Hydrogeologic evaluation of solid waste disposal in south central Wisconsin. No. 78 1974

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Madison, Wisconsin: Wisconsin Department of Natural Resources, 1974

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HYDROGEOLOGIC EVALUATION OF SOLID WASTE DISPOSAL IN SOUTH CENTRAL WISCONSIN

Technical Bulletin No. 78

DEPARTMENT OF NATURAL RESOURCES
Madison, Wisconsin

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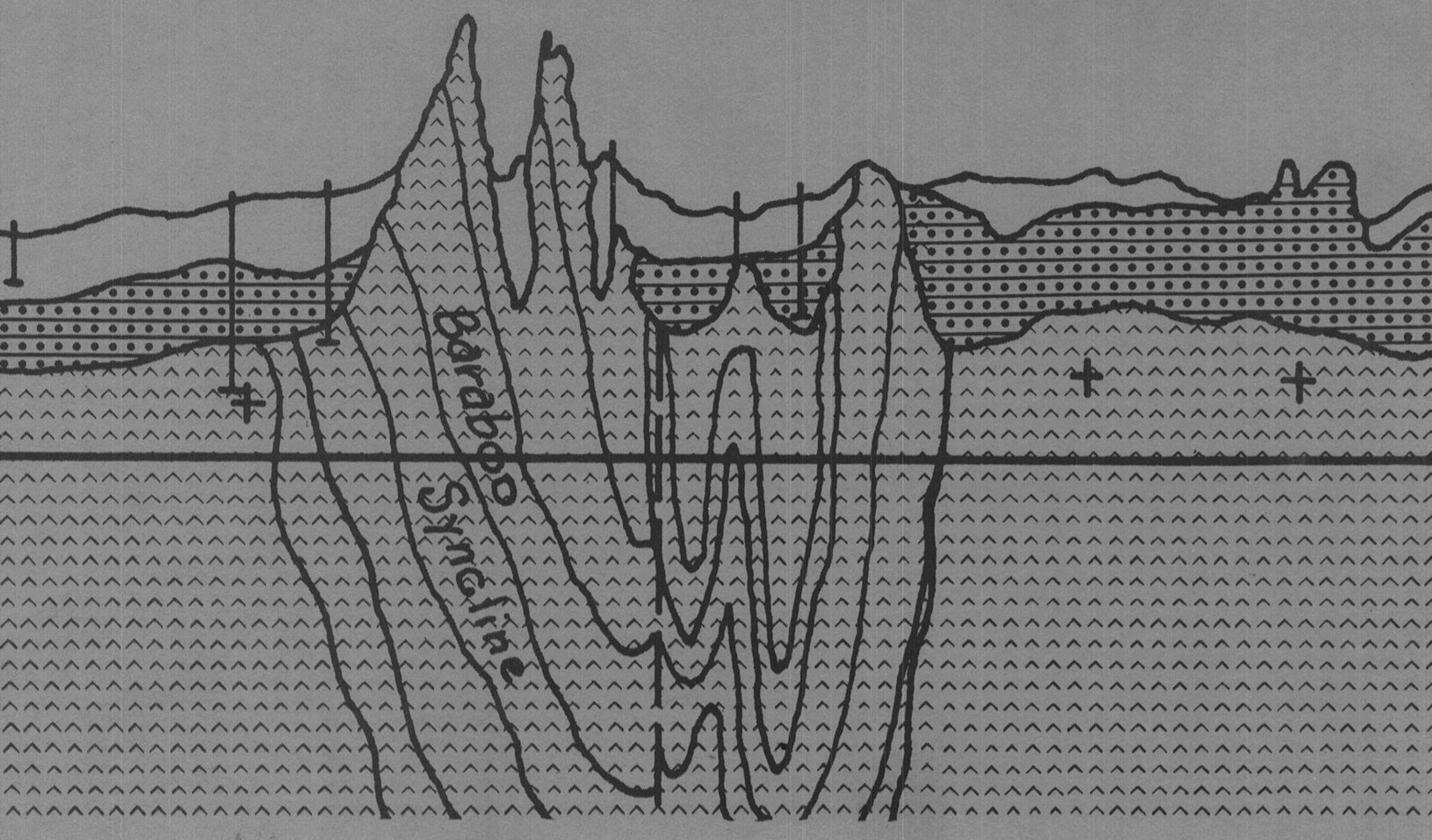

ABSTRACT

The conditions of 62 solid waste disposal sites in 10 counties of south central Wisconsin have been examined during the study. The evaluation was concentrated on physical environments of the existing land disposal sites and their potential for pollution of water resources. Generally, the physical environment offers good natural protection against undesirable effects of landfilling. Landfills can be constructed in almost any of the hydrogeologic environments in south central Wisconsin, provided that a suitable design is used for each particular environment.

Typical hydrogeologic environments were identified and classified into 10 groups. Three factors have been used for the classification of hydrogeologic environments: (1) the extent and character of surficial deposits, (2) the position of the site in the ground water flow system, and (3) depth to water table. Hydrogeologic environments were exemplified by 17 selected sites.

A set of criteria useful in siting sanitary landfills in south central Wisconsin was established and examined on a number of existing sites to see how the criteria relate to local conditions. Characteristics of good, acceptable and poor sites are described; and also the methods and procedures used in the investigation of a site. Physical factors important for establishing a tentatively acceptable site or an obviously unsuitable site have been defined. These factors can be used as general guidelines for the evaluation of prospective areas for landfilling.

Data needed for the evaluation of a site and the rating of their importance, along with a suggested procedure for evaluating environmental impact, are presented.

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By
Alexander Zaporozec

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GLOSSARY

For the purpose of this report the following definitions are provided (according to the requirements in Wisconsin Solid Waste Disposal Standards, 1969):

SOLID WASTE–garbage, refuse and all other discarded or salvageable material including waste material resulting from industrial, commercial and agricultural operations, and from domestic use and public service activities. This does not include solid or dissolved material in waste water effluents or other common water pollutants.

SANITARY LANDFILL–(as defined by the American Society of Civil Engineers)–"S" in tables– a method of disposing of refuse on land without creating nuisances or hazards to public health or safety, utilizing the principles of engineering to confine the refuse to the smallest practical area, to reduce it to the smallest practical volume, and to cover it with a layer of earth at the conclusion of each day's operation, or at such more frequent intervals as may be necessary.

MODIFIED SANITARY LANDFILL–"M"–serves the population equivalent of 2,500 or less, is located at least 1/4 mile from the nearest residence or public gathering place and must operate by promptly burying animal carcasses or large quantities of spoiled food, compacting and covering fill area with at least 6 inches of earth on a monthly basis, establishing a vector control program, practicing fire prevention, controlling wind-blown material and perhaps practicing burning under supervision of the local fire control agency if not in conflict with local or state air pollution requirements.

