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Hydrogeological Aspects of the Selection of Refuse Disposal Sites in Idaho.

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PREFACE

"The problems involved in sanitary landfill or final deposit of wastes are more involved with siting and public acceptance than with technology, although known technology is by no means fully employed. Available records indicate that there are about 90,000 more or less recognized land-disposal sites in the United States. Of this number, about 19,000 were planned, and some 12,000 are subject to a degree of local control that identifies them as "sanitary". Less than 14 percent of these partially controlled sites enjoy any degree of local acceptance. There is no question as to the low esteem in which the remaining 78,000 are now held by the public. The National Solid Wastes Survey has detailed information on about 6,000 sites, and finds that only 6 percent of these meet the minimum requirements of designation as "sanitary landfills". The Committee feels that this condition has developed more from a lack of use of available information and training than for any other reason".

. . . . . from "Policies for Solid Waste Management", a report of the _Ad Hoc_ Committee on Solid Waste Management, National Academy of Engineering, National Academy of Sciences, Washington, D. C. (1969) 63 pp.

The University of Idaho and the Idaho Health Department agree with the feeling of the _Ad Hoc_ Committee and have cooperated in preparing this pamphlet. Its purpose is to bring before interested parties the accumulated experience of many investigators with sanitary landfill site selection, and especially those aspects of landfill site selection which pertain to protection of existing water resources.

The writers are grateful to Dr. George Hughes, Geologist, Illinois State Geological Survey for permission to quote freely from _Environmental Note No. 17_, a Survey publication. Dr. Hughes also read the manuscript. Thanks are also due Mr. Carl Savage, Senior Geologist, Idaho Bureau of Mines and Geology and to Mr. Robert Olson, Chief of the Solid Wastes Program, Division of Environmental Improvement, Idaho Health Department for their review of the original manuscript and helpful suggestions.

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ABSTRACT

In this report geologic environments in Idaho have been evaluated in light of results of studies on refuse disposal and ground-water contamination that have been conducted elsewhere. The hydrogeologic environments commonly considered most safe for refuse disposal in any area are those with materials of low permeability and those that are well above the water table. A third type of environment, one which is hydrogeologically protective, also must be considered for disposal purposes in a few areas. Hydrogeologically protective implies that a site can be engineered to prevent the migration of leachate toward critical areas or that renovation of leachate by the porous medium will occur before the leachate reaches critical areas.

The hydrogeologic environments discussed herein are categorized according to geomorphic province or subprovince. The major communities in Idaho are placed within the appropriate geomorphic category for purposes of recommendations regarding the selection of safe refuse disposal sites.

This pamphlet contains information presented in support of the Idaho Department of Health's regulations and standards for solid waste control.

INTRODUCTION

The selection of refuse disposal sites must be viewed as a complex procedure involving several disciplines. Factors which must be considered cover a spectrum from local community acceptance, economics and traffic control engineering to air and water pollution. The necessity for an interdisciplinary approach in refuse disposal site selection is discussed by Landon (1969).

Several studies can be cited which have demonstrated that refuse disposal sites can contaminate ground water if care is not taken during site selection and maintenance. Examples of such studies are Ministry of Housing and Local Govt. (Gr. Br.), 1961, p. 36-39 and Engineering Science, Inc., 1961, p. 88-90.

Sites investigated recently in northeastern Illinois showed that dissolved solids leached from refuse had moved out of a disposal area, and in certain cases the leachate (the aqueous liquor produced during refuse decomposition) had moved more than 100 yards (Hughes, 1967; Cartwright and McComas, 1968).

Certain types of aquifers are particularly susceptible to contamination from near-surface refuse disposal. Other types of aquifers can be considered less susceptible. When potential refuse disposal sites are being evaluated, care must be taken to determine whether hydrogeologic conditions at the sites are adequate to protect the ground-water and surface-water resource from contamination. A proper evaluation of a disposal site should consider (1) the nature of the contaminants present in the landfill, (2) the conditions under which the contaminants are produced and mobilized, (3) the movement and final disposition of the contaminants, and (4) the effect of the refuse disposal operation on the hydrogeology of the site. The first consideration depends on the composition of the landfill; the others are primarily dependent on the hydrogeologic environment of the landfill site and the method of disposal.

In this paper the relation of refuse disposal practices to prevention of ground-water contamination is considered. Possible ways of using this information to evaluate disposal sites in Idaho are discussed. The objective here is to provide broad hydrogeological guidelines for the selection of safe refuse disposal sites.

INVESTIGATIONS OF POLLUTION BY SANITARY LANDFILLS

Major investigations of the production and movement of pollutants from landfill sites have been conducted in Illinois, California and Great Britain. In California, a series of studies was sponsored by the State Water Pollution Control Board and the U. S. Public Health Service. The first investigation was of the contaminants produced in ash dumps (Univ. S. Cal. Los Ang. Sanitary Eng. Research Lab., 1952); the second considered leaching from landfills composed of domestic garbage (U. S. C. L. A. Sanitary Eng. Research Lab., 1954, 1955, 1956, 1958, 1960); and the third compiled existing information about the effects of refuse fills on ground water, applied to conditions in California (Engineering-Science, Inc., 1961). Other studies were concerned with gases produced from landfills and factors affecting composition and shrinkage of refuse (Engineering-Science, Inc., 1963-1966; Merz, 1964; Merz and Stone, 1963, 1964).

The British study by the Ministry of Housing and Local Government (1961) dealt with domestic refuse deposited under saturated and unsaturated conditions in Great Britain and with the effects of various types of gravel and sand filtering systems on refuse leachate.

Some of the earliest landfill investigations were carried out in New York (Carpenter and Setter, 1940; Eliassen, 1942b). Existing fills of various ages were sampled to determine the composition of the refuse, leachate, and gases produced. Other studies pertinent to this subject are listed in a bibliography by Begg (1967). Such investigations have provided a general understanding of the kinds and amounts of products associated with disposal of the usual types of near-surface solid wastes. However, few data are available concerning the movement and abatement or attenuation of these products in various environments. Climatic, hydrologic, and geologic factors strongly influence the production and spread of contaminants from landfill sites, and findings of investigators in other areas should be applied with discretion to conditions in Idaho.

COMPOSITION OF REFUSE

Components of refuse, such as grass clippings, vegetables, and ashes, vary both regionally and seasonally (Engineering-Science, Inc., 1961, p. 34-35; Am. Public Works Assoc., Refuse Disposal Committee, 1961, p. 25-26). Because of these variations and the difficulty of obtaining representative samples, analyses are of limited value. The physical composition of Chicago refuse is described in "Municipal Refuse Disposal" (Am. Public Works Assoc. Refuse Disposal Committee, 1961, p. 45). Descriptions of refuse from other areas are given by Weaver and Keagy (1952, p. 21), Carpenter and Setter (1940, p. 386-388), the Ministry of Housing and Local Government [Great Britain] (1961, p. 43, 109), and Engineering-Science, Inc. (1961, p. 33-36). Chemical analyses of refuse are given by Weaver and Keagy (1952, p. 23) and Carpenter and Setter (1942, p. 388).

GASES AND LEACHATE

Formation

The production of gases and leachates parallels the settlement of the fill to a marked degree. It will be variable in different parts of the fill and will depend on many factors including composition of the fill material and the availability of oxygen and moisture. Initial decomposition is aerobic (in the presence of molecular oxygen), however, very soon after burial, anaerobic processes predominate, even in most "dry" fills (Engineering-Science, Inc., 1961, p. 44-45). The most rapid decomposition is known to take place in saturated fills. Water, present initially in the fill or from percolating rain or ground water, normally moves through the fill and leaches the soluble materials in the refuse. Carbon dioxide, produced as the refuse decomposes, dissolves in this water and, in the absence of other reagents, forms a weak acid that facilitates the solution and mobilization of some potential contaminants.

