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GROUND WATER POLLUTION FROM SANITARY LANDFILLS AND REFUSE DUMP GROUDS

—A Critical Review—

By

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FOREWORD

In discussions on the degradation of our water resources and the entire problem of water pollution, primary attention is usually given to surface water bodies. This is to be expected since these waters are in closer proximity to the life activities of most people than the other major segment of fresh water resource, namely, ground water. Because ground water is normally not visible there is a tendency to minimize the likelihood that this body of water is also subject to pollution by the operations and activities of man. Greater concern about this situation will be forced upon water users in the future, since it is apparent that available surface supplies will be inadequate in many areas to meet future water needs.

Ground water can be polluted in numerous ways in spite of the protective mantle which nature has provided. Liquid pollutants can originate, for example, from waste water stabilization ponds, sludge lagoons, barn yard runoff, septic tank leaching fields or seepage pits, pit privies and the deep well disposal of certain industrial wastes or treatment plant effluents. Pollutants can also originate from the leachates of decomposing solid wastes as in the case of open dumps, sanitary landfills, solid waste composting sites, industrial refuse, and treatment plant sludges. In the first case the pollutants are already dissolved or conveyed by the liquid stream, whereas in the second case, sufficient water must pass through the decomposing mass to "leach-out" the pollutants and convey them to the ground water resource.

This report is concerned with the second case of potential ground water pollution, that is, from the operations of dumps, sanitary landfills, and other practices of the land disposal of solid wastes. The report first presents a critical review of the important literature covering the area of the ground water pollution potential from sanitary landfills and dump grounds. This is followed by a review of the practices in twenty-one states in the U.S. related to this same topic. Based on the information derived from these two sources, a series of recommendations are suggested to a "regulatory agency" concerned with the task of approving and licensing of solid waste disposal sites.

P A R T I

REVIEW OF LITERATURE DEALING WITH GROUND WATER POLLUTION POTENTIAL FROM SANITARY LANDFILLS AND DUMP GROUNDS

INTRODUCTION

The magnitude of the solid waste problem in this country was discussed recently by Vaughan (1) in his interpretation of the preliminary findings of the National Solid Wastes Survey. He stated that the average amount of solid waste collected in the U.S. is over 5.3 pounds per person per day, or more than 190 million tons per year. According to predictions these values will increase to 8 pounds per person per day and 340 million tons by the year 1980. The amount of waste actually generated is considerably more than this, amounting in 1967 to 10 pounds of household, commercial, and industrial wastes for every man, woman and child per day, totaling over 360 million tons per year. The current annual expenditure to handle and dispose of these wastes in this country is estimated at $4.5 billion per year.

How do we dispose of all this solid waste generated in the United States? According to the Report on the Committee on Public Works -- United States Senate, July 22, 1968, it is a well known fact that:

> Incineration and landfill are the two primary disposal practices employed by solid waste managers and city officials today. Incineration of solid wastes is a volume reduction technique which reduces the amount of municipal refuse by about 75 percent; however, the residue must still ultimately be disposed of by some other method.... Sanitary landfill, which prohibits burning and minimizes ground and surface water contamination, is the most desirable technique and is the most common alternative to incineration. Rising land costs and shortages of suitable sites in the many urban areas have restricted the use of this method,however.

What is meant by a sanitary landfill? An often-quoted definition from the American Society of Civil Engineers is:

> Sanitary landfill is a method of disposing of refuse on land without creating nuisances or hazards to public health or safety, by utilizing the principles of engineering to confine the refuse to the smallest practical area, to reduce it to the smallest practical volume, and to cover it with a layer of earth at the conclusion of each day's operation or at such more frequent intervals as may be necessary. (2)

Using the above definition it is apparent that there are many operations involving the land disposal of solid wastes which certainly do not come under the strict egis of a sanitary landfill. This fact has been substantiated by Klee (1) who analyzed the data obtained from the National Solid Wastes Survey on over 6,000 land disposal sites. Using the modest criteria that a sanitary landfill is one in which there is daily cover of refuse, no open burning, and no water pollution problem, he estimated that only 6 percent of the 6,000 can be reasonably characterized as "sanitary landfills".

In view of the above, the terms "sanitary landfill" or simply "landfill" are used in the very broadest sense for the purpose of this report. The primary concern in this discussion was what effect land disposal of refuse or solid wastes of any kind, either in the form of a true sanitary landfill or an open dump, has on the ground water quality in the vicinity of the operation. In many of the references reviewed it was not clearly stated that an actual sanitary landfill operation was involved. In some cases it was evident that nothing more than open surface dumping was being practiced. It was virtually impossible to keep a factual distinction throughout the course of this report so no attempt was made to do so.

This portion of the report presents a critical review of the important literature on the general topic of the ground water pollution potential attributed to the disposal on the ground of refuse or solid wastes. For convenience of presentation the information is subdivided according to the groups or states that appear to have conducted and are still conducting most of the research in this area.

California Studies

Since the early 1950's a great deal of work has been carried out in California on various aspects of ground water pollution resulting from the land disposal of refuse. There has been more activity in this state in this regard than any other state in the country. In fact, in any written material covering this topic reference is invariably made to the so-called "California Studies." Most of these studies were conducted under the auspices of the State Water Quality Control Board of the State of California.

One of the first studies, published in 1952, was concerned with the factors that might influence the rate of leaching of soluble salts and alkalies from incinerator ash dumps, and whether the leach was derived from precipitation falling on the dump and percolating down through it, or from an actual rise of the groundwater itself into the dump and subsequent lateral movement through it. (3) A field investigation was conducted at an ash dump adjacent to a municipal incinerator. A 48-inch hole drilled through a 12-foot ash layer was lined with a corrugated metal pipe containing lateral sampling ports at various heights. The total depth of the hole was 23 feet. A water sprinkling system was installed to generate a leachate through the fill. In addition laboratory leach column studies, percolation studies, and ion exchange studies were conducted to augment the field studies.

The minimum pounds of the various material leached per cubic yard from four different ashes investigated are shown in Table 1. The first ash results are from the field studies, whereas the remaining three are from the laboratory leach studies.

The report concluded:

> The maximum amount of any cation leached was 2.89 pounds of sodium per cubic yard of ash. In a dump 25 feet deep, this would correspond to approximately 58 tons per acre. In the case of potassium, there would be 32 tons per acre of leachable ion present. Although these values appear high on first examination, the amount of water it required to obtain them and the length of time it would normally take to leach those quantities, with the consequent dilution factor available, must not be overlooked. There seems little doubt but that dilution of leach by ground water would result in concentrations of sodium and potassium which would not in any way adversely affect ground water quality....
>
> Ground water may be expected to leach an ash dump of its salts and alkalies. The precise rate at which such leaching will proceed while known to be slow, remains a matter of strong conjecture, for undoubtedly the answer lies in the volume of water that will percolate or move through the dump. Similarly, the net effect of the leach on a ground water can only be stated in terms of the volume of ground water receiving the leach, i.e., the available dilution. Certainly it may be stated that the use of a site for purposes of incinerator ash disposal constitutes no threat to the ground water, providing reasonable caution is exercised to prevent direct funneling of the leach into a limited volume of ground water, such as a well or group of wells.

TABLE 1

	Pounds per Cubic Yard of Ash			
	1	2	3	4
Sodium	0.974	2.87	0.586	1.28
Potassium	0.274	1.57	0.582	1.22
Calcium	0.484	0.424	0.377	0.299
Magnesium	0.110	0.385	0.368	0.137
Chloride	0.614	5.30	0.202	0.391
Sulfate	3.060	4.59	3.57	4.32
Alkalinity	0.680	1.33	0.686	0.444
Nitrate - Nitrogen	--	--	--	0.147

A similar investigation was conducted for two years on the leaching behavior of a sanitary landfill handling garbage, rubbish and mixed refuse. (4,5,6) The landfill, run and operated by the City of Riverside, California, had been in existence some 35 years at the time of the study and handled 70 tons of rubbish per day. It was fairly certain that some of the fill had been deposited directly in ground water, and further, only a small rise in the water table caused the lower portions of the fill material to become submerged. The average depth of the compacted fill was 10 feet.

The aquifer immediately below the landfill consisted of a 20-foot layer of coarse to medium find sand which in turn was underlain by a 10-foot impervious clay and silt layer.
During the course of the study 33 sampling wells were installed according to the ground water flow: upstream of the landfill, within the landfill, and downstream of the landfill. In addition to the ground water studies, two field percolation bins were constructed and packed with fresh domestic rubbish to study the characteristics of the leachate which was produced by the weekly application of water.

The ground water study showed that the water directly below the fill was anaerobic with a musty or swampy odor, but as the water moved away from the landfill, it improved in quality. A comparison of the ground water quality upstream from the landfill with that 1000 feet downstream and 3200 feet downstream is presented in Table 2.

TABLE 2

	Native Water	1,000 feet Downstream (Highest Conc. 30 ft. Depth)	3,200 feet Downstream (Highest Conc. 35 ft. Depth)
Total Hardness* (as $CaCO_3$)	297	752	316
Alkalinity (as $CaCO_3$)	269	768	265
Calcium	91	212	92
Magnesium	15	52	20
Sodium	73	212	57
Potassium	4.2	12	5.5
Chloride	69	267	64
Sulfate	69	--	75

* All measurements in mg/l

It is apparent from these data that dilution had a very favorable effect on the ground water quality.

Two conclusions from this study on the effects of landfills on ground water quality are:

1. A sanitary landfill, if so located that no portion of it intercepts ground water, will not cause impairment of the ground water for either domestic or irrigational uses.
2. A sanitary landfill, if so located as to be in intermittant or continuous contact with ground water, will cause the ground water in the vicinity of the landfill to become grossly polluted and unfit for domestic or irrigational uses.

Other conclusions drawn from this study are that limited vertical diffusion of pollutants occurs, dilution minimizes the effect of pollutant ions, and where the pollution load to the ground water is light, an increase in hardness in the upper parts of the ground water is the most serious problem as little as a half-mile downstream.

The field bin leach studies were also of interest since they provided some information on the characteristics of the leach under intensified degradation activities. The concentration of all materials in the leachate increased rapidly after the bin became saturated with water, and after a maximum level was attained the concentrations began to decline steadily with time. Analysis of leach samples at the first appearance of the leachate, two months after that, and approximately one-year after the maximum was achieved is presented in Table 3.

The conclusion derived from the bin study is:

> It may be expected that continuous leaching of an acre-foot of sanitary landfill will result in a minimum extraction of approximately 1.5 tons of sodium plus potassium, 1.0 tons of calcium plus magnesium, 0.91 tons of

TABLE 3

	Initial Sample	2 Months Following Initial	1 year and 2 Months Following Initial
pH	6.55	NR	7.18
Total Hardness* (as $CaCO_3$)	890	7,250	695
Alkalinity (as $CaCO_3$)	730	6,680	2,080
Calcium	240	2,190	135
Magnesium	64	340	105
Sodium	85	1,470	530
Potassium	28	1,115	520
Total Iron	6.5	270	40
Ferrous Iron	NR	68	4.1
Chloride	96	1,810	755
Sulfate	84	560	54
Phosphate	0.30	9.6	5.6
Organic Nitrogen	2.4	320	22
Ammonia Nitrogen	0.22	790	175
BOD	NR	33,100	125

* Measurements in mg/l

chloride, 0.23 tons of sulfate and 3.9 tons of bicarbonate. Removals of these quantities would continue with subsequent years, but at a very slow rate. It is unlikely that all ions would ever be removed.

Available data on the extent of pollution of ground water from dump leachates were reported in 1961, and a recommendation was made for future research programs to fill any gaps in knowledge available. (7) The report included a good literature review of such topics as vertical water movement, decomposition processes, gas production and movement, leaching, and travel of pollution.

In the discussion presented on leaching, an interesting table was included showing the leached substances most likely to control the necessary dilution of any percolate. (Table 4)

TABLE 4

Substances	Concentrations (ppm)			
	Percolate (Maximum)	1:100 Dilution	1:1000 Dilution	USPHS Drinking Water Standards
Total Dissolved Solids (inorganic)	20,000	200	20	500
Chloride	2,200	22	2.2	250
Total Hardness	8,000	80	8	--
NH_3 & Org. -N	1,300	13	1.3	NO_3 - N:10
Iron	300	3	0.3	0.3
Sulfide	30	.3	0.03	--
BOD	30,000	300	30	--

Dilutions which would bring solids, chloride and sulfide to an acceptable level would not be sufficient for hardness, iron and nitrate nitrogen.

The amount of infiltration into and percolation through a landfill depends upon the amount of surface water application. If the refuse material has high water retention properties, there may be insufficient rain to cause a problem.

The problems stemming from the aerobic and anaerobic biological decomposition of organic refuse are related to the large volumes of carbon dioxide and methane gas produced. Carbon dioxide, for example, can seriously degrade ground water by dissolving calcium, magnesium, iron and other substances which are undesirable at high concentrations.

There are apparently only three basic mechanisms by which solid refuse can impart undesirable qualities to the ground water: (1) direct horizontal leaching of refuse by the ground water, (2) vertical leaching by percolating water, and (3) the transfer of gases produced during refuse decomposition by diffusion and convection.