OPEN DUMP–"D"–serves a population of less than 1,000 when no large quantities of industrial or hazardous wastes are involved, must be located at least 1/2 mile from nearest residence or public gathering place and must operate in a similar manner to that of a modified sanitary landfill except that compaction and covering is required on a semiannual basis as a minimum.

NONCOMBUSTIBLE LANDFILL–"N"–deposition of inert materials, incinerator residue of low combustible content and other noncombustible materials. The site operation should comply with all provisions of a sanitary landfill except that compaction and covering with earth and fire control equipment are not required.

SALVAGE YARDS–site used for the storage or sale of salvageable materials or for the purpose of salvaging, wrecking, dismantling or demolition of salvageable materials.

INTRODUCTION

Solid waste disposal is one of the most pressing problems presently facing our society. The volume of the waste which is to be disposed of is increasing, and will probably continue to do so. Environmental aspects, economic considerations, and social and political problems are the dominant limiting factors in solid waste management. This report deals with the physical factors involved in land disposal of waste, and particularly with hydrogeologic aspects. Operational, engineering, economic and socio-political aspects are not discussed in detail, although every investigator must be aware of the importance of the other factors and consider them in his final recommendations.

Physical factors of the environment influencing the selection of disposal sites include climate, morphology of terrain, surface waters, soils, geologic structure and ground water. Usually the hydrogeologic conditions and soils (in a geologic sense) are the most important factors. The general understanding of these physical considerations in the selection of a site is well established by now (Hughes et al. 1971; Kaufman 1970; Zaporozec and Stephenson 1971). The intention of the present study was to apply this general knowledge to specific conditions.

Sanitary landfills and dump sites are the most widely used methods of solid waste disposal within the state. Over 1430 licenses have been issued for the operation of land disposal sites as of December 1972. Besides that, a great number of small sites are used for dumping wastes at farms, taverns and homes. Most of the sites were originally developed without adequate information, before state solid waste standards were adopted, and usually without knowledge of what conditions constitute a favorable location. Therefore, each of the existing sites represents a potential source of pollution. In order to minimize this condition, it is necessary to evaluate sites with regard to their locations.

Evaluation of the pollution potential of land disposal sites is an important aspect of solid waste management. The introduction of foreign material into the natural environment–especially in large concentrations onto a point, as represented by sanitary landfills–can disturb natural balances and may lead to degradation of the environment. This degradation can be of different kinds and degrees. Not all deterioration of the environment necessarily becomes pollution since some waste assimilation can be accomplished by natural processes.

Potential problems can be identified by examining the physical environment of the sites and the effects of the sites on the environment, and the method for accomplishing this is presented in this report. The physical environment offers a large degree of natural protection and it can, by combination of several processes, successfully reduce the concentration of pollutants to acceptable levels before they reach the source of water supply.

In humid climates, there are no "ideal" sites where no pollution can occur. At least some leachates are always produced and they affect the surrounding environment. In these areas, the search should be concentrated on suitable sites where we can control the pollution and limit it in time and space. This approach, which can be called "controlled pollution", will play an ever-increasing role in solid waste management in the near future, especially now with increasing recognition of the necessity to plan solid waste disposal on a regional basis. The principle of "controlled pollution" is to find, within the general area considered for disposal, a site with suitable characteristics, where the rate of generation of products released in the process of decomposition and stabilization of the fill will not exceed the capacity of the site to purify itself to an acceptable level. Careful selection of a site will result in minimum operating problems and little, if any, danger of water pollution.

Scope of the Study

The objectives of the study were to identify typical hydrogeologic environments in which land disposal sites in south central Wisconsin are located, to evaluate the pollution potential of existing sites in these environments, and from that, to develop methods and procedures which will assist in the