Composition and Quantities

Gases produced from decomposing refuse have been the subject of much study in California. In laboratory experiments, refuse packed in drums under controlled conditions was found to produce up to 0.210 cubic feet of gas for each pound of dry refuse (Merz, 1964, p. 1). The major gases found in the drums were carbon dioxide and nitrogen. In a fill at Azusa, California, it was calculated that approximately 330,800 pounds of CO_2 and 14,000 pounds of methane per acre (5640 tons of refuse) per year is being produced (Engineering-Science, Inc., 1965, p. 46). Production of nitrogen can also be expected, but it is not considered a problem. Variations in moisture and temperature cause variations in the amounts of these gases. As the fill stabilizes, the quantities produced generally decrease.

Characteristics most likely to prove objectionable if refuse decomposition products are leached into the ground water are hardness, iron, nitrate and total dissolved solids. Table 1 shows the percentages of various components leached from refuse and incinerator ash. Leachate from incinerator ash is included because it has a high dissolved solids content. Table 1 has been compiled from various sources, each of which reported different conditions under which leaching took place from a variety of types of refuse.

Table 2 shows concentrations of various constituents of refuse leachate and ground water associated with landfills of various ages in northeastern Illinois (Hughes, 1969, Personal communication). The data in Table 2 cannot be considered statistically representative of the identity or concentration of dissolved materials that can be expected in landfill leachates in general. These data should be viewed merely as a first indication of the identification and concentration of materials that may be produced.

The amount of water associated with the refuse strongly influences the production of leachates. California studies showed that, in the area studied, refuse placed "so that no portion of it intercepts the ground water, will not cause impairment of the ground water for either domestic or irrigational use" (U. S. C. L. A. Sanitary Eng. Research Lab., 1954, p. 13). Rainfall in the California study area did not penetrate a 7.5-foot thick landfill sufficiently to cause leachate to enter the underlying ground water. During the 21 month study period 18.69 inches of precipitation fell at that site.

In Britain, rainfall that penetrated one landfill was adequate to produce refuse percolate (Ministry Housing and Local Govt. (Gt. Brit.), 1961, p. 11); however, if the refuse was not deposited in standing water, the total quantity of pollutant produced was somewhat smaller. Out of 25 inches of rainfall per year, 10 inches percolated into the landfill. This fill had been compacted with a vibrating roller to a depth of approximately 5 feet and a density of 6.6 hundredweights per cubic yard. It had a flat surface covered with 18 inches of soil.

Movement of Gases and Leachate

The principal mechanisms involved in the introduction of contaminants from the landfill to surrounding water resources include infiltration, percolation, refuse decomposition, gas production and movement, leaching and ground-water travel. Carbon dioxide is produced during both aerobic and anaerobic decomposition. The action of

TABLE 1 - PERCENTAGES OF MATERIALS LEACHED FROM REFUSE AND ASH
(Based on weight of refuse as received) (Modified after Hughes, 1967)

	Percent leached					
Materials leached	1*	2*	3*	4*	5*	6*
Chloride	0.105	0.127		0.11	0.087	
Ammoniacal nitrogen	0.055	0.037		0.036		
Biochemical oxygen demand	0.515	0.249		1.27		
Organic carbon	0.285	0.163				
Sulfate (as SO_4)	0.130	0.084		0.011	0.22	0.30
Sulfide	0.011					
Albuminoid nitrogen	0.005					
Alkalinity (as $CaCO_3$)				0.39	0.042	
Calcium				0.08	0.021	2.57
Magnesium				0.015	0.014	0.24
Sodium			0.260	0.075	0.078	0.29
Potassium			0.135	0.09	0.049	0.38
Total Iron				0.01		
Inorganic phosphate				0.0007		
Nitrate					0.0025	
Organic nitrogen	0.0075	0.0072		0.016		

* Source of data and conditions of leaching:

1. Ministry of Housing and Local Government (Gt. Brit.), 1961, p. 117. Analyses of leachate from domestic refuse deposited in standing water.

2. Ministry of Housing and Local Government (Gt. Brit.), 1961, p. 75. Analyses of leachate from domestic refuse deposited in unsaturated environment and leached only by natural precipitation.

3. Montgomery and Pomeroy, 1949, p. 4 and 19. Refuse from Long Beach, California. Material leached in laboratory before and after ignition.

4. Engineering-Science, Inc., 1961, p. 39. Estimate based on data reported in "Final Report on the Investigation of Leaching of a Sanitary Landfill". (Sanitary Engineering Research Laboratory, 1954). Domestic refuse in Riverside, California, leached by water in a test bin.

5. Engineering-Science, Inc., 1961, p. 73. Based on data reported in "Investigation of Leaching of Ash Dumps" (Sanitary Engineering Research Laboratory, 1952). Leaching of California incinerator ash in a test bin by water.

6. Engineering-Science, Inc., 1961, p. 73. Based on data reported in "Investigations of Leaching of Ash Dumps" (Sanitary Engineering Research Laboratory, 1952). Leaching of California incinerator ash in a test bin by acid.

TABLE 2 - Analyses of samples of ground water adjacent to landfills in northeastern Illinois (in ppm), Hughes, 1969, personal communication)

Landfill	DuPage	DuPage	Blackwell
Well Identification	LW6B	LW5B	Blackwell
pH	7.0	6.3	
BOD	225.0	14080.0	54610.0
COD	40.0	8000.0	39680.0
Total Dissolved Solids	1581.0	6794.0	19144.0
Alkalinity	1011.0	4159.0	3255.0
Hardness	540.0	2200.0	7830.0^{c}
Chloride	135.0	1330.0	1697.0
Sulfate	2.0	2.0	680.0
Cyanide	0.02	<.005	0.024
Total Phosphate	8.90	1.20	6.0
Nitrate	1.60	0.70	1.70
Total Nitrogen	ND	ND	ND
Fluoride	0.31	2.0	ND
MBAS	0.30	0.72	ND
Hexane Solubles	7.0	18.0	350.0
Total Magnesium	90.0	450.0	600.0
Potassium	100.0	610.0	790.0
Sodium	74.0	810.0	900.0
Copper	<.05	<.05	<.05
Cadmium	<.05	<.05	<.05
Lead	<.05	<.05	ND
Zinc	<0.1	.13	ND
Iron	0.6	6.3	5500.0
Chromium	<.05	0.15	0.2
Silver	<.05	<.05	<.05
Calcium	105.0	475	2150
Boron	.91	5.35	ND
Aluminum	0.9	0.1	2.2
Manganese	0.06	0.06	1.66
Arsenic	4.6	<0.1	4.3
Selenium	<0.1	<0.1	2.7
Barium	0.30	0.80	8.5
Beryllium	<0.2	<0.2	<0.2
Bromium	2.8	10.0	ND
Date Installed	1952	1963	?
Remarks	screen 5' below base of refuse	screen 3' below base of refuse	samples refuse probably squeeze leachate in part

pH measured within 5 minutes at sampling
HCl added to all samples. No glass used in sampling.
c. Calculated from magnesium and calcium concentration
ND No data

this gas can seriously degrade ground water by dissolving calcium, magnesium, iron and other substances which are undesirable in high concentrations.

Work in California has indicated that of the total amount of carbon dioxide produced in a landfill, 23.5 times as much passes through a 1-foot silt cover into the atmosphere as remains in the ground (Engineering-Science, Inc., 1965, p. 46). While density variations may be responsible for some movement into the ground, the most effective transfer mechanism is probably molecular diffusion. The California investigation took place in a landfill that was well above the local water table and permitted little or no downward percolation of rainwater. A site with different characteristics probably would have a different rate of diffusion of gases into the ground.

