TECHNICAL RECORD

SEWRPC

VOL. 3 NO. 3

September 1971

* * * * * IN THIS ISSUE * * * * *

* * * HYDROGEOLOGIC CONSIDERATIONS IN LIQUID WASTE DISPOSAL, WITH A CASE STUDY IN SOUTHEASTERN WISCONSIN * * * * * *

SOUTHEASTERN WISCONSIN REGIONAL PLANNING COMMISSION

COMMISSION MEMBERS

KENOSHA COUNTY
George C. Berteau,
Chairman
Donald L. Klapper
Donald L. Knapp

RACINE COUNTY
Milton F. LaPour
Leonard C. Rauen
Garth R. Seehawer

MILWAUKEE COUNTY
Richard W. Cutler,
Secretary
Richard C. Nowakowski
Norman C. Storck, P. E.

WALWORTH COUNTY
Eugene Hollister
Henry S. Lauterbach
John D. Voss

OZAUKEE COUNTY
Thomas H. Buestrin
James F. Egan,
Vice-Chairman
Ralph J. Huiras

WASHINGTON COUNTY
Lawrence W. Hillman
Paul F. Quick
Joseph A. Schmitz,
Treasurer

WAUKESHA COUNTY
Charles J. Davis
Lyle L. Link
Theodore F. Matt

COMMISSION STAFF

Kurt W. Bauer, P.E. . . . . Executive Director

Harlan E. Clinkenbeard. . . . . Assistant Director

Philip C. Evenson . . . . Assistant to the Director

Dallas R. Behnke. . . . . Chief Planning Illustrator

William E. Creger, P.E. . . . . Chief Transportation Planning Engineer

Donald N. Drews . . . . Administrative Officer

James W. Engel. . . . . Chief of Systems Engineering and Data Processing

Robert L. Fisher . . . . Chief Land Use Planner

William D. McElwee, P.E. . . . . . Chief Natural Resources Planner

Eugene E. Molitor . . . . Chief of Planning Research

Norbert S. Theine, P.E. . . . . Chief Community Assistance Planner

THE TECHNICAL RECORD

Volume three Number three

September 1971

TABLE OF CONTENTS

HYDROGEOLOGIC CONSIDERATIONS IN LIQUID WASTE DISPOSAL, WITH A CASE STUDY IN SOUTHEASTERN WISCONSIN. 1
by Martha J. Ketelle, Department of Geology and Geophysics, University of Wisconsin, Madison, Wisconsin

The preparation of this publication was financed in part through a joint planning grant from the Wisconsin Department of Transportation, Division of Highways; the U. S. Department of Transportation, Federal Highway Administration; and the U. S. Department of Housing and Urban Development under the provisions of the Federal Aid Highway Legislation and Section 701 of the Housing Act of 1954, as amended.

Inside Region $1.00
Outside Region $2.00

Author's Acknowledgments

The work upon which this publication is based was supported in part by funds provided by the U. S. Department of the Interior, Office of Water Resources Research, authorized under the Water Resources Research Act of 1964, P. L. 88-379, Allotment Grant Number OWRR A-018-WIS, Agreement Number 14-01-0001-1870, and the University of Wisconsin, Alumni Research Foundation, Graduate School Committee Project Number 69-85200-1.

Dr. David A. Stephenson, Department of Geology and Geophysics, U. W., served as the academic advisor for the project. Credit for the approach used in developing the suitability map for liquid waste disposal for southeastern Wisconsin goes to James Hackett and Murray McComas. Their Illinois Survey publication, Geology for Planning in McHenry County, is a similar study for northeastern Illinois and inspired the system described in this report.

HYDROGEOLOGIC CONSIDERATIONS IN LIQUID WASTE DISPOSAL, WITH A CASE STUDY IN SOUTHEASTERN WISCONSIN

By Martha J. Ketelle, Department of Geology and Geophysics, University of Wisconsin, Madison

INTRODUCTION

Recently man has begun to realize the consequences of physical limitations of the earth's natural resources. This realization has created a whole new field in which planners, working with a variety of specialists, can utilize data to "manage the environment." A better statement might be, "manage man's activities in relation to the natural environment." Prior to the present era of environmental concern, applied geological research was developed principally for the solution of immediate problems; e.g., exploitation of mineral resources, construction of buildings and roads, or provision of adequate water supplies. However, a new role is evolving for geologists concerned with the broader concept of preserving the quality of our natural environment.

This new role is identified by John Frye in a recent Illinois Geological Survey publication, entitled Geological Information for Managing the Environment (1967), who cites four broad categories in which earth scientists can supply technical data required by planners and administrators in natural resources management: 1) physical data on terrain necessary for development of structures on and below the earth's surface; 2) data for management and disposal of wastes; 3) data for development and management of the water resource, including concern for its quality, availability, and diversity of use; and 4) data on earth materials, such as rock, minerals, and fluids, that are the necessary raw materials for maintaining our civilization.

The scope of this paper is to discuss criteria and develop data for efficient management and disposal of liquid wastes on land. The rising volumes of waste which must be dealt with in this country are predictable by-products of our expanding population, increasing standard of living, and increasing technological innovations, particularly in the packaging and production of noxious chemicals. "Inefficient and improper methods of waste disposal have caused an ever-increasing pollution of our vital air, land, and water resources threatening the utility of our resources and the quality of the environment in which we live."[1] The ultimate goal of waste management should be the protection of sanitary, physical, and aesthetic elements of the environment and preservation of natural resources.[2] In working toward that goal, it is believed that a time is approaching when comprehensive studies of the suitability of land for various uses must be made and development of the environment encouraged accordingly.

"Land use in our society is often regarded as solely the owner's business. There is a degree of social decision-making, but the extent of planning for the use of land is extremely variable among the larger urban areas, is frequently absent in smaller areas, and is virtually nonexistent elsewhere."[3] A complete analysis of land suitabilities would be first subject to physical constraints but should not neglect social and economic factors as well. The problem of waste disposal, once an issue solely for individual decision-making, is slowly being recognized as a problem which requires the use of social decision processes. Hopefully, the gap which now exists between this need for social decision-making and effective institutional arrangements for evaluation and decision-making will be closed as the consequences of continued practices are more fully appreciated.

---

[1] *Wisconsin Department of Natural Resources, Division of Environmental Protection, Solid Waste Disposal Standards, 1969, p. 1.*

[2] *R. F. Bergstrom, Environmental Geology Notes No. 20, Disposal of Wastes: Scientific and Administrative Considerations, Illinois Geological Survey, 1968, p. 1.*

[3] *H. J. Barnett and C. Morse, "Natural Resources and the Quality of Life," in Readings in Resource Management and Conservation by Ian Burton and R. W. Kates, Editors, University of Chicago Press, 1960, pp. 585-595.*

The purpose of this study is threefold: 1) to investigate geologic and hydrologic factors which influence waste disposal; 2) to establish a set of criteria for liquid waste disposal sites; and 3) to assimilate geologic data for a portion of Wisconsin and develop a system of priorities for waste disposal sites based on the data. The area selected for the last section includes the seven southeastern counties of the state. It was chosen in part because it recently has been the subject of intensive study by the Southeastern Wisconsin Regional Planning Commission, the U. S. Geological Survey, and the U. S. Soil Conservation Service and in part because it is the most densely populated and highly industrialized area of the state. It is felt that detrimental effects of urbanization on the environment will first reach a critical level in that Region rather than elsewhere in the state.

The first two sections of the project—investigating geologic and hydrologic factors influencing waste disposal and establishing criteria for liquid waste disposal sites—draw primarily on existing literature. The principal effort was to assimilate as many factors as possible from a variety of sources. The approach for the third section—the regional study of southeastern Wisconsin—involved, in part, a survey of existing data on geology of the area. The results of individual studies of bedrock, surficial glacial deposits, soils, and water resources were used in the preparation of an interpretive map for the Southeastern Wisconsin Region, illustrating the effects of geology on suitability of land for liquid waste disposal.

It should be stressed that the map is a first approximation to site location and should be used with caution. The approach used was experimental and should be verified by a field check. The importance of site investigations before location of specific disposal operations must not be neglected. Also, such information as is available on the map would be most valuable if similar studies could be made of land suitability for other uses; that is, industrial, commercial, residential, and recreational development.

GEOLOGIC AND HYDROLOGIC CONTROLS RELATING TO GROUND-WATER CONTAMINATION

Geologic factors provide the framework of the ground water environment. Many of these factors, from individual rock characteristics to stratigraphy, structure, and continuity of rock formations, influence the occurrence and movement of water in the subsurface. Geologic controls relating to ground water pertain primarily to the physical properties of earth materials which exert controls on occurrence and movement of water; e. g., size and nature of interstices and fractures. Hydrologic controls relate to movement of water through the geologic framework; e. g., principles of saturated and unsaturated flow and infiltration processes.

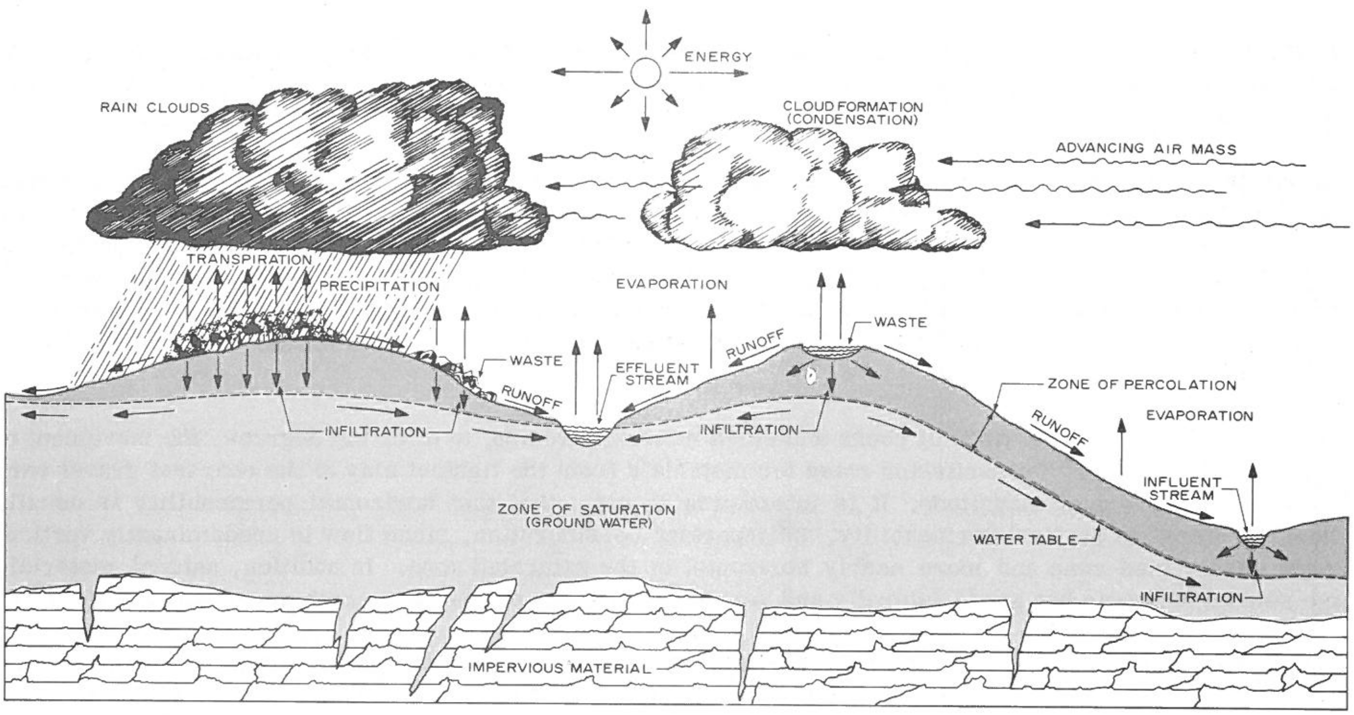
Hydrologic Factors

The dynamic nature of the hydrologic cycle is an important consideration in any waste disposal operation. Any waste, liquid or solid, placed in the natural environment is inevitably influenced by some portion of the hydrologic cycle, which affects its final disposition in time and space.

Figure 1 illustrates the interrelations between various phases of the hydrologic cycle. Water enters the subsurface through a process referred to as recharge, in which surface water (precipitation or streamflow) infiltrates the soil, moving downward through the zone of aeration. When it reaches the saturated zone, the top of which is called the "water table," it begins to move laterally toward a point of discharge, where it returns to the surface phase of the hydrologic cycle. The surface of the saturated zone conforms to the surface configuration of the land and can be considered a subdued replica of the surface topography. Thus, the water table is high in uplands where recharge commonly takes place and slopes toward lowlands where discharge occurs when the water table and land surface intersect. Solid and liquid waste disposal sites in Figure 1 illustrate possible routes of contaminants in the cycle.

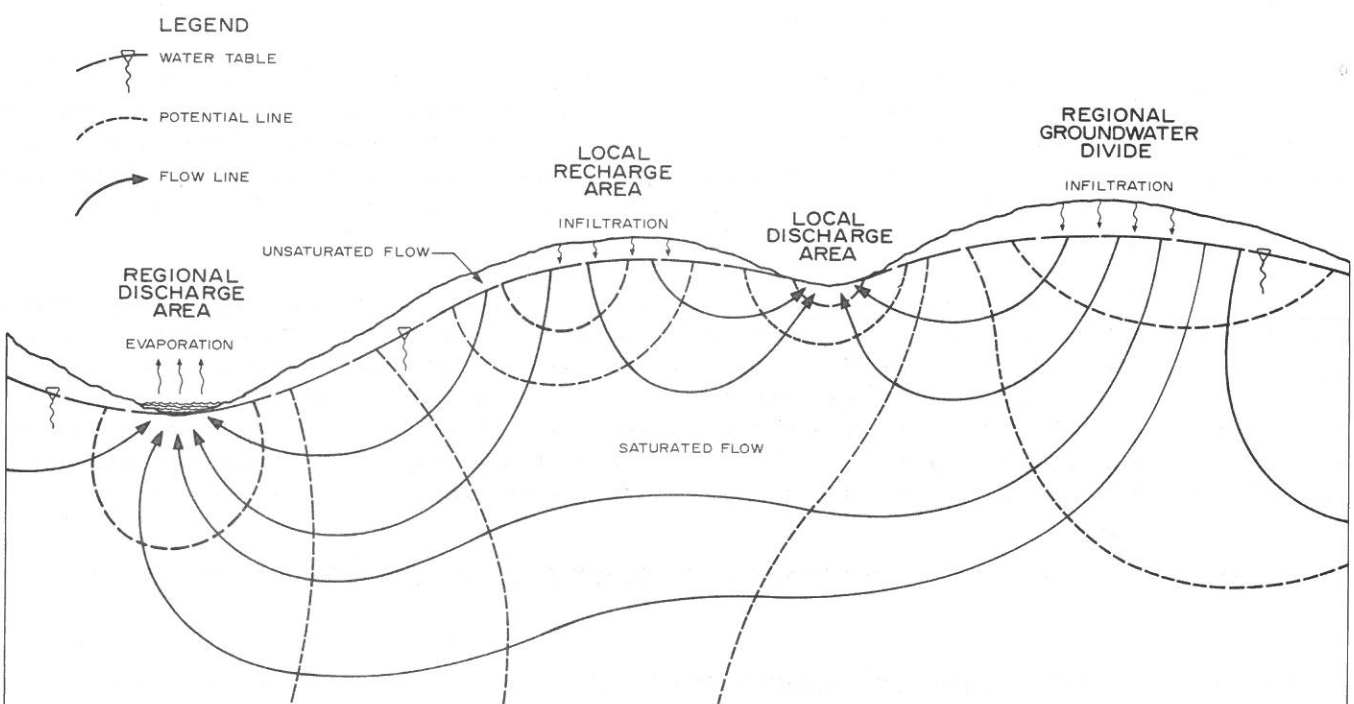
Two principles are particularly important to ground-water flow: the direction and rate of water movement. The direction of movement of the water is controlled by the potential head, a combination of the effects of elevation and hydrostatic heads. Flow always takes place along a line perpendicular to lines of equal potential (see Figure 2). In recharge areas the vertical ground-water gradient (change in potential) is downward from the water table, as illustrated by the flow lines; and, in a discharge area, the vertical gradient is up toward the water table. The rate of ground-water movement is directly related to the per-

Figure 1
THE HYDROLOGIC CYCLE
AND POSSIBLE ROUTES OF CONTAMINANTS



Source: Adapted from "Conservation and the Water Cycle" published by the U. S. Soil Conservation Service.

Figure 2
LOCAL AND REGIONAL GROUNDWATER FLOW SYSTEMS



meability of the material through which it passes and the hydraulic gradient (loss in potential per unit of flow-path distance).

Several specific hydrologic factors warrant discussion. Parameters of infiltration, permeability, flow in saturated and unsaturated zones, and attenuation are mentioned briefly below, with more complete coverage in Appendix A.

