UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

GEOLOGIC, HYDROLOGIC, AND CULTURAL FACTORS IN THE SELECTION OF SITES FOR THE LAND DISPOSAL OF WASTES IN WASHINGTON

By N. P. Dion, R. C. Alvord, and T. D. Olson

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 84-4279

Prepared in cooperation with the

STATE OF WASHINGTON DEPARTMENT OF ECOLOGY

Tacoma, Washington
1986

UNITED STATES DEPARTMENT OF THE INTERIOR

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CONTENTS

ILLUSTRATIONS

GEOLOGIC, HYDROLOGIC, AND CULTURAL FACTORS IN THE SELECTION OF SITES FOR THE LAND DISPOSAL OF WASTES IN WASHINGTON

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ABSTRACT

The Washington Department of Ecology (WDOE) is developing a major program to deal with the problems of waste disposal in the State. As part of this program, WDOE and the U.S. Geological Survey (USGS) began a cooperative study in 1983 that would provide the geologic, hydrologic, and cultural data needed to characterize, in an objective manner, land areas of Washington relative to the disposal of wastes.

The selection of specific factors for characterization of areas for waste disposal was made cooperatively between personnel of WDOE and USGS. Data portraying the distribution of those factors across Washington are presented in a series of 12 maps. The factors selected relating to a particular site for disposal of wastes include major geologic units; natural hazards from earthquakes, faulting, and volcanoes; climate; locations of major surface-water and ground-water bodies; population density; and land and water uses. Within most factors (maps) the data were grouped into class intervals and the intervals for most factors ranked according to their relative suitability/unsuitability for land disposal of wastes following criteria supplied by WDOE. Areas of the State considered completely unsuitable (as determined by WDOE personnel) for waste disposal because of current or proposed land uses were excluded from ranking.

INTRODUCTION

Among the many environmental issues facing the nation and the State of Washington, the disposal of wastes, especially hazardous wastes, is one of the more serious and pressing. Man produces wastes in progressively increasing quantity, complexity, and toxicity. Waste products result from municipal sewage and trash, manufacturing, processing, mining, agriculture, and power generation. The most common waste-disposal methods of the past involved dilution by water or air; however, those methods are now either illegal or strictly controlled. Even though land disposal is generally regarded as an inadequate long-term method of waste disposal, it is currently the cheapest and most common legal method.

For purposes of this report, wastes are broadly defined as the residues of man's use of the earth's resources that have little or no economic value. Hazardous wastes are defined as discarded materials that may pose a substantial threat or potential danger to human health or the environment when improperly handled, and include materials that are ignitable, corrosive, infectious, or toxic. The broader term "wastes" will be used in this report to include hazardous wastes.

The practice of land disposal can easily lead to serious health and environmental problems. The disposal of hazardous wastes in particular is a serious problem, both in reality and in the public's perspective. The State of Washington, through its Department of Ecology (WDOE), is developing a major program to deal with the problems of waste disposal. As part of this program WDOE is characterizing the land areas of the entire State for areas most and least suitable for the disposal of wastes. Inherent in this approach is the need to examine and assess, on a statewide basis, those factors that affect the suitability of land-based waste-disposal practices and sites. This investigation is directed to this latter need.

In 1983 the WDOE and USGS (U.S. Geological Survey) began a cooperative study that would provide the geologic, hydrologic, and cultural data needed to evaluate statewide, in an objective manner, the suitability of sites for the land disposal of wastes. This report is a summary of the results of that study.

Factors of Significance in the Land Disposal of Wastes

One of the problems associated with land disposal is the generation of leachate (Freeze and Cherry, 1979, p. 435), a solution that forms when water percolates through the disposal site and dissolves soluble substances contained in it. A second problem is the failure of containment of the waste itself and its movement away from the disposal site. If the leachate or wastes were to reach a ground-water or surface-water body, contamination of that resource could occur. Therefore, the safe disposal of wastes on land is closely interrelated with geologic and hydrologic phenomena and conditions. In addition, if damages to human health and the environment are to be avoided, certain cultural factors must also be considered. Throughout this report, the geologic, hydrologic, and cultural factors considered significant by WDOE to the land disposal of wastes are discussed in terms of their occurrence in Washington. Data that describe the distribution of those factors across

Washington are portrayed in a series of 12 maps, referred to in this report as plates 1 through 12.