The California study concluded that prevention of carbon dioxide movement underground might better be accomplished by its removal through draft or ventilation than by attempts to decrease the permeability of the landfill-soil interface through coatings because the diffusivity of such coatings to gases is rather close to that of the undisturbed soil.

INFLUENCE OF GROUND-WATER FLOW

Refuse leachate in the subsurface travels in the same direction as ground water, though retention characteristics of the medium may cause dissolved solids to move at a slower rate. In a homogeneous isotropic environment, water moves nearly vertically downward to the top of the zone of saturation and then in the direction of the fluid potential gradient. The principles governing this movement were discussed by Hubbert (1940), Toth (1962, 1963), Meyboom (1966), Meyboom, et al. (1966), Freeze and Witherspoon (1966, 1967) and by Williams (1968); its effect on the movement of contaminants were discussed by Geraghty (1962). The velocity , direction, and volume of ground-water movement are affected by the topography and the materials the water moves through. In addition some reduction of porosity and permeability may occur during filtration of the leachate by the porous medium.

Figures 1A and 1B illustrate the importance of considering the ground-water flow system when selecting refuse disposal sites. In the intervals labeled A, pollutants moving with the ground water could reach the basalt aquifer, and in intervals labeled B they could reach the sand and gravel aquifer before they are discharged to the surface. In intervals labeled C, pollutants moving with ground water would not reach any aquifer before being discharged to the ground surface, and in the intervals called D, ground-water movement is toward the surface only. Under the ground-water flow conditions shown in figure 1A, there is a much greater area where pollution of an aquifer from surface waste disposal is possible than under the flow conditions shown in Figure 1B. The location of the disposal site within the flow system is an important factor. In regional planning, the dimensions of the flow system or flow systems present can provide useful data.

The permeability of the material through which water is moving affects both the velocity and direction of water movement. Unjointed clays and shales are the least permeable of the common sedimentary materials. Sands, gravels, and sandstone are

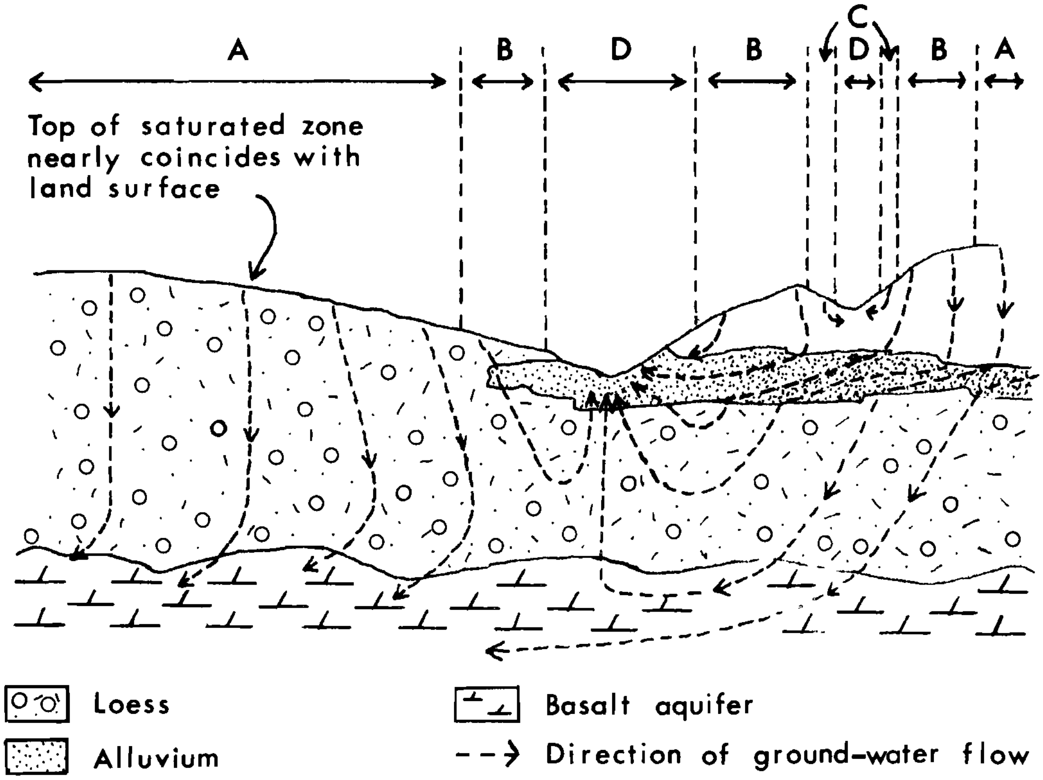

Fig. 1A – Hypothetical Flow System A (Modified after Hughes, 1967)

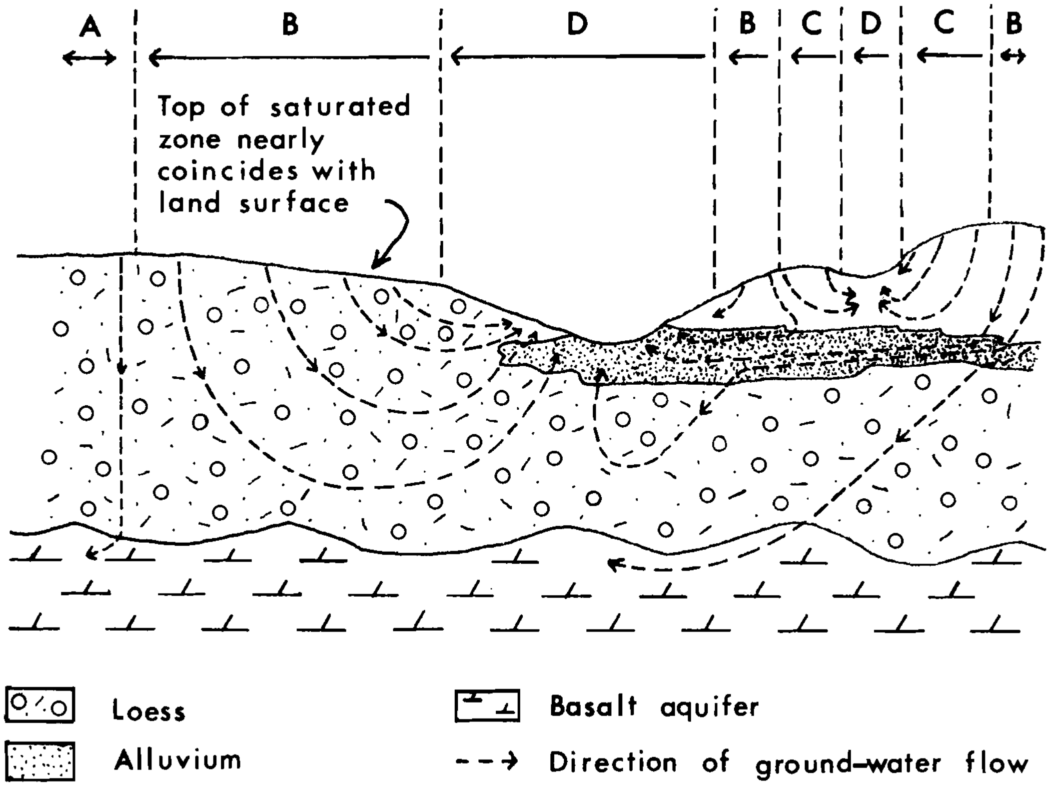

Fig. 1B – Hypothetical Flow System B (Modified after Hughes, 1967) generally most permeable. As water movement in permeable rocks is usually, though not always, through intergranular openings, local flow paths may be predicted with some accuracy. Openings due to solution or former gaseous phenomena and jointed or fissured rocks, such as dolomites, clays, shales, pyroclastics, and basalts may have high permeability, but, because the water is forced to move through a variety of openings, fissures or cracks, its travel direction and velocity are often difficult to predict, even for short distances.