Infiltration: Infiltration involves movement of water across the air-soil interface and should be distinguished from water flowing through porous substances. Initial rates of infiltration are higher than rates based on saturated conditions but, in general, "the finer-grained the material, the slower the infiltration rate."[4] When locating and operating a site for liquid waste disposal, a slow, steady rate has significant effect in delaying arrival of liquid contaminants at undesirable points. However, a balance must be reached to prevent ponding and subsequent overland flow, which may be a detrimental effect of the slow infiltration rate.

Permeability: "Different kinds of rocks and earth materials resist, to differing degrees, the movement of fluids through them."[5] Transmission rates for materials from the tightest clay to the coarsest gravel vary by nearly 10 orders of magnitude. It is interesting to note, too, that horizontal permeability is usually much greater than vertical permeability, an important consideration, since flow is predominantly vertical in the unsaturated zone and more nearly horizontal in the saturated zone. In addition, natural materials are seldom isotropic but grade laterally and vertically, thereby complicating patterns of water movement.

Unsaturated Flow: Unsaturated flow occurs where air or other gases are present in pore spaces, reducing the pore volume available for flow of water. Movement in the unsaturated zone results primarily from the action of capillary forces. The larger pores are filled with air, and liquid moves in small pores in the presence of numerous air-water interfaces. Movement of this sort may occur in an upward or downward direction. Downward and lateral movements of water are of primary concern in contamination of ground-water by a surface source.

Movement of liquids in the unsaturated zone is strongly influenced by the rate and manner of their application at the surface. Other factors which influence the flow include volume and geometry of pore spaces in the material; magnitude and direction of temperature and chemical gradients; and properties of the fluids, such as density, viscosity, and surface tension.

Saturated Flow: Movement of liquid in the zone of saturation where pore spaces are filled with fluids has been the subject of extensive research for the past two decades. Analysis of the flow regime necessitates knowledge of the geometry of the ground-water system and its interrelation with the surface water system and areas of ground-water recharge and discharge. Also required for an understanding of saturated flow is knowledge of the nature of the porous earth materials with respect to movement of fluids through them and distribution of heads (hydraulic gradients) within the system.

Attenuation: Studies have been made to determine the extent of mixing of pollutants from recharge waters with uncontaminated ground-water. Mixing was determined to be by molecular diffusion or by dispersion in studies conducted by Bruch and Street (1967).[6] It was concluded that the dispersion pattern was dependent on the pollution input area, the average seepage velocity, the kinematic viscosity of the fluid, and the 50 percent diameter of the medium. In most cases contaminants do not diffuse vertically into the ground water to any great extent when percolated down through the soil due to the slow velocities and differences in specific gravities. Pollutants are generally found in the extreme top layer of the water table.

---

[4] *Taft Sanitary Engineering Center, Taft Technical Report W61-5, Ground Water Contamination: Symposium Proceedings, 1961, p. 15.*

[5] *Ibid.*

[6] *"Two-Dimensional Dispersion," Proceedings of the American Society of Civil Engineers, Sanitary Engineering Division, Vol. 93, No. SA6, 1967, pp. 17-54.*

Concluding Comment—Hydrologic Factors: These foregoing statements relating to hydrologic controls in waste disposal are brief and incomplete. The reader is referred to Appendix A for further explanation and examples of the relationship. However, the important fact is that, given the location, areal distribution, and physical characteristics of the ground-water flow system, one can analyze relative merits of a variety of waste disposal techniques and describe probable consequences of each. "Thus the hydrologist can contribute effectively to the design of disposal systems that will minimize or eliminate the danger of contaminating those parts of the ground-water resource that are already being or may later be developed for beneficial use."[7]

Geologic Factors

An understanding of geologic conditions aids in determining ground-water flow systems and can be a critical consideration in liquid waste disposal. In discussing some of the geologic factors affecting movement of ground water, it is convenient to think in terms of the unconsolidated and consolidated formations separately. As a rule, unconsolidated deposits vary in character both horizontally and vertically to a greater degree than the consolidated bedrock. Therefore, detailed investigation of mantle material is often more critical to selection of individual disposal sites for liquid wastes than bedrock investigation.

Unconsolidated Materials: Unconsolidated surficial deposits are highly significant to the suitability of particular areas for liquid waste disposal. The effectiveness of the disposal process is determined by physical characteristics, thickness, and distribution of surficial deposits. In glaciated areas the nature of transport and deposition of unconsolidated materials gives rise to a heterogeneous deposit. Various modes of deposition—e. g., lacustrine, fluvial, and ice—within a limited area give rise to a highly variable distribution of deposits both horizontally and vertically. In addition to areal distribution, physical characteristics, such as porosity and permeability, are very diverse from deposits of one mode of sedimentation to the next.

Soils: Soils developed on the surficial deposits are a reflection of five interrelated factors: parent material, topography, climate, organic activity, and time.[8] Interaction of these forces gives rise to soil characteristics, of which texture, structure, slope, and position are the most critical to liquid waste disposal. Infiltration rate and permeability limit amounts of liquid that can be absorbed and are a product of soil texture and structure. Slope affects the amount of liquid available for infiltration versus the amount which runs off. Position in the landscape relates to the drainage characteristics of the soil; hence, its suitability as a disposal site.

Effectiveness of the system at removing contaminants in the effluent passing through is dependent on the ion exchange capacity of the soil and adsorption characteristics. Adsorption refers to the accumulation of an ion species from solution onto a solid in an extremely thin layer and is caused by ion exchange or other reactions. Adsorption from solution does not generally lead to formation of layers more than a single molecule thick. The process of ion exchange involves cations and anions passing between liquid and solid phases in contact with each other. The process is reversible and is of two separate types: exchange of cations for cations or anions for anions.

The capacity of soils to adsorb and exchange cations and anions varies greatly with particle size, organic matter, and mineralogical composition. The pH of the system affects the capacity of soil particles for holding ions; higher pH favors holding cations and lower pH, for holding anions. The common exchangeable cations in soils are Ca^{++}, Mg^{++}, H^+, K^+, Na^+, and NH_4^+. The common anions in soils are Cl^-, NO_3^-, $H_2PO_4^-$, HPO_4^-, and HCO_3^-.[9]

---

[7] *Ibid., Footnote 4.*

[8] *Southeastern Wisconsin Regional Planning Commission, Planning Report No. 8, Soils of Southeastern Wisconsin, June 1966, p. 33.*

[9] *G. J. Schroephfer and H. C. Preul, Sanitary Engineering Report 158-S, Travel of Nitrogen Compounds in Soils, Sanitary Engineering Division, Department of Civil Engineering, Institute of Technology, University of Minnesota, 1964, pp. 30-32.*

High concentrations of exchangeable ions in the solution in contact with a soil favor greater amounts of exchange of the ions. Adsorption is favored in soils with smaller particle size. Their larger percent of surface area per gram of soil enables more adsorption of contaminants per unit volume.

Consolidated Sediments: Many properties of consolidated earth materials relating both to primary characteristics and secondary features influence occurrence and movement of ground water. Of the primary characteristics, porosity and permeability are the most obvious; but such features as rock stratification, changing facies, unconformities, and deposition on a slope may also exert an influence. Post depositional events which may affect ground-water conditions include development of secondary porosity through fractures, jointing, or solution phenomena; effects of tilting or folding of strata; and faulting.

Concluding Comment—Geologic Factors: "Geology exercises a dominant control over the occurrence and movement of ground water. If a contaminant is released to the natural environment, the extent of its effect on ground water depends on the geologic factors that affect the movement of the water and the capacity of rock materials to adsorb and absorb the contaminant."[10]

CONDITIONS FOR LIQUID WASTE DISPOSAL

The potential of soil systems for waste treatment and disposal has not been fully exploited in the past, primarily because of the danger of ground-water contamination as a result of land application of liquid wastes. Recent researchers have provided considerable evidence that, under controlled conditions, soils can provide a high degree of treatment to liquid wastes, thus protecting ground water. In spite of this, relatively few full-scale operations have been studied to demonstrate the practical potential.

It is ironic to note that waste application by irrigation was the earliest organized treatment method and has been practiced for more than 100 years.[11] Despite its long history of use, there is a minimum of readily available design and operation criteria. Soil disposal systems are frequently carried out on a trial-and-error basis.

The purpose of any land-irrigation disposal system is to accomplish the complete disposal of wastes without discharge to surface water bodies. The irrigation process provides several possible means of water consumption: 1) evaporation to the atmosphere before ground contact (occurs in spray irrigation), 2) evaporation from the ground surface, 3) transpiration by cover crop, 4) soil capacity, and 5) subsurface drainage.[12]

There are three principal methods used in surface application of liquid wastes: flood or board irrigation, ridge and furrow irrigation, and spray irrigation. Comparisons of relative advantages and disadvantages of the methods have been made. In 1964, engineers at the Taft Sanitary Engineering Center conducted pilot-plant lysimeter studies to compare the efficiency of each technique with respect to degree of treatment obtained and continued hydraulic acceptance. An on-site study was also conducted to evaluate the performance of a ridge and furrow liquid waste disposal system serving the City of Westby, Wisconsin, after six years of operation. The results of the latter study suggest that the ridge and furrow method of applying waste to land has the advantage over spray or flood irrigation of longer life before remedial measures are required. However, all solid-liquid waste-treatment systems have a finite life before renovation is required.

---

[10] *Ibid., Footnote 4, p. 7.*

[11] *F. H. Schraufnagle, "Ridge and Furrow Irrigation for Industrial Waste Disposal," Journal of Water Pollution Control Federation, Vol. 34, No. 11, 1962, p. 1117.*

[12] *R. Westenhouse, Irrigation Disposal of Wastes, TAPPI, Vol. 46, No. 8, 1963, p. 160A.*

With respect to treatment effectiveness, no major differences were found to exist between the three common methods in the Taft study. Comparison of the controlled lysimeter studies with the full-scale land disposal system indicated that comparable degrees of treatment were being obtained.[13]

The ridge and furrow method was compared to the spray technique, with spray irrigation found, in some respects, to be superior to ridge and furrow for the following reasons: 1) the original cost is generally lower; 2) no preparation of the land itself is required; 3) the area can be readily expanded; 4) less possibilities exist for creating a nuisance, e.g., odors or flies; 5) harvesting of cover crop is easier; 6) a wider range of terrain and vegetation are acceptable; and 7) the equipment used has some salvage value. On the other hand, it was pointed out that ridge and furrow irrigation: 1) usually requires less total acreage, 2) costs less to operate and maintain, 3) requires less gross solids removal before application to land, 4) does not require pumping of wastes in some terrains, and 5) can be operated in a wider variety of climates in winter months than spray irrigation.[14]

The types of geologic data required in planning for liquid waste disposal and the optimum conditions for disposal are dependent on the method to be used. A search of the literature reveals widely scattered studies which provide quantitative data pertinent to disposal site criteria. However, there is no one source available which successfully brings together all the necessary criteria to be considered and attempts to place numerical limits on them. The following list of criteria for disposal sites has been compiled from a variety of sources in an attempt to establish what the important parameters are and place numerical limits on them where such are available. The considerations and criteria were compiled specifically with spray-irrigation disposal in mind, but in many aspects they may be applicable to other waste disposal methods. The site selection criteria were divided into five major categories: 1) geologic considerations, 2) hydrologic considerations, 3) surface conditions, 4) cultural limitations, and 5) long-range effects.

Table I

APPROXIMATE PERMEABILITY OF VARIOUS EARTH MATERIALS

MATERIAL	PERMEABILITY (GALLONS/DAY/SQ.FT.)
CLAY AND SILT...........	0 - 100
SAND, VERY FINE, SILTY...	100 - 300
SAND, FINE TO MEDIUM.....	300 - 400
SAND, MEDIUM.............	400 - 600
SAND, MEDIUM TO COARSE...	600 - 800
SAND, COARSE.............	800 - 900
SAND, VERY COARSE........	900 - 1,000
SAND AND GRAVEL..........	1,000 - 2,000

SOURCE- GEOLOGY AND GROUND WATER RESOURCES OF CLAY COUNTY, NEBRASKA, U.S. GEOLOGICAL SURVEY WATER SUPPLY PAPER 1468, 1959.

Geologic Considerations

Nature of Earth Materials: Unconsolidated materials overlying bedrock should have moderate rates of permeability, e. g., in the range of 10^{-1} to 10^{2} gallons per day/square foot (gpd/ft^2). Table 1 gives approximate ranges of permeabilities for various earth materials.

Sand and gravel at or near the surface allow for movement too rapidly with the filtering of bacteria but not chemical contaminants. Thick clays are usually effective in removing contaminants but will limit the rate of application of waste by their low permeabilities. Materials with permeabilities of less than 10^{-2} gpd/ft^2 will retard movement of contaminants from the site until their potency is reduced by chemical and organic processes.[15]

---

[13] *T. W. Bendixen, R. D. Hill, W. A. Schwartz, and G. G. Robeck, "Ridge and Furrow Waste Disposal in a Northern Latitude," Proceedings of the American Society of Civil Engineers, Journal of Sanitary Engineering Division, Vol. 94, No. SA1, 1968, pp. 147-157.*

[14] *Ibid., Footnote 11, pp. 1117-1132.*

[15] *G. M. Hughes, Environmental Geology Notes No. 17, Selection of Refuse Disposal Sites in Northeastern Illinois, Illinois Geological Survey, 1967, p. 15.*

Soils in the moderate range of permeability are preferable. It should be stressed that the least permeable horizon of the soil profile will be the limiting factor in rate of acceptance of wastes. Heavy clay soils will tend to become saturated rapidly, causing surface ponding and subsequent runoff. In some cases a tile drain line at 2.5 to 3.0 feet may aid in percolation of waste through the soil, providing the soil is not so tight that water never reaches the tiles.[16]

Structural Factors: Bedrock underlying disposal areas should be dense. Fractured limestones and dolomites which are highly susceptible to solution provide passages for rapid movement of contaminants without purification. Areas in which limestone, quartzite, or granite occur within 10 feet of the surface and sandstone occurs within 6 feet should not be used for waste disposal.[17]

Joints in unconsolidated materials, such as clay tills, are not uncommon and provide rapid transit of wastes with the same ill effects as are encountered in fractured bedrock. Similar structure in soils may provide unexpected high permeabilities locally.

Bedrock valleys beneath surficial material may be desirable since they provide large thicknesses of unconsolidated material. However, such valleys in glaciated areas commonly contain sand and gravel which are suitable for development as aquifers. Therefore, consideration to future ground-water resource requirements should be given before such areas are designated for waste disposal.

Hydrologic Considerations

Depth to Water Table: The water table ideally should be located deep below the ground surface to prevent contaminants from reaching an aquifer before passing through sufficient nonsaturated unconsolidated material in which they become attenuated. Observations by personnel of the Illinois Geological Survey indicate the following general relations in northeastern Illinois which are probably applicable to southeastern Wisconsin.

1. In fine-textured earth materials, such as clays and silts, in both uplands and lowlands, the zone of saturation is generally within 10 feet of land surface.

2. In coarse-textured earth materials, such as sand and gravel, in lowland areas, the zone of saturation is generally within five feet of land surface.

3. In coarse-textured earth materials on uplands and on valley walls, the depth to saturation varies from place to place and may be more than 10 feet below land surface.

When evaluating a disposal site, seasonal and annual variations in the water table should also be considered.[18] Seasonal fluctuations of the water table position in the range of several feet are not uncommon in southeastern Wisconsin.

Relation to Local and Regional Flow Systems: Position of the disposal site in the local and regional flow systems should be chosen to prevent the possibility of ground-water contamination. Under favorable conditions "movement of contaminants along lines of flow should be such that either they could not reach a useful ground-water or surface-water resource, or their attenuation to acceptable levels would occur before they reached such a water resource."[19]

---

[16] *G. W. Lawton, L. E. Engelbert, G. A. Rohlich, and N. Porges, Wisconsin Agricultural Experiment Station Research Report No. 6, Effectiveness of Spray Irrigation as a Method for the Disposal of Dairy Plant Wastes, 1960, p. 44.*

[17] *Ibid., Footnote 1, p. 12.*

[18] *Ibid., Footnote 15, p. 18.*

[19] *Ibid., Footnote 15, p. 15.*

The local flow system is relatively easily determined with the use of stratigically placed piezometer points to determine the distribution of potential, thus, the directions of ground-water movement. Sandpoint observation wells are frequently utilized as piezometers in unconsolidated soils; the function of these points is to measure potential distribution in depth. The water level within a cased observation well is an expression of this potential for the vicinity of the sandpoint.

The regional flow system may require much more intensive investigation. In general, disposal of wastes should never be attempted in lowlands adjacent to streams which are usually zones of ground-water discharge in the regional systems of temperate climates. Such a practice could lead to surface water contamination due to runoff. Disposal in uplands, or recharge areas, is preferable because of the long travel path to discharge areas. However, areas must be selected in which aquifers do not occur for several tens of feet below land surface.[20]

Knowledge of flow paths and rates of ground-water flow will aid in estimating whether contaminants infiltrating a specific position in the flow system will be introduced into an aquifer.