Map Compilation

In compiling the maps, the intent was to portray technical data in a nontechnical format and to provide a flexible data base that could be used by managers and decision makers with diverse backgrounds. Each map is restricted in coverage to one or two factors and was prepared at a scale of 1:500,000. The maps were then reduced in size to their current scale of 1:750,000. Within each factor (map), the data have been grouped into class intervals.

The class intervals of most maps were ranked according to their relative suitability/unsuitability for land disposal of wastes according to criteria supplied by WDOE. As pointed out by Pessl (1972, p. 3), "suitability is a complex judgment involving many factors, some of which are outside the technical competence of the geologist or hydrologist. Suitability maps also tend to become outdated as soon as the assumptions defining suitability change." The ranking of the intervals (as determined by WDOE) within a single factor is shown in the explanation of the map for each factor, with the exceptions of excluded areas, principal aquifers, and land use. No satisfactory method of ranking these three actors was found. No quantification or weighting of intervals was attempted, nor were the individual factors weighted in any way.

Throughout most of the mapping process, only areas greater than about 10 square miles were considered large enough to include at the working scale of 1:500,000. In preparing the maps, areas of the State where sufficient information did not exist to map a particular factor at the working scale were labeled as such. In addition, no attempt was made to map those areas deemed eminently unsuitable by WDOE for the disposal of wastes.

EXCLUDED AREAS

Many areas within Washington currently are dedicated to land uses considered eminently unsuitable by WDOE for the disposal of wastes. These areas are referred to in this report as primary, excluded areas and include wilderness areas, national parks, recreation areas, wildlife refuges, sole-source aquifers, municipal watersheds, and national monuments. These protected areas, shown by type on plate 1 and generally on all subsequent plates, were excluded from consideration in this study. That is, regardless of geologic, hydrologic, or cultural conditions in those areas, they were considered absolutely unsuitable as waste-disposal sites.

Other areas within Washington are dedicated to land uses which, although not as unsuitable to waste disposal as those areas mentioned above, could be considered as worthy of a limited degree of protection. These areas are referred to as secondary excluded areas and included national forests and Indian reservations; their distribution is also shown by type on plate 1. Unlike primary excluded areas, however, the secondary excluded areas are not shown on subsequent plates.

No attempt was made to rank excluded areas, either primary or secondary, as to their suitability/unsuitability for the land disposal of wastes.

GEOLOGIC FACTORS

Major Geologic Units

The major geologic units of Washington are shown on plate 2. The geologic data were generalized from Huntting and others (1961), from numerous published maps of local areas, and from unpublished maps supplied by the Washington Public Power Supply System (WPPSS; William Kiel, written commun., November 22, 1983). Geologic units with similar lithologic characteristics and permeability were grouped together, hence the resulting map portrays relative rock permeability as well as major rock types.

Permeability refers to the capacity of earth materials to transmit water through interconnected pore spaces or fractures. In loose, unconsolidated materials such as silt, sand, or gravel, water moves through pore spaces separating the individual particles. In dense, consolidated rocks, the only movement of water is through interconnected joints, fractures, faults, or solution channels.

According to LeGrand (1983), high permeability (1) allows infiltration of contaminated water to the ground, thus preventing or reducing surface contamination and runoff; (2) may result in a deep water table, allowing a better opportunity for contaminants to attenuate in the unsaturated zone; and (3) may lead to faster movement of water in the saturated zone, thereby providing less opportunity for decay with time. The same investigator states that, conversely, low permeability (1) retards movement, resulting in additional time for attenuation; (2) causes rejection of recharge and may shunt contaminants to surface drainages; and (3) may result in a shallow water table and less attenuation in the unsaturated zone.

Permeability determinations of earth materials have shown that permeability values commonly differ by several orders of magnitude for various materials, and that seemingly similar materials commonly have widely varying permeabilities (Todd, 1963; Maxey, 1964; Freeze and Cherry, 1979). For these reasons, permeabilities are discussed in this report in terms of expected ranges of values for the major rock types found in Washington.