Calculations of the velocity and direction of water movement based on the assumption that the earth materials are homogeneous and isotropic must be used with discretion because natural deposits often do not have these characteristics.

Less dilution and dispersion of contaminants take place in ground water than in surface waters because ground-water flow is almost always laminar, whereas flow of surface water frequently is turbulent. For this reason, the total volume in a ground-water reservoir cannot be considered effective for diminishing the concentration of contaminants (McKee and Wolf, 1963, p. 19).

McKee and Wolf (1963, p. 20) point out that the low travel velocities and diffusion rates in ground-water reservoirs can produce serious consequences if contamination occurs. Contamination may not be noticed for years or decades, and consequently no complaints are registered. After contamination is discovered, the quality of water is already degraded and the damage cannot be repaired merely by stopping the source of contamination. Purification by leaching and dilution may require a longer time than the contamination did.

NATURAL PURIFICATION OF LEACHATE

Ion exchange* may hold contaminants within the fill or within the earth material through which they move. Clays are particularly effective in this respect, but sands and silts also will retain contaminants. The amount of exchange a particular type of cation undergoes depends on several factors, including (1) the types of clay minerals present, (2) the cations already on the clays, (3) the other cations in solution and their concentrations, and (4) accompanying anions.

Laboratory experiments to determine how much exchange will take place as a solution is passed through a given material may yield useful results, although extrapolation to field conditions requires care (McHenry *et al.*, *in* de Laguna, 1955, p. 190). In such experiments most of the soil is in contact with the solution, but under field conditions in which permeability varies because of minor sand bands or fractures this may not be the case.

Considerable work has been done on ion exchange on soils in relation to radioactive wastes disposal (de Laguna, 1955). For more basic understanding of ion exchange on clay minerals, the reader is referred to Grim (1953, 1962).

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* Grim (1953, p. 126) explains ion exchange as follows: "The clay minerals have the property of sorbing certain anions and cations and retaining these in an exchangeable state, i.e., these ions are exchangeable for other anions or cations by treatment with such ions in a water solution . . ."

Self purification, particularly of organic matter, takes place within the fill itself (Ministry Housing and Local Govt. (Gt. Brit.), 1961, p. 11, 26). The degree of purification depends on the length of time the refuse leachate remains in the fill.

The Ministry of Housing and Local Govt. studies in England (1961, p. 23) established that by passing refuse leachate through sand and gravel filters "general purification from organic matter can be effected". Purification from chlorides, sulfates, and ammonia was found to be much less complete. Although aerobic purification would be more efficient, it is not likely to be operative in ground waters.

Investigation by McCormick (1966, p. 46) in South Dakota disclosed that the hardness and alkalinity of leachate-contaminated ground water were substantially reduced as the water passed through a small surface pond. Although no use has been made of this method, it may be worth considering in the selection of disposal sites.

Preul (1968, p. 659) has demonstrated that ammonia nitrogen, nitrate, phosphate and alkyl benzene sulfonate (ABS) are all materially reduced in concentration as ground water into which these substances have been introduced flows through a fine-grained medium. He considers that the major removal mechanisms are adsorption (both ion-exchange and physical) and biological action and cautions that if percolation from a contamination source occurs over a period of time, the adsorptive capacity will become progressively exhausted and contamination can be expected to occur farther and farther from the source.

Davidson et al. (1968, p. 629) studied the movement of substituted urea herbicides through soil columns. Their results showed that these compounds were adsorbed and retained but the retention properties were vastly different for different herbicides, even when they were from the same chemical family.

STABILIZATION OF LANDFILLS

Stabilization of landfills depends primarily on the rate of decomposition of their organic matter, which Eliassen (1942a, p. 913) found in New York proceeded most rapidly when the refuse had a moisture content of 40 to 80 percent. The most rapid stabilization described in the literature is for a fill in a swamp near New Orleans (Schneider, 1953, p. 84). After three years the materials in this fill were inert enough to be used as cover for subsequent disposal operations. In San Francisco, however, (Am. City, 1947, p. 11), a 12-year old fill showed little evidence of decomposition. Other descriptions of disinterred refuse of various ages have been given by Carpenter and Setter (1942, p. 388), Longwell (1957, p. 423, 424), Montgomery and Pomeroy (1949, p. 14) and Weaver and Keagy (1952, p. 22).

ENGINEERING PROCEDURES TO PROTECT GROUND WATER

Impermeable Liners

To prevent movement of liquid and some gaseous pollutants, the base and/or sides of a disposal area are commonly lined with a 1- or 2-foot layer of compacted clay. One of the few detailed studies of how efficiently a clay liner prevents water movement was conducted on a 3-foot deep freshwater lagoon at the 1938 Golden Gate

International Exposition in San Francisco (Lee, 1941). The liner was 10 inches thick and had been compacted with a 14-ton flat roller. Loss through the liner was initially 1.00 inch per day, but the loss was reduced to 0.10 inch per day after the liner had been treated with sea water, which contains free sodium ions.

The results of this study should be applied with discretion to refuse disposal problems as the conditions described above differ from those expected of a landfill in four respects. First, the composition of landfill leachate differs from that of sea water, and it is possible that the clay minerals would react to the ions dissolved in the leachate in a manner that produced an increase rather than a decrease in permeability. Next, the lagoon at San Francisco was used to hold fresh water, which in time leached the clay and necessitated retreatment with high sodium sea water. A liner in a refuse pit is constantly in contact with leachate, and treatment of the liner would be impractical. Third, the liner in San Francisco was not as greatly compacted as liners beneath disposal sites might be. Finally, clay liners located in ground-water discharge zones may be susceptible to buckling during filling due to build-up of pore water pressure beneath the liner.

In Lake County, Illinois, contaminants from a landfill operation lined with uncompacted clay were found to have moved a few feet into the surrounding materials (Hughes and Duel, 1966, p. 7). In South Dakota a bentonite seal used in a waste stabilization pond in extremely sandy soil was found to leak (Carl and Kalda, 1960, p. 122). The use of clay liners for sealing refuse disposal sites, where minor amounts of leakage may be significant, must be carefully evaluated. Where liners are relied upon to control the movement of leachate from a saturated refuse disposal site the absence of nearby water supply wells down-gradient from the site should be ascertained. In general, clay liners offer the most economically feasible safeguard against pollution by landfills. For fills below the ground-water table plastic and jute, and plastic liners are being experimented with (Stearn, 1967, p. 82).

Impermeable Covers

It has been suggested that graded, compacted clay covers be used on completed landfills to prevent the downward percolation of rain that might leach the fill materials. This procedure offers advantages particularly in areas with heavy rainfall; however, such a liner would also restrict movement of landfill gases, principally carbon dioxide, into the atmosphere, diverting it downward and laterally into the surrounding soil. This problem has been considered in California (Engineering-Science, Inc., 1965).

Collection and Disposal of Leachate

Landfill sites possibly could be waterproofed at the base and tiled to divert leachate to a collection point where it can be removed and treated in lagoons (Ministry of Housing and Local Govt. (Gt. Brit.), 1961, p. 28). However, the cost of such an operation can be expected to be high.

Re-Use of Proved Sites

Removal of nearly stabilized and inert refuse from a site proved safe so that the site could be re-used for disposal of new refuse has been proposed (Ministry of Housing and Local Govt., Gt. Brit., 1961, p. 28). The old refuse could then be disposed of at other sites, where, because of its reduced potency, it would have no harmful effects. The expense of this procedure would probably not be warranted unless the environment was such that additional safe sites could not be found or easily constructed.