According to the report the first two mechanisms above are subject to control, whereas, the gas transfer may be very costly to abate once refuse has been deposited.

The concern about gas production was the impetus for another study, (8, 9, 10). This study proved to be of interest since up to that time most work had been done on the question of refuse leachates affecting ground water supplies, whereas practically no work had been done on refuse-produced gases as potential ground water pollutants.

The investigators found (a) that over 90% of the gas produced by refuse decomposition in large landfills was CO_2 and CH_4 and that most of this gas goes upward to the atmosphere; (b) refuse gas poses more of a hazard to ground water than do leachates since the latter problem can be avoided whereas gas is produced constantly; (c) an asphalt membrane can be used in a prototype landfill as a CO_2 gas barrier, if necessary; ventilation and burn-off are also potential gas control procedures; and (d) in one test site the maximum CO_2 concentration in the refuse was reached in two to three weeks after the completion of the fill.

Merz and co-workers (11) conducted a five-year study on sanitary landfill using four specially constructed cells at the Spadra Landfill operated by the Los Angeles County Sanitation District. The four test cells referred to as A, B, C, and D were built for the following purpose: Seattle rainfall pattern replication; turf development and irrigation; maintenance of aerobic environment; and refuse encapsulation in polyethylene membrane to measure gas production. The cells were carefully fitted with numerous measuring devices and filled to a depth of 20 feet with normal domestic refuse collected from the surrounding area. Two feet of earth cover was placed over the fill.

This study was concerned primarily with gas production and settlement. The anaerobic cells after two years aging produced gas with equal amounts (by volume) of methane and carbon dioxide. The aerobically operated cell produced a gas high in nitrogen and oxygen. A special study using 73 cubic yards of refuse packed into an underground sealed and instrumented steel tank produced 2,027 cubic feet of gas, or 27.7 cubic feet per cubic yard of refuse over 907 days, virtually all between the 230th and 600th day. As for volume reduction, 21.5% was achieved in the aerobic cell in comparison with 11.5% in the anearobic cell.

In 1965 the California Legislature directed that a study be made of water quality problems in the San Francisco Bay-Delta area including water contamination and pollution resulting from disposal of solid wastes. (12) One chapter in the resulting report entitled, "Influence of Solid Wastes on Water Quality" presents a short review of some of the literature on leachates and gas production from disposal sites. Reference is particularly made to past California studies. Included also is a rather extensive survey of all land disposal sites in the Bay-Delta area from the stand-point of surface and ground water quality. A water quality evaluation scheme was worked out and applied to each disposal site. Appendix E of the report presents, "Preliminary Guide Lines for Solid Waste Management to Protect Water Quality." This portion serves as a valuable, fairly detailed reference on recommended means of handling various types of municipal solid wastes, agricultural wastes, and industrial wastes considered from the point of view of protecting ground and surface waters.

South Dakota Studies

Anderson and Dornbush (13, 14) studied over a six-year period the effects on ground water quality of dumping refuse from the city of Brookings, South Dakota, in an abandoned gravel pit located 2 miles south of the community. The disposal operation is not operated as a conventional sanitary landfill since the refuse is first sorted into various classes and the combustible material burned. The refuse is periodically covered with soil and compacted. The ground water table at the site is about 6½ feet below ground surface and the principal geological feature of the area is a sandy-gravel outwash covered at the surface by about 1-foot clay and silt alluvium. The cation exchange capacity of the area was felt to be very low. The estimated ground water velocities were in the range of 1 to 3 feet per day.

A total of 45 test wells were constructed "upstream" and "downstream" of the dump area. All except 4 of the wells were 1½-inch diameter pipes with sand points from which water samples could be pumped. The other wells were of larger diameter to accomodate floats for continuous water lever recorders. The test wells were interspersed among two surface water ponds which were present downstream of the refuse disposal area. Because it was found that these surface water bodies had a marked effect on the ground water emanating from the disposal area, a long trench was excavated at approximately right angles to the ground water flow to expose more surface water and study this situation in greater detail.

They found that chloride, sodium, specific conductance, and total and calcium hardness were the inorganic parameters of ground water quality which could be used most effectively to denote any changes attributable to leachates from the disposal area. On the basis of statistical studies they found that chloride level is the most sensitive parameter with wells, for example, the center of the disposal area experiencing a 50-fold increase in concentrations in comparison to the unaffected ground water. Specific conductance was also a fairly sensitive quality parameter exhibiting a 3-fold increase as described above. Hardness concentrations increased in the immediate vicinity of the disposal area but showed a marked decrease as the water flowed through the surface water pond. There was a correlation between height of ground water table and concentration of quality parameters which means the rise in ground water initiated a higher degree of leaching from the fill area.

Isoconcentration lines drawn for hardness and specific conductance demonstrated clearly that the significant leaching effects of these two parameters on ground water quality remained in the immediate vicinity of the disposal area. High concentrations of these parameters were confined to a relatively narrow band but extended as far as 1,000 feet from the landfill disposal area.

Seasonal variations were also observed to cause some changes in the ground water quality. For example, greater rainfall and snow melt periods caused intensified leaching of ions from the disposal area. The effect of increased leaching rates were felt to be greater than that of the dilutional effects of more ground water.

Studies of trace chemical ions were also conducted on water samples obtained from test wells around the disposal site. The maximum concentrations of the various ions analyzed were usually found at the well site in the immediate vicinity of the site. Manganese was the only ion detected in a concentration greater than that recommended by the U.S.P.H.S. Drinking Water Standards. In general the concentration of the trace element was greater in water downstream of the disposal site than that above the site. As the water moved from the disposal area, the quality of the water tended to improve. This same pattern was found to be true for three organic parameters as well, namely, chemical oxygen demand, threshold odor and carbon filter extract.

The most recent work at the Brookings site was directed toward an evaluation of the effects of constructing a long trench on the quality of the degraded water flowing from the disposal area. The trench was constructed along the downstream edge of the disposal site. Upon an evaluation of the water quality data above and below the trench, the author concluded that the intercepting trench improved the quality of the degraded ground water flowing from the fill area. They felt that this beneficial effect was caused by the dilution and photosynthetic activity afforded by the surface water.

British Studies

The pollutional effects on ground water was determined under two conditions. (15) In the first case the refuse was dumped under dry conditions and a known amount of water was applied to the refuse until a percolate was obtained. The percolate was measured and analyzed. For example, the BOD of the percolate averaged 6,000 mg/l during the first four months of application and thereafter it diminished rapidly to a value less than 50 mg/l in two years. The maximum concentration of ammonia nitrogen was about 700 mg/l and this declined to 40 mg/l by the end of the experiment. The concentration of sulfate varied from 2 to 1,800 mg/l with no definite pattern discernable. The chloride level reached 1,700 mg/l and it was estimated that it would take about three years of percolation to extract all the chloride from the refuse.

A second series of experiments was carried out with the refuse dumped into water. The actual amounts of polluting matter leached from refuse during the almost two years of the study are shown in Table 5.

TABLE 5

Constituent	lbs. per ton refuse
Permanganate value:	
30 min.	0.77
4 hrs.	1.20
BOD	10.3
Organic carbon	5.7
Organic nitrogen	0.15
Ammonia nitrogen	1.1
Albuminoid nitrogen	0.10
Chloride	2.1
Sulfate	2.6
Sulfide	0.22

Also an interesting comparison was presented on the total amount of organic polluting matter extracted from the refuse under the dry dumping conditions vs. the wet dumping condition. The results presented in Table 6 are in kilograms per 100 tons refuse leaving the dry dump by way of percolation and leaving the wet dump in the water passed through.

TABLE 6

Dump	Period	BOD	4 hour Permanganate	Organic Carbon	Org. + NH_3 Nitrogen
Dry	28 mo.	226	34	148	40.0
Wet	18 mo.	468	54	258	44.0
Ratio:	wet/ dry	2.1	1.6	1.7	1.1

In addition to a discussion on some of the practical applications of the investigation, there was also a short literature review on the subject of water pollution arising from garbage and refuse dumps, with most of the reported literature being from Europe. Some work was presented on the possibility of setting up a landfill site to collect all leachates, direct them to a central point and provide treatment prior to disposal just like any other waste water, and the possibility of removing stabilized refuse from an "ideal" site for reuse of a fresh refuse.

More recently, a symposium was held on the effects of tipped domestic refuse on ground water quality in which the results of four different investigators were reported. (16) Waterton examined the results of well water analyses over a period of years and found no evidence of serious deterioration as the result of a nearby refuse dump. McLeon studied the effects on ground water of filling abandoned brickearth, chalk, sand and gravel pits and as a result suggested that potassium levels could be used as a sensitive indicator of pollution of underground water by domestic refuse. Davison made a similar type study with the following conclusions in part: (1) The effluents from dry refuse tips are highly polluted liquors. (2) It is essential that the sites of refuse tips are chosen correctly. (3) The amount of refuse tipped per year on any particular gathering ground is important. (4) Potassium may be the most useful indicator for tracing pollution. (5) Taste and odor may be the main difficulty for ground water affected by refuse leachates. Finally, Holden found little change in ground water quality in an area where domestic refuse could likely have been a factor.

Illinois Studies

Some of the most useful studies in recent years on landfill site selection and evaluation from the standpoint of practical applicability of the information have been conducted by investigators of the Illinois State Geological Survey. Hughes (17), for example, wrote a very helpful publication on a method for evaluating a disposal site considering the hydrologic environment of the site and the method of disposal. He stressed that climatic, hydrologic, and geologic factors strongly influence the production and spread of contaminants from landfill sites and therefore it is dangerous to overgeneralize the findings from one area to another. Also it is important to know the underground flow system, that is, whether the landfill is located in a recharge area or a discharge area. Less dilution and dispersion of contaminants takes place in the ground water than in surface waters because of the laminar flow rather than turbulent flow. Thus the velocities are low and contamination may not be noticed for years or even decades. He listed several conditions which are necessary in order to have a favorable site for refuse disposal.

1. A disposal site is usually considered favorable if the refuse will remain dry or unsaturated, thus reducing the production of contaminants and preventing their mobilization.
2. A disposal site is considered satisfactory if the permeability of the earth materials at the site is low enough to retard movement of contaminants from the site. In most instances, materials with permeabilities of less than 10^{-2} gal/day/ft^2 are considered as relatively impermeable.
3. Under conditions that are hydrologically favorable, movement of contaminants along lines of flow would be such that either they could not reach a useful ground water or surface-water resource or their attentuation to acceptable levels would occur before they reached such a water resource.

Cartwright and McComas (18) conducted earth resistivity and soil temperature surveys around four sanitary landfills in northeastern Illinois. The following statement from their conclusion aptly expresses the applicability of their work.

> The movement of soluble salts leached from sanitary refuse can be detected and traced reasonably well with electrical earth resistivity survey methods. Only when the movement of leachate from the fill is rapid, as in permeable gravels of drain tiles, is the movement directly detectable by temperature measurements. Geophysical surveys are not a substitute for hydrogeologic studies, but can be used with moderate control as a preliminary tool in the investigation of sanitary landfills, and can be extremely useful in the location of piezometers for detail studies.

Bergstrom (19) (20) discussed the feasibility of disposing of industrial wastes into deep geological formations in the State of Illinois. He divided the state into five different regions and described the geological features in each which would either make it a likely area for deep-well disposal of industrial wastes, or preclude it from any consideration for this type of operation. Though no mention is made of sanitary landfills, specifically, the articles do point out the importance of sufficient geological information for the safe disposal of certain industrial wastes in the ground.

Bergstrom (21) also discussed in general the disposal of wastes of all types in the ground from the broad standpoint of waste management. He stated that instead of viewing waste disposal on land immediately as a ground water pollution problem, many ground water workers are beginning to take a more positive role by studying and classifying hydrogeologic environments relative to waste disposal. In his conclusion he presents an interesting suggestion to his fellow ground water practitioners:

> . . . in addition to maintaining a vigilance over pollution hazards connected with waste disposal, we should exercise our knowledge of hydrogeologic conditions to promote sites and environments for waste disposal where there are natural safeguards that will assure protection of health and resources. We should also point out environments where risks of pollution hazards are high. Even the use of fairly broad hydrogeologic generalization with reference to disposal conditions are useful to the regulatory and planning agencies and to the interested public, and they can keep ill-advised projects from being developed.