Permeability values (inset on plate 2) for most rock units mapped were estimated, based on the known lithology of the unit and the permeability range commonly assigned to that lithologic type in the references cited previously. The assigned permeability values are for the strata commonly tapped by wells and have a large range due to lithologic variations that are commonly encountered in a single rock type. Many of the more permeable units tapped by wells are separated stratigraphically by units of lower permeability. In addition, the thicknesses of the strata commonly tapped by wells vary greatly and some of the rocks, especially the layered basalts of the Columbia Basin, exhibit marked differences in permeability areally and with depth. Values for the Columbia River Basalt were calculated, based on known aquifer characteristics and well-yield data.

As shown in the inset on plate 2, glacial outwash, alluvium, and terrace deposits are generally the more permeable rock units, and glacial till, mudflows, and consolidated rock are generally the less permeable. Although the consolidated rock unit is generally considered to be relatively impermeable, locally it can be highly permeable because of the presence of joints and fractures, hence it has been assigned a wider range of permeability than most other units. In the Puget Sound trough, most of the glacial drift has not been differentiated to outwash and till, hence the permeability of that unit is depicted as spanning the range from outwash to till.

Natural Hazards

Earthquakes

The principal hazards posed by an earthquake lie in its potential to physically disrupt a waste-disposal operation and to destroy existing conditions of waste containment and isolation.

The most widespread earthquake damage is generally a result of ground shaking, the severity of which generally increases as the magnitude of the earthquake increases. The intensity of ground shaking in certain frequency bands can be amplified by thick deposits of unconsolidated material; the greatest structural damage commonly occurs in areas underlain by unconsolidated sedimentary deposits. In a study of the San Francisco (California) area, Borcherdt (1975) found that for sites equidistant from the source of an earthquake, the effects of ground shaking are normally least for sites underlain by bedrock, intermediate for those underlain by alluvium, and greatest for those underlain by artificial fill or bay muds. In describing the 1964 Prince William Sound (Alaska) earthquake, Hays (1981) noted that much of the resulting damage was the result of the loss of strength in clay layers.

The severity of ground shaking is usually described in terms of peak ground acceleration, expressed as a percentage of gravity. The ground-shaking hazard for Washington is depicted on plate 3 in terms of the peak horizontal ground acceleration that can be expected within a 50-year period at the 90-percent probability level for sites underlain by rock, and is based on research by Algermissen and others (1982). A 90-percent probability of not being exceeded in a 50-year period is equivalent to a mean recurrence interval of 475 years. Plate 3 is based, in part, on a knowledge of the regional geology and seismic history of the State. The map does not, however, include a consideration of the seismic events associated with the eruption of Mount St. Helens in May 1980.

On a large scale, the most intense earthquake activity is found in the Puget Sound lowland; recent major earthquakes were recorded in that region in April 1949 and April 1965. Although the exact cause of seismicity in the Puget Sound area has yet to be identified, Yount and Crosson (1983) have concluded that very young alluvium and artificial fill, deltas and steep bluffs bordering Puget Sound, and steep rock slopes are particularly susceptible to earthquake-induced ground failure.

In a nationwide assessment of seismic risk zones (Hays, 1980), the Puget Sound region was assigned the same degree of risk as the San Francisco (California) Bay area. This suggests that the Puget Sound region could experience heavy damage as the result of a major earthquake.

As shown on plate 3, the areas of lowest seismic activity in Washington are in the south-central and eastern parts of the State.

Faulting

Surface faulting is the differential movement of the two sides of a fracture in the crust of the earth; faults are closely associated with earthquakes and ground shaking. During an earthquake, the most violent ground shaking generally occurs in a narrow band adjacent to the fault and decreases with distance away from the fault. According to Hays (1981), the length of fault rupture seems to be closely related to the magnitude of earthquakes associated with it.

Movement of land areas adjacent to an active fault poses a threat to the integrity of a waste-disposal site and could lead to the uncontrolled release of wastes to the environment.