The only case in which this technique was utilized was reported by Stone and Israel (1967, p. 86). A one year old anaerobic fill was excavated and the decomposed solid waste recompacted in a new cell. Odor problems were severe during the operation but the greatest drawback was that a 26 percent volume expansion resulted.

FAVORABLE SITES FOR DISPOSAL

Dry Conditions

A disposal site is usually considered favorable if the refuse will remain dry or unsaturated, thus reducing the rate of production of contaminants and preventing their mobilization.

Two types of sites fall into this class. In the first category are sites where disposal takes place below the ground surface but above the zone of saturation. The second type includes sites where refuse is disposed on the ground surface and, if necessary, covered and graded to prevent the entrance of water.

In arid areas, investigations have shown that leachate from refuse deposited in either of the two aforementioned ways will not pollute the ground water. In humid areas the same would probably hold true, but in humid areas it becomes difficult to find sites where excavations will not intersect the zone of saturation and even more difficult to place a permanent impermeable cover on the completed fill.

Geologically Favorable Conditions

Even a saturated disposal site may be 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. In laboratory measurements, clays and glacial tills fall into this class (Todd, 1959, p. 53). At a hydraulic gradient of 1 foot per foot and a specific yield of 5 percent, ground-water velocity through such material would be approximately 0.026 feet per day, or nearly 10 feet per year. Such materials also frequently have favorable ion exchange characteristics.

Safe disposal in this type of environment depends on the low permeability of the surrounding earth materials to

(a) retard movement of contaminants from the disposal site until their potency has been considerably reduced by bacterial or chemical processes;

(b) attenuate contaminants in their passage away from the disposal site by adsorption and filtration with possible concomitant reduction of permeability; and

(c) minimize the rate at which any contaminants could be introduced into a potable water supply.

Few comprehensive investigations have been made of disposal sites in materials with low permeability, and the actual extent of spread of contaminants in such environments is not extensively documented. Cartwright and McComas (1968) and Hughes et al. (1969b) point out that a resistivity survey in homogeneous silty sand outwash traced mineralized water from a landfill for a distance of more than 1000 feet. The results of the resistivity survey were supported by the results of a geochemical sampling program.

Table 3 lists hydrogeological criteria for evaluating sanitary landfill sizes. Table 3 is based on information presented by Cartwright and Sherman (1969).

Hydrologically Favorable Conditions

Under conditions that are hydrologically favorable, movement of contaminants along lines of flow would be such that either they could not reach a useful groundwater or surface-water resource, or their attenuation to acceptable levels would occur before they reached such a water resource.

The major advantage of disposal in such environments is that pollutants need not be retained at a site for an indefinite period, and the refuse need not be kept dry until the fill has stabilized. In a hydrologically safe site, the continued presence of contaminants should not be a problem.

Selection of hydrologically safe sites depends on an understanding of the groundwater flow system, which may be difficult to acquire. This is perhaps the greatest drawback to consideration of this kind of environment for disposal purposes. If pollution of a water supply at a proposed site is judged to be likely, then utilization of a flow system evaluation technique such as that described by Freeze and Witherspoon (1966, 1967) may be necessary.

Other disadvantages include the necessity of imposing some control over factors that may change the ground-water flow system, such as installation of reservoirs or pumping of wells nearby. In some cases, the rate of contamination attenuation and the concentration of contaminants that could be tolerated in aquifers or surface waters must be established prior to approval of a proposed site.

In spite of these disadvantages, hydrologically safe environments show a great deal of promise as sites for waste disposal, and the possibility of their use in Idaho is discussed in more detail later.

TABLE 3
CRITERIA FOR EVALUATING SANITARY LANDFILL SITES
(Modified after Cartwright and Sherman, 1969)

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, metamorphic rocks, unweathered igneous rock
   Unfavorable - sandstone, fractured basalt, weathered igneous rock
   Questionable - basalt not known to be fractured

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 fractured basalt or other crystalline rock) sand and gravel wells with logs showing thin cover over aquifer

5. Site topography:
   Favorable - flat upland areas, ridges above heads of gullies and ravines, dry open pit mines or quarries
   Unfavorable - (require operational engineering) - depressions where water accumulates, lower reaches of gullies, stream floodplains, other sites near surface water areas where leachate might discharge into the water

NOTE: If 1, 2, 4, and 5, or 1, 3, 4, and 5 are favorable, there is little probability that ground-water contamination will occur.

CONDITIONS RELATED TO REFUSE DISPOSAL IN IDAHO

Climate

A major factor influencing the production of leachate from landfills is the amount of precipitation that penetrates the refuse. The mean annual precipitation at selected cities in Idaho is presented in Table 4. Judging from the studies on leaching previously noted, rainfall in much of northern Idaho could be expected to be adequate to penetrate a landfill unless protective measures were taken. In much of the Snake River Plain on the other hand, rainfall probably would be insufficient to penetrate a landfill if it is covered properly with fine-grained materials.

Geology and Geomorphology

The above values of average annual precipitation can be categorized according to the general geomorphic province wherein the measuring stations are located. With the exception of Lewiston, the communities receiving less than 14 inches average annual precipitation are located within the Middle Rocky Mountain Province, the Eastern Snake River Plain Section of the Columbia Intermontane Province, or the Malheur-Boise-King Hill Section of the Columbia Intermontane Province. Those communities receiving more than 14 inches average annual precipitation are located within the Tri State Uplands Section of the Columbia Intermontane Province, the Palouse Hills section of the Columbia Intermontane Province or the northern Rocky Mountain Province (Ross and Savage, 1967, p. 144). Lewiston, which receives 13.85 inches average annual precipitation, is in the same subdivision of the Columbia Intermontane Province as is Grangeville which receives 22.10 inches average annual precipitation. In this case the difference in precipitation is due to a difference in elevation.

The significance of categorizing refuse disposal sites according to average annual precipitation lies in the fact that studies elsewhere have indicated that landfills receiving more than about 14 inches average annual precipitation can be expected to be fully penetrated by precipitation. Consequently, extra care must be exercised in these areas because of the production and movement of leachate from the site. (It should be noted that the figure 14 inches is an upper limit and may be slightly optimistic and that the effects of different distributions of precipitation throughout the year has received little attention.) The significance of categorization by geomorphic province or section of geomorphic province lies in the fact that provinces or sections of provinces are delimited so that they are structurally and geologically similar, contiguous units. By utilizing similarities in precipitation and in geology and geomorphology, it is possible to make certain generalized statements about refuse disposal site selection.

SELECTION OF SITES

In those geomorphic provinces or subprovinces which receive less than about 14 inches average annual precipitation, the selection of refuse disposal sites usually can be reduced to locating a fine-grained unconsolidated sediment (preferably silt size or finer) where the water table is at optimal depth below the ground surface and over which surface water drainage is minimal. Valley bottoms should generally be avoided, partially because they are likely to be underlain by coarser grained alluvial deposits

TABLE 4 - Mean Annual Precipitation at Selected Idaho Cities (after Ross and Savage, 1967, p. 204-207 and Idaho Water Resources Board, 1968, p. 27-28).

City	Average Annual Precipitation (inches)
Montpelier	13.80
Idaho Falls	10.74
Pocatello	12.23
Twin Falls	8.70
Boise	12.93
Grangeville	22.10
Lewiston	13.85
Moscow	21.70
Wallace	41.64
Sandpoint	32.50

which will conduct leachate if the water table rises above the bottom of the fill, and partially because valley bottoms represent areas of maximum hazard from surface run-off. If precipitation is seasonal the allowable distance to the water table should be determined during the wet portion of the year. The "optimal" depth to the water table must be based on a compromise between the economics of transporting the wastes to a proposed site and the economics associated with the risk of the occurrence of pollution of ground water at the refuse disposal site. The State of Illinois for example recommends between 30 feet and 50 feet of relatively impermeable material between the base of a landfill and the shallowest, underlying water yielding formation (Cartwright and Sherman, 1969). The U. S. Public Health Service states that a report accompanying the plans for a sanitary landfill shall indicate geological formations and ground-water elevations to a depth of at least 10 feet below proposed excavations and lowest elevation of the site (U. S. P. H. S., 1969). The greater the thickness of fine-grained material between the bottom of a landfill and the water table, the greater the insurance against undesirable consequences of an unusually wet year. Maximum thickness of fine-grained material beneath a site also provides insurance against damages if less than 14 inches of annual precipitation will penetrate a landfill completely.