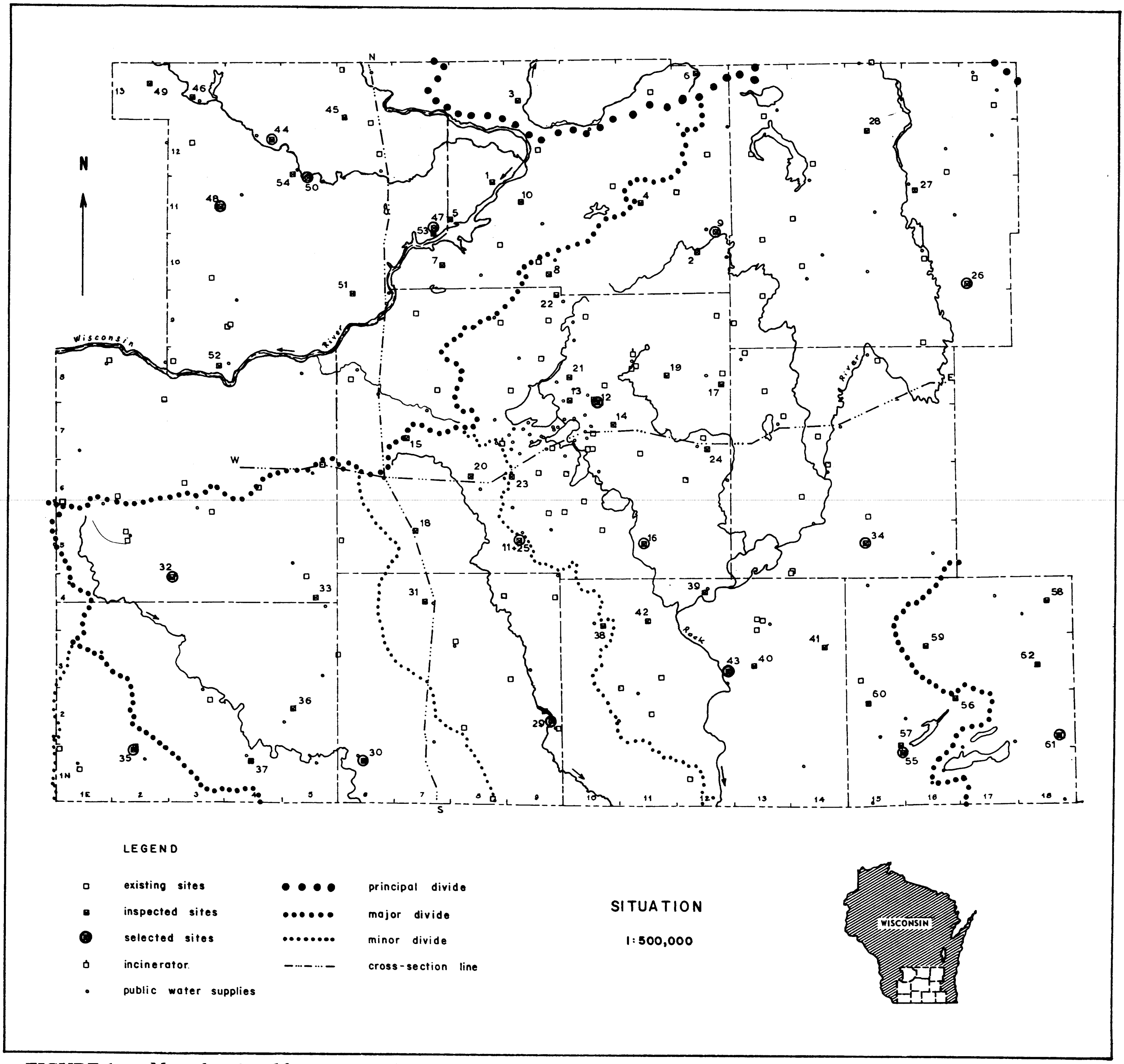


FIGURE 1. *Map showing 10-county study area in south central Wisconsin.*

selection, investigation and evaluation of future sites and will help to minimize their impact on the ground water resource.

South central Wisconsin was chosen because of its diversified physical conditions and because it includes disposal sites in many different environments. It has a varied topography, a variety of all important soils present in Wisconsin, varied character and thickness of unconsolidated sediments (from less than 5 ft in "Driftless" Area to more than 300 ft in buried valleys of Rock and Walworth Counties), all types of bedrock formations present in Wisconsin and various hydrogeologic environments. It is also located in the denser populated part of the state where problems of solid waste disposal will probably increase in the future.

The following sources of information were used to obtain data:

(1) Results of licensed site investigations conducted in the area by the Solid Waste Disposal Section of DNR;

(2) Field inspection of 62 land disposal sites (which is more than one-third of the sites existing in the area);

(3) Published and unpublished reports and maps available in the University of Wisconsin libraries, U. S. Geological Survey and Wisconsin Geological and Natural History Survey in Madison;

(4) Well drillers' reports and well logs available at DNR and Wisconsin Geological and Natural History Survey;

(5) Results of the author's previous research study for the Environmental Protection Agency and a report for the Wisconsin DNR.

Physical Setting of the Study Area

Location. The area under study included ten counties in the southern part of Wisconsin: Columbia, Dane, Dodge, Green, Iowa, Jefferson, Lafayette, Rock, Sauk and Walworth, representing approximately 7,600 miles^2 (i.e. 13.6% of the total state area) (Fig. 1).

Physiography. Geomorphologically, western and eastern parts of the study area are markedly different due to bedrock structure and texture and glaciation. The western unglaciated part is characterized by deeply dissected upland with a rough relief. The eastern part, covered by glacial drift to varying degrees, consists of belted plains with low level topography. The dividing line between these two parts follows roughly the border of Wisconsin Drift (Fig. 3).

Climate. Average annual precipitation is about 32 inches, and ranges from 29 inches in the northern part of Dodge County to 34 inches in southwestern Lafayette County. Between 65 and 80% of the average precipitation is lost by evapotranspiration, 6-25% runs off into surface waters and 10-14% percolates into the ground. Average seasonal snowfall is less than 40 inches. Soil freezing begins in the latter part of November and lasts until the middle of April. Average frost depth is at maximum in the middle of March when it reaches between 12 to 18 inches with values decreasing to the south.

Surface waters. Most of the area drains into the Upper Mississippi River basin, except for the small part of northern Columbia County, which is the headwater area of the Fox River belonging to the St. Lawrence River drainage system. Principal streams are the Wisconsin River in the northwestern part of study area, and the Rock River, which drains the bigger portion of the area (Fig. 1).

Soils. The difference in soil types appears to be distinct between the western and eastern parts of the area, with the dividing line being the border of Older Drift (Fig. 2). Most of the eastern part is covered by well-drained, moderately permeable, medium-textured soils underlain by glacial till of varying thickness. These soils are generally suitable for landfilling (either as a cover material, or in case of disposal on the ground). The western part has soils generally unsuitable for landfilling. The soils are shallow and the bedrock, very often fractured, is near or at the surface. Steeper slopes create operational difficulties. Suitable soils for small-scale operations can be found locally in the well-drained soils, moderately to moderately slow permeable, underlain mainly by clayey residuum over carbonate rocks.

Of less extent are sandy soils of kettle moraines and outwash plains occupying smaller areas in the southeastern part of the study area. These soils are well-drained, of medium to coarse texture and moderate to rapid permeability, underlain by sand and gravel.

Soil characteristics for a specific site could be determined from soil maps which are available for the entire study area at the U.S. Soil Conservation Service. Soil characteristics which should be considered in the evaluation of a site are in Table 7.

Geology. Surface unconsolidated sediments in the western "Driftless" Area consist of loess, weathered and disintegrated bedrock material and alluvial deposits in well-developed preglacial valleys of the Wisconsin, Baraboo and Pecatonica Rivers. A great majority of unconsolidated sediments in the glaciated part of the area is formed by till deposits of drumlins and the ground and terminal moraines which compose favorable conditions for landfilling. Of smaller extent are sandy deposits of kettle moraines in the southeastern part. Sandy outwash deposits occur primarily in Rock and Walworth Counties, in deep preglacial valleys of the Sugar and Rock Rivers, and in deep buried bedrock valleys, well exemplified by the Troy Valley in Walworth County. The thickness of glacial deposits varies considerably within small distances (Fig. 3). In areas covered by ground moraine, the till thickness ranges from 25 to 100 ft. Sediments are thicker on outwash plains and morainic ridges: 100-200 ft. The greatest thickness—more than 300 ft—is found in buried bedrock valleys in Walworth County.

Bedrock geology is relatively simple, consisting of Paleozoic sedimentary rocks which rest unconformably on the peneplaned Precambrian surface (Fig. 4). Precambrian rocks are exposed in Sauk County in the form of a quartzite ridge forming the famous Baraboo Range. Otherwise, they form relatively impermeable bedrock to Paleozoic aquifers. Paleozoic sedimentary rocks (sandstones, carbonates and shales) are deposited in flat, nearly horizontal beds, slightly dipping to the south and east. Most of the Paleozoic rocks are permeable and form ground water reservoirs. Any Paleozoic formation may be considered an aquifer except Ordovician Maquoketa Shale and the Cambrian Eau Claire Formation.