A key factor in the assessment of a fault's potential for producing an earthquake in the future is its history of displacements, especially the age of its last movements. Faults that have moved in the most recent past are considered most likely to move in the future. In fact, Borcherdt (1975) pointed out that a fault that has moved within the past 10,000 years is considered still active.

The categorizing of fault zones on plate 3 was accomplished on the basis of relative fault age. The underlying assumption was that the youngest (most recent) faults are those most likely to move in the future and those to be avoided in the siting of waste-disposal facilities. The dating of the faults was accomplished by determining the age of the youngest geologic materials cut by the fault, as based on the generalized geologic map (pl. 2). An inherent source of error in this method of dating, however, is that the absence of young geologic materials, for whatever reason, in the vicinity of a "young" fault could result in its being assigned a misleading "old" age. The relative fault ages shown on the plate, therefore, should be considered maximum ages.

Fault locations used to prepare plate 3 were taken from McLucas (1980) and unpublished maps supplied by the Washington Public Power Supply System.

Volcanic Activity

Large parts of Washington could be affected by volcanic activity originating from volcanoes in that State (Mount Baker, Glacier Peak, Mount Rainier, Mount St. Helens, and Mount Adams) and in Oregon (Mount Hood). The volcano-related hazards considered in this study were those most likely to affect a waste-disposal installation, and include hazards from both tephra and mudflows (pl. 4). Tephra is transported through the air; mudflows move along the land surface and are usually, although not always, restricted to stream and (or) river valleys (Hyde and Crandell, 1978).

Tephra--The volcanoes of the Cascade Range are characterized by violent, explosive eruptions that are derived from a viscous, silica-rich magma. Such eruptions tend to produce large amounts of tephra, pyroclastic flows, and mudflows. Tephra consists of solid or molten rock particles of any size that are erupted into the air at the time of a violent eruption and carried away from the volcano by winds. The distance the particles are carried is determined by the size and density of the particles, the height to which they are ejected, and the wind speed. Large, dense particles usually fall back to earth close to the volcano; small, light particles can be carried by the wind for several hundred miles. The direction the particles are carried is determined chiefly by the wind direction at the time of eruption. Damage to structures and machinery is caused by the weight of the tephra and by its smothering and abrasive effects.

Areas most likely to be affected by tephra are certain sectors downwind from potentially active volcanoes. As would be expected, most tephra deposits thin gradually with increasing distance from the source. Variable meteorological conditions, however, can cause the deposits to fluctuate considerably in thickness.

The tephra-hazard zones shown on plate 4 are based on the locations of volcanic peaks, records of wind directions, and the expected decrease in hazard away from the volcano. The zones portray an outward-decreasing relative risk and not a specific level of risk. Although the risk-zone boundaries in the downwind direction have been drawn at arbitrary distances of 10, 25, and 50 miles away from the major volcanoes, these distances approximate those used by Crandell (1973) and Crandell and Mullineaux (1967, 1978) in assessing the volcanic risks of Mount Rainier and Mount St. Helens. In presenting the volcanic risks of Cascade volcanoes for this study, all cones were assigned an equal likelihood of eruption, regardless of their eruption histories.

In a study of the volcanic risks of Mount Rainier, Crandell (1973) pointed out that at altitudes above that peak that are likely to be reached by an eruption cloud, winds blow most often from the west-southwest; the volcanic-risk zones determined as part of this study were oriented accordingly. The windward (western) limits of the zones were reduced arbitrarily to 50 percent of those limits to the east. Beget (1981) indicated that most tephra deposits associated with historic eruptions of Mount St. Helens, Mount Rainier, and Mount Baker have been found generally east of the cones.

Mudflows.--A mudflow is a mass of water-saturated rock debris that moves downslope as a fluid under the influence of gravity. The rock debris is generally composed of loose material from an explosive volcanic eruption; the water can be provided by rain, melting snow or ice, or the overflow of a lake or reservoir.