If the elevation of the water table at a proposed site is determined by the water level in an open hole or holes, care should be taken not to drill the hole too deep initially. The elevation of the water level in many open holes drilled to more than 20 or 30 feet below the water table will not coincide with the elevation of the water table. In addition, in fine-grained materials 3 to 6 days should be allowed for the water level in a drillhole to reach equilibrium in order that an indication of the true water table elevation may be obtained.

Middle Rocky Mountain Province

The communities of Montpelier and Soda Springs are located in this province. In the Middle Rocky Mountain Province, anticlinal and synclinal structures, as well as thrust faults have produced linear valleys and ridges (Ross and Savage, 1967, p. 148). The valley bottoms are farmed; most are irrigated. In most valleys Quaternary alluvium, basalts or the Salt Lake Formation are exposed at the surface. A water table map of the Bear River Basin presented by Dion (1969) indicates that in that area the water table can be expected to coincide with the ground surface near stream channels, but that the ground surface rises more rapidly away from streams than does the water table. The Salt Lake Formation, or its equivalent, commonly crops out along valley margins, and it can be expected to contain more fine-grained materials than the alluvium or the basalt (Dion, 1969, personal communication). Consequently ideal refuse disposal sites would be expected along the valley margins in the Salt Lake Formation or its equivalent.

Eastern Snake Plain Section of the Columbia Intermontane Province

The communities of Bliss, Jerome, Twin Falls, Buhl, Burley, Pocatello, Idaho Falls, St. Anthony and Shoshone are among those located in this subprovince.

The eastern Snake River Plain Section of the Columbia River Intermontane Province is a lava-filled structural and topographic basin about 60 miles wide extending east and northeast from the City of Bliss (Ross and Savage, 1967). The northern boundary of the plain is well defined and consists of several mountain ranges in the northern Rocky Mountain Province. To the south, east and west this subprovince grades more gradually into terrain which is less rugged than the mountains to the north.

Most of the surface of this subprovince is a youthful lava plateau, partially covered with thin wind-blown, or other, unconsolidated materials; the plateau is almost featureless except for a few low shield volcanoes, cinder cones and lava ridges (Ross and Savage, 1969, p. 151; Mundorff et al., 1964, Plate 3). Only a few permanent streams exist on the plain. Some streams disappear and serve as recharge to the underlying aquifers. Much of the 14,000 square miles of the Eastern Snake River Plain receives less than 10 inches average annual precipitation (Mundorff, et al., 1964, Plate 2).

The water table map presented by Mundorff et al. (1964, Plate 4) shows equipotential lines that in general are oriented perpendicular to the trend of the Snake River; however, most of the equipotential lines away from the river are dashed, meaning that there are insufficient data to establish them with certainty. Because the slope of the ground surface parallel to the Snake River is less than the slope of the ground surface perpendicular to the Snake River it probably is safer for purposes of refuse disposal site selection to assume that some component of the water table gradient is oriented perpendicular to the stream and that the water table rises under some local topographic highs or where major fault zones are encountered. Well and spring data for the wet portion of the year can be used to verify this assumption for specific localities. According to Mundorff (1967, Plate 5) the ground water in the vicinity of American Falls reservoir definitely moves in a direction perpendicular to the Snake, except at the downstream end of the reservoir, where the head in the reservoir is sufficient to impose on the ground-water flow system a component of velocity directed nearly parallel to the river.

Most of the population centers in the Eastern Snake River Plain section of the Columbia River Intermontane Province are located near the Snake River. All the cities mentioned except Bliss and Pocatello are situated on alluvium underlain at some depth by Snake River Basalt intercalated with sedimentary materials or Quaternary alluvium and lake sediments (Mundorff et al., 1964, Plate 3; Crosthwaite, 1957, Plate 5; Malde, Power and Marshall, 1963). Where the river flows in a deep gorge, as it does near Bliss, the water table can be expected to rise less rapidly than the ground surface; consequently refuse disposal sites can be selected beneath which the depth to ground water is nearly the same as the depth of the gorge in which the river flows. In most localities where a deep gorge exists, the land surface is underlain by basalt. Because basalts normally are fractured and permeable it would be advisable to select as refuse disposal sites locations where the basalt is covered with the maximum available thickness of unconsolidated materials. In some cases such materials may be of eolian origin, lake sediments, or ordinary soil produced by weathering. If the previously mentioned valley alluvial deposits are selected as refuse disposal sites, maximum care should be exercised because they are likely to be coarse-grained and permeable, and most are likely to contain a relatively shallow water table. Unfortunately, in this area some disposal has occurred in cavernous and porous, fractured volcanic vents with direct connection to underground tubes and fragmental volcanic debris.

Where the Snake River is not situated in a deep gorge, as in the eastern portion of the subprovince (approximately upstream from American Falls) a different approach will be required for the selection of safe refuse disposal sites. Sites beneath which the water table is deep and which are also near population centers are likely to be few in number. Consequently the selection of sites underlain by fine-grained, unconsolidated material is critical. If it becomes necessary to establish refuse disposal sites in alluvium near the river, only the fine-grained portions of the alluvium should be utilized; areas such as high terraces beneath which the water table is at maximum depth should be selected. In some localities low, broad volcanic hills may prove to be useful because of the expected greater depth to ground water beneath them. Savage (1961a, Fig. 3) presents a geologic map of Bonneville County which should be consulted for the generalized distribution of fine-grained sediments in that area.

Malheur-Boise-King Hill Section of the Columbia Intermontane Province

Included among those communities located in this subprovince are Boise, Caldwell, Nampa, Payette, Bruneau, Mountain Home, and King Hill. The 10,000 square miles of this subprovince are characterized by thick lake and stream sediments that are interbedded with basalts. The subprovince encompasses lowlands on both sides of a portion of the Snake River, and ridges and nearly flat uplands along other portions of the Snake River (such as near King Hill)(Ross and Savage, 1967).

According to the geologic map published by Mundorff et al., (1964), the principal communities in this subprovince are situated on the Idaho and Payette Groups, which consist of lake and stream sediments of variable grain-size including clays with intercalated local basalt flows. Quaternary alluvium consists of stream, lake, and eolian deposits with some terrace gravels.

In the eastern portion of the subprovince (near Mountain Home or King Hill) higher portions of the ground surface are sufficiently above the water table so that little difficulty should be encountered in selecting refuse disposal sites that are well above the zone of saturation. Some Pleistocene unconsolidated sediments overlie the basalt in the Mountain Home area; these may constitute the fine-grained materials needed for waste disposal sites. Another alternative is the fine-grained portions of the Idaho Group to the southwest of the city. According to the geologic map of Littleton and Crosthwaite (1957, Plate 6) similar alternatives exist for Bruneau. Littleton and Crosthwaite (1957) also present data on depth to ground water and on the distribution of wind blown silt in the vicinity of Bruneau. Care should be taken to avoid the gravel portions of the Quaternary alluvium, particularly at locations where the water table is near the ground surface.