Existing Solid Waste Disposal Practices

According to DNR's Bureau of Air Pollution Control and Solid Waste Disposal, Solid Waste Disposal Section, 163 licensed sites were in operation in the area of the study in December 1972. All these sites have been considered in the study and are referred to as existing sites. Table 1 lists the sites by county; their locations are shown

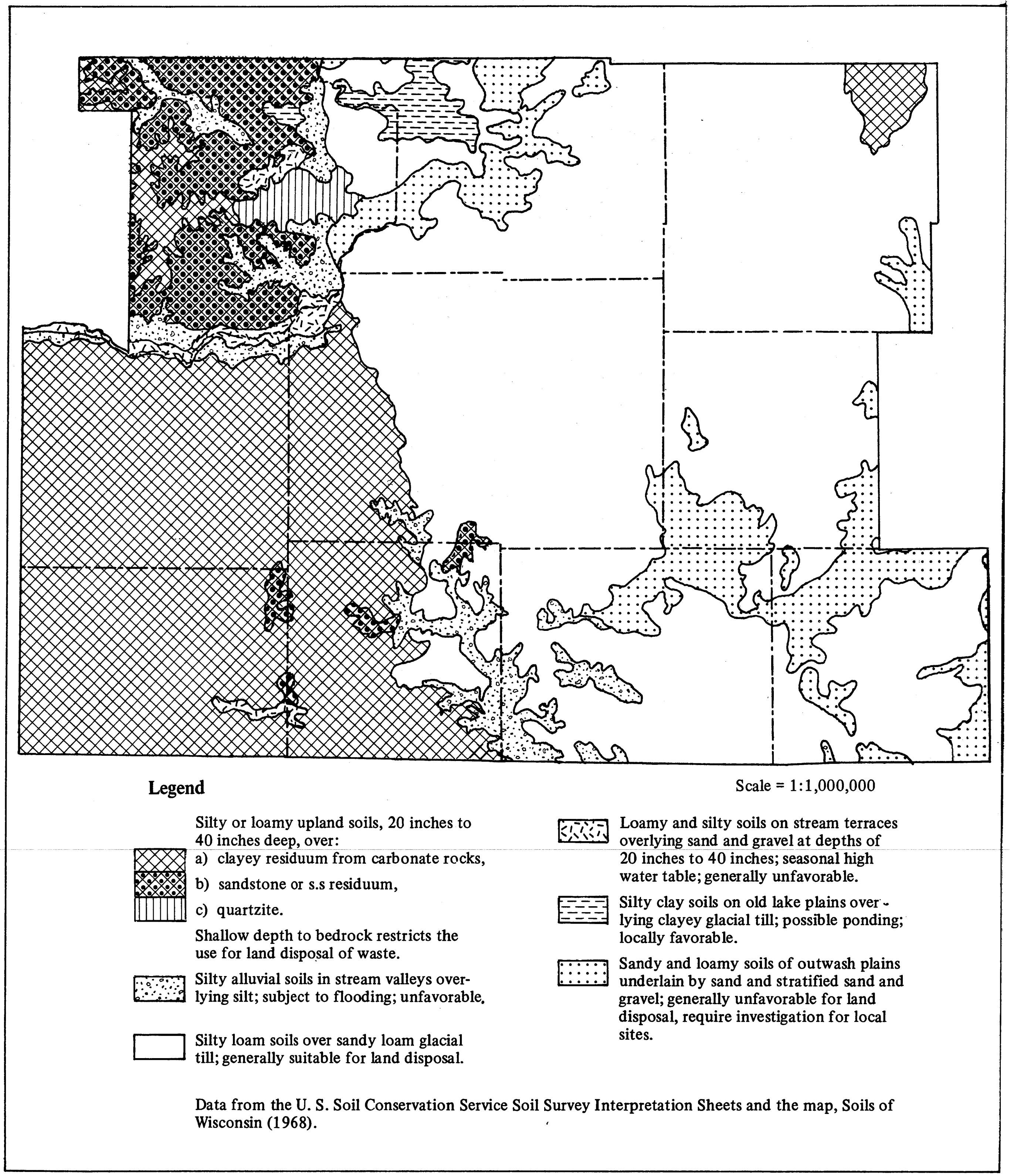


FIGURE 2. *Basic characteristics of soils with respect to land disposal.*

on Figure 1. In addition, 95 salvage yards are authorized in this area; and a great number of small sites are used for dumping wastes at farms, taverns and homes, for which a license is not required. The total number of sites in the area is constantly changing. Most are small and have been developed without adequate investigation. Therefore, many do not conform to the sanitary landfill criteria or location requirements given in the Wisconsin Solid Waste Disposal Standards (revised effective July 1, 1973) and are subject to license revocation, temporary suspension of operations or to closing. On the other hand, many new sites suddenly appear in the attempt to cope with continuing increases in the volume of solid waste. Thus, the total number of sites in the area has in-