Cartwright and Sherman (22) pointed out the Department of Public Health's concern with the pollution potential of ground water by sanitary landfill leachates. This concern is reflected in an old rule that land disposal not only be confined to areas above the water table, but also to maintain a minimum of 30 feet, and preferably 50 feet, of relatively impermeable material between the base of the landfill and the shallowest underlying water-yielding formation. They indicated that limestone quarries and gravel pits are rarely, if ever, acceptable refuse disposal sites from the hydrogeologic standpoint. Sanitary landfills on the other hand can be located in relatively impermeable, or slowly permeable, material so that movement of refuse leachate will be retarded. The most common materials in this category are clays, shale, silt and glacial till. They suggested the following criteria for evaluating sanitary landfill sites:

1. Type of unconsolidated material:
   - Favorable - glacial till, lake silts and clays, windblown silt (loess)
   - Unfavorable - sand, gravel
2. Thickness of unconsolidated material:
   - Favorable - 50 feet or more (30 feet if no trenching is proposed)
   - Unfavorable - less than 50 feet (30 feet if no trenching is proposed)
3. Type of bedrock:
   - Favorable - shale
   - Unfavorable - sandstone, fissured limestone or dolomite
   - Questionable - limestone or dolomite not known to be fissured.
4. Local sources and potential sources of water:
   - Favorable - deep bedrock wells, sand and gravel wells with logs showing thick impermeable cover over aquifer, dug wells if 500 feet or more from the site.
   - Unfavorable - shallow bedrock wells (particularly in fissured limestone) sand and gravel wells with logs showing thin cover over aquifer.
5. Site topography:
   - Favorable - flat upland areas, heads of gullies and ravines, dry strip mines.
   - Unfavorable - (require operational engineering) - depressions where water accumulates, lower reaches of gullies, stream flood plains, other sites near surface water areas where leachates might discharge into the water.

If 1, 2, 4 and 5 or 1, 3, 4 and 5 are favorable, there is little probability that ground water contamination will occur. The authors also pointed out that the above criteria are merely guidelines and that test borings may be required for the proper evaluation of some sites.

Hughes, Landon and Farvolden (23) described the hydrogeologic environments in the vicinity of four existing landfill sites in northeastern Illinois, in order to determine the controls on the movement of the ground water and the solids dissolved in the ground water. They hoped that this information could then be used by regulatory agencies to help determine environments most suitable for near-surface disposal of waste insofar as contamination of ground water and surface water is concerned.

Hydrogeologically, leachates at some landfill site that infiltrates the ground become part of a local flow system and are discharged into a nearby stream or swamp with little risk of contaminating an aquifer. At other sites these same leachates may become part of a regional flow system and enter productive aquifers and thus cause a serious contamination problem. After selecting four sites which represent common hydrogeologic environments in northeastern Illinois borings were made in and around the filled areas for geologic information and for the installation of piezometers to determine the ground water flow system. Ground water samples for analysis were also taken from these same holes. After collection of data and interpretation of results some interesting and practical conclusions and recommendations were offered by the authors. They found that once the flow patterns around a landfill are known, the dispersion of dissolved solids can be predicted with reasonable accuracy. At each of the sites studied, precipitation moved downward through the fill surface and the refuse to produce a leachate of high dissolved solids content which then migrated out of the fill. At three of the sites the high solids load was attenuated to a considerable degree after a short travel distance. At the other site the dissolved solids affected a shallow well a short distance away. No evidence that the dissolved solids moved downward through the clay tills underlying the four sites was found. As for leachate quality, high organic acids and chemical oxygen demand were found in relatively young refuse and these materials did not appear to travel far from the landfill area at three of the sites. Hardness was high within the landfill but decreased rapidly with distance away from the landfill.

Chlorides were found to be the best indicators of leachate migration, traveling farther than any of the other dissolved solids. Chlorides within the landfills were in the thousands of mg/l and dropped to tens of mg/l some distance away. An interesting conclusion of the authors is:

> Under conditions existing in northeastern Illinois there appears to be no practical method of landfill construction that would completely eliminate the movement of dissolved solids from a disposal site. If this assumption is accepted, the problem of selecting suitable sites becomes that of choosing hydrogeologic environments that can accept or eliminate dissolved solids without ill effects. Although there are areas in northeastern Illinois where solid waste disposal would be harmful to the ground-water resource, these appear to be relatively rare compared to the number of favorable areas.

Surprisingly the authors pointed out that abandoned gravel pits and quarries can be used for solid waste disposal providing rather rigid hydrogeologic criteria are met. Recharge zones in permeable materials normally should not be used for landfill sites. The authors also presented helpful comments and recommendations on such topics as: use of abandoned strip mines for landfill sites, landfill sites in entirely clay areas, time of waste stablilization as influencing site selection, sealing thick surficial gravel sites, effects of reducing infiltration into a landfill, and problems associated with "hill" type landfill operations.

Drexel Institute of Technology Studies

Fungaroli and others have been involved in studies on ground water pollution potential of sanitary landfills for several years. Two recent reports were published containing useful information on the design of a laboratory lysimeter for sanitary landfill investigations, and the design of a sanitary landfill field experiment installation (24) (25). Though both of these publications do not contain any actual operating data and results, they do provide useful hints for anyone interested in instigating an investigation of this type.

Remson et al. (26) proposed a method of moisture routing first through the soil cover and then through the underlying compacted refuse. Their method was illustrated by its application to a hypothetical landfill. The practical usefulness of being able to control the moisture regimen through a landfill was stressed by the authors in their conclusion. The amount of moisture passing through a landfill will have a significant effect on the rate of stabilization and consolidation, as well as rate of leachate production--all conditions which the landfill operator may wish to control depending upon the situation at each particular landfill. The authors suggested other techniques that might be used to control the moisture regimen of a sanitary landfill.

> The infiltration capacity and permeability of the soil cover can be adjusted by choice of cover soil or by use of artificial impermeable materials. The storage capacity of the soil and fill might be adjusted by the design of thickness, choice of materials, use of additives, and treatment. The type of vegetative cover can affect evapotranspiration.

U.S. Geological Survey Studies

LeGrand has published a series of papers on the general topic of ground water contamination from various sources. In one (27) he suggested a point evaluation system for assessing the contamination potential of a waste disposal site. The method applies to areas where wastes are released in loose granular earth at or near the surface. The rating scheme includes five environmental conditions at the site, namely, distance from surface to water table, sorption capacity of the soil, permeability, water table gradient, and distance from point of contamination to point of water use. He admitted however:

> . . . that the method should not be used in evaluation of disposal sites for mixed wastes, such as those found in refuse dumps and sanitary landfills, if the critical consideration is the movement of chemical wastes that attenuate slowly.

In a second paper (28) he presented a very basic and informative discussion on the management aspects of ground water contamination. He considered the different ways of contamination of ground water, the classification of the various types of ground water contamination problems, the fate of different wastes once they are released near the ground, and the hydrogeologic factors which influence ground water contamination including an interesting discussion on how the activities of man can alter the ground water pattern. Finally a discussion of the attenuation of contaminants discharged on the ground is also presented.

In still another paper (29) he discussed the manner of estimating the areal extent of contaminants in the ground. The extent of these contaminated zones, or "malenclaves" depends on the type of waste material, pattern of waste disposal, pattern of water development from wells, behavior of each contaminant in the soil, water, and rock environment, ranges in geologic and hydrologic conditions in space, and ranges in hydrologic conditions in time. The following excerpt for the author's conclusion interestingly points out the applicability of his "enclave" concept.

> The upper part of the zone of saturation in populated parts of the Earth may be considered a galaxy in which millions of enclaves of contaminated water are scattered in uncontaminated ground water. Interspersed with these contaminated enclaves are millions of water-supply wells, some of which pump contaminated water or help to disperse it even if it does not reach them. Although too few contaminated zones have been delineated to enable a statistical analysis of area patterns, an approximation of their patterns of distribution can be deduced.

Finally the author presented a discussion on a sensible methodology of approaching a ground water monitoring program. (30) He stressed that improved technology is needed for estimating the distribution of contaminated water in the ground before any monitoring wells are actually dug. Once it is felt that monitoring is actually needed than a necessary prerequisite is a synthetic hydrogeologic framework or model in which the behavior of the contaminated water is conceived; otherwise, "unplanned, indiscriminate monitoring of water from wells is expensive, inefficient and fallible."

Other Studies

Qasim and Burchinal (31, 32) studied the chemical and pollutional characteristics of leachates from different heights of refuse columns containing similar fill materials of approximately the same age, and operating under similar conditions of percolation and leaching. Three-foot-diameter columns of heights 4, 8, 12 and 16 feet were used as simulated landfills. The cylinders were filled with municipal refuse and dosed with water in amounts equivalent to normal precipitation for the area for periods ranging from 121 to 163 days. According to the authors:

> . . . initial leach samples were dark green and became darker and septic soon after collection. These samples contained

large amounts of organic and inorganic components. Concentrations of extracted material increased initially but began to decrease after about four weeks. Concentrations again started to increase and attained a second maximum after eight weeks, and again there was a gradual decline.

Examples of maximum concentrations of some leachate constituents obtained from the 12-foot column as well as the reduction of maximum concentrations at the end of the test period are shown in Table 7.

The authors concluded that the deeper fill under similar conditions of water application consume more water before leaching occurs, take a longer time to decompose, and the bulk of extracted material is distributed over a longer period. For these reasons they felt that deeper fills pose less of a pollutional problem than do the shallow fills simply because the rate of pollution production is greater initially in the case of the latter. On the basis of results obtained with the simulated landfills, estimates were made on the amount of materials extracted from one acre-foot of landfill subjected to a percolate volume of 45 inches annually. Typical values in tons per year for a 10-foot bed are as follows: BOD - 12.33, chloride - 0.801, hardness - 4.208, and solids - 19.59.

TABLE 7

Constituents	Conc. (mg/l)	% Reduction
BOD	33,360	23.9
Calcium	2,790	4.1
Chloride	2,310	36.6
Hardness ($CaCO_3$)	10,950	22.4
Total Iron	860	14.9
NH_3-N	1,106	25.1
Org. N	1,416	57.5
Total Solids	59,200	38.8

Kaufmann (33) summarized his review concerning hydrogeological aspects of the disposal of solid wastes on the ground with a comment on the present state of knowledge:

> Such knowledge is distinctly qualitative at the present and future research will undoubtedly be largely directed toward "pinning down" and assigning values to the important factors and determining which factors, if any, can be largely disregarded. Although hydrologic and geologic factors have been somewhat divorced in the presentation herein, the two are intimately related and must continually be dove-tailed in the final solution. The expense of doing a complete study to determine site suitability is not feasible for a variety of reasons, hence the goal is to determine quantitative criteria with which an area can be rather quickly evaluated.

Kaufmann (34) has also been investigating the overall hydrogeology of two sanitary landfills in the Madison, Wisconsin area. A great deal of work has been done at these two sites to establish the ground water flow pattern around each site using numerous test wells and piezometers. The investigation of the travel of pollutants from the landfill was done by chemical analyses of water samples and earth resistivity measurements. The data are still being collected, and upon completion of this work, it appears that a significant contribution will be made to the available body of knowledge on how hydrogeological factors influence the production and dissemination of pollutants from a sanitary landfill. Also there should be a better understanding on how to predict the suitability of proposed sites for landfill operation knowing some of the basic hydrogeological features.

Landon, who feels that site selection for final disposal of solid wastes is one of today's most critical solid wastes problems, showed the necessity for application of hydrogeologic knowledge and concepts to the selection of refuse disposal sites. (35) He pointed out that refuse could be hydrologically confined so that minimal leachate is produced, or none at all, but that such a procedure would not only be very costly but also subject to failure which could in turn subject the ground water to localized dosages of high strength leachates. Thus he concluded:

> . . . that it would be best to let the leachate migrate from the landfill at a known rate and direction for natural renovation and dilution in route to the ground water. To do so, however, would necessitate an application of hydrogeologic knowledge for the selection of the refuse disposal site.

He presented three alternatives to abate and prevent leachate pollution. The first alternative would utilize a knowledge of existing hydrogeologic conditions at the site which would favorably control the rate and direction of leachate migration for natural renovation. Using some data from Illinois studies on actual landfills he concluded that:

> Through a determination of the type, texture, relative permeability, and sequence of geologic materials and the ground water flow system through borings and piezometers prior to a landfill operation, it is possible to know the direction and rate at which leachate will migrate from the completed landfill into the surrounding surface and ground water. An evaluation of the natural conditions at a proposed landfill site can be made, therefore, that will determine whether natural renovation and dilution of leachate is sufficient to prevent ground-water pollution.

The second alternative suggested would be at those sites where it is found that the leachates cannot be satisfactorily assimilated, because of hydrogeological situations, to provide engineering facilities for the collection and treatment of the leachate produced. The author felt that such an arrangement can be economically justified in those cases where hauling costs can be reduced to closer sites otherwise normally considered to be unusable for hydrogeologic reasons.

Finally the third alternative suggested is a combination of the first two where limited collection facilities are constructed to supplement natural conditions. The author concluded:

> It is time to approach the solid waste disposal problem on a more sophisticated level by requiring at proposed sites: test drilling to define hydrogeologic conditions; one or more points to monitor ground water quality; and engineering design and operation, which may include leachate collection and treatment facilities so that man's health and environment are not jeopardized.

The use of resistivity measurements for economically obtaining hydrogeological information on a potential landfill site and operating landfill sites appears to have merit. Page (36) successfully correlated soil types, recharge rates, and resistivity data while in the process of searching out ground water recharge areas. He stated that resistivity methods have the advantage of low cost, ease of operation, speed and accuracy. Warner (37) demonstrated with partial success the use of resistivity measurements for detecting and outlining zones of ground water contamination in situations where there is a resistivity contrast between contaminated and uncontaminated ground water.