Surface Conditions

Topography: Ground surfaces used for spray irrigation should be relatively level and free of gullies to prevent surface runoff. In general, a slope of less than 6 to 8 percent is preferable,[21] although there are examples in the literature in which greater slopes have been utilized successfully.

Cover Crop: The cover crop is critical to the success of a liquid waste disposal system. The purpose of the crop is to protect the soil from erosion, plus provide the maximum surface for evaporation and transpiration. The plant selected must be capable of withstanding the physical stress inherent in disposal field operations, such as beating down by constant sprinkling and excessive water. Plants with deep root systems and large networks of roots are able to transpire the greatest quantities of water. Two examples of these types of plants are Reed's canary grass and alfalfa.

Most cover crops require harvesting which necessitates a week to 10 days for drying the field, cutting, and baling. A study by the Ohio Department of Agriculture showed that hay grown on a liquid disposal field from a paper processing plant was edible, although less palatable, than other forages.[22] Wastes from canneries and milk processing plants have been found to have beneficial effects on soil and growth of vegetable crops.

Climate: Seasonal temperature variations limit the usefulness of spray irrigation systems. Where disposal takes place during the winter months, pipes and pumps must be constructed so that complete drainage occurs after each pumping cycle to prevent freezing in pipes and equipment. To prevent ground freezing, application can be made to only a localized area of the disposal field continuously. At a latitude comparable to central Wisconsin, spray irrigation is possible the year-round from a mechanical standpoint; but it must be assumed that complete kill of the cover crop will occur. The ice cones which build up around spray nozzles killing vegetation also cause runoff from the field as they melt before the ground thaws. Effects of such runoff on streams and elsewhere should be evaluated in advance. For most satisfactory waste disposal in northern climates, one should go to a ridge and furrow system in the winter, increasing cost, but decreasing the risk of contaminating water supplies.[23]

---

[20] *Ibid., Footnote 15, p. 21.*

[21] *H. G. Luley, "Spray Irrigation of Vegetable and Fruit Processing Wastes," Journal of Water Pollution Control Federation, Vol. 35, No. 10, 1963, p. 1256.*

[22] *W. A. Flower, Purdue University Extension Bulletin 118-119, Spray Irrigation--A Positive Approach to a Perplexing Problem, 1965, p. 681.*

[23] *Ibid., Footnote 16, p. 46.*

Precipitation is a second climatic factor to be considered. The disposal site must be capable of infiltrating the proposed volume of waste water in addition to the natural "background" of rainfall.[24] The amount of rainfall affects the moisture conditions in the soil and, therefore, its ability to absorb effluents. Weather records should be consulted for amounts and seasonal distribution of precipitation and compared to the proposed scheduling of plant operation.

Required Acreage: Acreage required for irrigation depends on a variety of factors, including: "1) slope of the terrain, 2) characteristics and amount of soil surface cover, 3) characteristics of the earth layers in the upper part of the soil profile, 4) depth of the water table, and 5) amount and character of the waste effluent."[25] In general, rotation patterns involve four to eight hours of application, followed by six days of rest, although particular site conditions may dictate otherwise.[26]

Cultural Considerations

Distance from Buildings: Spray irrigation areas should be at least 500 feet from occupied buildings.[27]

Distance from Roads: Distance to public roads should be great enough to prevent wind-blown spray and odors from reaching them.[28] Standards for solid waste disposal in Wisconsin require a distance of 1,000 feet from any state trunk highway.

Distance from Wells: The distance of the disposal field from wells used for water supply is extremely variable and depends on direction of ground water movement, rate of movement, and degree to which the earth materials through which the contaminants pass are capable of purifying the waste. A system of wells for monitoring the quality of ground water leaving the disposal area should be installed and samples analyzed at regular intervals. Studies made on travel of contaminants from stabilization ponds and septic tank absorption fields suggest that 100 feet from disposal field to the nearest well is a minimum distance. It is possible for concentrations of some more persistent contaminants to be above acceptable levels, as established by the U. S. Public Health Service in Drinking Water Standards,[29] at a distance of 100 feet in some soil environments.

Distance from Surface Water: Disposal areas should be located a sufficient distance from surface water bodies to prevent contamination from runoff. Solid waste standards for Wisconsin stipulate that there must be 1,000 feet to navigable lakes, ponds, or flowages. Of course, disposal should never be attempted on the floodplain of any waterway.

Man-Induced Changes in Land: Mechanical compaction may have a very serious effect on reducing soil permeability and should be kept to a minimum. Heavy equipment for construction or crop harvesting or grazing of animals may reduce permeability substantially.

Tilling before or during use for liquid waste disposal may cause a breakdown of soil structure and subsequent reduction of permeability from the ideal value.

---

[24] *S. M. Born and D. A. Stephenson, "Hydrogeologic Consideration in Liquid Waste Disposal," Journal of Soil and Water Conservation, Vol. 24, No. 2, 1969.*

[25] *Ibid., Footnote 21, p. 1252.*

[26] *Ibid., Footnote 21, p. 1268.*

[27] *K. Glasshof, Waste Disposal by Ridge and Furrow Irrigation, Wisconsin Department of Natural Resources, Division of Resource Development, 1968, p. 1.*

[28] *Ibid., Footnote 27, p. 1.*

[29] *U. S. Department of Health, Education, and Welfare, Public Health Service, Public Health Service Publication 956, Drinking Water Standards, 1962, Washington, D. C.*

Long-Range Effects on Soil

Some of the significant long-range effects of liquid waste disposal on the soil are discussed below.

1. Clogging of pores in the soil by bacterial slime and mold may result in poor aeration due to over-irrigation. This condition can usually be remedied by restoring proper aeration which allows for oxidation of organics and eventual return of normal permeability.[30]

2. After several years of continuous pounding of heavy sprays, plus accumulation of solids, soils may become compacted and the surface become crusted, with a resultant development of low permeability conditions. This condition may require subsoiling to restore permeability.[31]

3. A substantial increase in ions present in the soil can be expected to occur after a year or more of irrigation. A report by the Wisconsin Engineering and Agricultural Experiment Station on spray irrigation of dairy wastes showed that increases in all ions had occurred in the soil after a year of irrigation, especially in the top six inches of the soil. With milk wastes, sodium and chloride ions exhibited the greatest increase in the soil.[32]

CASE STUDY—SOUTHEASTERN WISCONSIN

Background Information

A regional analysis of geologic factors relating to liquid waste disposal was undertaken for a seven-county area in southeastern Wisconsin. Many physical factors limiting site utilization are only determined through individual field studies. However, preliminary decisions on disposal site feasibility can be determined through the use of techniques delineated in this study.

The Counties of Kenosha, Milwaukee, Ozaukee, Racine, Walworth, Washington, and Waukesha were studied (see Map 1). This seven-county area contains more than 40 percent of the state's population yet occupies less than 5 percent of the area. Along Lake Michigan are several major metropolitan areas containing large industrial complexes, such as Milwaukee County, the state's largest urban area. West of the metropolitan area is a highly developed agricultural region intermixed with rural subdivisions and communities.[33]

The Southeastern Wisconsin Regional Planning Commission serves the area and has developed extensive data pertaining to description of the natural resources and to comprehensive development of the land and water resources. It is the feeling of the Commission that "...the basic problem facing the Region is not one of actual depletion of the land and water resources available, but a deterioration in the quality of these resources, and an imbalance in their distribution across the Region...."[34] Solution to the problems will come only after recognition of the factors primarily responsible for natural resources deterioration. These factors are: 1) rapid growth and decentralization of the population across the Region, and 2) tremendous advances in technology which give man the ability to change his environment at will. Therefore, efforts should be concentrated on prevention of further deterioration and initiation of much needed conservation and resource management programs.

---

[30] *J. M. Cain and M. T. Beatty, "Disposal of Septic Effluents in Soils," Journal of Soil and Water Conservation, Vol. 20, No. 3, 1965, p. 103.*

[31] *W. W. Fisk, "Food Processing Waste Disposal," Water and Sewage Works, Vol. III, 1964, p. 420.*

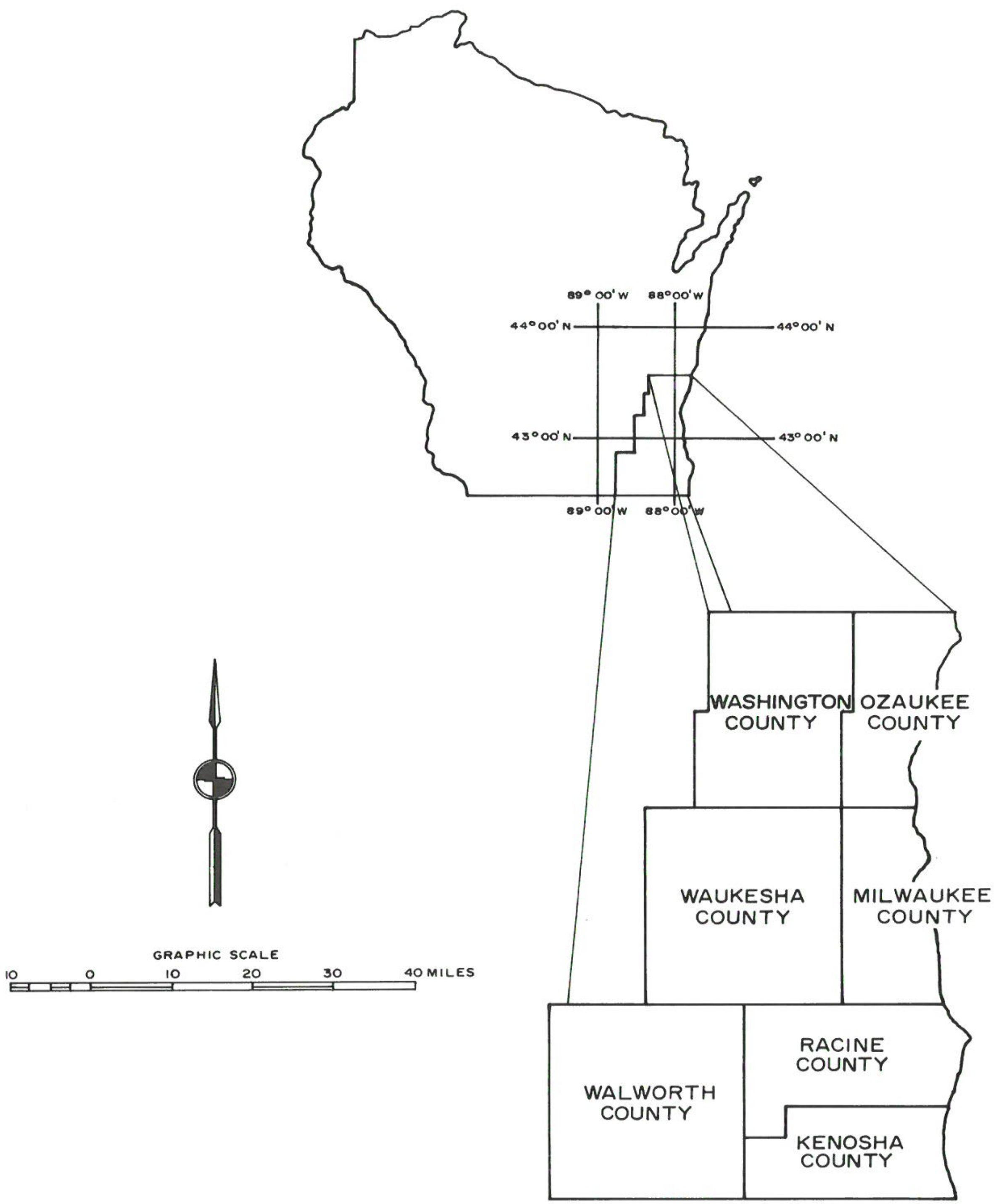
[32] *Ibid., Footnote 16, p. 37.*

[33] *Wisconsin Department of Natural Resources, Water Resources Management in Wisconsin, 1968, p. 22.*

[34] *Southeastern Wisconsin Regional Planning Commission, Planning Report No. 5, The Natural Resources of Southeastern Wisconsin, 1963, p. 1.*

Map I

STUDY AREA LOCATION MAP
THE SOUTHEASTERN WISCONSIN REGION



Source: SEWRPC.

The continued growth and urbanization of southeastern Wisconsin is dependent upon the ability of the resource base to sustain development without the occurrence of severe environmental problems. Therefore, a complete evaluation and analysis of resource capabilities and formulation of long-range resource management programs is needed. In addition, a constructive public policy toward the natural resources of the Region is necessary which may require some drastic changes in life style of the population.

In this study the geologic factors in the Southeastern Wisconsin Region which come to bear on defining the locations where liquid waste disposal will work most effectively were investigated. It is felt that additional studies to determine the suitability of land in the area for other uses, such as industrial parks and residential and recreational areas, would be a valuable complement. The availability of all of these studies would make possible a total land use suitability map for the area which may ultimately be necessary for coordinated development.

Geography and Climate: The entire Southeastern Wisconsin Region underwent glaciation during the most recent North American ice advance, ending some 11,000 years ago. The advances and retreats of different ice lobes during the Wisconsin glaciation formed most of the present physiographic features in the Region (see Map 2).

The area is divided in a general northeast-southwest direction by the prominent Kettle Moraine, an interlobate moraine formed between the Green Bay and Lake Michigan ice lobes. Maximum relief is 200 feet along the system of steep ridges, extending from northwest Walworth County, across the western half of Waukesha County, and through central Washington County. Minimum relative relief of 100 feet or less occurs in the region adjacent to Lake Michigan.

The remainder of the Region is composed of a variety of glacial features, including ground moraine, or heterogeneous earth materials deposited by glaciers; recessional moraines, or ridges formed by a temporary decrease in the rate of a retreating glacier; lacustrine basins, or peri-glacial lake sites; and outwash plains and terraces of glacial meltwater streams. Other local features include drumlins, or elongated hills of drift parallel to direction of ice movement, in south central Waukesha and northwestern Washington Counties; kames, or conical hills of rudely stratified drift, common along the interlobate moraine; and eskers, or long, curving ridges of rudely stratified water deposited sand and gravel.[35]

The Region is sprinkled with glacial lakes—lakes resulting from uneven post-glaciation topography—particularly in Walworth and western Waukesha Counties. Lakeshores in the Region tend to be heavily developed with year-round homes and represent a major vacation area for Illinois residents.[36] The lakes are also rich in nutrients and have problems with excess aquatic plant growth and algae.

Climate in the Region is typically continental, with relatively warm summers and long, cold winters. During the winter months (December through February), the average temperature ranges from 20 to 30°F, while 70 to 75°F is average for the months of July and August. Precipitation is fairly uniform over the Region. The average annual precipitation in Washington County is 27.35 inches minimum to 32.88 inches in Walworth County. In the area as a whole, about 60 to 66 percent of precipitation accrues during the growing season in the months of May through September.