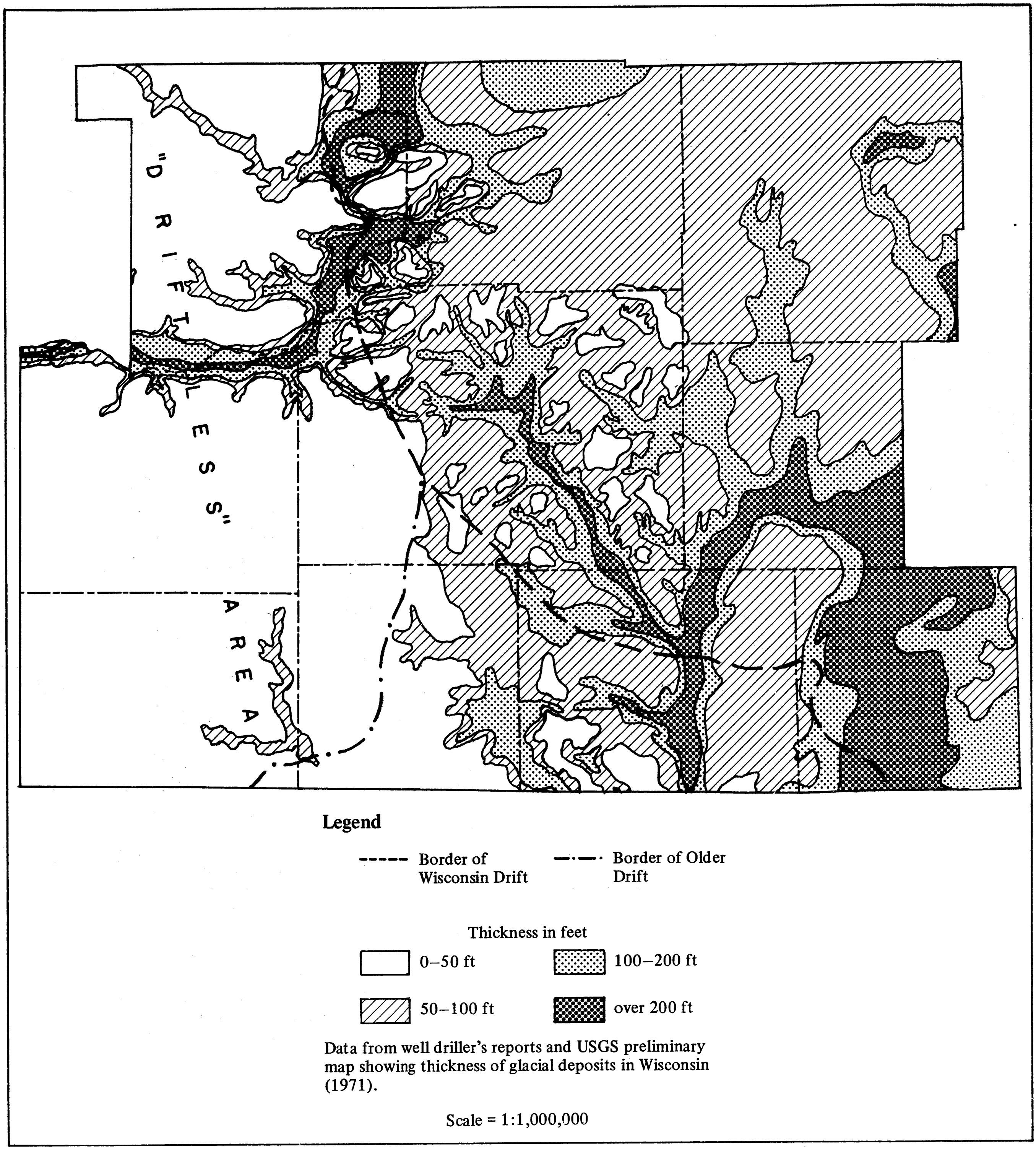


FIGURE 3. *Generalized thickness of glacial deposits.*

creased to 183 during the study period, 22 having been closed or cancelled for various reasons and 42 new sites having been authorized.

At the time of the study (December 1972), more than 95% of solid waste in south central Wisconsin was disposed of directly on land. Only 2 incinerators were used for solid waste disposal in Dane County. Presently, there are 5 incinerators in operation in the area. In the remaining 161 sites, solid waste was disposed on land by various methods. The DNR Landfill Inspection Reports indicate that 59 sites, more than 36% of total land disposal sites in the area, are considered sanitary landfills. This number is well above the national average. (The results of the National Survey of Community Solid Waste Practices in 1968 [Black et al. 1968] showed that only 5% of almost 14,000 authorized land disposal sites in the United States can be considered sanitary landfills.) The remaining 102 licensed land disposal sites are listed in DNR reports as modified landfills (34%), open dumps (24%), or special sites (5.6%).

Nearly 85% are public landfills

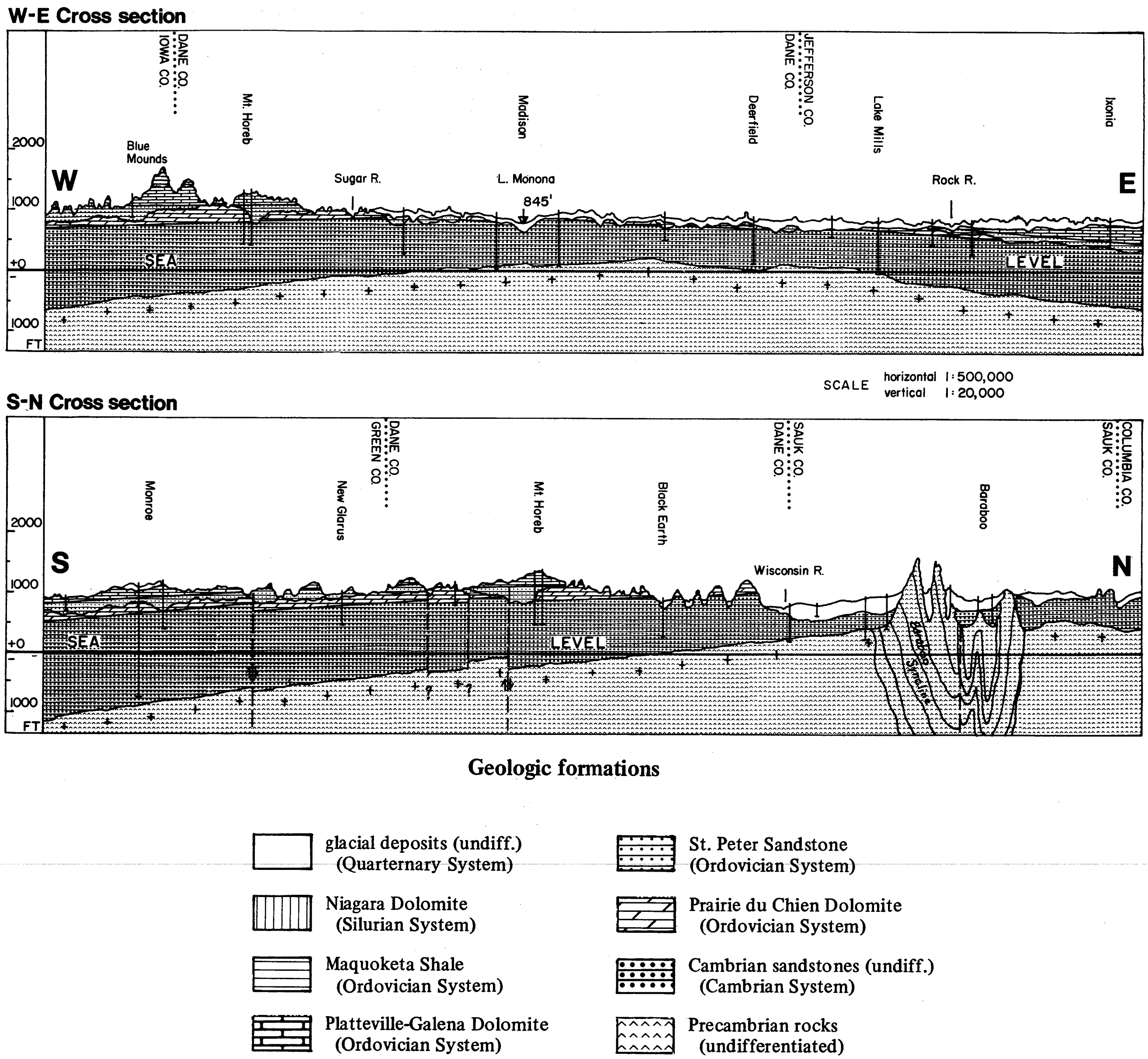


FIGURE 4. *Geologic cross sections (vertical scale exaggerated 25x).*

(Table 1). Only 25 sites are operated privately. In Green, Iowa and Sauk counties all landfills are public. The most widely used type of landfill operation is disposal on ground in natural (valleys, ravines) or man-made depressions (pits, quarries). Other types, used mainly for larger-scale operations, are cut and cover (hillsides) and trenching. Because nearly 20% of the sites are located in gravel pits or quarries, almost all of them were included in the study.