Hart (38) reported on a study which has been going on for three years at the Berlin, Germany landfill to determine the effect of the compaction of refuse upon the water regime within the fill. The fill is instrumented to measure temperature, moisture, and specific weight, as well as quantity and quality of leachate. Though actual data were not presented he noted that results to date (1968) indicated that maximum leachate occurs with maximum compaction.

General References

There are a number of references which include a general discussion of the relationship between sanitary landfills and ground water pollution problems. Most of these sources present brief summaries of the studies which have been presented earlier in this report, particularly the California studies. Some are fairly complete and helpful while others are quite brief and of limited usefulness regarding the topic at hand. The main point is that by reviewing several of these sources one can obtain a general overview on the ground water pollution-solid waste disposal relationship.

In a short review, Cummins (39) included most of the important studies in the 15 references cited, but presented very little detail on results.

Golueke (40) wrote a 300-page report which includes abstracts and excerpts from the literature on the broad topic of solid waste management. Because of the nature of the topic, it is not surprising that some of the important investigations in the area of ground water pollution do not appear in this publication.

Two of the ASCE Manuals of Engineering Practice (2) (41) include a short discussion on ground water pollution, as does the APWA book. (42) All three of these discussions draw mainly from the California studies.

Sorg and Hickman (43) have written a small semi-technical report for the U.S. Public Health Service which includes some discussion of water pollution problems. A bibliography is added to the end of the report. The U.S. Public Health Service has also made available a number of helpful bibliographies on the topic of sanitary landfills specifically and refuse collection and disposal in general (44) (45). The sanitary landfill bibliography was prepared by Steiner and Kantz of Drexel Institute of Technology and covers the literature for the period 1925 to 1968.

Finally Weaver (46) and Black (47) have briefly discussed the ground water pollution problems in some of their writings on sanitary landfills.

Health and Nuisance Problems Related To Leachates from Landfills and Dump Grounds

Considering the tremendous amount of solid wastes which have been deposited on the land, there are still relatively few recorded instances of serious ground water pollution problems linked to leachates from landfills and dump grounds. No doubt there have probably been many small localized nuisance conditions which have never been reported. There have also been and still are many cases in which impairment of water quality has not been detected because there have been no noticeable deleterious effects traceable to the water being used. A review of some of the health and nuisance problems recorded is presented in this section. Some of the information on instances reported are quite detailed and very specific, whereas, many others are similar to the following statement:

> Landfills should be so located that seepage from them will not cause hazards or nuisances. (48)

Forty years ago, Calvert (49) reported on the deterioration of well water caused by the pit disposal of liquor drained from cooked garbage. The well water before and after contamination showed a substantial increase in iron, total hardness, total solids, CO_2 and total organic nitrogen. The characteristics of this garbage liquor was very similar to those of a fresh leachate.

The University of California (50) in 1952 conducted field studies of refuse collection and disposal operation in 13 California cities. In the section on public health problems, no mention was made of ground water pollution problems other than a minor reference that the possibility of ground water contamination should be considered in selecting a site for landfill disposal of refuse.

Publication No. 24 of the California State Water Pollution Control Board (7) includes several pages on the reported experiences from the literature on health and nuisance problems. A case in Surrey County, England is cited where refuse was dumped into three water-filled gravel pits between 1940 and 1960 at the rate of 100,000 tons per year.

Chloride levels in the pit increased from the native water 50 mg/l concentrations to over 800 mg/l. However, in a quarry 3,500 feet downstream the maximum chloride concentration was 70 mg/l. Organic and bacterial pollution has disappeared within one-half mile from the refuse pits. This case also demonstrated the benefit of having large water-filled pits along the path of flow to provide for the dilution of leachates.

Reference is also made to a garbage dump in Krefeld, Germany where 650,000 cu. yds. of refuse were dumped between 1913 and 1929. Water was standing in the bottom of the empty gravel pit. After nine years high salt and hardness concentrations began to appear in wells one mile downstream. Eventually wells 5 miles away were seriously affected. Chloride increased from 40 to 260 mg/l and hardness from 200 to 900 mg/l. The problem lasted 18 years. Another case in Shirrhof, Germany where ashes and refuse were dumped into an empty sand pit which extended below the water table, pollution problems began in wells 2000 feet downstream some 15 years later. The hardness increased from 200 to 1,150 mg/l. Again in Germany, a refuse dump caused water quality problems in well water, four to six years after dumping. Maximum chloride concentrations increased from 13 to 120 mg/l, and maximum carbonate hardness from 90 to 210 mg/l.

An interesting case of ground water pollution from dumping water softener regeneration brine into seepage basins at Saugus, California is also reported. From 1942 to 1949 approximately 50,000 gallons/day of brine were discharged to seepage basins. Wells downstream became affected with very high concentrations of salts, some wells as far as 2000 feet. It required 4 years after dumping was terminated for the ground water to be restored to its original quality.

An ASCE publication (41) makes reference to potential ground water pollution problems from disposal of wastes of any kind in the land. A listing of typical industrial wastes together with common characteristics affecting ground water were presented.

Oil field brine - High mineral content, largely sodium chloride in amounts ranging from a few thousand parts per million to several times the concentration of sea water.
Steel pickling liquor - Highly acidic; contains large amount of iron.
Electroplating wastes - Contain hexavalent chromium, cyanides, and other heavy metals in toxic concentrations.
Pulp mill wastes - Sulfates and sulfites; mercaptans; lignis; tannins.
Citrus packing wastes - High boron content.
Chemical plant wastes - Corrosive toxic salts and heavy metals; phenolic compounds.
Gas and coke plant effluent - Ammonia, phenols; cyanide; other organic taste and odor-producing substances.
Textile mill wastes - Toxic salts.
Food processing waste - Concentrated brines and other chemicals.
Tannery wastes - Nitrogen; chrome salts, tannins.
Water softener wastes - High mineral content.
Mine drainage - Highly mineralized; toxic metals; may be acidic.

The point was made that underground disposal of industrial wastes is in some ways more hazardous than discharge to surface water since the resulting degradation is cumulative and long lasting. The ground water reservoir may be permeated with pollutants to the point of being rendered virtually unusable, by the time effects are detected. The publication goes on to state that:

> The land disposal of ashes, refuse, and other solid wastes, though closely related to underground disposal of sewage, does not usually constitute as great a threat to a ground water reservoir. This does not mean, however, that dumps and disposal areas can be indiscriminately located, without consideration of pertinent geologic and hydrologic conditions and possible effect on ground water quality.

The point is stressed that from a water quality standpoint, the principal precaution required in locating refuse disposal sites is to keep them well above the maximum expected water table and out of areas subject to inundation.

Anderson (51, 52) has written on the general topic of the public health aspects of solid waste disposal. He lists potential water pollution problems as one of the matters of public health concern, and regarding the contamination of ground water by leachates he makes the general observation that:

> Bacterial and organic contamination may be very limited in range, but chemical pollution, that is, mineral salts may travel some distance before the effect of dilution is evident. Although the passage of landfill leachate through sand or gravel may be expected to improve conditions so far as bacterial and organic pollution is concerned, chemical pollution can be expected to reach the ground water along with percolating water. Therefore, proper location and operating practices that prevent supersaturation of a fill are essential, thus compounding the problem of the engineer out searching for new ground for landfill operations.

Hanks (53) in detailed and well-referenced report for the Solid Wastes Program of the U.S.P.H.S., under the topic of diseases associated with chemical wastes, cited several references on the pollution of ground water from the leachates of sanitary landfills. Numerous other references were cited on specific industrial waste materials, such as electroplating wastes, cyanide, chromium and other chemicals but insufficient data were presented to ascertain if the contamination occurred from typical landfill or dump ground operations or from the discharge of liquid wastes on or into the soil.

In the proceedings of a 1961 symposium (54), on ground water contamination, Weaver discussed the significance of refuse disposal in this regard. Much of the discussion makes reference to the California studies of Merz and others, but the following statement does provide an overview of the main problem.

> If leaching of a landfill does occur, it has been shown that the ground water in the immediate vicinity can become

grossly polluted and unfit for human or animal consumption or for industrial and irrigational use. Where essentially anaerobic conditions exist in a landfill, the decomposition of organic matter results in the formation of gases, principally methane, carbon dioxide, ammonia and hydrogen sulfide. . . . Carbon dioxide, due to its high solubility combines with water to form carbonic acid and will dissolve iron from tin cans and lime from calcareous materials and deposits. Chemically, the effects of carbon dioxide and ammonia are the most significant products of decomposition of organic matter in a landfill operation. Carbon dioxide increases the hardness of the water, and ammonia, on oxidation, increases its nitrate content.

Weaver also referred to a survey conducted by ASCE which found that 6% of the 200 replies from cities with Class A sanitary landfills had "water pollution" problems. Also, 27% operated fills wherein the depth of ground water was from 0 to 5 feet. The few cases investigated in more detail which had water pollution problems showed that the wells involved were quite shallow and in close proximity to the landfill site.

Regarding underground water pollution the ASCE reported (2):

> Although some apprehension has been expressed about the underground water supply pollution of sanitary landfills, there has been little, if any, experience to indicate that a properly located sanitary landfill will give rise to underground pollution problems.

Reference is also made to the California studies, and analyses of data on leachates obtained in New York and Illinois studies are cited to point out the potential danger. The latter work showed that seepage from sanitary fills had BOD values ranging from 170 to 5000 mg/l, coliform organisms to 9500 per ml, nitrogen and ammonia to 62 mg/l and iron to 52 mg/l. These data served as the impetus for the recommendation that drift wells should not be nearer than 500 feet to any landfill unless studies indicate that subsurface drainage will not occur. A summary statement on this topic is worth noting:

> . . . under certain geological conditions, there is a real potential danger of chemical and bacteriological pollution of ground water by sanitary landfills. Therefore, it is necessary that competent engineering advice be sought in determining the location of a sanitary landfill.

Walker (55) recently considered garbage disposal as one category of pollution:

> Serious contamination of the ground water reservoirs near these dumps (garbage dumps) can readily occur if the bottom of the depressions is below the water table, or if the earth material separating the dump from the aquifer is primarily silt, sand, or other relatively permeable material.

He presented two actual cases of pollution of ground water supplies traceable to leachates from garbage dumps. In the first case a garbage dump was located from 0.25 to 0.80 miles from a municipal well in a sand and gravel aquifer and it was also 10 to 20 feet higher than the well field elevation. Evidently, the leachate from the dump was intercepted by the cone of influence of the municipal well and caused a progressing increase in the hardness, sulfate and chloride content of the community's water. The second case resulted in the pollution of some 12 shallow domestic wells in a dolomite aquifer. The dump was located in the flood plain of a nearby river. The water from the wells became polluted with an inky black substance.

As part of the City of Santa Clara demonstration landfill study, Stone and Friedland (56) conducted a survey of American cities with populations greater than 10,000. They received replies concerning 120 landfill sites operated by 102 governmental agencies serving a combined population of 17,800,000. Ground pollution problems were reported at 11 of the sites or approximately 9 percent of the total 120 sites.

Williams (57) who discussed the overall topic of ground water pollution claimed that:

> Sanitary landfill seepage into sand or an overly deep excavation for a lagoon so that shallow subsurface water in the stream alluvium is intercepted, are two of the most common ways of polluting shallow ground water supplies.

An interesting case of the contamination of a ground water supply by an industrial waste occurred when a large company in the Minneapolis-St. Paul area dumped isopropyl ether in a disposal site for several years before it was realized that the industrial solvent contaminated the aquifer (58). The company had to spend $600,000 to remedy the situation.

Another example of how an industrial waste landfill can affect a public water supply is a case in Kansas City, Missouri, reported by Hopkins and Popalisky (59). The landfill which is located along the shore of the Missouri River and approximately one mile upstream from the water works intake had been used as a site for the disposal of industrial refuse from plastic operations, two major fiber glass operations, a large oil refinery, and a large automobile assembly plant. The landfill operation was closed in 1956 and reopened in 1969. After reopening the landfill, the operator used as cover material a mixture of partially decomposed refuse and soil and some of it got into the river. This material was found to be saturated with hydrocarbons, phenolic resins and other organic products from industrial waste that readily leached out when in contact with water. The chlorination of the treated water containing these compounds imparted a disagreeable "medicinal" or "iodine" taste and odor to the water. An important point to be learned from this experience is that even after 15 years of storage and "decomposition" certain wastes can still cause troublesome water pollution problems.

Two additional interesting publications should be noted at this point though they are not specifically addressed to the topic of ground water pollution from refuse decomposition on the land. One is concerned with the artificial recharge of aquifers with sewage treatment plant effluents and thus the principal item of concern is the fate of microorganisms, and organic and inorganic chemicals as the liquid passes through the subterrainean soil (60). The report includes a literature review on the subject and the conclusion was made that without doubt chemicals are expected to travel farther than bacteria. The values presented in Table 8 are excerpted from a summary table.

The second report (61) includes a comprehensive literature search including better than 700 references on the characteristics and status of knowledge on the various contaminants which can be found in ground water. This report can serve as a valuable reference when specific information is desired on the effects of a particular leachate chemical.