Prevailing winds are westerly in the winter, southerly in the summer, and northeasterly in the spring during the months of April through June. Annual lake evaporation ranges from 28 inches per year near Lake Michigan to 30 inches per year inland. Eighty percent of the yearly total precipitation occurs during the warm season of May through October.[37]

---

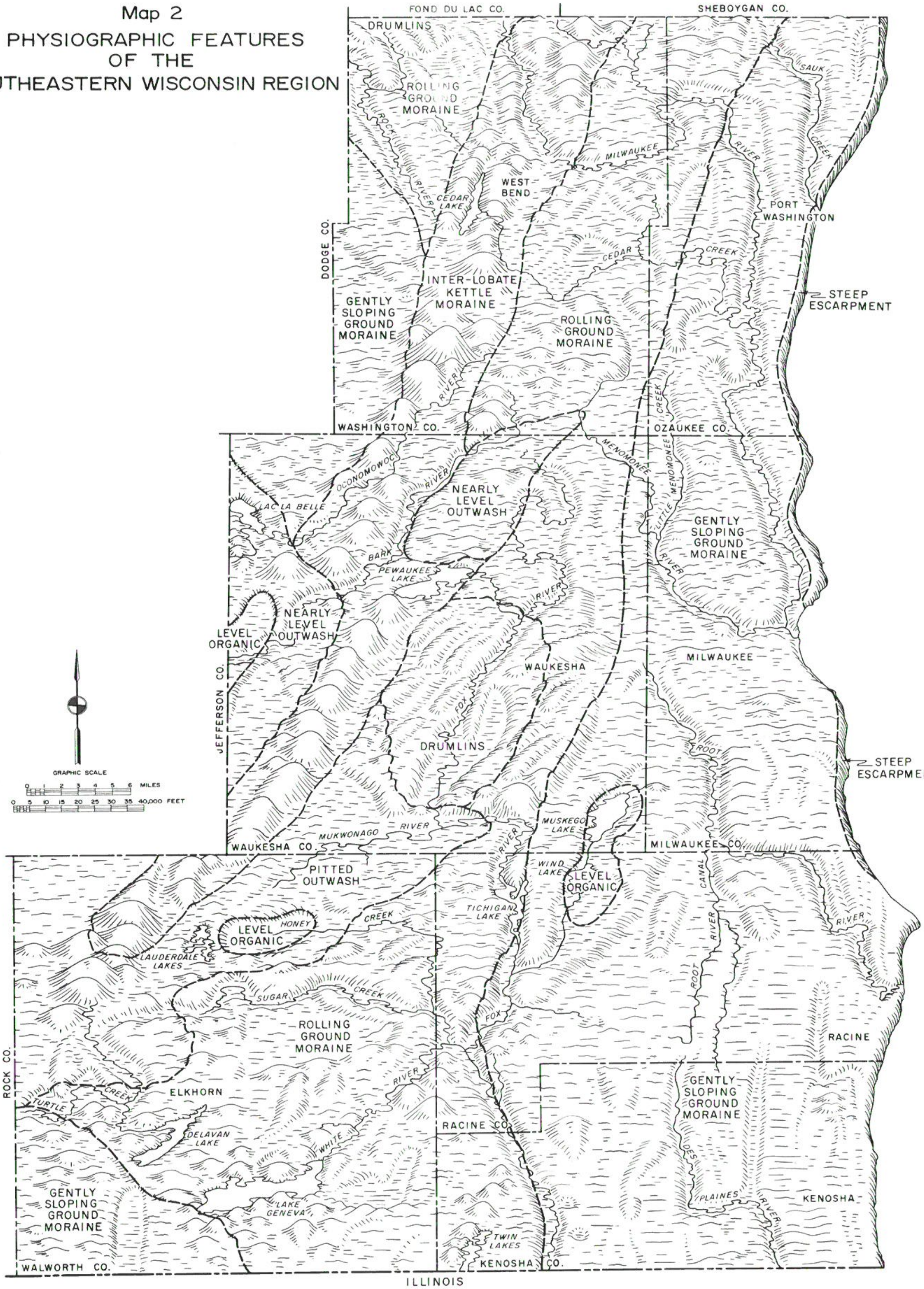
[35] *Ibid.*, *Footnote 34, p. 35.*

[36] *Ibid.*, *Footnote 32, p. 22.*

[37] *Ibid.*, *Footnote 8, pp. 23-28.*

Map 2

PHYSIOGRAPHIC FEATURES OF THE SOUTHEASTERN WISCONSIN REGION



Source: SEWRPC.

Geology: In considering geologic conditions, two factors were taken into account. These are: surficial deposits and bedrock.

Surficial Deposits: The surficial deposits, as mentioned earlier, are the result of glaciation during the Wisconsin stage of the Pleistocene Epoch. Illinoian drift underlies these deposits and crops out in southwestern Walworth County. The most comprehensive study and mapping of the deposits was made by W. C. Alden in the early 1900's and is published as USGS Professional Paper 106, 1918. Map 3 was drawn from Alden's original map of surficial deposits and shows, in a somewhat simplified way, the distribution of various glacial deposits.

In northwestern Walworth and western Washington and Waukesha Counties, the drift consists of terminal (marking furthest ice advance) and ground moraine of the Green Bay ice lobe (upper Wisconsin). The remainder of the Region eastward was glaciated by the Lake Michigan lobe (also upper Wisconsin), which left a series of terminal moraines separated by ground moraine and areas of outwash. Map 3 distinguishes between terminal moraines and ground moraine for the two ice lobes and also indicates areas of outwash, lacustrine deposits, the trend of the interlobate Kettle Moraine, and the location of the red drift in the northeast of the Region which is a recessional stage of the Lake Michigan lobe.

As a general rule, the outwash deposits are stratified sand and gravel (water-lain) and have the highest permeability of any units in the Region. The terminal and ground moraines are clay tills with varying permeabilities dependent on grain-size distribution within these deposits. In a very general way, the deposits in the western part of the area contain coarse material and have more layers of sand and gravel intercalated with the clay tills. Moving eastward, the deposits are increasingly rich in fines (silts and clays), with decreasing occurrence of sand and gravel layers.

The thickness of surficial deposits varies from zero in areas of bedrock outcrop to greater than 500 feet in buried preglacial valleys. Information gathered by soil scientists in the area indicates that areas of shallow bedrock (less than 20 feet from the surface) are parallel to the Kettle Moraine in Washington and Waukesha Counties. Small areas are scattered through southern and central Ozaukee County in a roughly northeast-southwest direction and occur in Milwaukee, Racine, and Walworth Counties in a random pattern[38] (see Map 4). The points of deepest drift in the area are probably associated with the preglacial Rock River valley, which extends northward from Illinois into Wisconsin, in Walworth County (see Map 4). The areas of greatest drift thickness (greater than 500 feet) in the Region exist along the Troy valley in southwestern Walworth County and in a northeast-southwest trending line in south central Washington County.[39] Map 5 illustrates drift thickness over the entire Region.

Bedrock: The underlying bedrock formations in southeastern Wisconsin consist of Paleozoic formations of Cambrian through Devonian age, overlying the crystalline basement complex. The formations dip gently toward the east off the Wisconsin arch. Figure 3 is a map view and cross section of the bedrock geologic formations. In the westernmost part of the Region, Ordovician Galena dolomite is the bedrock surface overlain to the east by a narrow band of Maquoketa shale. The Silurian Niagara dolomite overlies the shale. The eastern border along Lake Michigan has a narrow outcrop of Devonian Milwaukee formation. Table 2 gives the stratigraphic column for southeastern Wisconsin in greater detail. Although it does not crop out in the seven-county area of southeastern Wisconsin, the thick Cambrian sandstone sequence is found over the entire area dipping eastward beneath the younger sediments.

Soils

Soil characteristics and the distribution of soil types within the Region are dependent to a large extent on the glacial history. The Pleistocene deposits vary considerably across the Region from calcareous till with much clay along Lake Michigan to extensive sand and gravel deposits left by glacial meltwater adjacent to the Kettle Moraine.

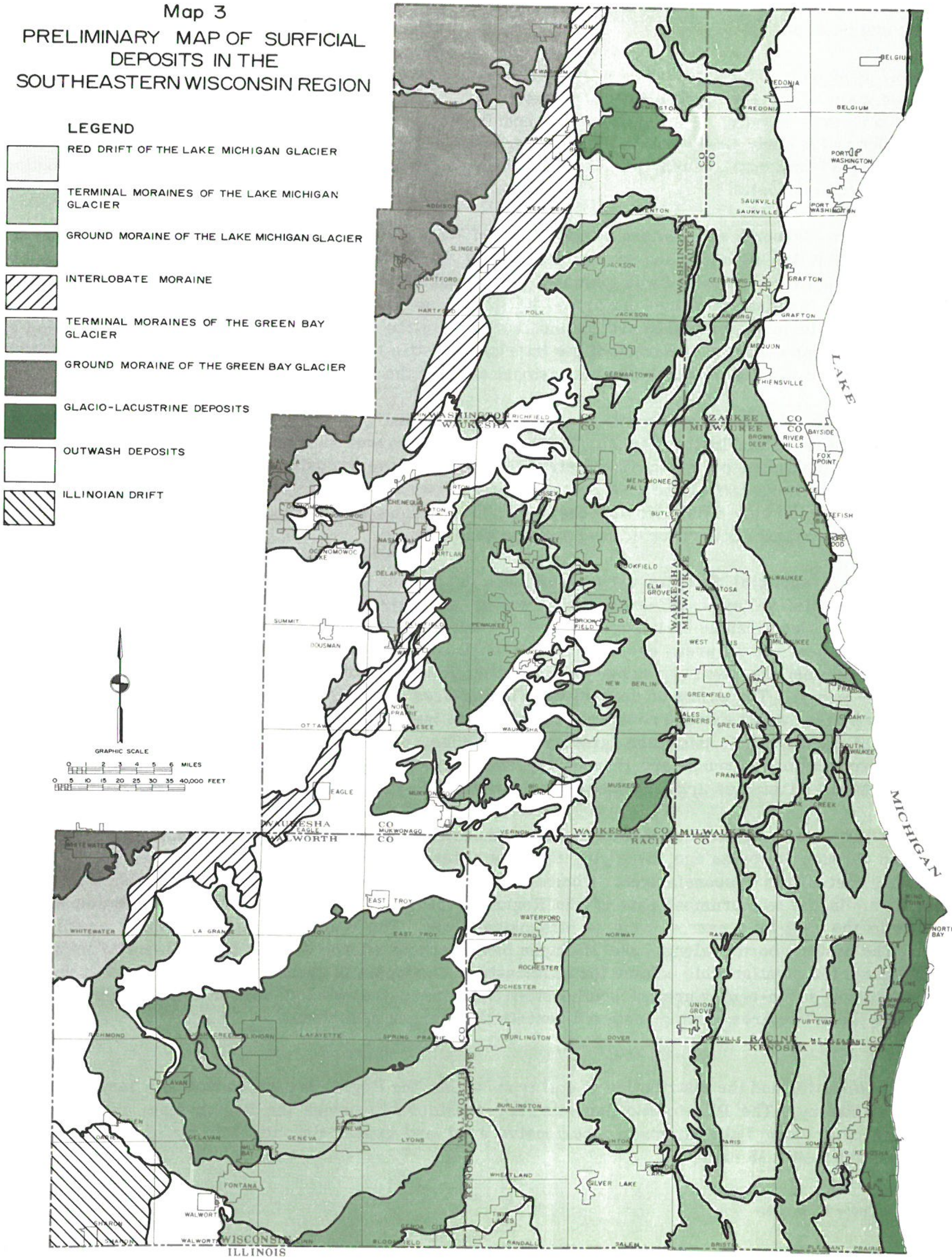
---

[38] *Ibid., Footnote 8, p. 22.*

[39] *T. O. Friz, Ph.D. Dissertation, Man and the Minerals of Construction, How They Interrelate in the Seven Counties of Southeastern Wisconsin, University of Wisconsin, Madison, Wisconsin, 1969.*

Map 3

PRELIMINARY MAP OF SURFICIAL DEPOSITS IN THE SOUTHEASTERN WISCONSIN REGION



(After Alden, 1918)

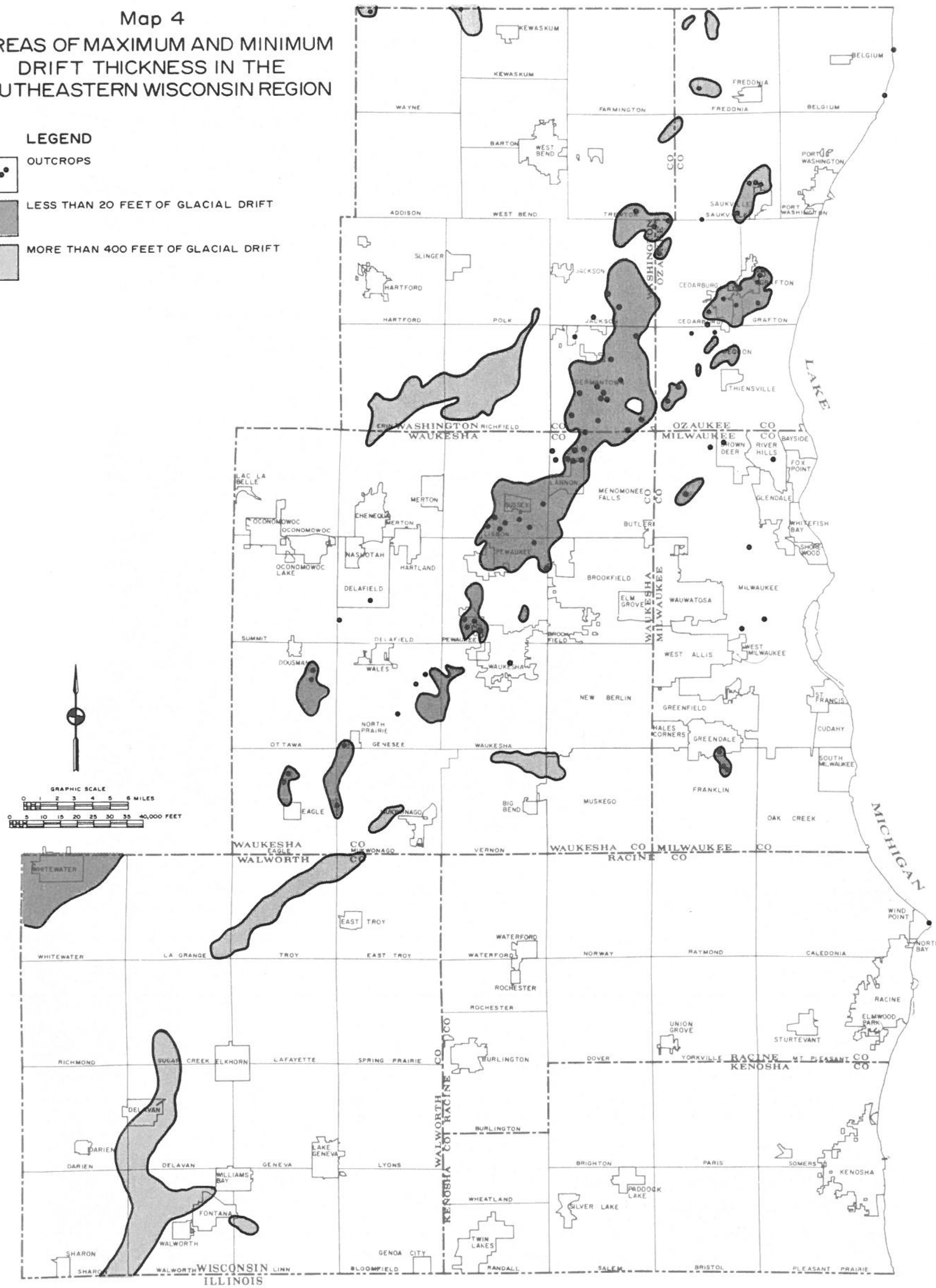
Map 4
AREAS OF MAXIMUM AND MINIMUM DRIFT THICKNESS IN THE SOUTHEASTERN WISCONSIN REGION

LEGEND

OUTCROPS

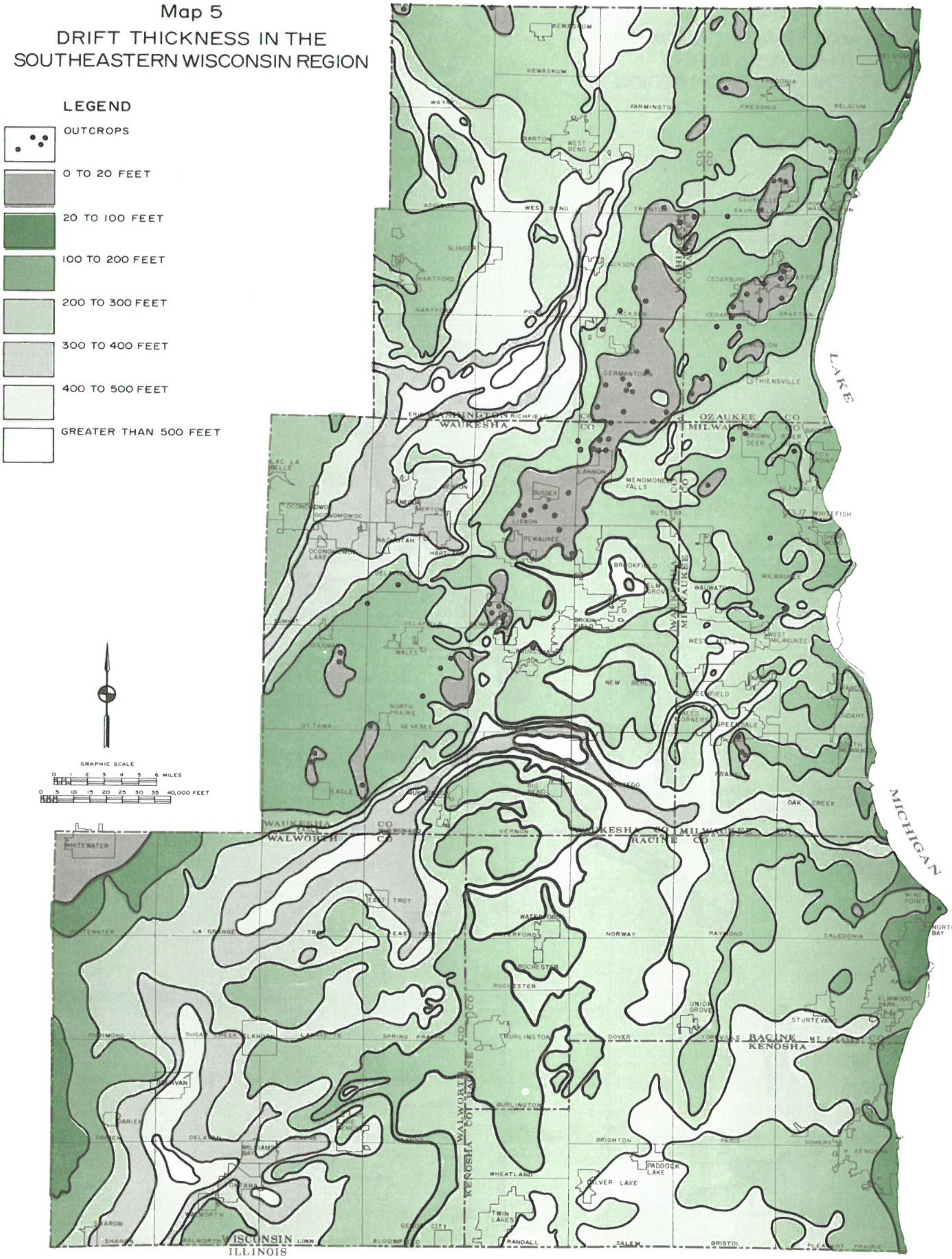
LESS THAN 20 FEET OF GLACIAL DRIFT

MORE THAN 400 FEET OF GLACIAL DRIFT



(After Friz, 1969)

