1977 include the following.

Material disposed of as solid waste can and does migrate beyond the geometric confines of the initial receiving area or volume. Principal mechanisms by which materials migrate are water and air movement and biological uptake.

Subsurface disposal generally reduces the rate and amount of material which enters the environment.

Although toxic wastes represent a small fraction of the total solid wastes generated and disposed of, the consequences of disregarding the potential for their migration has resulted in some environmental and health effects.

Even though experience has shown that, due to poor siting and operating practices, materials have been mobilized and have caused some environmental and health effects, the magnitude of these effects has been small, probably because of the capacity of the natural system to contain or sequester and to dilute migrating waste materials.

Radionuclides are not unique when compared with stable elements in regard to the potential for migration from a disposal site.

Utilization of existing science and engineering principles in siting and operating solid waste disposal facilities could make significant improvement in containing potentially toxic waste materials.

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