The type of waste which is disposed on land is mostly household and street refuse and garbage. Less than 6% of the existing sites (9 sites) are used for special disposal: 5 of them for disposal of inert waste, construction material and demolition debris; 2 for disposal of wood matter; 1 as a brush burning site and 1 for disposal of dead animals used for laboratory tests.

For the study, 62 sites were selected from 163 existing sites and inspected in the field. Technical data on these sites (later referred to as inspected sites) are compiled in Table 2. Most of these sites are small, serving only one municipality with a population less

TABLE 1. Solid Waste Disposal Operations in South Central Wisconsin as of December 1972*

County	No. Sites	Type of Operation: Sanitary Landfill	Modified Landfill	Dump	Non-combustible	Other	Incineration	Operator: Public	Private	Private Salvage Yards	Changes (Since Beginning of Project, as of March 1973): New sites	Closed	Differences
Columbia	18	7	5	6	–	–	–	17	1	14	7	–	+ 7
Dane	45	16	18	4	1	4	2	37	8	10	13	4	+ 9
Dodge	17	8	6	2	1	–	–	13	4	14	2	2	0
Green	10	2	5	3	–	–	–	10	–	5	3	3	0
Iowa	13	2	3	8	–	–	–	13	–	5	3	2	+ 1
Jefferson	12	7	3	1	1	–	–	7	5	15	1	3	- 2
Lafayette	8	2	4	2	–	–	–	6	2	7	–	4	- 4
Rock	13	3	5	3	1	1	–	10	3	14	3	1	+ 2
Sauk	18	4	5	9	–	–	–	18	–	4	6	2	+ 4
Walworth	9	8	1	–	–	–	–	7	2	7	4	1	+ 3
TOTAL	163	59	55	38	4	5	2	138	25	95	42	22	+20

*Data from DNR. Location of sites in Figure 1.

than 2,000. Sites serving more than two communities are rare. They are only 5, 2 of them being operated privately. This disposal system does not seem to be economically efficient, especially when the sites are often close to each other, such as in Dane County. The unified county-wide management of solid waste disposal could bring economic benefits and improved services to the community. Of course, such considerations would require a thorough inventory of existing solid waste management systems in the county; analysis of inventory data and forecasts of demands; evaluation of alternative solutions from technical, economic and political points of view; and development of a flexible plan. Furthermore, county-wide sites could be operated more efficiently than the small sites. In many cases, operations of existing sites seem to be inefficient indicating the lack of knowledge of engineering design and principles.

According to the DNR Landfill Inspection Reports, most existing sites comply with location requirements. They are usually located in relatively remote areas, which indicates the intention of municipal officials to put them out of sight. With only few exceptions, they are located in reasonable distances from residences, municipal wells, major highways and surface waters (Table 3). However, there is no measure of the effect they have on ground water. This is the factor which is most difficult to determine and not readily measurable. The only parameter which could be included in Inspection Reports is the depth to water table. This would give at least some indication of whether the site will be in direct contact with ground water or not.

Not many communities or private proprietors submitted material on site prior to the approval of a site. The information, required by Wisconsin Solid Waste Disposal Standards, has been found on only 17 from 62 inspected sites (about 27%) in the DNR files. The quality of submitted material greatly varied. From these 17 sites, reports were submitted for only 7.

A similar ratio could be expected for the other existing sites in the study area. This can be explained by the fact that most of the sites were put into use before the State Solid Waste Disposal Standards were adopted in 1969. At the beginning of the licensing program, early efforts were to license sites to control operations. Small sites usually were licensed with little or no information. Now, DNR has initiated the program to resubmit information on such sites by 1975.

TABLE 3. Distances of Existing Sites (in percent of sites).

Distance to Nearest	1,000 ft or more	500 ft or more	Minimum Distance
Residence	62%	87%	150 ft
Municipal well	85%	94%	150 ft
Major highway	86%	93%	200 ft
Surface water	98%	*92%	60 ft