TABLE 8

Nature of Pollution	Pollutant	Observed Distance of Travel	Time of Travel
Industrial Wastes	Tar residues	197 feet	
	Picric acid	several miles	
Garbage leachings	Misc. leachings	1,476 feet	
Industrial wastes	Picric acid	3 miles	4-6 years
Industrial wastes in cooling ponds	Mn, Fe, Hardness	2,000 feet	
Garbage reduction plant	Ca, Mg, CO_2	500 feet	
Chemical Wastes	Misc. Chemicals	3-5 miles	
Industrial Wastes	Chromate	1,000 feet	3 years
	Phenol	1,800 feet	
	Phenol	150 feet	
Salt	Chlorides	200 feet	24 hours
Gasoline	Gasoline	2 miles	
Weed killer waste	Chemical	20 miles	6 months
Radioactive rubidium chloride	Radioactivity	--	5 days

Discussion of the Literature Findings

After some review of the literature on sanitary landfills one point becomes clear almost immediately: there are very few case histories of serious or even troublesome contamination of ground water which are directly attributable to the leachates from sanitary landfills. There may of course have been unpublished instances or unknown cases of people currently using water impaired in quality somewhat as the result of the land disposal of solid wastes. But the writer has not learned of a single person who has died as the result of ground water being contaminated by a landfill. Considering the number of landfills past and present and the amount and variety of solid wastes generated in our modern technological society, this is a remarkable situation. This statement is not made at the outset of this discussion to belittle the potential for serious harm to many people through this mechanism, nor to cast any aspersions on the fine research which has been and currently is still being done in this area. But, nonetheless, this point is most critical when considering recommendations for future action in this area, since it is this type of statistic which ultimately motivates action in any similar activity. For example, the greatest impetus for improved public water treatment and distribution works at the turn of the century was no doubt the 20 to 30 typhoid deaths per 100,000 per annum occurring at that time.

The above situation attests to the almost miraculous capability of most soils to attenuate the leachates generated from sanitary landfills. From the results of the literature there is no question that these concentrated leachates are of extremely high pollutional strength. There are few industrial waste flows that would match this material and without doubt no responsible governmental agency would tolerate the discharge of a material like this untreated into a surface body of water. There is an important difference in the subterranean regime, however. The soil provides the site for active microbial degradation of the organics which are present in the leachates. The inorganics are absorbed to the soil surface and many of the more undesirable ions are exchanged for the more desirable ones. The extremely low velocity of the underground water resource provides the necessary time for these activities to reach a fair degree of stabilization, thus confining most of the degradation processes to the immediate vicinity of the landfill. The soluble end products are attenuated even further by dilution in the sheer vastness of the underground water body. The highly soluble chloride ion provides a useful tracer for the situation described above. In most of the research studeis examined, the chloride concentration in the leachate directly below the landfill was always extremely high. The chloride concentration dropped drastically in water samples taken only a short distance from the landfill operation. At distances of several hundred feet the concentration drops down to almost native or background levels.

Unfortunately the described process does not hold true to the same degree for all geological formations, and therein lies the crux of the problem. The above will usually hold true for unconsolidated formations consisting of varying proportions of clay, silt, fine sand and loam with low to medium permeabilities. For unconsolidated materials of coarse sand and gravels with high permeabilities or consolidated materials such as limestone or shale with fissures, faults or fractures of any kind, the protective mechanism breaks down because of one important reason, that is, time. In formations of the latter type there is much less time available for the degradation process to take place within the vicinity of leachate generation because the underground velocities are much higher. Thus partially "treated" and poorly diluted leachates can appear at greater distances from the landfill. The assumption made here is that the ground water flow is through and away from the landfill site. If all flow lines are directed toward the site this situation will not necessarily occur and what probably will happen is that the ground water will discharge at the surface somewhere nearby. Such a situation could then have a deleterious effect on the surface supply.

It is convenient to think of a mass of refuse stored in a landfill site as representing a certain mass or quantity of pollutants. Some of the researchers have in fact done just this when they express specific leachate constituents in terms of weight per cubic yard or per ton of deposited refuse. This mass of pollutants will eventually be generated from the landfill, since the processes of weathering and biological degradation always take place. The important variable again is time. In order to speed up the degradation and weathering process moisture and favorable temperature are necessary. Usually temperature is not a restricting factor even in northern latitudes since the interior of the refuse mass is insulated from the ambient temperature and the degradation process is exothermic in character. Available moisture then becomes the limiting factor. Rapid degradation will occur in a more loosely packed landfill where surface waters are permitted to percolate freely through the refuse. The degradation process can be slowed up considerably by allowing less surface water to pass through the fill. It is virtually impossible to abate this activity completely. Obviously if the degradation process is retarded by restricting passage of water in any way, more time will be allowed for the natural attenuation process to take place beyond the landfill site. A combination of retarded degradation in a geologic formation of ideal attenuation provides the least likelihood of serious ground water deterioration. Speeding up the degradation process imposes a greater load on the surrounding geologic formation; and if the geologic formation is a poor one, the problem is compounded. Again it must be remembered that the same pollutional mass is involved in both cases.

It is possible to engineer and operate a landfill with the intent of minimizing the amount of percolation through the deposited material. Bottom liners of various types, high degree of refuse compaction, shredding, and highly impervious earth covers are examples of what can be done. These measures would, on the other hand, be highly ineffective in situations where the moisture sources originates from below the landfill. There is no question that in areas where wide fluctuations in the ground water table occur to the point where the refuse becomes repeatedly saturated with water and then drained, the degradation process is intensified to probably its optimum level. If the attenuation capability of the geologic formation surrounding this site is limited, a situation again exists for serious pollution of the ground water.

Some in the field of solid waste disposal argue that a landfill should be designed for optimum degradation and weathering to occur. This means that an ample amount of water should be permitted to percolate through the fill. It also means that the leachates must then be collected in a drain system and treated prior to discharge to a surface water body or possibly back through the fill. After a reasonable degree of stabilization has occurred the leachates will no longer be collected in the drain system but allowed to pass into the surrounding soil. In this way they argue that the degradation process can be controlled as desired and the possibility of future pollution problems are reduced considerably. Some for example argue that huge quantities of stored refuse located in the earth close to large population centers are akin to geologic pollutional "time bombs" which could be very troublesome to future generations. There is no doubt that landfill sites can be engineered to speed up the degradation process and collect and treat the leachate. However, the economics of this arrangement may favor other disposal methods which relative to traditional landfills were formerly considered too expensive.

Another point becomes quite apparent after reviewing the literature in this area. Much more geologic, or more specifically, hydrogeologic expertise should be employed prior to the selection of a landfill site. Someone with training in hydrogeology can establish with a fair degree of accuracy upon an examination of the site and often with a limited amount of field testing what the leachate attenuation potential of a site will be and if the cover material will permit a slow or rapid percolation of water into the fill. Too many landfill sites are selected on a purely political, economic or convenience basis with no or little attention given the geology of the site. It is surprising that regulatory agencies have been somewhat lax in this regard, also. The writer is convinced that attention to this matter alone will minimize many future problems of ground water pollution attributed to landfills.

The major threat to ground water quality in the future will likely be from the land disposal of industrial wastes. Many of these wastes are non-degradable which means the protective mechanism of attenuation afforded by the soil is no longer available. Many industrial wastes can import odor, taste and even toxic problems to ground waters at extremely low concentrations. With advances in technology and the increase in over-all affluence there will undoubtedly be an increase in the amount and complexity of solid industrial wastes produced. Many new compounds will also be synthesized in the future which will pose either acute or chronic threats to the well-being of future users of ground water. The present trend toward more stringent surface water quality standards will cause some industries to look toward land disposal for the solution to their industrial waste problems. It is important to keep in mind in this regard that much empirical evidence is available to substantiate the generally innocuous effects to humans resulting from the decomposition of ordinary municipal refuse in the ground. On the other hand, practically each new solid industrial waste completely nullifies the dependence on this past evidence as the primary basis for establishing guidelines to dispose of this particular waste. For this reason alone it is imperative that extreme caution be exercised in the land disposal of all solid industrial wastes in the future.

Following a critical review of the literature dealing with the ground water pollution from sanitary landfills and dump grounds, one writer editorialized (62):

> There has been some fears that our present methods of refuse disposal, as landfills, may seriously contaminate ground waters. While this is always possible under certain conditions, it must be remembered that refuse dumps, which have existed from time immemorial have not often been proved at fault in this respect. The construction of the landfill, with a cover of earth to shed water, provides an added degree of protection through reduction of rain water seepage through the mass. Nevertheless, we feel that research on this and other phases of sanitary landfills is desirable. In addition to ground water contamination studies, we suggest investigation of surface water pollution; and perhaps a study aimed at developing an additive which will hasten a composting and stabilizing process within the fill.

PART II

SURVEY OF TWENTY-ONE STATES CONCERNING LANDFILL PRACTICES AND RELATED GROUND WATER POLLUTION PROBLEMS

As a means of becoming acquainted with the numerous problems associated with ground water pollution from disposal of solid wastes, a survey of the activities and policies related to this area in twenty-one of the states in the U.S. was conducted. The states selected comprise a total present population of approximately 140,000,000 which amounts to 70 percent of the U.S. population. The basis for selection was somewhat arbitrary, but the list was intended to include the larger states, states in the mid-western part of the country and states in which it was known that some activity in this area was taking place.

Letters were sent in June, 1969 to the regulatory officials known to be familiar with the solid waste practices within their particular state. The letters first explained the reasons for the information requested and specifically solicited comments on the following four questions:

1. Are you aware of any research activities in your state that are concerned with ground water pollution from sanitary landfill and open dump type of operation? If so, what are they? Are research reports available?

2. Does your state have published codes or guidelines regarding site selection for sanitary landfills and dump grounds? Do you have regulations pretaining to the operation of such areas? We would appreciate receiving such published information.

3. Does your state specify a minimum distance that a water well can be located from a landfill or dump ground?

4. Do you anticipate that your state will be engaged in some aspect of this question in the immediate future, such as writing new or revising old codes, field research programs, etc.?

A complete copy of the letter which was sent plus a list of the regulatory officials who responded are presented in Appendixes A and B, respectively.

Most of the officials responded to the letter within several weeks after it was sent. Several who had not responded within that time period were contacted directly by telephone and the necessary information was obtained verbally or received shortly after the telephone contact. The replies varied in the detail of information supplied, from one case in which the short replies were written directly on the original letter, to several cases in which the responding officials sent numerous codes, laws and research reports. The information received was examined with essentially one objective in mind: how do the solid waste disposal practices employed within the state influence or affect the ground water quality? No attempt was made to present a complete analysis of the solid waste collection and disposal practices in general but only limited reference to ground water pollution potential specifically.

The discussion which follows is a review of the solid wastes practices employed in the twenty-one states which are related to ground water pollution potential. Since most of this information is taken out of lengthy laws, regulations and similar documents the preciseness of their intent may be lost or distorted in the editing process. The intention of this review is to present a general idea or concept, and if more specific interpretating is required, the reader is urged to examine the actual document.

The discussion of each state's practice is divided into four sections: (1) research activities, (2) published codes or standards, (3) landfill to water well distance, and (4) future state activities. These sections essentially cover the responses to the four questions included in the original letter to the state.

SURVEY OF STATE PRACTICES

California

Research Activities

California has been, and is probably currently, the state carrying on the most research activities in the general area of ground water pollution from landfills and refuse dump grounds. Current reported research activities includes a study entitled, "Development of Construction and Use Criteria for Sanitary Landfills" which is being conducted by the Los Angeles County Department of County Engineer with Engineering-Science, Inc. as the contractor. Involved in this study has been the evaluation of gas movement from landfills, and literature and data research on the possibility of ground water quality impairment from landfills. The first annual report to the U.S. Public Health Service published in October, 1968 is available.

Professor R. C. Merz of the University of Southern California is also conducting special studies on landfills. These studies primarily involve measurement of the quantity of gases produced in landfills. Several reports and published articles are available from the Department of Civil Engineering of the University of Southern California.

Finally, as part of the state Solid Wastes Planning Study and the activities involving solid waste and water quality, information relating to the water quality aspects of solid wastes has been assembled. These include an annotated bibliography for solid waste disposal and water quality and a summary of the solid waste and water quality studies under way in the United States.

Published Codes or Standards

Presently, the only type of code or guideline regarding the site selection for landfills is the waste discharge requirements administered by the nine Regional Water Quality Control Boards in the state. Most of the boards have adopted a policy which classifies disposal sites into three categories and which also limits the type of wastes which may be disposed of in each category of disposal site. The format of these policies varies for each regional board, but essentially two variations exist ranging from a brief policy description to a detailed definition of the classification procedure. An example of one such policy statement of the brief format type, namely that of the Central Valley Regional Water Quality Control Board, presenting a classification of solid waste disposal sites follows:

(1) Class I Sites: Sites located on formations through which no appreciable seepage to usable waters can occur, or underlain by isolated bodies of usable ground water, and which are protected from flooding and surface runoff and where waste materials and all internal surface drainage can be restricted to the site.