The chief dangers of a mudflow include the burial or removal of manmade structures (including waste-disposal sites), the filling of lakes and reservoirs, and the creation of downstream flooding. The locations of mudflow-hazard zones are relatively predictable in that they are restricted to the flanks of the volcano and the valleys leading from it. In general, the risk from mudflows decreases gradually downvalley, but decreases abruptly with increasing height above the valley floor.

The stream areas considered likely to be affected by mudflows from Washington volcanoes are depicted on plate 4. Despite the fact that risk decreases downvalley, the entire reach of the stream under consideration has been assigned an equal degree of risk in an attempt to compensate for the uncertainties inherent in predicting the size of the mudflow that could be generated by any single eruption.

In addition to the susceptible river valleys depicted on plate 4, many low-lying areas of the Puget Sound trough could also be inundated by mudflows and therefore should be considered susceptible. In the interest of simplicity and clarity, however, those areas have not been depicted on plate 4.

HYDROLOGIC FACTORS

Climate

A knowledge of local climatic conditions is of considerable importance in the selection of a waste-disposal site in that should containment fail, the chances of additional contamination are higher in areas of greater precipitation. Wastes transported by precipitation could flow overland to nearby streams or lakes, or infiltrate into the ground to an aquifer. In general, excessive precipitation abets the dispersion of contaminants and could, by itself, cause the failure of containment.

The generalized precipitation pattern for Washington is shown on plate 5 and is based on an isohyetal map prepared by the U.S. Weather Bureau (1965) and published by the U.S. Soil Conservation Service. Although the map is dated, it remains the most current source of precipitation data for the State as a whole.

Plate 6 presents a map of mean annual potential evapotranspiration, that is, the maximum amount of water loss that can be expected from evaporation on bare soil and transpiration by vegetation. Potential or maximum evapotranspiration is governed chiefly by climatic conditions and can only occur under ideal conditions of climate and moisture availability. The concept assumes that there is sufficient moisture in the soil at all times and that a moisture stress never exists in the vegetation. The map is an approximation of an unpublished map prepared by the U.S. Weather Bureau for the U.S. Soil Conservation Service in 1961 using standardized formulas for the calculation of evapotranspiration.

Precipitation surplus or deficiency (pl. 7) is defined and calculated as the difference between mean annual precipitation (pl. 5) and mean annual potential evapotranspiration (pl. 6).

Locations of Major Surface-Water Bodies

Waste-disposal sites should be located away from usable water supplies, including streams and lakes, in order to lessen the chances of contaminating those supplies either in the course of normal site operation or by catastrophic accident, and to avoid damage to the site from floods or mudflows.

The locations of major streams and lakes of Washington are highlighted on plate 8 by "buffer" zones extending about 1.5 miles from the edge of the water body. The choice of width for the buffer zones was arbitrary and based solely on what could be considered reasonable and adequately portrayed on a map of 1:750,000 scale. For purposes of this report, a major surface-water body is defined as any stream with an average annual discharge of at least 100 ft^3/s (cubic feet per second) in western Washington, 50 ft^3/s in eastern Washington, or as a lake larger than about 2,500 acres (U.S. Geological Survey, 1981a, 1981b; Wolcott, 1964, 1965).

There are major saline-water bodies contiguous to Washington land areas that should also be protected from contamination. These include the Pacific

Ocean, Strait of Juan de Fuca, and Puget Sound. In the interest of map clarity, however, buffer zones have not been applied to those water bodies.

Locations of Principal Ground-Water Aquifers

The distribution of major aquifers in Washington shown on plate 9 is based in large part on a report by Molenaar and others (1980), as is much of the following discussion. The rock units shown as non-aquifers consist of dense, consolidated sedimentary, metamorphic, and igneous rocks that have local secondary permeability because of fractures and faults. These rocks, in general, are geologically older than rock units shown as aquifers. Although the "non-aquifers" do indeed supply varying amounts of water to wells locally, the rock units as a whole are neither dependable nor productive sources of ground water. In those regions underlain by two or more aquifers, the uppermost aquifer has been portrayed on the map.