*300 ft or more

TABLE 2. Technical Data on Inspected Solid Waste Disposal Sites*

No.	Type of Oper.**	Type of Wastes[1]	Average Active Fill Area (ft) Width	Length	Popul. Served	No. of Munic. Using Site	Approx. Trench Depth[2] (ft)	Gen. Char. of Site[3]	Shortest Distance (ft.) to Nearest Resid.	Surf. Water	Munic. Well	High-way		
COLUMBIA COUNTY														
1	S	NWTG	14	70	–	–	7	G	1,250	2,000	2,600	1,750	No	
2	S	NWTG	35	40	4,504	1	7	G	1,100	1,000	–	300	Yes	
3	S	NWTG	50	50	8,494	2	0	H	1,320	1,320	2,600	2,600	Yes	
4	S	NWTG	12	20	6,300	4	15	L	1,100	2 mi.	1,100	1,200	No	Private Site
5	M	NWT	12	90	855	1	8	L	2,600	1,000	2,600	2 mi.	No	
6	D	NWT	25	300	1,030	2	0	G	500	1,000	500	3,000	No	
7	M	NWTG	20	60	873	1	0	G	900	1,000	900	8,000	Yes	
8	D	NWTG	40	150	379	1	15	G	2,400	1,200	2,400	7,920	No	
9	M	NWT	12	90	633	1	0	L	800	300	1,400	3,000	No	
10	M	NWTG	35	250	2,881	2	10	H	300	2,600	300	2 mi.	No	
DANE COUNTY														
11	S	NWT	60	150	–	–	12	G	1,300	2,500	2 mi.	2 mi.	No	Ace's Pit
12	S	NWTG	900	1,200			30	UL	200	2,640	2,640	2,640	Yes	
13	S	NWTG	80	40	173,258	1	30	L	2,500	1,700	1 mi.	2,400	Yes	Finished
14	M	NWT	40	70	1,608	1	0	G	800	1,000	800	7,500	Yes	Rolfsmeyer Pit
15	D	T	50	50	995	1	0	H	800	7,000	2 mi.	5,000	No	
16	M	NWT	15	220	2,154	1	0	M	1,300	5,000	2 mi.	5,200	No	
17	D	NWT	110	120	961	1	0	G	1,200	5,000	2 mi.	2 mi.	No	
18	D	T	100	35	664	1	0	G	1,400	3,000	8,000	9,000	No	
19	S	NWTG	8	40	1,490	1	0	G	500	1,000	500	–	Yes	
20	M	G	50	100	2,235	1	0	G	1,300	5,000	5,000	5,000	No	
21	M	NWTG	25	300	1,974	1	20	LoL	1,000	500	5,000	1,200	Yes	
22	S	NWTG	20	40	1,911	1	0	G	700	5,000	2 mi.	600	No	
23	D	NW	30	180	–	–	0	Q	900	1,700	2 mi.	1,700	No	Private Site
24	M	NWT	10	50	855	1	0	G	800	1,000	800	5,300	Yes	
25	M	G	75	500	1,115	1	10	G	1,100	2,500	2 mi.	2 mi.	Yes	Ace's Pit
DODGE COUNTY														
26	S	NWTG	40	210	1,964	2	0	G	1,000	4,500	1,000	1,200	Yes	
27	S	TG	400	700	4,682	2	0	M	1,000	15	4,000	1,000	Yes	
28	D	G	250	250	875	1	0	G+Q	1,500	2 mi.	2 mi.	2,500	No	
GREEN COUNTY														
29	S	NWTG	80	120	6,767	7	0	M	1,000	20	2 mi.	3,000	No	Closed
30	M	NWTG	15	100	253	1	0	H	700	3,300	5,200	5,000	No	
31	D	G	150	400	1,454	1	0	H	3,000	3,500	4,000	500	No	
IOWA COUNTY														
32	M	TG	75	200	2,969	2	0	L-M	900	300	7,000	3,300	No	Closed
33	D	G	50	300	671	1	0	M	2,000	400	5,000	5,000	No	Abandoned
JEFFERSON COUNTY														
34	D	NWT	20	80	1,018	1	0	G	750	1 mi.	700	–	Yes	Freemont Disp.
LAFAYETTE COUNTY														
35	M	G	100	100	1,376	1	0	Q	5,000	1,100	2 mi.	1 mi.	No	Closed
36	M	G	35	50	1,068	1	0	H	2,000	1,500	5,000	300	Yes	
37	D	TG	25	500	249	1	0	Q	1,800	400	8,000	300	No	
ROCK COUNTY														
38	M	NWTG	40	60	2,992	1	0	G	1,500	1,500	1,500	2,500	No	
39	S	NWTG	40	80	4,118	1	0	G	2,000	3,000	2,000	3,000	No	Private Site
40	M	NWT	35	220	1,364	1	0	G	800	2 mi.	1,000	–	No	Private Site
41	D	NWT	35	20	914	1	0	G	2,500	4,000	2,500	1,000	No	
42	D	G	100	150	884	1	0	H	1,500	2,000	3 mi.	9,000	No	
43	S	NWTG	60	40	52,825	3	0	G	1,320	1,000	8,000	1,500	No	
SAUK COUNTY														
44	S	NWTG	40	100	8,524	7	0	L	2,500	4,200	2,500	2,600	No	
45	M	NWTG	10	20	–	–	5	L	1,200	3,000	1,200	1,800	No	
46	D	WTG	15	110	614	2	10	H	2,000	1,000	5,280	5,280	No	
47	D	NWTG	12	350	435	1	0	L	1,500	1,000	4,750	4,000	No	
48	D	NWTG	25	110	756	1	0	H	1,800	3,200	8,800	5,900	No	
49	D	NWT	100	120	617	1	0	Q	1,800	4,800	1,400	2 mi.	No	
50	D	NWTG	15	200	967	2	0	H	1,200	1,000	1 mi.	3,300	No	Closed
51	S	TG	15	75	1,840	1	15	UL	4,000	700	8,000	2 mi.	No	
52	M	TG	200	1,200	2,061	2	12	L	3,000	5,500	–	5,000	No	
53	M	NWTG	20	80	376	1	0	L	25	1,000	2,500	2,500	No	
54	M	NWT	100	150	432	1	0	H	1,500	450	1,500	1,600	Yes	Closed
WALWORTH COUNTY														
55	S	NWTG	30	20	18,831	9	0	G	1,300	5,900	7,920	2,500	No	
56	S	NWT	40	50	4,000	1	0	L	500	400	2,000	900	Yes	
57	M	NWT	50	15	1,413	1	10	G	300	2,640	7,920	2,640	No	
58	S	NWTG	15	80	4,416	2	0	G	1,000	2,800	2 mi.	600	No	
59	D	NWT	75	300	1,811	1	0	G	20	7,300	2 mi.	3 mi.	No	
60	S	NWTG	20	40	1,251	1	0	G	2,640	1,320	3 mi.	2,640	Yes	Private Site
61	S	NWT	100	20	2,143	1	0	M	800	marsh	4 mi.	1,850	No	
62	S	NWT	10	100	1,197	1	0	H	500	2,640	–	5,280	No	

*Data partly from the DNR Landfill Inspection Reports.
**Type of operation: S–sanitary landfill, M–modified landfill, D–dump.
[1]Type of wastes: N–noncombustible, W–wood matter, T–trash, G–garbage.
[2]0–ground disposal.
[3]General character of site: G–gravel pit, Q–quarry, M–marsh, H–hillside, L–level area, U–upland, Lo–lowland.

HYDROGEOLOGIC EVALUATION OF SITES

General Principles of Leachate Generation and Movement

In order to understand the problem of the potential of a landfill for the pollution of natural environment, it is necessary to explain some basic theories and processes.

Generation of leachates

Continuous or intermittent contact of refuse and water produces undesirable constituents called leachates. Leachate is defined as a grossly polluted liquid characterized by high concentrations of dissolved chemicals, chemical and biological demand and hardness. Leachate composition is extremely variable, being a function of the composition of refuse and the volume of water.

Factors that influence generation and movement of leachates from the fill are: the nature of leachates, available moisture, topography, soils, geologic structure and texture, amount of water allowed to come in contact with refuse and the ground water flow system of the site. Because Wisconsin lies in the zone of humid climate with excess of moisture, most of the sites will eventually produce leachates. Therefore, disposal success will depend on how leachate production and movement will be prevented or minimized (either by engineering design or by locating the site in protective environment) to the extent that it will not create a water pollution problem. This study was concerned with the problems of regulating the pollution problem through natural protection provided by the environment.

Leachate movement

In the subsurface, leachates travel first vertically (downward within the unsaturated zone), and after reaching the top of the saturated zone (water table), in the same direction as ground water.