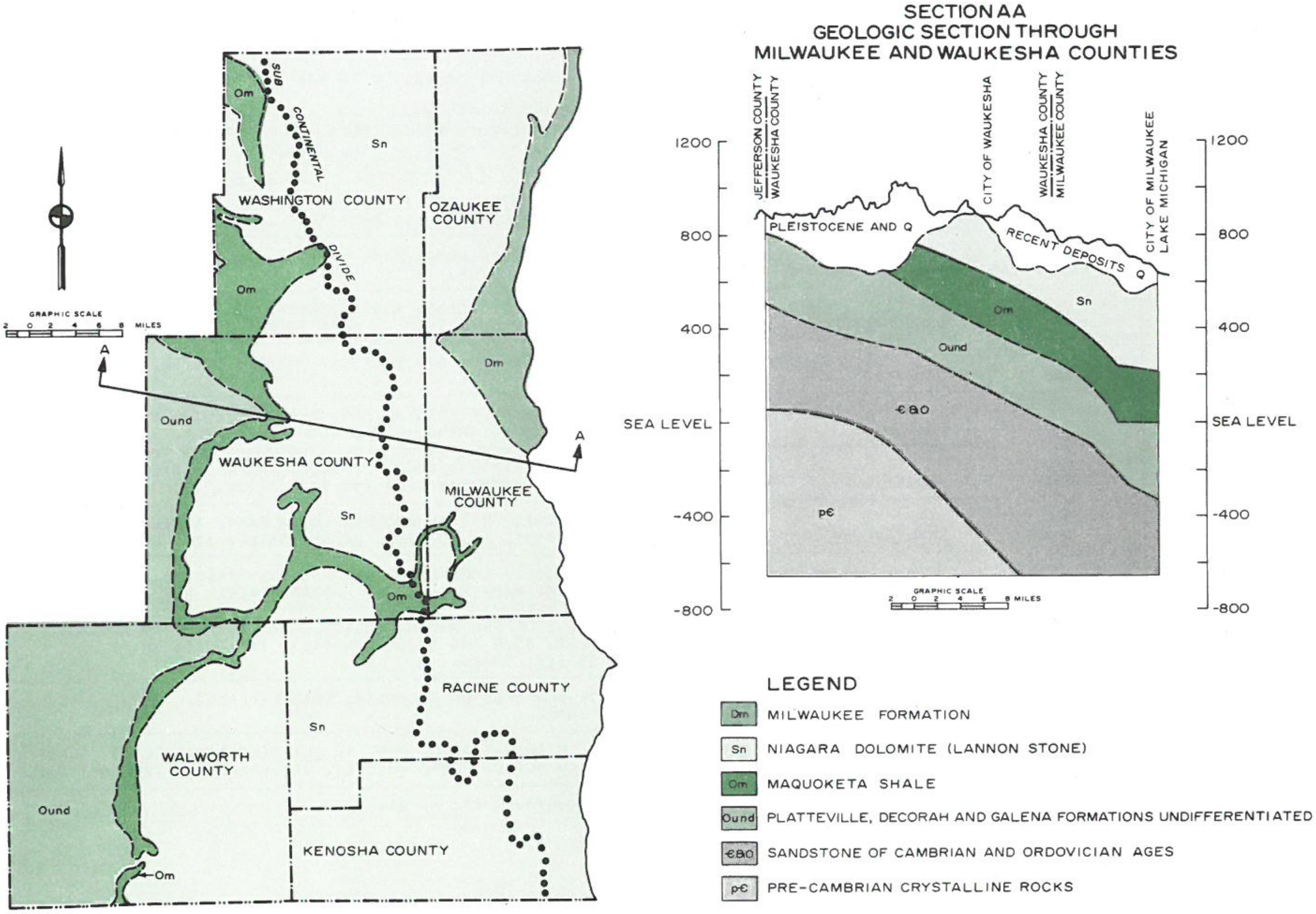
Map 5
DRIFT THICKNESS IN THE SOUTHEASTERN WISCONSIN REGION



(After Friz, 1969)

Figure 3

MAP VIEW AND CROSS SECTION OF BEDROCK GEOLOGY IN THE SOUTHEASTERN WISCONSIN REGION



Source: *SEWRPC.*

In general, the soils of Kenosha, Racine, and eastern Ozaukee Counties are characterized by deep to moderately deep brown to black silt loams. Walworth County and western Racine and Kenosha Counties have brown to black prairie loam soils. Washington and Waukesha Counties are characterized by grayish-brown, rolling silt loams or gravelly grayish-brown loams.[40]

One of the major soil associations in the Region includes a group of soils, such as Dodge, Miami, and McHenry silt loams, developed from loamy till and loess on highlands under forest vegetation. The surface soil is a well-drained silt loam texture which grades into a subsoil more clayey than either the surface soil or the underlying till. In the lowlands or along stream bottoms, the soil association consists predominantly of Pella, Brookston, and Poygan silty clay loams. The soils are wet and have developed from calcareous lacustrine deposits, outwash, loess, and clayey calcareous drift. In the eastern part of the Region, including Kenosha, Milwaukee, and Racine and eastern Waukesha Counties, the soil association consists of Ashkum, Blount, Elliott, and Morley silt loams. These soils have high clay contents, especially in deeper horizons, reflecting the more clayey nature of the drift compared to the western part of the Region. Drainage in the subsoils is restricted, especially in the Blount and Elliott silt loams, which occur in nearly level terrains. Morley silt loam, which occurs on the most sloping areas, is moderately well drained.

---

[40] *Ibid., Footnote 34, p. 55.*

Table 2

STRATIGRAPHIC COLUMN - SOUTHEASTERN WISCONSIN

SYSTEM	SERIES	FORMATION	LITHOLOGIC DESCRIPTION
QUATERNARY		RECENT DEPOSITS	SOILS, MUCK, PEAT, ALLUVIUM, BEACH SAND AND GRAVEL. 0 TO 5 FEET THICK.
		PLEISTOCENE DEPOSITS	TILL AND OUTWASH SAND AND GRAVEL. 0 TO 430 FEET THICK.
		KENWOOD	SHALE, BLACK, CARBONACEOUS. FOSSILIFEROUS. NO OUTCROPS. FOUND IN CITY OF MILWAUKEE INTAKE TUNNEL - LAKE MICHIGAN. APPROXIMATELY 55 FEET THICK.
DEVONIAN		MILWAUKEE	SHALE, SHALY LIMESTONE; LOWER 1/3 DOLOMITE. FOSSILIFEROUS. APPROXIMATELY 130 FEET THICK.
	MIDDLE ERIAN	THIENSVILLE	DOLOMITE, THICK TO THIN-BEDDED. SOME FOSSILS. SMALL AMOUNTS OF BITUMEN. APPROXIMATELY 65 FEET THICK.
		LAKE CHURCH	DOLOMITE, THICK TO THIN-BEDDED. FOSSILIFEROUS. PYRITIC IN PLACES. APPROXIMATELY 27 FEET THICK.
SILLURIAN	CAYUGAN	WAUBAKEE	DOLOMITE, THIN-BEDDED, HARD AND BRITTLE. FOSSILS SCARCE. APPROXIMATELY 30 FEET THICK.
		RACINE	DOLOMITE, FINE TO COARSELY CRYSTALLINE. THICK TO THIN-BEDDED. BARREN TO FOSSILIFEROUS. APPROXIMATELY 100 FEET THICK.
	NIAGARAN	MANISTIQUE	DOLOMITE - LOWER PART THIN-BEDDED. FOSSILS. UPPER - FAIRLY THIN-BEDDED, CHERTY. MANY CORALS. APPROXIMATELY 150 FEET THICK.
		BURNT BLUFF	DOLOMITE, THICK BEDDED OR THIN-BEDDED. LOWER PART, A FEW FOSSILS. UPPER PART, SEMILITHOGRAPHIC. NO FOSSILS. APPROXIMATELY 110 FEET THICK.
	ALEXANDRIAN	MAYVILLE	DOLOMITE, THICK BEDDED, COMPACT TO COARSELY CRYSTALLINE. BRECCIATED IN PLACES, CHERTY, MANY REEF STRUCTURES. APPROXIMATELY 175 FEET THICK.
ORDOVICIAN	CINCINNATIAN	NEDA	RED-BROWN OÖLITIC IRON ORE AND NONOÖLITIC ORE. MISSING IN RACINE, MILWAUKEE, OZAUKEE, DOOR AND DODGE COUNTIES. IN LENSES UP TO APPROXIMATELY 55 FEET THICK.
		MAQUOKETA	SHALE, DOLOMITIC AND BEDS OF DOLOMITE. FOSSILIFEROUS. 90 TO 225 FEET THICK.
	CHAMPLAINIAN	GALENA	DOLOMITE, THICK TO THIN-BEDDED, FINE TO COARSELY CRYSTALLINE. CHERTY. SHALY AND SANDY IN PLACES; SOME FOSSILS. APPROXIMATELY 225 FEET THICK.

SOURCE- SEWRPC PLANNING REPORT NO. 8, SOILS OF SOUTHEASTERN WISCONSIN, 1966, P. 21.

In the immediate area of the Kettle Moraine, soils underlain by sand and gravel are extensively developed. The principal soils are the Casco, Rodman, Fox, Warsaw, and Wea. The nature of the soils varies from the excessively drained Rodman gravelly loam, which consists almost entirely of sand and gravel, to the Fox, Warsaw, and Wea soils, which are medium-textured and developed to greater depth. The Casco is intermediate and consists of 1 to 1.5 feet of loamy material over sand and gravel.[41]

Ground Water

Ground water for the Region is derived from two principal aquifers. The "sandstone," or deep, aquifer is composed of Cambrian and Ordovician sandstones and Ordovician carbonates. The "dolomite," or shallow, aquifer consists of the Silurian Niagara dolomite and overlying Pleistocene deposits. These two hydrostratigraphic units (groups of saturated rock units which react to pumping as if they are hydraulically connected) are separated by the relatively impervious Maquoketa shale. Table 3 indicates the geologic units occurring in the area and their thickness, lithology, water-yielding characteristics, and chemical quality of water. It was developed for the entire eastern part of the state in which drift occurs above Paleozoic formations, so ranges of values may be broader than occur in the seven-county Region alone.

The sandstone aquifer generally yields large volumes of high-quality water from deep wells for industrial and municipal uses. The water level in the sandstone aquifer is marked by a substantial pumping cone of depression centered around the metropolitan area of Milwaukee and Waukesha Counties. This problem is due in part to concentrated withdrawals in the urban area, which is located a great distance from the

[41] *State of Wisconsin, "Natural Resources of Wisconsin," Wisconsin Blue Book, 1964, pp. 101-102.*

Table 3

CHARACTERISTICS OF AQUIFERS IN EASTERN WISCONSIN, DRIFT-BEDROCK FEATURE

SYSTEM		THICKNESS	LITHOLOGY	WATER YIELDING CHARACTERISTICS	CHEMICAL QUALITY
QUATERNARY	RECENT AND PLEISTOCENE UNDIFFERENTIATED	0- 500'	DRIFT IS PRIMARILY OF WISCONSIN AGE UNDERLAIN BY OLDER TILLS, CONSISTS OF UNCONSOLIDATED CLAY, SILT, SAND, GRAVEL, AND BOULDERS.	MOST PRODUCTIVE AQUIFERS ARE STRATIFIED SAND AND GRAVEL IN A) OUTWASH PLAINS AND VALLEY TRAINS, AND B) BEDROCK CHANNELS. YIELDS SMALL TO LARGE SUPPLIES FROM SAND AND GRAVEL. SUITABLE PRIMARILY FOR DOMESTIC SUPPLIES OF LIMITED EXTENT.	USUALLY FAIRLY GOOD QUALITY SUBJECT TO LOCAL CONTAMINATION FROM WASTE DISPOSAL OPERATIONS AND SEPTIC TANKS. IRON CONTENT IS HIGH, ESPECIALLY IN AREAS OF POOR DRAINAGE.
DEVONIAN	MILWAUKEE GROUP	0- 160'	CONSISTS OF ZONES OF SOFT, GRAY, SHALEY, LIMESTONE; MASSIVE, DARK GRAY, DOLOMITIC, LIMESTONE; BLUE GRAY SHALE AND SHALEY DOLOMITE; AND BLACK SHALE. FAUNA INCLUDES PELECYPODS AND BRACHIOPODS.	YIELDS SMALL SUPPLIES OF WATER FROM FRACTURES AND SOLUTION CHANNELS.	
SILURIAN	NIAGARA GROUP	0- 600'	DOLOMITE; WHITE TO GRAY, FINE TO COARSELY CRYSTALINE, LOCALLY ABUNDANT CHERT; CREVICES AND SOLUTION CHANNELS LOCALLY ABUNDANT. FAUNA INCLUDES SOME SILICIFIED <u>FAVOSITES</u> AND HALYSITES COROLS.	USUALLY YIELDS MODERATE SUPPLIES; IMPORTANT IN EAST WHERE SANDSTONE AQUIFER IS SALINE.	
ORDOVICIAN	MEQUOKETA FORMATION	0- 240'	SHALE; GRAY TO BROWN, SILTY WITH SOME INTERBEDDED DOLOMITES UP TO 40' THICK; PHOSPHATE NODULES AT BASE; LOCALLY ABUNDANT FOSSILS.	USUALLY NOT AN AQUIFER; MAY YIELD SMALL SUPPLIES LOCALLY	GENERALLY GOOD QUALITY, TEND TO BE QUITE HARD - SALINE WATERS ARE ENCOUNTERED IN EXTREME EASTERN PART OF THE AREA IN ST. PETER SANDSTONE AND DEEPER UNITS. POLLUTION FROM SEPTIC TANKS; SURFACE DISPOSED OF EFFLUENTS; AND SANITARY LAND FILLS MAY EASILY LEAD TO CONTAMINATION OF CARBONATE WATER SUPPLIES.
	GELENA FORMATION	0- 230'	DOLOMITE; GRAY TO BUFF; VERY VUGGY WEATHERING IN PLACES; SEVERAL THIN CHERTY LAYERS CONTAINING <u>RECEPTACULITES</u>	YIELDS MODERATE SUPPLIES, USUALLY IN AREAS NOT OVERLAIN BY SHALE AND NOT DEEPLY BURIED.	
	DECORAH FORMATION	0- 25'	SHALE; BLUE-GRAY; INTERBEDDED WITH LIMESTONE; THIN TO MEDIUM BEDDING; ABUNDANTLY FOSSILIFEROUS; <u>ISOTELUS</u>, <u>LEPERDITIA</u>, <u>HORMOTOMA SOWERBYELLA</u>.	YIELDS VERY SMALL SUPPLIES.	
	PLATTEVILLE FORMATION	0- 100'	DOLOMITE AND LIMESTONE INTERBEDDED; BLUE-GRAY TO BUFF; SOME THIN SHALES AND LIMESTONE CONGLOMERATES. ABUNDANT FOSSILS AS IN DECORAH; BASAL UNIT OF QUARTZ SANDSTONE, WHITE, COARSE-GRAINED, INTERSTRATIFIED GREEN SHALES.	YIELDS SMALL SUPPLIES, PRINCIPALLY IN AREAS NOT OVERLAIN BY SHALES AND NOT DEEPLY BURRIED.	
	ST. PETER FORMATION	0- 345'	QUARTZ SANDSTONE; FINE TO MEDIUM-GRAINED; LIGHT GRAY TO WHITE TO PINK; WELL ROUNDED AND SORTED, VERY FRIABLE, CROSS STRATIFICATION PROMINENT LOCALLY; PERMEABLE; DOLOMITIC IN PLACES; RED SHALE NEAR BASE.	YIELDS MODERATE TO LARGE SUPPLIES.	
	PRAIRIE DU CHIEN GROUP	0- 275'	DOLOMITE; GRAY TO BUFF; LOCALLY OÖLITIC; SOME QUARTZ SAND GRAINS AND GLAUCONITE; LOCAL BRECCIATED ZONES. CONTAINS INTERBEDDED QUARTZ SANDSTONE LAYERS; WHITE, CROSS-STRATIFIED; DOLOMITIC LENSES. SMALL ALGAL MASSES SCATTERED THROUGH DOLOMITE.	YIELDS SMALL TO MODERATE SUPPLIES ESPECIALLY WHERE NOT OVERLAIN BY SHALE.	
CAMBRIAN	TREMPEALEAU GROUP	250-1200'	QUARTZ SANDSTONE; YELLOW TO WHITE; FINE TO COARSE GRAINED; INTERBEDDED WITH DOLOMITE & SHALE; CROSS-STRATIFICATION COMMON; SOME FOSSIL FRAGMENTS OF <u>DIKELOCEPHALUS</u>, <u>OSCEOLA</u>, <u>PROSAUKLA</u>.	PRINCIPAL AQUIFER OF THE AREA; ESPECIALLY NEAR CENTERS OF POPULATION AND INDUSTRIALIZATION. YIELD SMALL TO LARGE SUPPLIES DEPENDING ON LOCAL CONDITIONS OF PERMEABILITY AND THICKNESS. GALESVILLE AND MT. SIMON FORMATIONS USUALLY THE MOST HIGHLY PRODUCTIVE. CAMBRIAN SANDSTONES ARE GENERALLY CONSIDERED A HYDROSTRATIGRAPHIC UNIT AND CALLED THE 'DEEP' OR 'SANDSTONE' AQUIFER.	WATER TENDS TO BE QUITE HARD (335 - 435 PPM) SANDSTONES HAVE HIGH IRON CONTENTS (0 - 30 PPM) WHICH INCREASE WITH DEPTH. GENERAL QUALITY DETERIORATES WITH DEPTH IN THE AQUIFER. A BELT OF HIGHLY MINERALIZED (SALINE) WATERS EXTENDS FROM GREEN BAY TO ILLINOIS ON EXTREME EASTERN BORDER OF AREA - FLUORIDE CONTENT IS HIGH (2.8 PPM AT GREEN BAY).
	FRANCONIA FORMATION		QUARTZ SANDSTONE; WHITE TO BUFF TO GREEN; FINE-GRAINED; ABUNDANT GLAUCONITE IN MANY ZONES; OFTEN SHALEY AND MICACEOUS; CROSS-STRATIFICATION AND RIPPLE MARKS COMMON. FOSSIL FRAGMENTS RARE.		
	DRESBACH GROUP: GALESVILLE FORMATION		QUARTZ SANDSTONE; WHITE TO BROWN; MEDIUM-GRAINED; USUALLY WELL SORTED; MASSIVE BEDDING WITH SOME GIANT CROSS-LAMINAE; FRIABLE INFRESH SURFACES; GRAY AND HARD WHEN WEATHERED.		
	DRESBACH GROUP: EAU CLAIRE FORMATION		QUARTZ SANDSTONE; WHITE TO YELLOW TO BROWN; MEDIUM TO FINE-GRAINED; INTERBEDED WITH SILTSTONE AND CLAY LAMINAE; SOME CROSS-STRATIFICATION.		
	DRESBACH GROUP: MT. SIMON		QUARTZ SANDSTONE; WHITE TO YELLOW TO BROWN; MEDIUM TO COARSE-GRAINED; GENERALLY MASSIVE BEDDING; SILTY LAMINAE NEAR BASE; LARGE AND SMALL SCALE CROSS-STRATIFICATION.		
PRE-CAMBRIAN				SANDSTONES YIELD HIGHLY MINERALIZED WATERS. OTHER ROCK TYPES YIELD SMALL SUPPLIES FROM ZONES OF FRACTURE OR INTENSE WEATHERING. USUALLY NOT CONSIDERED AN AQUIFER IN THIS AREA.	