The principal aquifers of Washington are most easily categorized by lithology and include basalt, sand and gravel, glacial drift, and alluvium. The older basalt aquifer includes lava flows and some interbedded sedimentary rocks that occur in great thickness chiefly beneath the Columbia Plateau. Ground water in this aquifer occurs mostly in fractures, rubble zones, and sand-and-gravel units between lava flows. Because of the great vertical and horizontal heterogeneity of this thick, extensive aquifer, well yields are highly variable. In addition, most reported yields on which this discussion is based are for wells completed in the upper layers of individual basalt flows. The more productive wells generally draw from several water-bearing zones or several lava flows and yields of 1,000 to 3,000 gal/min (gallons per minute) are common. Because of its high yields, this aquifer is relied on heavily for the irrigation of crops on the Columbia Plateau (see ground-water use, plate 11).

Basalt younger than that beneath the Columbia Plateau occurs in the headwaters of the Klickitat River basin between Mount Adams and Goldendale. Although this basalt is moderately productive (as much as 1,000 gal/min), the region is sparsely populated and use of the ground water is light.

Sand-and-gravel aquifers occur along the lowlands of the Olympic Peninsula and Willapa region, north and east of Vancouver, in the lowlands of the Ellensburg and Yakima regions, and near Walla Walla. Yields from these aquifers range from a few gallons per minute, suitable for domestic purposes, to more than 1,000 gal/min near Vancouver, where the water is used primarily for industrial purposes.

The glacial drift aquifer is composed chiefly of sand and gravel units of glacial outwash, or the more permeable units found locally of sand and gravel units of glacial outwash, or the more permeable units found locally in glacial till. In the Puget Sound region and in northeastern Washington, this aquifer provides most of the water used for domestic, municipal, and industrial purposes. In the Columbia Plateau region, the aquifer is used primarily for domestic purposes as greater yields for public supply and irrigation can usually be obtained from the underlying basalt.

Owing to various modes of deposition, the glacial drift aquifer varies greatly in composition and water-yielding capacity. Wells tapping thick layers of highly permeable coarse sand or gravel yield more than 1,000 gal/min; wells tapping layers of less-permeable silt or till may yield only enough water for single-family domestic supplies.

Alluvial aquifers consist of unconsolidated silt, sand, gravel, and cobbles deposited along streams, deltas, and coastal beaches. Reported yields from these aquifers are commonly small (up to 50 gal/min) but are a reflection of its predominant use; most water withdrawn from alluvium is used for domestic purposes. In some areas, large-diameter wells in the alluvial aquifer yield 50 to 200 gal/min for municipal and industrial purposes.

In assessing the importance of an aquifer, the great areal differences in supply of and demand for ground water must be considered. For instance, on the San Juan Islands an aquifer capable of yielding 100 gal/min is of great significance. However, in the Columbia Basin, where aquifer yields from the basalt are generally quite high, an aquifer that yields only 100 gal/min is relatively insignificant. For this and other reasons, no truly representative method of ranking aquifers, either by principal water use or well yield, was found.

Depth to the Water Table

The water table is defined as the top of the saturated part of the ground-water body. As pointed out by LeGrand (1964), the chief factors that control the depth of the water table are frequency and intensity of precipitation, topography, and permeability. Humid regions, such as western Washington, tend to have shallow water tables that closely follow the topography of the land surface. Conversely, drier regions, such as parts of eastern Washington, tend to have deep water tables that bear little relation to surface topography. In both areas, however, the water tables tend to lie deeper beneath interstream areas and to be closer to land surface beneath lowlands. All other factors being equal, the water table tends to be deeper in relatively permeable materials than in relatively less permeable materials. In regions of dense, consolidated rock ground water is either absent or discontinuous.

The earth materials above the water table are not saturated with water, and wastes in this "zone of aeration" tend to remain stationary except when carried downward by infiltrating water. Wastes within the zone of aeration tend to be attenuated with time through the processes of decay, sorption, dilution, and dispersion. For these reasons, areas underlain by a deep water table are generally more suitable for waste disposal than areas underlain by a shallow water table.

The depths to the water table for the major aquifers of Washington are shown on plate 9, and are based on numerous published and unpublished maps and reports, water-level data from individual wells, and the records of dug wells throughout the State. For reasons of conservatism, in areas of artesian ground-water conditions the piezometric surface was considered a water table and depicted accordingly.