Materials: No limitations.

(2) Class II Sites: Sites underlain by usable ground water where the minimum elevation of wastes can be maintained above the maximum anticipated capillary fringe and which are protected from flooding and where surface drainage can be controlled and discharged without creating pollution or nuisance conditions.

Materials: Limited to ordinary household and commercial refuse, garbage, other decomposable organic materials, scrap metals, and solid inert materials.

(3) Class III Sites: Sites located as to afford little or no protection to usable waters of the state.

Materials: Limited to solid inert materials.

The Board provides a fairly detailed list of typical wastes acceptable for disposal at each class of disposal site. An interesting inclusion under Class II Disposal Sites for example, is sewage treatment residue including solids from screens and grit chambers, sludge, and septic tank pumpings. The Board is currently working on a more detailed policy which will be adopted in the near future.

The Lahontan Regional Water Quality Control Board, on September 25, 1969, adopted a new policy regarding the disposal of solid wastes which is much more detailed than the policies of the other California regional boards. The policy first presents a classification of wastes into Group 1 (any type of solid waste including dangerous and toxic materials), Group 2 (ordinary household and commercial refuse, decomposable organic waste, and solid waste mixtures containing decomposable organic material), and Group 3 (non-water soluble, non-decomposable inert solids). This is followed by a detailed classification of disposal sites based on such characteristics of the disposal site as geology, ground water hydrology, and topography. Class I sites provide the maximum degree of protection for area ground and surface waters and thus are unlimited as to solid waste group; Class II sites do not provide complete protection and are restricted to Group 1 and 2 wastes with some reservations; finally Class III sites afford little or no protection to surface and ground waters and are restricted to Group 3 wastes only.

Prior to the selection of a landfill disposal site, the developer must submit to the Lahontan Board detailed information concerning the plan of development, wastes to be discharged, geology, ground water hydrology and topography. Included in the geology and hydrology data requested is liquid and gas permeability of the soil, location of ground water bodies, ground water quality, highest anticipated ground water level among other things. Regarding the operation of the solid waste disposal site the Board states flatly, "There shall be no degradation of the quality of any usable surface or ground water due to the disposal of solid wastes on land."

Landfill to Water Well Distance

The state does not specify a minimum distance that a water well can be located from a landfill. There are instances where wells are located on the landfill site adjacent to filled areas. Usually these wells are used to monitor the quality of the underlying ground water in addition to being a source of water supply for the landfill. In locating a new landfill site, considerable evaluation is made of the location of existing wells and the potential effect of the landfill on the quality of water pumped by these wells.

Future State Activities

It is anticipated that as part of its solid waste planning activities, the state will become more involved in the control of solid waste management and the coordination of solid waste activities at the state level. A part of this future program will be the development of criteria for disposal site locations and standards for site operation. Also, it is likely that the state will continue to be involved in studies of solid wastes and water quality such as those that were sponsored by the State Water Quality Control Board (now the State Water Resources Control Board).

Florida

Research Activities

No specific research projects are now being conducted in the state regarding this problem. Because Florida has one of the lowest elevations in the nation and thus problems relating to ground water pollution are considered to be greater than in most other states, considerable investigative work including test borings, etc. is made preliminary to any approval of new landfill sites.

Published Codes or Standards

Rules of the State Board of Health, the Sanitary Code of Florida (Chapter 170C-10) entitled, "Garbage and Rubbish" includes some directives pertaining to landfill site selection. A general statement is made that:

> . . . . garbage and other solid wastes shall not be disposed of by being placed in any natural or artificial body of water or on the watershed of any surface public water supply; nor within one-half mile of any habitation or place of business where it may become a sanitary nuisance or menance to health through the breeding of flies and/or harboring of rodents; nor shall such material be dumped on or upon public highway, road or alley of the state or within one-half mile of such public highway, road or alley or other place except when said material has been rendered completely stable by a process approved by the board.

No specific mention is made of potential ground water pollution problems in site selections. Briefly the location of landfill sites must first be approved by county health officials and the state board will review the prospective plan and make necessary field investigations before any final approval is given. Regarding operation of landfills the requirement is made that when working in watered areas the trench or pit should be kept de-watered during operating periods.

Landfill to Water Well Distance

The code cited above makes a general reference to distance in the use of the term "watershed". The code relating to water supplies specifies that wells should be a minimum of 100 feet from septic tanks and similar pollution sources. The state officials feel the distance should be increased.

Future State Activities

The state is planning to revise the present code to provide new, more stringent and concise regulations. These revisions are a part of the development of a state plan for solid waste management which follows a statewide survey of solid waste practices conducted in cooperation with the federal government's Bureau of Solid Waste Management.

Illinois

Research Activities

The Illinois State Geological Survey and Water Survey has been actively engaged in research dealing with ground water pollution from the land disposal of both municipal and industrial wastes. These studies are concerned with the effect of geologic features on leachate travel and the development of rational criteria for the proper selection of disposal sites.

Published Codes or Standards

In March, 1966, the State of Illinois, Division of Sanitary Engineering adopted, "Rules and Regulations for Refuse Disposal Sites and Facilities" which states among other things that before landfill sites are approved, maps showing topographical features and other information including all pertinent information to indicate clearly the soil characteristics, water table, etc. must be submitted for review. In addition, before final approval is granted the subsurface structure shall be such that there is reasonable assurance that the leachates from the landfill will not contaminate the ground water or streams in the area, or that suitable procedures to prevent such contamination will be followed. The provision is also made that high ground water tables may be restricted to landfill operation which will maintain a safe vertical distance between deposited refuse and the maximum water table elevation. If refuse is to be deposited within or near the maximum water table, corrective or preventive measures which will prevent contamination of the ground water stratum are to be taken. Monitoring facilities may also be required. The area around the landfill site must be graded such that surface runoff will not flow into or through the operational or completed area. Regarding the deposition of sewage solids or liquids, septic tank pumpings and other liquids or hazardous substances to landfill, the rule states that written permission must first be obtained from the Department of Health.

The Division of Sanitary Engineering also published a pamphlet entitled, "Suggested Minimum Requirements for Sanitary Landfill Operations" which was written as a guide for landfill operators and which includes the salient features of the Division's rules presented above. In the discussion of site selection it is suggested that where practical a minimum of 30 feet clayey till overburden should be present between rock strata and refuse deposits. Further, refuse should not be placed in mines or other places where resulting seepage or leachate may carry waste to water bearing strata or surface water courses. Finally it is stressed that the Department of Public Health be consulted prior to site selection regarding the possibility of underground pollution.

Landfill to Water Well Distance

Drift wells should not be located closer than 300 feet to any landfill and where the minimum overburden does not exist (quarries, pits, etc.), distance to location of wells in general should be greater as determined by local health authorities.

Future State Activities

It is expected that the State Geological and Water Survey will continue their interest in the area of ground water pollution potential from sanitary landfills.

Indiana

Research Activities

None.

Published Codes or Standards

The Indiana State Board of Health in August, 1968 published a "Manual for Storage, Collection and Sanitary Landfill Disposal of Refuse" to be used as a guide by individuals and communities concerned with the disposal of solid wastes. Suggestions are made that borings and test pits would be helpful to obtain information on soil types and ground water elevations, that refuse should not be placed in standing water, and that surface and ground water pollution can be avoided by applying engineering practices to the location and operation of the landfill.

In October, 1968 the State Board of Health also published "Standards for the Selection, Operation and Maintenance of a Sanitary Landfill " The specifications included in the standards are considered to be minimum ones for the selection and operation of landfill sites. Under location it is stated that landfill sites should be at least 100 yards from any industrial building and 200 yards from any dwelling. Soil with good drainage characteristics and generally free of rock formations within 4 feet of the ground surface are considered satisfactory sites for landfills. Landfills must only be located when surface drainage can be controlled and never in standing water or areas where springs exist. Landfills must not be located in areas where leachates, chemicals or other hazardous material will contaminate the ground waters. Finally a landfill is not to be established in areas containing sand, gravel, or rock as a major portion of the soil composition when wells in the vicinity of the landfill site are used for a source of water supply.

Landfill to Water Well Distance

None specified.

Future State Activities

Acts have been recently passed by General Assembly of the state concerning solid waste disposal but none pertain to the ground water pollution problem.

Iowa

Research Activities

None.

Published Codes or Standards

The Iowa State Department of Health, Environmental Engineering Service published "Guide Policies Relating to Municipal Refuse Disposal" which includes a statement that the site of every sanitary landfill shall be such that no pollution of surface waters used as a source of potable supply in the vicinity will result from run-off or seepage.

Landfill to Water Well Distance

No specific distance is regidly followed since each case is considered separately. Approximate guidelines which are used are that sanitary landfills, like sewage treatment plants, should be at least 1200 feet from any residence, and that wells should not be located any closer than 200 feet from landfills.

Future State Activities

Future legislation pertaining to landfills is not anticipated at the present time. However the state passed recent (April 10, 1969) air pollution control regulations which may indirectly affect the landfill operation. Open burning of refuse is no longer permitted in the state which means that all the refuse must now be buried.

Kansas

Research Activities

Some work is being done by the University of Kansas in which ground water is being monitored along river flood plains. The ground water is also being monitored at a refuse dump site near Wichita.

Published Codes or Standards

At the present time the state does not have a standard pertaining to the location of landfill sites. A law is currently being written which will include a policy for the state approval landfill sites.

Landfill to Water Well Distance

No specific distance between wells and landfill sites is specified by the state. This comes under the responsibility of the local community and some do have guideline distances.

Future State Activities

A new law is currently pending (House Bill No. 1141) which is modelled after the Pennsylvania law and calls for the formation of an advisory committee for the purpose of recommending to the state a set of rules, regulations, standards and procedures for solid waste storage, collection, transportation, processing and disposal within the state. It will also require that by January 1, 1972 a permit will be required from the Department of Health to carry on any solid waste processing or disposal activity and that the department will have the power to intercede if such activities cause pollution of the land, air or waters of the state, or is creating a public nuisance.

Maryland

Research Activities

Except for the studies dealing with a strip mine sanitary landfill, no other research activities in the state are concerned directly with ground water pollution from sanitary landfills. One of the objectives of this study is to determine whether special precautions are needed to prevent ground or surface water pollution caused by water leaching through the fill. As a part of the study acid mine water will be passed through an experimental bed consisting of 6 feet of refuse and the chemical characteristics of the feed water and leachate will be monitored.

Published Codes or Standards

The State Department of Health has regulations governing the submission of plans for refuse disposal sites which requires the location of streams and water courses of occupied property on location maps, but no reference is made to ground water or geologic features of the site. The State Department of Health under Article 43 of the Code of Maryland has however broad powers regulating the pollution from any source of waters of the state which includes ground water.

The Department's Division of Solid Wastes published in June, 1969 a procedure for the approval of sanitary landfill operations. Phase I of the procedure provides for a preliminary site investigation by all interested state agencies. Following approval, Phase II commences which provides for a surface and subsurface water sampling program by the department. Also the applicant must supply such hydrogeologic information as location, depth and type of underground water sources, methods for the prevention of surface and subsurface water pollution, soil borings including type and depth of bed rock, and finally, a piezometric map showing the seasonally high water table. The final phases provide for appeal mechanism if the site is not approved and monitoring provisions with powers to make operational charges for sites which are finally approved.

Landfill to Water Well Distance

An informational pamphlet by the Division of Sanitary Engineering notes that sanitary landfills should not be located where springs exist, should be at least 500 feet away from any well, and should be placed far enough away from streams so that leaching from the compacted refuse will not cause a nuisance or stream pollution. However state officials consider this to be an arbitrary figure and it is not really enforced. Where problems might develop, the requirement is made that test wells be placed at or very near the landfill site.

Future State Activities

At the present time it is not anticipated that any revision of existing codes or regulations will be made. An attempt will be made to make necessary adjustments as new information becomes available.

Massachusetts

Research Activities

None. A few master's theses have been written in the general area in the past at some of the universities in the state.

Published Codes or Standards

Generally the responsibility for the location of landfills and dump grounds falls on the local health boards. Anytime within sixty days after the site has been put into operation, the State Board may intervene and make revisions if necessary in the site location. The State Board can become involved at any time if nuisance or public health problems develop, as for example, ground water pollution. These requirements which assign most of the responsibility to the local community are contained in Section 150 of Chapter 111 of the General Laws of the State. No specific reference is made to ground water pollution problems in these laws except possibly indirectly in the requirement that landfills be located more than 300 feet from any dwelling house and that public health be protected at all times during the operation of these facilities.

Landfill to Water Well Distance

The minimum distance between a well and landfill employed by the state at the present time is 400 feet although this figure does not appear in any state law or regulation.

Future State Activities

A complete revision of the law governing landfills is currently under way and it is expected that the law will be adopted some time during the fall of 1969. The new law will increase the power of the state in the selection and operation of landfill sites.

Michigan

Research Activities

None. Information is available in a number of situations where refuse deposited directly into ground water and surface water has resulted in a pollutional problem.