recharge area for the aquifer, and also to the relatively low rate of natural recharge into the area of heavy pumping.[42] The Ordovician formations in the deep aquifer are important aquifers where they are exposed or covered only by drift. They yield very little water where they occur beneath the Maquoketa shale. These carbonate aquifers also run a high risk of contamination where drift covering is absent or highly permeable.

Recharge to the deep aquifer occurs primarily from precipitation percolating through the glacial deposits and carbonates to reach the sandstone. This phenomenon is effective only in the area west of the Maquoketa outcrop.[43]

The shallow aquifer includes the Silurian Niagara dolomite and some Devonian dolomites in parts of Milwaukee and Ozaukee Counties and the Pleistocene aquifers. The latter unit is often hydrologically connected to the dolomites but may be locally an independent hydrostratigraphic unit. The aquifer provides much water in the eastern part of the Region, particularly to private domestic and farm wells and small industries.

Water is recharged to the shallow aquifer via precipitation by percolation of water through overlying glacial materials to the dolomite. As in the case of the shallow dolomite in the west, this aquifer is highly susceptible to contaminants introduced at the ground surface.

Ground water in the Region is generally of good quality. It is very hard (greater than 400 ppm); and high concentrations of sulphate and chloride occur along Lake Michigan, centering around the Milwaukee-Ozaukee County line. Saline water at depth in the sandstone aquifer is a potential source of contamination to usable supplies if it is allowed to spread from its localized areas due to overpumping of the aquifer.[44]

Industry in the Region is also a potential source of pollution to the ground-water reservoirs when waste disposal is not handled properly. The principle industries which occur outside the metropolitan area, where collection systems should eliminate direct ground-water pollution are dairies and canneries. The dairy industry is well developed in the rural regions, with a high concentration of cheese factories and creameries producing milk wastes. Most of the canning plants and pickle factories in the state are located along the eastern margin adjacent to Lake Michigan.

Method of Study

Preliminary Maps: Four maps constructed for the entire Region were used to develop the final liquid waste disposal suitability map. The preliminary maps display nature of the bedrock (see Map 6), thickness of surficial deposits (see Map 5), nature of surficial deposits (see Map 7), and soil permeability (see Map 8).

The bedrock map was modified from Alden's map of 1918. Minor changes were made from more up-to-date sources, including the Geologic Map of Wisconsin by E. F. Bean, Revised Edition (1949).

The thickness of surficial deposits was done by Tom Friz in a doctorate thesis in mining engineering at the University of Wisconsin in 1969. It has been updated somewhat with the addition of a zero to 20-foot interval obtained from the Southeastern Wisconsin Regional Planning Commission publication, Planning Report No. 8, Soils of Southeastern Wisconsin, June 1966.

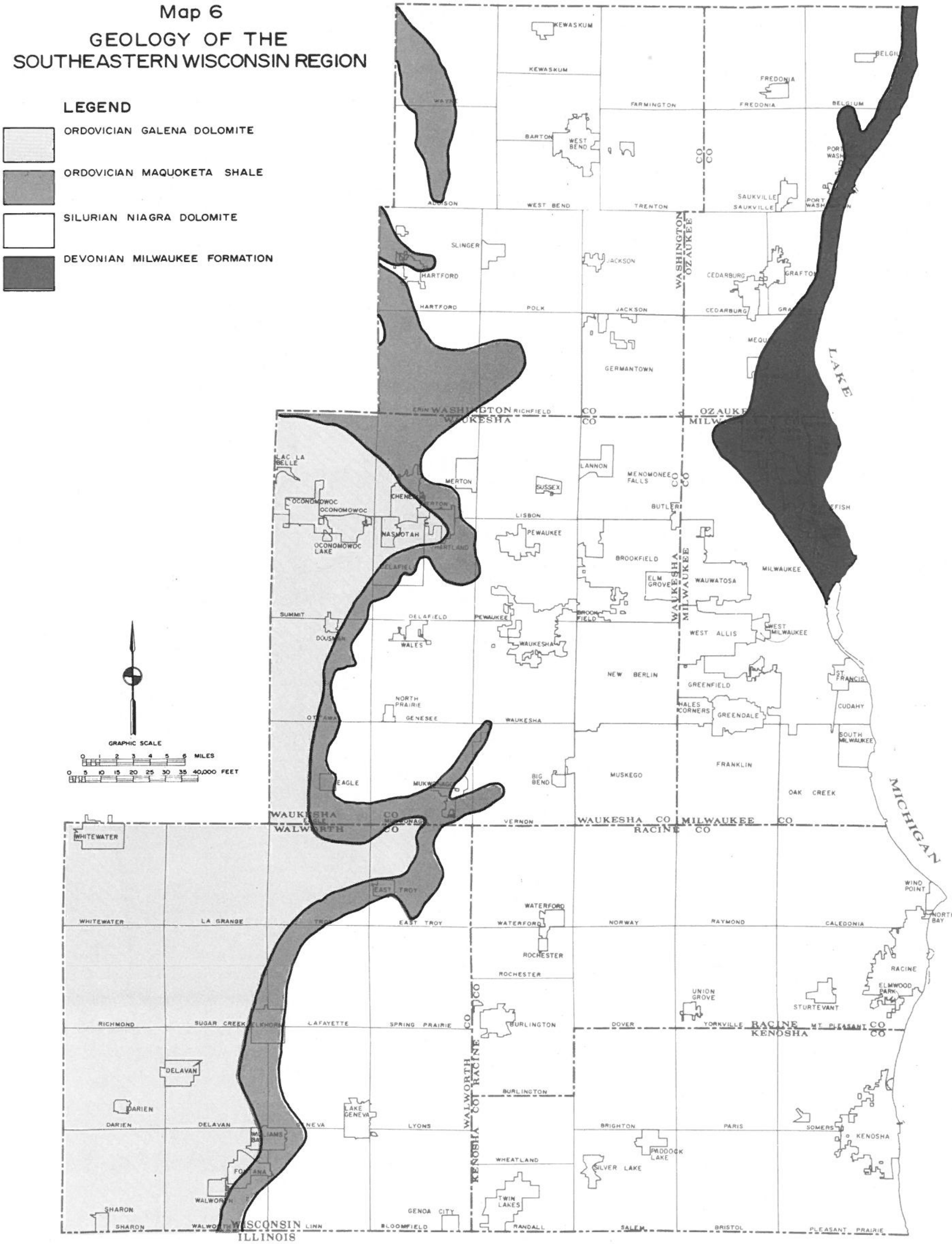
---

[42] *Ibid., Footnote 34, p. 81.*

[43] *Ibid., Footnote 41, pp. 124-126.*

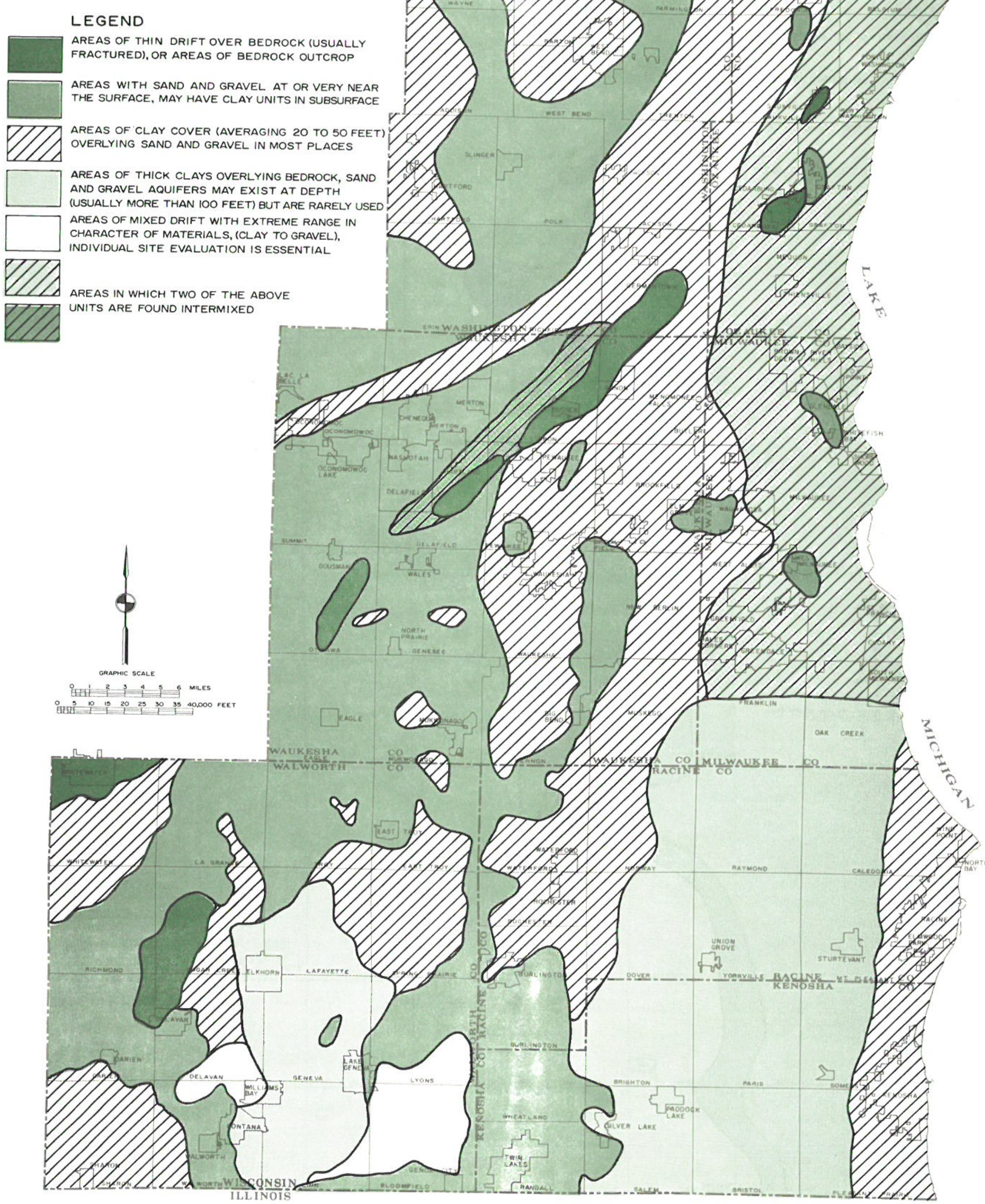
[44] *W. J. Drescher, Information Circular No. 3, Ground Water in Wisconsin, Wisconsin Geological and Natural History Survey, 1956, pp. 9-33.*

Map 6
GEOLOGY OF THE SOUTHEASTERN WISCONSIN REGION



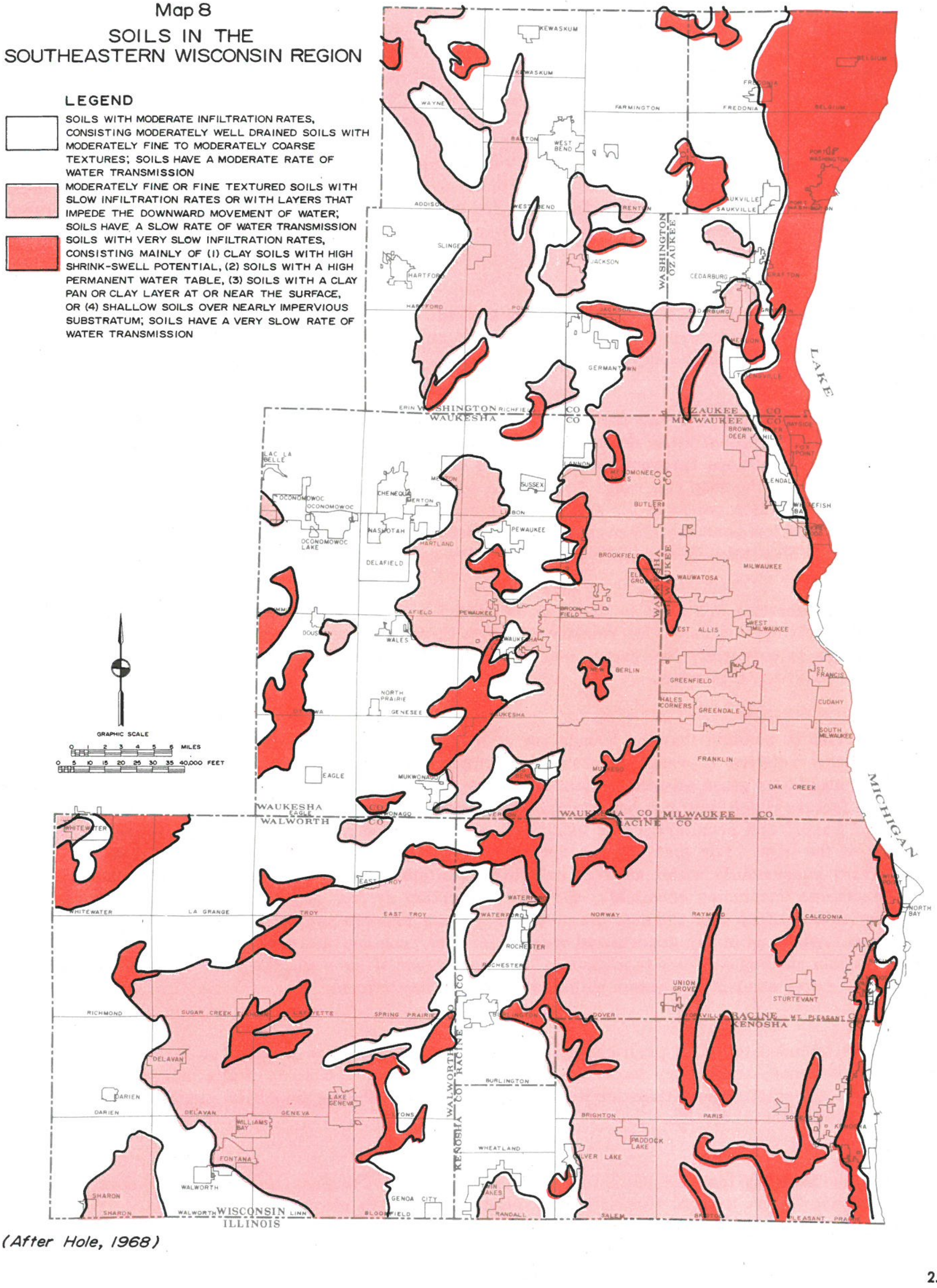
(After Bean, 1965)

Map 7
GENERALIZED SURFICIAL DEPOSITS IN THE SOUTHEASTERN WISCONSIN REGION



Map 8

SOILS IN THE SOUTHEASTERN WISCONSIN REGION



(After Hole, 1968)

The nature of the surficial deposits map was developed in two steps. A preliminary sketch of the Region was made from Alden's map of surficial deposits. General physical characteristics of the drift across the Region were determined from the accompanying text of Alden's report. Since this proved to be inadequate for the sort of detail necessary, a second approach was taken, utilizing well schedules and accompanying logs available through the USGS. The following breakdown by county gives the number of drillers' logs utilized for construction of the map: Kenosha, 140; Milwaukee, 220; Ozaukee, 50; Racine, 120; Walworth, 330; Washington, 140; and Waukesha, 480. The deposits were divided into five broad categories for mapping: 1) areas of very thin drift over bedrock or bedrock outcrop; 2) sand and gravel at, or very near, the surface; 3) areas of clay cover 20 to 50 feet thick, with sand and gravel generally occurring at depth; 4) areas of thick clays overlying bedrock; sand and gravel aquifers may exist at depth, but are rarely mentioned in well schedules as water supplies; 5) areas of mixed drift with extreme range of characteristics, clay to gravel at the surface.