Near Nampa, Caldwell and Boise area problems with the selection of waste disposal sites can be anticipated because of near-surface ground water in the Quaternary alluvium which covers the valley bottoms. However, in the uplands and terraces near these cities the Idaho Group and the Nampa and Caldwell Sediments crop out. In the Idaho Group the water table can be expected to occur at depths sufficient to permit refuse disposal operations at selected locations. The Nampa and Caldwell Sediments contain fine-grained materials which should constitute safe refuse disposal sites if care is taken to avoid near-surface water tables. Clay beds occur in all these younger materials. Maps of the distribution of the Idaho Group and the Nampa and Caldwell Sediments are presented by Savage (1958, Fig. 4); these maps should be consulted when delineating prospective areas.

With respect to refuse disposal sites, hydrogeologic conditions in Payette County to the north are similar to those in Ada and Canyon Counties; consequently similar procedures can be followed. Savage (1961b, Fig. 4) presents detailed geologic maps of that area which can be utilized to identify unconsolidated, fine-grained materials in the refuse disposal site selection process.

Tri-State Uplands Section of the Columbia Intermontane Province

Lewiston, Orofino, Grangeville, Cottonwood, Craigmont and Winchester are among the principal communities located in this subprovince.

As noted earlier the City of Lewiston receives less than 14 inches average annual precipitation; consequently, under our basic premise, precipitation should not be sufficient fully to penetrate a landfill in this area provided the disposal site is not located near the top of the valley wall where precipitation increases considerably. The selection process then reduces to the delineation of as fine-grained a material as is available which does not occupy a valley bottom. In the Lewiston area the greatest promise for such a sediment lies in the deposits designated by Bond (1963) as the Pleistocene conglomerate or areas where clays, silts and sands of the Latah Formation are exposed at higher elevations. Some contain fine-grained sediments which should be satisfactory as a refuse disposal medium. These deposits occur locally on the escarpment called Lewiston Hill to the north of Lewiston as well as to the south and east of Lewiston. They have been mapped in considerable detail by Hollenbaugh (1959). Because of the nature of the terrain north of the city, potential landfills should first be sought to the south and east. The ground surface rises more rapidly away from the Snake and Clearwater Rivers than does the water table; consequently sites well above the water table should be available. Other less desirable deposits in the area are likely to be underlain directly by fractured basalt or by a near-surface water table.

Topographically higher communities in the Tri-State uplands subprovince can be expected to receive more than 14 inches average annual precipitation; consequently greater care must be taken both in site selection and in disposal site engineering. Near-surface, fractured basalts occur in the Craigmont, Cottonwood, and Grangeville areas; therefore, emphasis should be placed on the selection of sites where thick, unsaturated, relatively impermeable loess deposits overlie the basalt. Valley bottoms, such as those on the northwest side of the ridge lying to the south and east of Grangeville, should be utilized only after careful evaluation of ground-water conditions in them and after precautionary engineering measures have been taken (see section entitled, Engineering Procedures to Protect Ground Water).

Valley bottom communities, such as Orofino and Kamiah, are likely to experience a shortage of satisfactory refuse disposal sites. Alluvium in the valley bottoms is likely to be saturated, and steep valley walls will limit the availability of unconsolidated, fine-grained materials above the area of a near-surface water table. Nevertheless, these deposits of clay and silt of the Latah Formation probably are most promising. Under these conditions site evaluation should take into account the possible influence of refuse emplacement on slope stability. A landfill at the top of a slope is likely to be more permeable than the slope itself; consequently a refuse disposal site near the top of an unconsolidated slope may induce ground-water recharge to the underlying materials, thereby enhancing the probability of a slope failure. Areas which contain abundant evidence of earlier slumps or slides should be examined carefully before receiving approval as refuse disposal sites.

Palouse Hills Section of the Columbia Intermontane Province

Communities in this subprovince include Moscow and Potlatch. Both of these localities receive more than 14 inches average annual precipitation, which should be sufficient to penetrate a landfill. Loess covers much of the surface of this subprovince, particularly in the vicinity of population centers. It ranges in thickness from 0 to 300 feet (Foxworthy and Washburn, 1963). Data presented by Williams and Allman (1969) and by Ross (1965) suggest that near-surface water table can be expected, even in shallow valley bottoms in the loess. Consequently landfills installed at these locations can be expected to become saturated and to produce undesirable leachates. Where permeability is sufficiently great and ion exchange capacity limited, such leachates may travel down-gradient in the ground-water flow systems. If wells, developed springs or small streams are located down-gradient from a potential refuse disposal site in this type of environment, the prospective sites should receive intensive hydrogeologic investigation prior to use.

The Palouse Hills subprovince does contain areas with hydrogeologic characteristics that are suitable for refuse disposal. Broad ridge tops underlain by a maximum thickness of loess offer the most promise. The loess is fine-grained and relatively impermeable, provided any discontinuities are plugged, as would be the case in the disturbed and reworked bottom of a refuse disposal pit. The water table beneath such ridges can be expected to be at depths which are maximum for the subprovince, thereby precluding disposal in the saturated zone. Lastly, a disposal site on such a ridge top would receive only a minimum of surface runoff, which would minimize the probability of the refuse becoming saturated after emplacement. The rate of production and migration of leachate would thereby be minimized.

Northern Rocky Mountain Province

The communities of St. Maries, Coeur d'Alene, Kellogg, Wallace and Sandpoint are located within this province. With the possible exception of Coeur d'Alene these communities are situated topographically in what might be termed mountain valleys. All communities can be expected to receive more than 14 inches average annual precipitation. Therefore, landfills in these areas can be expected to produce some leachate. Consequently, great care should be taken in the selection of hydrogeolgic environments in which refuse is disposed. Relatively impermeable deposits with deep water tables are essential. The availability of safe refuse disposal sites near all of these communities is likely to be limited because of the nature of the topography and hydrogeology in their vicinities.

According to the geologic map of Anderson (1940, Plate 2) the deposits in the vicinity of Coeur d'Alene consist of Quaternary alluvium, Pleistocene glacial deposits (mostly sand and gravel), Tertiary basalts and Pre-Cambrian metamorphosed rocks. The water table in the alluvium will generally be found at or near the surface; the glacial deposits consist of permeable outwash and the basalts and metamorphic rocks are consolidated with most having only a thin cover of unconsolidated material.

If wastes are disposed in the stream channel alluvium, they can be expected to lie beneath the water table, at least during a portion of the year. Because portions of alluvial deposits can be expected to be permeable, leachate from a saturated fill can often be expected to move with the ground water if the leachate is allowed to escape from the fill. Consequently the installation and careful maintenance of an impermeable liner in a disposal pit is essential. A clay cover will reduce infiltration if erosion can be prevented. Limited clay and glacial till may be located locally for this purpose. In addition, prior to site approval, an inventory of water supply sources down-gradient from the site should be conducted in order to ascertain that any leachate which does escape will do no damage prior to its renovation. The probability of damage to a down-gradient stream should be considered also. The question of whether the dilution capacity of such a stream is sufficient to handle the discharging leachate must be answered.

Utilization of the glacial outwash to the northwest of Coeur d'Alene as a waste disposal medium may offer more promise than does the alluvium. The water table is known to occur at depths of at least 150 feet below land surface at several localities within six miles to the northwest of the city (Crosthwaite, 1969, Personal communication). Even though the saturated outwash usually can be expected to be permeable, thicknesses of gravel in this order of magnitude should serve as a satisfactory filtering medium for refuse leachate, especially if an effective clay liner is installed or occurs naturally in disposal pits. Nevertheless, care should be taken to ascertain that no water supply wells are located near a prospective disposal site.

Weathered slopes of the ridges underlain by basalt and metamorphic rocks adjacent to Coeur d'Alene may also offer some promise as waste disposal sites. However, the soil profiles on these ridges are thin and under precipitation conditions present in the Coeur d'Alene area the zone of saturation is likely to be near the ground surface at most such locations. Consequently safe disposal sites in this type of medium will be limited in number. Abandoned quarries that are high above the water table in nearby Pre-Cambrian metamorphic rocks also may represent satisfactory refuse disposal sites. However, joints and fractures should be examined prior to use.