Published Codes or Standards

Act 87 of the Public Acts of 1965 of the state requires that all sites for the disposal of refuse must be licensed and inspected by the Department of Public Health. The design submitted to the state must include among other things all pertinent information to indicate clearly the soil characteristics and water table. Geological characteristics of the site are to be determined by on-site testing or from earlier reliable survey data to indicate soil conditions, water tables and subsurface characteristics. A general statement is included which states that landfill operations shall be so designed and operated that conditions of unlawful pollution will not be created and injury to ground and surface waters avoided which might interfere with legitimate water uses. For example, hazardous materials, including liquids and sewage are not to be disposed of in a landfill unless special provisions are made for such disposal through the local health department. Further, the entire site, including the fill surface shall be graded and provided with drainage facilities to minimize runoff onto and into the fill to prevent erosion or washing of the fill, to drain off rainwater falling on the fill, and to prevent the collection of standing water.

Landfill to Water Well Distance

The policy has been to require that water wells be located at least 200 feet from landfills under normal conditions, but if the geological data from the area in question suggest additional protection should be provided, the distance is increased accordingly.

Future State Activities

It is expected that some changes will be made in the regulation governing solid waste disposal and protection of ground and surface waters in the not too distant future. One requirement at the present time is a minimum of 2 feet of inert material be placed above the high water table at a disposal site. It is suggested that this figure be increased to 5 feet with a minimum of 2 feet of impervious material between the base of the fill and the high water table.

In a future law greater authority will be requested over the discharge of liquid industrial wastes. The construction of liquid waste incinerators will be promoted since present installations are felt to be successful.

Proper grading during landfill operations and following their completion will continue to be stressed. In a number of instances the department has required the installation of peripheral gravity drains on a landfill site to eliminate the lateral movement of water into a filled area with satisfactory results.

Minnesota

Research Activities

None.

Published Codes or Standards

On August 5, 1968 the Pollution Control Agency, Division of Solid Waste published a statement on recommended land disposal site practices for the express purpose of protecting the surface and underground waters of the state from pollution by refuse or other wastes or solid materials of a pollutional nature. An ideal site for a landfill is described as one above flood levels, far removed from lakes, wells or drainage courses, and having a substantial depth of relatively impervious surface soil above the ground water table. Included under undesirable areas are areas adjacent to, and which drain to, lakes or streams; areas where water is present at or near the surface, such as sloughs or swamps; areas near municipal or private supplies, either surface or underground.

The Control Agency must approve all landfill operations and such approval may be contingent on the inclusion of certain safeguards among which is included ground and surface water protection.

It is further recommended that sites not be used in a location where runoff from the site itself may enter underground water aquifers. Areas of very pervious soil or fragmented rock formations which either reach the surface or lie close to the surface should be avoided, otherwise artificial sealing of the bottom of the site with such materials as clay, bentonite, asphalt, synthetic mats, etc. may be required to prevent percolation of contaminated runoff and leach waters into the underground formations. In some cases, construction of special wells or drains may be necessary to permit sampling and analysis of the waters surrounding the site. If the ground water is high the use of the site may be limited to those parts well above the water table. Deposition of refuse or other materials at depths normally subject to leaching or movement of ground water is not recommended.

Plans which are submitted should include information on soil conditions and ground water level in the area, in addition to details of any structures necessary to guard against pollution of surface or underground waters.

Landfill to Water Well Distance

No specific distance, since each situation is considered individually.

Future State Activities

The Pollution Control Agency is currently in the process of drafting a proposed set of standards for solid waste disposal modeled somewhat after the recently promulgated Wisconsin standards.

Missouri

Research Activities

None.

Published Codes and Standards

The Missouri Division of Health of the Department of Public Health and Welfare has available a set of guidelines called, "Rules and Regulations Governing Refuse Disposal Areas" which provides that the location of a disposal area shall be such as to not endanger potable water supplies and shall be a sufficient distance from dwellings, commercial establishments and places of public assembly so as not to create a nuisance. No specific reference is made to possible ground water pollution problems in the discussion on landfill operations.

Landfill to Water Well Distance

The Division of Health recommends a distance of 100 feet between a disposal area and a drilled well which has been cased and sealed to the depth recommended by the Missouri Division of Geological Survey and Water Resources. A much greater distance is required where shallow water formations are utilized and it is not possible to case and seal the well to the depth of an impervious formation. Under such conditions the policy has been to review each individual case and make recommendations after an on-site investigation and evaluation of geological information.

Future State Activities

The Division of Health is presently conducting a solid waste planning study. As a result of this study it is expected that some revisions will be made of regulations governing landfills from the standpoint of potential ground and surface water pollution. No field research programs are being planned for the immediate future.

New Jersey

Research Activities

None.

Published Codes and Standards

New Jersey regulates its sanitary landfills through enforcement of Chapter VIII of the State Sanitary Code, adopted June 11, 1962. The Code first prohibits the use of open dumps and then gives approbation to sanitary landfill as an acceptable disposal procedure. The Code provides that the location or site of a sanitary landfill should be chosen with the approval of the local board of health. No specific measures are suggested for the prevention of ground water pollution from landfill operation.

Landfill to Water Well Distance

The state does not specify a minimum distance that a potable water well can be located from a landfill operation.

Future State Activities

Chapter VIII of the State Sanitary Code is currently in the process of being revised. The new revision will contain specific references to surface and ground water pollution problems.

An effort is also being made to obtain the necessary funds to undertake an engineering study related to the problem of pollution of ground waters from landfills.

New York

Research Activities

No research studies are currently underway though evidence is available that poor design of sanitary landfills has been a major cause of pollution. The Department of Health is of the opinion that a properly designed, operated and maintained sanitary landfill should not cause any significant ground water pollution.

Published Codes and Standards

The New York State Department of Health has published a pamphlet in 1969 entitled, "Sanitary Landfill--Planning, Design, Operation and Maintenance," which describes in detail the State Sanitary Code on refuse disposal and also provides much useful landfill design information. All landfill operations must be approved by the local health officer, who must be satisfied that the operation will not constitute a nuisance or hazard to public health.

Regarding the selection of a landfill site, the requirement is made that the location of bedrock, the ground water table and finished grade must be determined. Test borings or test holes over the area under consideration may be required. The location of bedrock and the highest ground water table is of utmost importance in planning for a refuse disposal area, and the bottom of sanitary landfills must be well above the high ground water level and bedrock.

In order to prevent ground water pollution it is suggested that mixed refuse be placed no deeper than 3 to 5 feet above the ground water table and bedrock. If refuse is placed below the ground water table, or directly on bedrock, serious pollution of the ground water can result. This pollution will mainly be the result of leachings from the refuse in contact with water and the transfer of gases such as carbon dioxide, methane, hydrogen sulfide, nitrogen and ammonia, by diffusion and convection, which are produced during refuse decomposition. The substances most likely to prove objectionable are hardness, iron, nitrate and total dissolved solids.

The pamphlet suggests further that proper surface must be provided around a landfill site in order to, among other reasons, prevent the rapid travel of dissolved organics and chemical pollutants through the refuse to the ground water table. Also sites should be at least 200 feet from the streams, lakes or other bodies of water. If a geological and hydrogeological study is made and special arrangements are made to contain and prevent the travel of pollution, a lesser distance may be used if acceptable to the Health Department.

Finally, the disposal of certain industrial wastes and scavenger wastes at a sanitary landfill must take into account possible ground water and surface water protection. Industrial wastes which introduce hazards, such as toxicity, explosion and flammability must be evaluated and adequate protection provided.

Landfill to Water Well Distance

No specified distance. The general guideline is that landfill sites should be operated such that ground water supplies are not polluted.

Future State Activities

A number of studies are currently under consideration to monitor existing and new sanitary landfills.

North Dakota

Research Activities

None.

Published Codes and Standards

None.

Landfill to Water Well Distance

All public wells must be a minimum of 100 feet from sources of contamination whereas the minimum for private wells is 50 feet. No distinction is made between different sources of contamination.

Future State Activities

A new state code pertaining to the disposal of solid wastes will become available the early part of 1970.

Ohio

Research Activities

While the state is not currently involved in a formal research program, some water quality monitoring programs have been initiated at landfill sites. At one sanitary landfill used for a small volume of dry industrial and residential waste plus some paint wastes, a stream receiving surface runoff from the site is monitored monthly. The COD of the stream varied from 20 to over 3000 mg/l with a definite correlation between method of operation and magnitude of COD.

Changes in ground water characteristics are also being checked at a city-operated sanitary landfill located directly over a gravel deposit. No changes have been noted following 5 months of testing.

Published Codes and Standards

The State of Ohio adopted a revised Code relative to the disposal of solid wastes which became effective December 14, 1967. The purpose of the revised Code is to provide "...regulations having uniform application through the state governing solid waste disposal sites and facilities and the inspections and issuance of licenses for all solid waste disposal sites and facilities in order to assure that such sites and facilities will be located, maintained, and operated in a sanitary manner so as not to create a nuisance cause or contribute to water pollution, or create a health hazard."

Under the authority of this Code, the Department of Health Public Health Council, has issued a set of regulations which states that disposal sites and facilities shall not be located in areas where they constitute a hazard to the quality of the ground water or surface water resources. Further, solid wastes cannot be disposed of in any ditch, stream, river, lake, pond, or other water course, except those waters which do not combine or effect a junction with natural surface or underground waters. Plans and other pertinent information on landfill sites must be submitted for approval. Sewage solids and liquids, and other liquids or hazardous substances are not to be included with the usual municipal solid wastes but deposited in areas approved by the Department of Health.

Prior to licensing of landfill sites, the Ohio Department of Health sends out an application form which requests information indicating soil conditions, depth to rock and depth to maximum elevation of ground water saturation of proposed landfill sites. Also requested is the number of wells within 1000 ft., 1500 ft., and 2000 ft. of the landfill area. When deemed necessary the assistance of state geologists is solicited regarding the possible ground water and surface water pollution of a disposal site.

Landfill to Water Well Distance

The state requires a minimum distance of 100 ft. from a well to a source of contamination for semi-public water supply wells, and 300 ft. for municipal water supplies.

Future State Activities

No specific plans.

Oklahoma

Research Activities

None.

Published Codes and Standards

None.

Landfill to Water Well Distance

In the regulations governing the installation of ground water wells, it is stipulated that a public well must be at least 50 feet from a source of pollution. This figure is used guardedly when applied to landfill situations.

Future State Activities

The state is presently in the process of preparing standards and regulations pertaining to the disposal of solid wastes.

Pennsylvania

Research Activities

The state soil scientist and geologist are in the process of preparing contracts to have monitoring wells drilled at several landfill sites with different geological features to determine what effect if any these landfills are having on ground water quality. It is expected that samples will be collected for several years. Also, the Drexel Institute of Technology is undertaking the study of solid waste leachates and their effect on ground water.

Published Codes and Standards

In August, 1968, the Commonwealth of Pennsylvania passed the Solid Waste Management Act to provide for the planning and regulation of solid waste storage, collection, transportation, processing and disposal systems; requiring municipalities to submit plans for solid waste management systems in their jurisdiction; and authorizing grants to municipalities among other things. The Act states further that every plan for solid waste management system or systems shall insure that the pollution of waters and air not occur. In general the act encourages an area-wide approach to the disposal of solid wastes.

Landfill to Water Well Distance

No specified instances.

Future State Activities

The state is working on sanitary landfill guidelines and standards at the present time.

South Dakota

Research Activities

Probably some of the most extensive monitoring of ground water quality in the vicinity of a land disposal site in the country has been and is still being conducted just outside of Brookings, South Dakota. This work, which has been in progress for approximately 10 years, is under the direction of two investigators from the State University of South Dakota, namely J. Andersen and J. Dornbush. The results of this work have been published in numerous reports and graduate theses as well as the technical literature. No other research work is being conducted in the state covering this area of study.

Published Codes and Standards

Detailed guidelines and regulations are not currently promulgated by the state regarding the selection and operation of solid waste disposal sites. The State Department of Health has regulations requiring that all new disposal sites be approved prior to use. Plans and specifications for the site must be submitted to the Department. No specific mention is made to ground water pollution in the regulations. However, the problem of potential ground water pollution has been encountered in the past and thus the Department often contains the recommendation of the State Geological Survey for site location with respect to possible water pollution.

Landfill to Water Well Distance

No specified instances.

Future State Activities

The State is currently in the process of preparing site selection criteria and guidelines for the operation of disposal sites.

Texas

Research Activities

None.

Published Codes and Standards

In December, 1963 the Texas State Board of Health approved "Rules and Standards" regulating the disposal of solid wastes. The regulations state that the operator of a disposal site which is located nearer than 300 yards from a public highway must among other things furnish satisfactory evidence to the Department of Health that geological characteristics have been adequately investigated. Special provisions for the disposal of hazardous materials are also recommended, but for the protection of the employees on the site, rather than for the potential of ground water pollution. Finally provisions are included covering drainage requirements to minimize surface water runoff onto, into and off the treatment area.