The degree of certainty with which the depth to the water table can be portrayed is highly variable; this condition is reflected in the intervals chosen to portray some of the depth-to-water data on plate 9. For instance, in some areas the water table is known to be within 25 feet of land surface.

In other areas, where fewer data are available and where there is a large amount of relief on the water table or on the land surface, depths to the water table are portrayed as being either less than 50 or 100 feet.

Seasonal and annual fluctuations can be expected in the depth to the water table. These fluctuations may be natural and the result of both seasonal precipitation patterns and year-to-year variations in amount of total precipitation; the fluctuations may also be caused by man as he withdraws water from the aquifer for any of a number of beneficial uses.

As shown on plate 9, depths to the water table in the alluvial aquifers are generally less than 25 feet. These aquifers are relatively thin and of limited lateral extent. The expected seasonal fluctuations in depth to water are small (commonly 1 to 10 feet).

The depths to the water table in both the glacial-drift and sand-and-gravel aquifers are generally less than 50 feet. Although the glacial drift category has not been differentiated into till or outwash on the map, based on permeability the depths to water can logically be assumed to be shallower in the till units and deeper in the outwash units. The expected seasonal fluctuations in depth to water in these aquifers are moderate (5 to 20 feet).

The depths to water in the basalt aquifers are variable and relatively deep, and expected seasonal fluctuations in depth to water are large (up to 50 feet).

CULTURAL FACTORS

Population Density

In order to avoid or lessen damages to human health, waste-disposal sites, especially those containing hazardous wastes, should not be located in or near densely populated areas--usually the greater the separation the less the risk.

A population density map (pl. 10) was prepared as part of this study by first determining the population density of each county subdivision recognized by the U.S. Bureau of the Census (1982). This value was calculated by dividing the 1980 population of each subdivision (as reported by the Census Bureau) by the area of the subdivision (as determined by planimetering). The 235 individual subdivisions and their densities were then portrayed on an intermediate statewide map and the densities categorized according to the composite range of values (0.0-3,700 persons per square mile). The resulting distribution of population density is shown on the final map (pl. 10) by class intervals.

It should be emphasized that because the county subdivision was the smallest geographic area considered, population densities within the subdivisions and class intervals may not be uniform but, instead, localized. More detailed information, however, is lacking.

Principal Land-Use and Land-Cover Types

The land-use and land-cover categories in Washington portrayed on plate 10 were generalized from more detailed maps prepared by the U.S. Geological Survey, most of which are published at a scale of 1:250,000. The nine categories chosen for mapping are listed on the map and are explained in detail in a report by Anderson and others (1976). Most of the data portrayed on the original, more-detailed maps were compiled by aerial photography and other remote sensing techniques. As shown on plate 10, land-use and land-cover data presently are lacking in the northeastern and southwestern parts of Washington. No satisfactory method was found to rank land-use and land-cover types as to their suitability/unsuitability for the land disposal of wastes.

Water Use

Land areas of Washington that receive large amounts of water, from whatever source and for whatever purpose, were considered inherently more valuable and worthy of a greater level of protection from waste contamination than areas using lesser amounts of water. Plate 11 portrays the relative amounts of water used from ground- and surface-water sources; plate 12 portrays the total amounts used from both sources. The illustrations are based on data collected in a study of water-use patterns in Washington in 1975 (Dion and Lum, 1977) and do not take into account the specific uses of the withdrawn water.

In preparing the maps, water use by source was determined for each of the 62 Water Resource Inventory Areas (WRIAs) recognized by the Washington Department of Ecology; these WRIAs correspond to major surface-water drainage basins of the State. The 62 individual water-use amounts were then portrayed on a statewide basis and categorized in a relative manner according to the resulting range of values.

It should be emphasized that because the WRIA was the smallest geographic area considered, water use within the basins and composite areas shown on the map may not be uniform but, instead, localized. More detailed information, however, is lacking.

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*U.S. GOVERNMENT PRINTING OFFICE: 1987-791-634