The soil permeability map was constructed from the 1968 Soil Map of Wisconsin, with available data pertaining to permeability of various soil types obtained from the U. S. Soil Conservation Service, SEWRPC, and the Wisconsin Geological and Natural History Survey.

Final Map: From the sources just discussed, a map entitled "Geologic Conditions Relating to Suitability for Liquid Waste Disposal" was derived (see Map 9). A list of seven categories was established, giving consideration to conditions favorable to liquid waste disposal and the local area conditions. These units are described with the map and range from areas where bedrock is exposed or covered by only a thin drift layer and in which potential for ground-water contamination is extremely high to areas of moderate to thick drift with low permeability overlain by soils with intermediate permeability which are well suited for liquid waste disposal. Intermediate categories have various degrees of limitations of use.

Principal consideration was given to potential for ground-water pollution when evaluating the suitability of a unit for receiving wastes. The relative permeabilities of units were also considered, with special attention given to extremely low rates, which are known to cause problems with ponding and runoff, as well as to excessively high rates.

It is important to mention that the boundaries of areas interpreted as having favorable or unfavorable characteristics relative to waste disposal are generalized. Exact sites for individual waste disposal operations should be given on-site evaluation before they are developed for that use. There are also a number of factors which have not been taken into account here, such as volume of waste to be disposed, toxicity of waste, and peculiarities of individual sites, which can alter suitabilities within the general divisions of the map. For instance, an operation to dispose of very limited amounts of wastes might operate very successfully within an area exhibiting limitation due to slow rates of permeability. If an effluent contains uncommon chemicals, the soil absorption system may become inoperable even under ideal conditions indicated on the map because of reactions between the soil and chemical constituents in the effluent. Also, as in any generalized map, it is very probable that small areas of one category are included within another category in mapping. The occurrence of such an area could allow for satisfactory operation of a soil absorption system within an area with limitations.

The map is intended to aid in preliminary decisions pertaining to the location of liquid waste disposal sites. For instance, an industry locating in the Region may have a number of alternative sites. General knowledge of the relative conditions for waste disposal might influence priorities placed on sites and help eliminate an unsuitable location.

As a land use planning tool, the suitability map for liquid waste disposal may aid in the construction of a complete map for the Region, lending guidance for future growth and development.

SUMMARY AND CONCLUSIONS

The use of soil systems for waste disposal and treatment is becoming increasingly common as the problem of growing quantities of waste is faced. Carried out under controlled conditions, land disposal of liquid wastes can provide treatment and return of the resource to storage without contamination. Physical criteria for disposal sites for liquid waste are important to the success of the method. The following factors, summarized from the foregoing discussion, serve as guidelines to site selection.

Geologic Factors

- In areas of unconsolidated materials overlying bedrock, the upper units should have moderate rates of permeability. It is essential that they provide adequate filtration to prevent bacterial or chemical contamination of the underlying aquifer. Soils of moderate permeability are also preferable.

- Bedrock beneath the disposal area should be dense and unfractured to prevent rapid movement of effluents through channels and subsequent danger of contamination to aquifers.

Hydrologic Factors

- The water table in a disposal area should be located at sufficient depth beneath the land surface to allow for attenuation of wastes as they pass through the zone of aeration.

- The local and regional ground-water flow systems should be investigated and disposal sites located with regard to the patterns of water movement. There are merits to the use of both recharge and discharge areas for waste disposal, depending on numerous factors, including local water supplies.

Surface Conditions

- The slope and configuration of the land surface must not allow surface runoff and the possibility of direct entrance of effluent to surface water.

- Cover crops used on disposal sites should provide protection to the underlying soil and maximize the effects of evaporation and transpiration.

- Climate affects the operation and success of the disposal area. Ground freezing in northern latitudes increases the chances for surface runoff of effluent. In addition, cover crops are frequently killed off during winter operation. It is recommended that the ridge-and-furrow method be used during the cold months to decrease the risks of contamination to water supplies.

- Precipitation should be considered as it affects moisture conditions in the soil and ability to absorb effluents. Seasonal distribution of rainfall in relation to timing of disposal operations may be critical.

- The acreage required for a disposal field can be calculated if the above physical factors are known, in addition to the volume and nature of the waste to be disposed. It is important to bear in mind that rotation patterns involving periods of several days of rest must be considered in computing the required acreage.

- Mechanical compaction and tilling should be minimized on the land, as both may lead to reduction of soil permeability from the ideal.

- Long-term effects on the soil may result in decreasing permeability with time. Pores can become clogged with bacterial slime due to poor aeration, and surface pore space can be diminished due to pounding of spray and collection of solids. These conditions may require remedial treatment.

Cultural Limitations

- State standards require that disposal areas be located specified distances from occupied buildings, roads, wells, and surface waters.

Map 9

GEOLOGIC CONDITIONS RELATING TO SUITABILITY FOR LIQUID WASTE DISPOSAL IN THE SOUTHEASTERN WISCONSIN REGION

LEGEND

AREAS OF THIN DRIFT OVER HIGHLY FRACTURED BEDROCK OR AREAS OF BEDROCK OUTCROP.
POTENTIAL FOR POLLUTION OF BEDROCK AQUIFERS IS HIGH

AREAS OF THICK SAND AND GRAVEL DEPOSITS AT OR NEAR THE SURFACE; DILUTION OF CONTAMINANTS MAY TAKE PLACE RAPIDLY
POTENTIAL FOR POLLUTION OF SHALLOW AQUIFERS IS HIGH

AREAS OF SOILS WITH VERY SLOW INFILTRATION RATES CONSISTING MAINLY OF CLAY SOILS WITH HIGH SHRINK-SWELL POTENTIALS, SOILS WITH HIGH PERMANENT WATER TABLES, SOILS WITH A CLAY PAN OR CLAY LAYER AT OR NEAR THE SURFACE, OR SHALLOW SOILS OVER NEARLY IMPERMEABLE SUBSTRATUM; SUITABILITY FOR LIQUID WASTE DISPOSAL IS LOW.
POTENTIAL FOR SURFACE WATER POLLUTION IS MODERATE TO HIGH

AREAS OF CLAY COVER RANGING FROM 20 TO 50 FEET IN THICKNESS OVERLYING SAND AND GRAVEL WHICH MAY SERVE AS WATER SUPPLIES.
POTENTIAL FOR POLLUTION OF SHALLOW AQUIFERS IS MODERATE

AREAS OF MIXED DRIFT WITH EXTREME RANGE OF CHARACTER OF MATERIAL FROM CLAY TO GRAVEL AT SURFACE; SOILS ALSO VARY WIDELY; INDIVIDUAL SITE EVALUATION IS ESSENTIAL.
POTENTIAL FOR POLLUTION OF SURFACE WATER AND GROUND WATER RANGES FROM LOW TO HIGH

AREAS IN WHICH SURFACE MATERIALS AND SOILS WOULD BE SUITABLE FOR WASTE DISPOSAL, HOWEVER, BECAUSE RECHARGE OF DEEP AQUIFERS OCCURS, EXTREME CAUTION SHOULD BE EXERCISED
POTENTIAL FOR POLLUTION OF GROUND WATER RANGES FROM LOW TO HIGH

AREAS OF THICK CLAY TILLS OVERLYING BEDROCK; VERY MINIMAL GROUND-WATER SUPPLIES WITHIN 150 FEET OF GROUND SURFACE; SOILS ARE FINE TEXTURED WITH SLOW INFILTRATION RATES AND IN SOME CASES LAYERS THAT IMPEDE THE DOWNWARD MOVEMENT OF WATER; SUITABILITY FOR LIQUID WASTE DISPOSAL VARIES DUE TO LOW PERMEABILITIES AND IS DEPENDENT ON LOCAL FACTORS; I.E. AMOUNT OF LAND AVAILABLE AND VOLUME OF WASTE TO BE DISPOSED

AREAS OF SOILS WITH MODERATE INFILTRATION RATES; MODERATELY FINE TO MODERATELY COARSE TEXTURED SOILS WITH GOOD DRAINAGE; UNDERLYING DEPOSITS ARE GREATER THAN 20 FEET THICK AND CONSIST OF MODERATELY LOW PERMEABILITY CLAYEY TILLS
POTENTIAL FOR POLLUTION OF SURFACE WATER AND GROUND WATER IS LOW

NOTE: THE POSITION OF THE WATER TABLE AT INDIVIDUAL DISPOSAL SITES IS A CRITICAL FACTOR INFLUENCING THE ASSIGNED CATEGORIES. SEE TEXT FOR EXPLANATION

In the application of these criteria to the Southeastern Wisconsin Region, only the geologic conditions relating to suitability for liquid waste disposal were considered. The remaining parameters, hydrologic factors, land surface characteristics, and cultural limitations were found to be either too highly variable to fit into this type of generalized classification, such as cultural limitations and distance from wells, or not sufficiently well defined to be of value. For example, a hydrologic flow systems analysis was not available.

Therefore, the final map (see Map 9), "Geologic Conditions Relating to Suitability for Liquid Waste Disposal," is meant to serve as a preliminary guide to be supplemented by more detailed information during the actual on-site evaluation.

The eight categories generated are described in the following section and range from areas in which extreme danger of pollution of water supplies exists from disposal operations to areas which are well suited to assimilating effluents. These descriptions are meant to be used in conjunction with the map and should somewhat depict the physical conditions prevailing in the area, danger of pollution to ground-water or surface-water supplies, and the general distribution of land of this type within the seven-county Region. The eight categories described below are presented in an order ranging from least suitable to most suitable and correspond to the order of the legend shown on Map 9.

- In the first category of areas unsuitable for liquid waste disposal, the bedrock formations are overlain by thin glacial deposits or none at all. In addition, the bedrock itself may be fractured. Such conditions may not provide sufficient attenuation of the wastes to prevent pollution of ground-water supplies. Areas of this type can be found scattered throughout the Region, more prevalent in the north than in the south.

- In the second category of areas unsuitable for liquid waste disposal, thick sand and gravel deposits are found near the surface. Such formations are frequently used for small water supplies. Because of the proximity of these shallow aquifers to the surface, the potential for their contamination is high. Within the Region these areas are widespread in the western half.

- The controlling feature in the third category is the low infiltration rate soils in these areas. The problem may be a clay soil with a high shrink/swell potential, a high permanent water table in the soil, a clay pan or clay layer at or near the soil surface, or a weakly developed soil over impervious substratum. In any case the ability of the soil to accept effluent is low, which may lead to surface ponding or runoff to surface watercourses and subsequent danger of pollution. Areas of this type within the Region are generally restricted in size and scattered throughout the seven counties.

- The surficial deposits in these areas of the fourth category are clay-rich and vary in thickness. They overlie sand and gravel aquifers at varying depths. The potential for contamination of these shallow sand and gravel aquifers is moderate. Therefore, disposal in such areas should be with caution. Within the Region such areas seem to be concentrated in eastern Waukesha, central Walworth, and northwestern Washington Counties.

- The areas in the fifth category encompass a variety of unconsolidated sediment types, with widely varying characteristics; and, because of this variability, the potential for contamination of water supplies ranges from low to high, necessitating individual site analysis.

- Areas of the sixth category have suitable surficial characteristics for waste disposal. However, the fact that they lie within the recharge zone for the deep sandstone aquifer limits their usefulness as disposal sites. The potential for contamination of the deep aquifer varies; but, due to the importance of this water supply, extreme caution should be used where potential for pollution of them exists. These areas fall along the western boundary of the Region.

- In the seventh category, these areas are suitable for liquid waste disposal from the standpoint that only very minimal ground-water supplies come from the units near the surface. The important aquifers are at great depth. However, the soils and glacial materials tend to have relatively slow infiltration rates which place limitations on volumes of liquids which can be assimilated. Potential for pollution is low if this latter limitation is observed. Within the Region these conditions exist primarily along the eastern border.

- Areas in the eighth category are the best suited in the Region for liquid waste disposal. The soils have moderate infiltration rates and good drainage, and the underlying glacial deposits are thick and consist of low permeability tills. Potential in these areas for pollution of either ground or surface water resources is low. Areas of this type are found throughout the Region but are especially prevalent in the north.

Appendix A

SUPPLEMENT TO GEOLOGIC AND HYDROLOGIC CONTROLS RELATING TO GROUND-WATER CONTAMINATION

The purpose of this appendix is to provide additional information and examples pertaining to the section on geologic and hydrologic controls relating to ground-water contamination.

HYDROLOGIC FACTORS

Infiltration

The ability of water to permeate the air-soil interface is referred to as infiltration capacity and, for obvious reasons, is a critical concept to liquid waste disposal. Infiltration is controlled by several variables. Included in these are nature of the material, topography, initial degree of saturation, and man's activities. The nature of the original rock which has weathered to form the surficial material and the degree of its breakdown controls porosity texture and thickness. Topography controls the distribution of liquids, and, therefore, the availability for infiltration. The degree of saturation of a soil profile is also important, particularly in liquid waste disposal operations. The initial infiltration rate of a dry soil is often as much as twice the rate of infiltration of the same soil once it becomes saturated. And finally, mans' activities can greatly affect infiltration, usually reducing it. Mechanical compaction by livestock and, more dramatically, machinery, reduce infiltration. Solids from liquid wastes percolating through soils will tend to clog pores, also reducing infiltration. Effects of cultivation vary from one soil to another but may lead to breakdown of the soils' natural structure, reducing porosity and decreasing the rate of downward movement of water.

Permeability

Once a liquid has reached the saturated zone and enters the ground-water flow system, the velocity of its movement is controlled by the hydraulic gradient in the flow system and permeability of the surrounding material. Permeability can be defined as the ability of a material to transmit fluid and is determined by the size and shape of pores and the nature and extent of their interconnections. Permeabilities for different earth materials range from impervious clays (10^{-4} gallons/day/square foot) to clean gravels (10^{6} gallons/day/square foot). A normal range of velocities in nature extends from a low of five feet per year to a high of five feet per day, or 1,800 feet per year, excluding extremes on either end of the scale. However, many relatively impermeable rock types, such as carbonates, volcanic lavas, intrusive igneous rocks, and metamorphic rocks, may have secondary channels of water movement caused by fractures and joints which transmit water at anomalously high rates. In this case velocity and direction of flow are very difficult to predict.