The State of Texas Sanitation and Health Protection Law enacted in 1945 includes a general reference to the relationship between ground water pollution and refuse disposal: "No waste products, offal, polluting material, spent chemicals, liquors, brines or other wastes of any kind shall be stored, deposited or disposed of in any manner as may cause the pollution of the surrounding land or the contamination of the well waters to the extent of endangering the public health."

Landfill to Water Well Distance

The Department of Health requires that no water well shall be located within 500 feet of dump grounds or sanitary landfills.

Future State Activities

While no specific research projects are planned at the present time, the State Legislature has given the Department of Health greater responsibilities in the area of solid wastes. New rules and regulations are being developed for all phases of solid waste disposal.

Washington

Research Activities

None. Preliminary work has started in Clark County to determine if a sanitary landfill in the old river bed of the Columbia River is in fact contaminating wells geologically downstream from the disposal site. In addition, there is a proposal being studied at this time by the City of Seattle to identify and treat leachates from their sanitary landfill.

Published Codes and Standards

None.

Landfill to Water Well Distance

In the guidelines for the location of wells, the recommendation is made that a well be no closer than 100 feet to any source of contamination.

Future State Activities

At the present time the Department of Health is developing model rules and regulations covering the topic of solid waste disposal.

Wisconsin

Research Activities

The City of Madison has recently completed a three-year study financed partly by a federal demonstration grant directed principally toward the feasibility of milling solid wastes for the purpose of extending the life of a sanitary landfill. Among other things, the study considered the influence of milling on leaching rates and gas production from the landfill.

The City of Madison has also been supporting a hydrogeological study of two existing sanitary landfills in the Madison area. This study, which is under the direction of the Geology Department of the University of Wisconsin, is concerned with pollution migration from landfill sites and its effect on the ground water quality.

Published Codes and Standards

The Wisconsin Natural Resources Board adopted a new set of Solid Waste Disposal Standards on March 12, 1969, for the purpose of governing ". . . the storage, collection, transportation, treatment, utilization, processing and final disposal of solid wastes by any person or municipality, and the licensing of solid waste disposal sites and facilities for the protection of the environment." The standards specify that solid waste disposal operations are prohibited within 100 feet of any navigable lake, pond or flowage; within 300 feet of a navigable river or stream; within the flood plain of any water course within a city or village; within an area from which solid waste or leaching therefrom may be carried into any surface water; and within an area from which leaching from solid waste may have a detrimental effect on ground water.

The standards also include a list of requirements prior to the establishment of any sanitary landfill site, one of which is that plans should indicate geological formation and ground water elevation to a depth of at least 10 feet below proposed excavation and lowest elevation of the site. As for site operation, the standards state that no solid waste shall be deposited in such a manner that material or leachings therefrom will have a detrimental effect on any ground or surface water. Finally, toxic and hazardous wastes are to be disposed at least 10 feet above ground water level; at least 10 feet above limestone, quartzite, or granite-type bedrock; and at least 6 feet above sandstone. Such wastes should be disposed of in clay-type soils, if possible, and downgrade and away from any wells and buildings.

Landfill to Water Well Distance

Generally the Division of Environmental Protection reviews each case separately depending on geological features. The general criterion which is used is that 1000 feet should be the minimum distance between sanitary landfills and wells.

Future State Activities

None anticipated.

DISCUSSION OF STATE SURVEY

A convenient overview of the information obtained is presented in Table 9 for the 21 states surveyed, representing about 70 percent of the present U. S. population.

It is apparent that there has not been a great deal of research activity in the area of ground water pollution from the land disposal of solid wastes. A little more than half of the states queried responded that no research activities of this type were taking place in their own particular state. Probably the most extensive work in the past has been confined to three states: California, Illinois, and South Dakota. Most of the recent work which has been published in this area has originated from universities and public and private research agencies within these states. Maryland, Pennsylvania and Wisconsin are beginning to become a little more active in this regard. Another interesting observation is that a number of states are making plans to monitor the ground water quality in the vicinity of landfill sites. Other states will undoubtedly become involved in this activity in the future.

It is also readily apparent that there is much variation in the details given to codes and guidelines pertaining to the selection of landfill sites, particularly with reference to the possible ground water pollution problems. These range from a few states which do not have any published codes or guidelines to others like California where one of the Water Quality Control Boards recently published a ten-page "Statement of Policy" going into numerous details on classification of wastes and disposal sites primarily to guard against the pollution of ground and surface waters. Many of the state regulations merely include broadly worded statements of the type, "Sanitary landfill and other solid waste disposal activities shall not pollute the ground waters and surface waters of the state." Of the states queried, California, Illinois, Maryland, Michigan, Minnesota, New York, Ohio and Wisconsin have made the most detailed reference to ground water pollution potential. For the most part, these states require as a matter of policy geological data, water table and other hydrological data prior to the approval of landfill sites. Other states may have local health departments which require the same information, but it is not expressed as a matter of state policy. The states with the most stringent regulations in this regard are the ones with the most recently enacted laws.

The policy on landfill to water well distance employed by the states surveyed appears for the most part to be a tenuous one. Eight states would not commit themselves to a specific distance, stating in effect that each case is considered individually before a specific distance is set. For the states that gave a value, the distances varied from 50 to 1000 feet with most of the values in the 100 to 500 ft. range. Some states indicated that no specific value is used for sanitary landfills and thus they gave the values used for the location of water wells. Most of the states which presented a value cautioned that the value was only used as a rough guide and it was by no means a rigid value. The tenor of the remarks in this regard is that no one really knows what a "correct" value is and empirical evidence from the past indicates that a particular value was used in the past without any adverse effects. The lack of ground water monitoring in the vicinity of landfill sites is probably the primary reason for this dilema.

Very little research activity is being contemplated in the states surveyed in the immediate future. Some ground water quality monitoring around landfill sites will be conducted in a few of the states. Most of the states, however, will be active in the area of rules and regulations pertaining to solid waste disposal. Many states are either in the process of revision of current laws or have new laws pending. It also appears that more emphasis will be placed on ground water pollution problems in the new regulations. There also appears to be a trend toward more rigid state control of these activities than there has been in the past.

P A R T I I I

RECOMMENDATIONS

A review of the literature on the subject of the relationship between land disposal of solid wastes and ground water pollution, plus the survey of practices employed by twenty-one states in this regard, have suggested certain steps that regulatory agencies can take to minimize problems in this area. The term "regulatory agency" pertains to the governmental entity, agency or department which has the primary responsibility of regulating and licensing sanitary landfill operations within the state.

1. The regulatory agency should have available a geologist on its staff, ideally one trained in the area of hydrogeology, to assist in the sanitary landfill site selection processes within the state.

2. The geologist on the staff should begin to accumulate geological data within the state and broadly outline areas considered to be either good or poor potential landfill sites. The activities in Illinois serve as a good example in this regard.

3. The trend should be towards the requirement of more hydrogeologic and hydrologic field data for sites that are questionable for landfill operations. The burden of proof should be placed on the landfill operator or owner. The staff geologist should be given the responsibility of deciding when additional field data are required. Much useful information can be obtained even with a modest amount of field testing.

4. The regulatory agency should be very cautious in approving the ground disposal of industrial wastes. An up-to-date file should be maintained on various types of industrial wastes, their degradation properties, and their effects on the

aquatic environment. A literature search should be periodically made in this area.

5. The use of ground water monitoring wells should be considered in those cases where some doubt exists as to future effects of a particular landfill operation. This is somewhat akin to requiring that water samples of an effluent discharge be periodically taken downstream to maintain a check on waste water disposal operations.

6. The regulatory agency should follow as its basic policy the concept of trying to slow down the refuse degradation process by minimizing water percolation through the refuse mass. Slowing down degradation provides more time for leachate attenuation. Past experiences have demonstrated that longer times provide the most effective safety measure when it comes to separating sources of ground water contamination from points of ground water use.

7. The regulatory agency should not discourage novel methods of collecting and treating refuse leachates for certain installations where proper monitoring and control can be exercised. When considering facilities of this type, an important lesson to be learned from waste water treatment plant operations is that the smaller and the more remote the treatment facility is, the greater the likelihood of poor operation regardless of the original design and the degree of automation.

8. It is virtually impossible to hold to a specified distance between a point of water use such as a well and the site of a sanitary landfill. Tremendous variations in the hydrogeology surrounding each site precludes the establishment of such a published figure. However, lacking any field data the distance should be as long as possible in order to have the built-in safety factor of greater time. Distances of 500 to 1000 feet are not unrealistic if adequate field data are insufficient to prove otherwise.

9. The regulatory agency should encourage the practice of regional or district approaches to solid waste collection and disposal. Economic incentives should be available to provide funds to make area-wide feasibility studies. This approach will reap great benefits in the control of solid waste disposal practices.

10. The regulatory agency should as a general rule prohibit the use of abandoned rock, gravel or sand quarries as sites for the disposal of refuse of any type. Standing water in such depressions is usually nothing more than a visible direct link to the ground water supply. The leachate attenuation mechanism under such conditions is completely lost. If extensive hydrogeologic studies demonstrate that the depression is in a discharge ground water zone it is possible that such a site can be used for landfill disposal. However, nearby future ground water withdrawals may change the flow network around such a site considerably. The burden of proof plus any remedial safeguards should be placed on the owner of such a site. As a rule, such sites should not be used unless a thorough hydrogeologic study is made.

11. The regulatory agency should support some research work in this area. Some good examples are the studies on existing landfills which have been conducted in California, Illinois and South Dakota.

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PART V

APPENDIX A

MARQUETTE UNIVERSITY
1515 WEST WISCONSIN AVENUE / MILWAUKEE, WISCONSIN 53233 / 344-1000

COLLEGE OF ENGINEERING
DEPARTMENT OF CIVIL ENGINEERING

Dear ____________:

I am currently conducting an investigation for the Wisconsin Department of Natural Resources concerning the ground water pollution potential from sanitary landfills and refuse dump grounds. We in Wisconsin have been increasingly concerned about this situation and we felt it would be advisable for us to examine what the present status of information is in this general area. At the present time I am examining the literature and research reports to establish what work has been done in the past. I am also checking with persons that I know of who are presently engaged in research studies in the general area.

As part of this study we felt that it would be fruitful to contact a number of other states and obtain some additional information if possible. We would appreciate it if you could assist us in this study. Any information would be most helpful since, as I am sure you are aware, there appears to be a dearth of information about the potential for ground water pollution from landfill operations.

Specifically, your comments on the following questions would be helpful:

1. Are you aware of any research activities in your state that are concerned with ground water pollution from sanitary landfill and open dump type of operations? If so what are they? Are research reports available?

2. Does your state have published codes or guidelines regarding the site selection for sanitary landfills and dump grounds? Do you have regulations pertaining to the operation of such areas? We would appreciate receiving such published information.

3. Does your state specify a minimum distance that a water well can be located from a landfill or dump ground?

4. Do you anticipate that your state will be engaged in some aspect of this question in the immediate future, such as, writing new or revising old codes, field research programs, etc?

Once I gather all this information, I will be summarizing all the findings in a report which should be available around the end of the year. This report will also contain my recommendation to the Wisconsin Department of Natural Resources regarding what its future activity should be in this area. If you desire, I would be pleased to provide you with a copy of the report.

Thank you for your consideration to this matter.

Sincerely,

A. E. Zanoni
Associate Professor

AEZ/ped

APPENDIX B

State	Responding Official
California	Peter A. Rogers, P.E. Senior Sanitary Engineer Department of Public Health
Florida	Nick Mastro, P.E. Director, Division of Industrial Waste Florida State Board of Health
Illinois	William H. Walker Hydrologist Illinois State Water Survey
Indiana	B.A. Poole Assistant Commissioner State Board of Health
Iowa	Jack W. Clemens, Director General Sanitation Division State Department of Health
Kansas	Ivan F. Shull, Chief General Engineering and Sanitation
Maryland	Wilfred H. Shields, Jr., Chief Division of Solid Wastes Department of Health
Massachusetts	Vic Karaian Senior Sanitary Engineer Masachusetts Department of Public Health
Michigan	Fred B. Kellow, Chief Environmental Health Planning Unit Department of Public Health
Minnesota	G. B. Seaborn Division of Solid Wastes Pollution Control Agency
Missouri	Louis F. Garber Acting Director Section of Environmental Health Department of Public Health and Welfare
New Jersey	Arthur W. Price, Chief Solid Waste Disposal Program Department of Health

State	Responding Official
New York	Joseph A. Salvato, Jr., P.E. Associate Director Department of Health
North Dakota	Everett Lobb Director, Division of Environmental Sanitation and Food Protection
Ohio	Clarence M. Robinson Engineer-in-Charge Department of Health
Oklahoma	Herman Groseclose, Head Solid Waste Section State Department of Health
Pennsylvania	William C. Bucciarelli, Chief Solid Waste Section Department of Health
South Dakota	Charles E. Carl, Director Division of Sanitary Engineering State Department of Health
Texas	Charles K. Foster, P.E. Assistant Director Division of Sanitary Engineering
Washington	Roy J. Myklebust, R.S. Program Director Solid Waste Program Department of Health
Wisconsin	Avery N. Wells Acting Chief Solid Wastes Disposal Section Wisconsin Department of Natural Resources