The communities of St. Maries, Kellogg and Wallace are in similar hydrogeologic environments with respect to the selection of safe refuse disposal sites. The valley bottoms are underlain by alluvium or glacial outwash and the valley walls rise abruptly from the valley bottoms. (Johns, 1933, and Hobbs et al., 1965, for geologic maps of the St. Maries and Coeur d'Alene valley areas, respectively). Water levels in the Elks' well at Wallace, the Zanetti well at Osburn and the Lions' well near Pinehurst indicate that the water table is within 10 feet of the surface in the bottom of the Coeur d'Alene River valley. The presence of marshes, springs and seeps indicate a similar situation in the St. Joe River valley near St. Maries. This condition, combined with the fact that wells in these valleys are utilized as sources of domestic water, precludes the use of the outwash deposits as a refuse disposal medium. The thin soil profiles on the valley walls can be expected to preclude the disposal of refuse in the unconsolidated medium at most locations.

It appears that the greatest promise for safe refuse disposal sites for these communities lies in the virtually impermeable Precambrian metamorphic rocks which crop out above the Coeur d'Alene and St. Joe River valley bottoms. A few abandoned quarries have been excavated in these rocks and with proper care given to the routing of surface drainage, they may constitute safe disposal sites. St. Maries currently utilizes such a site with no apparent leachate problems. Jointed and fractured rocks should be avoided. Disposal in local valley bottoms should be avoided because of the probability of the production and escape of leachate concomitant with saturation produced by surface runoff.

The community of Sandpoint is also similar in some ways to St. Maries, Kellogg and Wallace with respect to the availability of safe refuse disposal sites. According to the geologic map of Savage (1967, Fig. 2B), the unconsolidated materials in the broad valley bottoms adjacent to Sandpoint consist of clays, silts, sands and gravels. For the most part these materials will be permeable except for the clay layers. Consequently there is a risk of any leachate produced being carried with the ground water moving through the sediments. Some clay deposits to the north and northeast of the city may constitute safe disposal sites; however, these sites may be unfavorable because of transportation economics.

Higher on the slopes above Sandpoint the metamorphic rocks of the Precambrain and the igneous rocks of the Kaniksu batholith crop out. These rocks, particularly the metamorphics, have low permeability; consequently properly engineered excavations in them may constitute satisfactory refuse disposal sites provided sufficient overburden is present to operate a landfill project properly. Unfortunately, however, the readily available gravels of the glacial deposits near Sandpoint have minimized the number of excavations for crushed rock in the metamorphic rocks. Therefore, ready-made excavations in the metamorphic rocks are limited.

The cost of creating such an excavation in hard rock exclusively for the purpose of refuse disposal would be unreasonable. Consequently Sandpoint and nearby communities may be forced to select the finest-grained and driest valley fill deposit available, carefully engineer the operation, and ascertain that no nearby water supply wells are located down-gradient. Such a site would be termed protective rather than absolutely safe. Additional insight into ground-water conditions and the distribution of lake sediments in the area is provided by Walker (1964).

EVALUATING PROPOSED REFUSE DISPOSAL SITES

Refuse disposal sites should be located in relatively impermeable material within which the water table is 30 to 50 feet below the bottom of the proposed fill. Disposal in standing water should not be permitted. Under these conditions movement of any refuse leachate produced will be retarded or prevented. Clays, silts and certain unfractured metamorphic rocks meet these requirements in Idaho. Sites underlain by sand and gravel generally are least desirable. Table 3 summarizes favorable and unfavorable hydrogeologic conditions. Prospecting for ideal disposal sites reduces to determining whether these conditions exist at a proposed site. Preliminary information can be obtained from inspection of surficial outcrops, from published geologic maps, from published water table maps, and from drillers' logs or other well logs. This report contains references which should prove helpful to the major communities in Idaho. In all areas where no information is available test holes will be required. Samples for grain size analysis should be obtained from such holes to depths of at least 30 feet below the bottom of the proposed pit. The elevation and direction of slope (gradient) of the water table can be obtained from open holes or from piezometers. Other more elaborate techniques, such as resistivity or seismic surveys are available; however, these will involve considerable expense. In all cases prospective sites should be evaluated by an experienced geologist who is familiar with the movement of ground water in various types of rocks.

If investigation determines that a community has no available sites which meet the ideal hydrogeological conditions mentioned above and summarized in Table 3, then that community may be forced to select a less than ideal site and take precautionary measures to minimize the risk of pollution by its refuse disposal operation. These measures include the careful installation of a clay liner, determining the direction of ground-water motion at the site, ascertaining that no nearby water supply wells or springs are located down-gradient from the site and ascertaining that the dilution capacity of any nearby down-gradient stream is capable of handling any refuse leachate that discharges into it. The communities in the South Fork, Coeur d'Alene River valley may find themselves in this position. Most communities in Idaho have available refuse disposal sites with good potential from the hydrogeological point of view.

SUMMARY

Ideal hydrogeological conditions for refuse disposal sites consist of the occurrence at the site of fine-grained unconsolidated sediments 30 to 50 feet thick.

A thickness of 50 feet of unconsolidated, fine-grained material permits the excavation of 20-foot deep trenches commonly used in the cut and fill emplacement technique. Under these conditions 30 feet of unconsolidated material will remain beneath the disposal pit or trench. The water table should not intersect the bottom of the disposal pit even during the wettest portion of the year. Sediments which meet these geologic requirements are glacial till, lake silts and clays, shales, and windblown silt (loess). Sediments which should be avoided if at all possible are sand and gravel, or fractured sandstone, limestone, dolomite and basalt, as should rocks known to contain soluble minerals producing large voids and solution cavities. The geology adjacent to most of the major communities in Idaho has been mapped in sufficient detail to provide considerable insight into where both desirable and undesirable conditions can be expected to occur. This report includes references to publications containing geological maps of areas adjacent to most of Idaho's major communities. Also included herein are references of hydrogeologic studies which may provide insight into the depth at which the water table can be expected to occur and into the direction of ground-water motion. The availability of this latter type of information, however, is much more limited than is geological information.

In areas where hydrogeological information is not available it may be necessary to examine drillers' logs (available through the Idaho Department of Reclamation), or to call upon knowledgeable investigators to conduct on-site field studies, including test borings, piezometer installation, permeability tests, and possibly resistivity or other geophysical surveys.

Ideally, from a hydrogeologic standpoint, refuse disposal sites should be located on flat upland areas, on ridges at the heads of draws, gullies or ravines and in dry open-pit mines or quarries. These sites are likely to have minimum damage from surface runoff and are likely to be well above the water table. Undesirable sites consist of depressions where water accumulates, lower or middle reaches of gullies, draws or small valleys, stream floodplains or at the upper portions of alluvial fans where permeable sediments crop out.

A few communities in Idaho lack topographically and hydrogeologically ideal refuse disposal sites. These communities may have to resort to the use of what has been termed a hydrogeologically protective site. The use of such sites requires the careful installation of a relatively impermeable clay liner beneath the refuse and perhaps even a series of settling lagoons for effluent. As additional insurance, the ground-water flow system adjacent to such sites should be determined prior to approval. Additional precautionary measures include ascertaining that no nearby water supply wells or springs are located down-gradient from the proposed site and ascertaining that any stream located down-gradient has sufficient dilution capacity to handle the leachate that might be discharged into it. Because hydrogeologically protective sites depend to some degree on the ion exchange capacity of the sediments down-gradient from the site to renovate escaping leachate, it may be advisable to evaluate this parameter if the detrimental consequences of pollution are great.

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