Unsaturated Flow

Flow through the unsaturated zone occurs in recharging the ground-water reservoirs. Flow also occurs in the zone when liquid wastes are disposed of at the surface. A crucial factor affecting the time required for liquid to pass through the unsaturated zone is the rate and manner in which the liquid is disposed of on the surface. An example utilizing disposal pits helps elucidate the point.[1] Assuming a disposal pit for liquid wastes in a medium-grained sand, two techniques of disposal can be compared. Application of the liquid can be made continuously at a rate synonymous with the ability of the sand to accept it; thus, no ponding occurs. Assuming steady-state flow, the liquid should move through the unsaturated zone at approximately the same rate as that of infiltration. If, on the other hand, instead of continuous disposal, a slug of liquid effluent is dumped in a pit every other day equivalent in volume to what can be applied continuously over the same period, the rate of fluid movement in the unsaturated zone changes. With ponding at the surface,

---

[1] *Taft Sanitary Engineering Center, Taft Technical Report W61-5, Ground Water Contamination: Symposium Proceedings, 1961, pp. 10-12.*

the rate of movement increases drastically. For medium sand, rates approximate a few inches to a few feet per day for continuous disposal, compared to about 17 feet per day for intermittent disposal.[2] Therefore, the technique of disposal is important in predicting the length of time required for liquid wastes to reach the water table.

In nature, uniform conditions in the subsurface are generally the exception to the rule. It is not uncommon to encounter zones or lenses of materials, such as clays, with lower permeability than the surrounding material. If the impeding material is local (a lense), fluids moving downward will collect on the upper surface of the lense, forming a small perched zone of saturation, eventually spreading laterally until it can continue downward in the sand. In this case it is possible for the fluid to arrive at the saturated zone a considerable distance from the area of disposal. If the material of lower permeability comprises a layer in the subsurface, it is likely to impede downward movement more severely than the lense, perhaps causing surface accumulation, unless the rate of disposal is adjusted to the rate of flow of the least permeable unit. Such problems can arise at any boundary between materials of substantially different permeabilities, regardless of the nature of the boundary, into a region of lower or higher permeability.

Saturated Flow

Once a fluid has reached the saturated zone, its route of travel is of interest. Contaminants reaching the ground-water reservoir undergo less dilution and dispersion than those entering surface waters. This can be attributed to the laminar nature of most ground water flow compared with more turbulent surface water movement. Therefore, it would be incorrect to include the total volume of a ground-water reservoir when considering diminishing the concentration of contaminants.

Assuming idealized uniform conditions, the movement of the liquid is controlled by the principles touched on earlier in this section. Under such homogeneous conditions, a contaminant entering the system will move with the ground water in a reasonably predictable path. However, the natural flow system is often modified by wells which may be withdrawing water for municipal or industrial use or may be discharging wastes into an aquifer.

In the case of a pumping well, it is possible to define the width of the area in a region of parallel flow within which the flow lines will be bent to converge upon the discharging well. For one unit thickness of the aquifer, the relation can be stated as:

$$W = \frac{Q}{PI}$$

where:

W = maximum width of area contributing ground water to the well,

Q = rate of discharge from well per unit length of hole,

P = saturated permeability of aquifer, and

I = regional hydraulic gradient.

For example, in a homogeneous aquifer of medium-grained sand with a hydraulic gradient of 10 feet per mile and permeability of 70 feet per day, a well discharging one gallon per minute per unit length of hole could be contaminated by a pollutant reaching the water table upgradient anywhere in a region with a maximum width of 1,450 feet. Conversely, assuming the same conditions in the aquifer, a well disposing of a liquid contaminant at 1 gpm could ultimately affect ground-water quality down-gradient in a band 1,450 feet wide.[3]

---

[2] *Ibid.*, *Footnote 1.*

[3] *Ibid.*, *Footnote 1, pp. 10-12.*

A second factor influencing contamination of ground water is the interconnection between ground and surface supplies. Commonly in humid temperate climates ground water contributes to flow in streams. However, the reverse is usually true in more arid environments and, perhaps, seasonally in humid climates or under man-induced conditions, with surface water infiltrating through the channel bottom to add to the ground water reservoir. Such recharge from streams can also be caused by a discharging well placed near the stream which causes sufficient drawdown of the water table beneath the stream to reverse the flow of ground water.

GEOLOGIC FACTORS

Unconsolidated Materials

Unconsolidated surficial deposits are highly significant to the suitability of particular areas for liquid waste disposal. The thickness, physical characteristics, and distribution of deposits determine the effectiveness of the disposal process.

Permeability of various unconsolidated sediments varies widely. In glaciated areas the mantle materials may vary from pure clay deposits to clean gravels, with attendant differences in permeability. A clean gravel is the most productive unconsolidated water-bearing material, but it is also considerably less effective at adsorbing and absorbing contaminants in water passing through. Ordinary glacial tills are generally a heterogeneous mixture of coarse to fine particles.

In addition to their heterogeneous nature, glacial deposits are exceedingly variable in horizontal and vertical distribution. Alluvial outwash deposits of well-sorted sand and gravel with high permeability occur within unsorted clay tills with low transmission rates of water. The occurrence of a particular material at the surface does not necessarily ensure that it is present continuously down to bedrock.

Thickness of glacial deposits also affects the suitability of sites for liquid waste disposal. Where surficial materials are extremely thin, wastes can be expected to reach the bedrock formations, unless the drift is highly impermeable. In areas of thick surficial deposits, wastes are less likely to reach bedrock aquifers; but they may contaminate water supplies present in the unconsolidated zone, again depending on the nature of the drift. Also, in areas of thick tills containing fractures, additional thickness may be of little value, since contaminants are moving to the saturated zone through fractures.

Soils

Soils which develop from surficial deposits reflect the interaction of five basic factors: parent material, topography, climate, organic activity, and time. Within a given region, climate, organic activity, and time vary the least, with parent material and topographic relief generally responsible for variations in soils. Parent material in a glaciated region varies in texture from outwash deposits of sand and gravel to wind-blown fine silts (loess) to lacustrine clays and sands, each exerting an influence on the type of soil developed. Topography determines the degree of soil drainage. For instance, of two soils formed on essentially the same parent material, one located in high lands is usually sloping and well-drained, while one occupying lower, nearly level positions will often be poorly drained. Time has some effect on soil differences in glaciated terrains where numerous ice advances have occurred. Those soils occurring on the oldest drift may be more mature with better developed horizons than soils on younger drift or in outwash deposits.

Interaction of these processes gives rise to soil characteristics, of which texture, structure, reaction, slope, and position are the most critical in liquid waste disposal. Texture, which expresses the proportions of clay-, silt-, and sand-sized particles in a soil is important because of the number of properties which are affected by it. Soil permeability and infiltration rate are determined mainly by texture. Fine-textured soils with high proportions of clay and silt generally have low infiltration capacities and slow to very slow permeabilities, while coarse-textured soils have the higher infiltration capacities and permeabilities. Moisture capacity is also related to texture, with fine-textured soils capable of holding more water than coarse ones.

Soil structure, or the shape and stability of aggregates of soil particles, influences permeability and infiltration also. Generally, soils with closely fitted aggregates and horizontal cleavage are less permeable than granular structures with spheroidal aggregates. Soil slope affects the amount of runoff and susceptibility to erosion. Position in the landscape, as mentioned before, affects drainage.

Ion exchange is particularly effective in holding contaminants in water passing through clays and, to a lesser degree, through sands and silts. "The amount of exchange a particular type of cation undergoes depends on several factors including (1) the type of clay minerals involved, (2) the cations already on the clay, (3) the other cations in solution and their concentration, and (4) accompanying ions."[4] It is possible to make approximations on amounts of exchange in the laboratory using soil samples and solutions of the liquid to be disposed of, although extrapolation to field conditions should not be done without care.

Consolidated Sediments

Interstices in consolidated rocks can be primary (related to the original formation of the rock) or secondary (formed later in the rock's history). Primary porosity is sufficient in most sandstones to make them productive aquifers. Although porosity is high in fine-grained shales, the permeability is low, limiting very severely the amount of water which can be yielded. Sedimentary precipitates, such as limestone and dolomite, rely on secondary features for their water-bearing capacity. This is generally true for all igneous rocks formed intrusively and metamorphic rocks as well.

These latter types are commonly broken into blocks by post-formation activity in the earth's crust, leaving joint cracks or fractures in which water may accumulate. Limestone and dolomite, which are composed of soluble salts, may have additional porosity developed by solution as water passes through joints.

Sedimentary rocks usually consist of horizontal layers of material. Such stratification is important to the occurrence and movement of ground water and may be an advantage or disadvantage in problems of ground water contamination. The interlayering of permeable and impermeable rock types forms the classical artesian flow system and definitely affects movement and occurrence of water, but minute stratification within a single rock type also controls ground-water movement.

In the course of deposition of a given rock type over a large area, there is usually variation or gradational change, horizontally and vertically, in the size and character of the materials being deposited. These gradations are termed "facies changes" and influence permeability and, therefore, ground-water movement.

Most rock units have some inclination rather than lying in a perfectly horizontal position. A slight angle of slope may represent deposition in a sloping position, but steeper inclinations are indicative of deformation. Degree of folding or tilt may influence the movement of ground water or contaminants. The degree of influence of structure over flow can be determined through knowledge of subsurface geology and existing flow patterns.

In a geological rock section, it is not uncommon to find unconformities, contacts between older and younger rocks representing zones where rock has been eroded or was perhaps never deposited. Rocks beneath may be folded and those above, horizontal, or the whole sequence may have been deformed, complicating the situation. Extensive unconformities are prominent structural features and influence occurrence of ground water. It is common for aquifers above and below to be distinct hydrostratigraphic units.

During deformation joints and fractures often occur in the rock. Faults, which are fractures along which the rocks have been displaced, have great influence on occurrence and movement of ground water. A fault may serve as a conduit joining surface and near-surface water with deeper aquifers when it is filled with coarsely broken material. On the other hand, fault zones may contain finely powdered rock of a more impermeable nature, gouge, or cemented material deposited by ground water which leaves the fault a barrier to ground water motion rather than a conduit.

---

[4] *G. M. Hughes, Environmental Geology Notes No. 17, Selection of Refuse Disposal Sites in Northeastern Illinois, Illinois Geological Survey, 1967, pp. 10-11.*

Appendix B

SELECTED BIBLIOGRAPHY

Alden, William C., The Quaternary Geology of Southeastern Wisconsin, U. S. Geological Survey Professional Paper 106, 1918.

Barlowe, Raleigh, Land Resource Economics, Prentice Hall, 1958.

Barnett, H. J., and Morse, C., "Natural Resources and the Quality of Life," Readings in Resource Management and Conservation, by Ian Burton and R. W. Kates, Editors, pp. 585-595, University of Chicago Press, 1960.

Bean, E. F., Geologic Map of Wisconsin, Wisconsin Geological and Natural History Survey, 1 Sheet at Scale 1: 1,000,000, 1965.

Bendixen, T. W., Hill, R. D., Schwartz, W. A., and Robeck, G. G., "Ridge and Furrow Waste Disposal in a Northern Latitude," Proceedings of the American Society of Civil Engineers, Journal of Sanitary Engineering Division, Vol. 94, No. SA1, pp. 147-157, 1968.

Bergstrom, R. F., Disposal of Wastes: Scientific and Administrative Considerations, Illinois Geological Survey, Environmental Geology Notes No. 20, 1968.

Born, S. M., and Stephenson, D. A., "Hydrogeologic Consideration in Liquid Waste Disposal," Journal of Soil and Water Conservation, Vol. 24, No. 2, 1969.

Bruch, J. C., and Street, R. L., "Two-Dimensional Dispersion," Proceedings of the American Society of Civil Engineers, Journal of Sanitary Engineering Division, Vol. 93, No. SA6, pp. 17-54, 1967.

Cain, J. M., and Beatty, M. T., "Disposal of Septic Effluents in Soils," Journal of Soil and Water Conservation, Vol. 20, No. 3, pp. 103-105, 1965.

Drescher, W. J., Ground Water in Wisconsin, Wisconsin Geological and Natural History Survey, Information Circular No. 3, 1956.

Fisk, W. W., "Food Processing Waste Disposal," Water and Sewage Works, Vol. III, pp. 417-420, 1964.

Flower, W. A., Spray Irrigation—A Positive Approach to a Perplexing Problem, Purdue University Extension Bulletin 118-119, pp. 679-683, 1965.

Friz, T. O., Man and the Minerals of Construction, How They Interrelate in the Seven Counties of Southeastern Wisconsin, Ph. D. Dissertation, University of Wisconsin, Madison, 1969.

Frye, J. C., Geological Information for Managing the Environment, Illinois Geological Survey, Environmental Geology Notes No. 18, 1967.

Gilde, L. C., Experiences of Cannery and Poultry Waste Treâtment Operations, Purdue University Extension Bulletin 129, pp. 675-685, 1967.

Glasshof, K., Waste Disposal by Ridge and Furrow Irrigation, Wisconsin Department of Natural Resources, Division of Resource Development, 1968.

Hackett, J. E., and McComas, M. R., Geology for Planning in McHenry County, Illinois Geological Survey Circular 438, 1969.

Hanson, G. F., and Bergstrom, R. E., Ground Water Supplies in Wisconsin and Illinois Adjacent to Lake Michigan, Illinois Geological Survey Reprint Series 1962-U, 1962.

Hole, F. D., et al., Overlay Soil Map of Wisconsin, Wisconsin Geological and Natural History Survey, 1 sheet, scale 1:250,000, (for use with the U. S. Geological Survey 1:250,000 topographic map), 1968.

Hughes, G. M., Selection of Refuse Disposal Sites in Northeastern Illinois, Illinois Geological Survey, Environmental Geology Notes No. 17, 1967.

Keech, C. F., and Dreeszen, V. H., Geology and Ground Water Resources of Clay County, Nebraska, U. S. Geological Survey Water Supply Paper 1468, 1959.

Landon, R. A., Geological Studies as an Aid to Ground Water Management, Illinois Geological Survey, Environmental Geology Notes No. 14, 1967.

Lawton, G. W., Engelbert, L. E., Rohlich, G. A., and Porges, N., Effectiveness of Spray Irrigation as a Method for the Disposal of Dairy Plant Wastes, Wisconsin Agricultural Experiment Station Research Report No. 6, 1960.

Luley, H. G., "Spray Irrigation of Vegetable and Fruit Processing Wastes," Journal of the Water Pollution Control Federation, Vol. 35, No. 10, pp. 1256-1261, 1963.

Ostrom, M. E., Paleozoic Stratigraphic Nomenclature for Wisconsin, Wisconsin Geological and Natural History Survey, Information Circular No. 8, 1967.

Rorabaugh, M. I., "Problems of Waste Disposal and Ground Water Quality," Journal of the American Water Works Association, Vol. 52, pp. 979-982, 1960.

Schraufnagle, F. H., "Ridge and Furrow Irrigation for Industrial Waste Disposal," Journal of the Water Pollution Control Federation, Vol. 34, No. 11, pp. 1117-1132, 1962.

Schroephfer, G. J., and Preul, H. C., Travel of Nitrogen Compounds in Soils, Sanitary Engineering Report 158-S, Sanitary Engineering Division, Department of Civil Engineering, Institute of Technology, University of Minnesota, 1964.

Scott, R. H., "Disposal of High Organic Content Wastes on Land," Journal of the Water Pollution Control Federation, Vol. 34, No. 9, pp. 932-950, 1962.

Southeastern Wisconsin Regional Planning Commission, The Natural Resources of Southeastern Wisconsin, SEWRPC Planning Report No. 5, 1963.

______, Soils of Southeastern Wisconsin, SEWRPC Planning Report No. 8, 1966.

Taft Sanitary Engineering Center, Ground Water Contamination: Symposium Proceedings, Taft Technical Report W61-5, 1961.

Todd, D. K., Ground Water Hydrology, John Wiley and Sons, 1967.

University of Wisconsin, Land Disposal of Liquid Wastes, Extension Division Publication, 1956.

U. S. Department of Health, Education, and Welfare, Public Health Service, PHS Publication 956, Drinking Water Standards, 1962.

Walker, W. H., Illinois Ground Water Pollution, a paper presented on March 13, 1968, at the Illinois Section Meeting of the American Water Works Association.

Westenhouse, R., Irrigation Disposal of Wastes, TAPPI, Vol. 46, No. 8, pp. 160A-161A, 1963.

Wisconsin Department of Natural Resources, Water Resources Management in Wisconsin, 1968.

Wisconsin Department of Natural Resources, Division of Environmental Protection, Wisconsin Solid Waste Disposal Standards, 1969.

Wisconsin, State of, "Natural Resources of Wisconsin," Wisconsin Blue Book, 1967.

Wisniewski, T. F., "Irrigation Disposal of Industrial Wastes," Public Works, Vol. 92, p. 96, 1961.

SOUTHEASTERN WISCONSIN REGIONAL PLANNING COMMISSION

KENOSHA · MILWAUKEE · OZAUKEE · RACINE · WALWORTH · WASHINGTON · WAUKESHA

OLD COURT HOUSE
P.O. BOX 769
WAUKESHA, WISCONSIN
53186
PHONE 547-6721