Ground water moves along a precisely predetermined flow path from areas of high potential (recharge area, or upland) to areas of lower potential (discharge area, or lowland) (Fig. 5). At any given point in the flow system, each water particle has the tendency, or potential, to flow toward the point of discharge. Ground water potential is expressed as water table elevation in feet above mean sea level. Lines connecting points of equal potential are called potential lines and they are basically perpendicular to flow path lines. In a recharge area, the ground water potential is decreasing with depth—water moves downward, away from the water table. In a discharge area, it is increasing with depth—water moves upward, toward the water table.

The pattern of ground water flow from a recharge to a discharge area

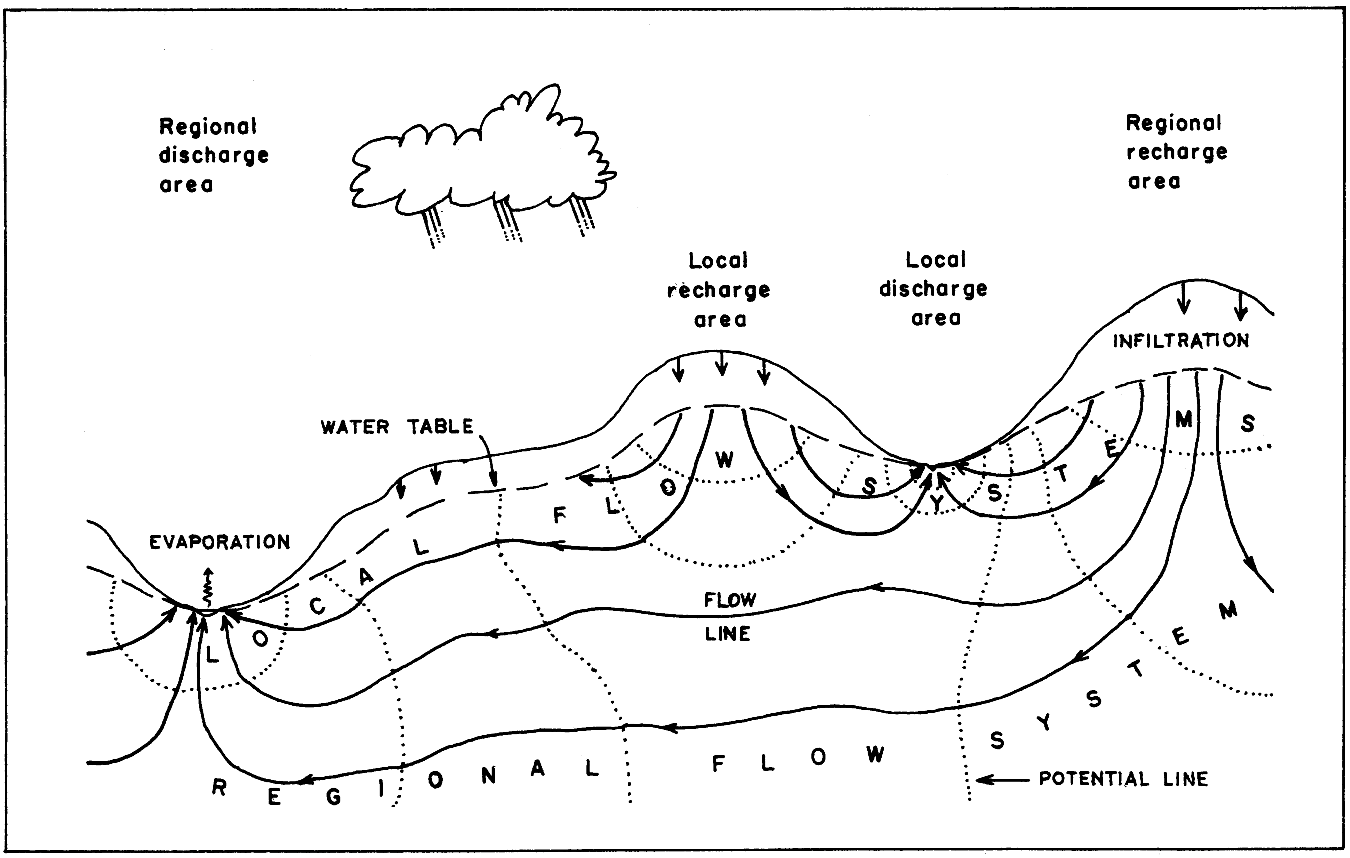


FIGURE 5. *Idealized ground water flow system.*

constitutes a dynamic flow system (Fig. 5). It is composed of several superimposed elements. The largest one is the regional flow system, in which the deeper portion of the ground water flows from a regional recharge area (major topographic divide) to a regional discharge area (major stream which represents regional base level). Water level in that stream represents the lowest water table elevation in the system.

The shallow portion of ground water flow consists of several local systems depending upon the configuration of terrain. Possible pollution of ground water from a landfill is essentially limited to shallow zones, and therefore the determination of small, local flow systems is of prime interest in solid waste disposal. The local flow system will originate in a well-defined relief. The higher the topographic relief, the greater is the importance of local systems. Increasing topographic relief tends to increase the depth and the intensity of the local flow system. If the local relief is negligible and if there is a general slope only, a local system might not form at all. Flow in local systems is limited to areas from local recharge zone to local discharge zone that are adjacent to each other. The approximate size of a local system might be 2,000-3,000 ft horizontally and 200-500 ft vertically. Once the ground water flow system around a landfill is determined, it is possible to predict the movement of leachate with reasonable accuracy.

Pollution potential of a site

Four basic factors should be considered in evaluation of the ground water pollution potential of a site: (a) nature of leachates, (b) their access to aquifers, (c) distribution of leachates within an aquifer, and (d) distance to the points of water use.

(a) The degree of pollution depends to a large degree on the mobility of leachates. Leachates usually contain both biological and chemical constituents, which may eventually result in pollution. Chemical pollutants travel more extensively than biological pollutants, which are effectively filtered by porous media.

(b) Access of pollutants to aquifers is controlled by the character of the unsaturated zone, geology of a site and depth to water table. The access is greatest where highly permeable materials are present between the landfill and the aquifer. Depth to water table influences the rate of leaching. Leaching is most active when the fill is deposited below water table.

(c) Distribution of leachates within the aquifer is controlled by the pattern of the ground water flow system. The movement of leachates from a landfill is a function of infiltration and percolation rates, permeability of material, hydraulic head and direction of flow system.

(d) Location of a site relative to the point of water use is a function of the physical environment of a site. In areas where the environment offers reliable natural protection, or where the site is located upstream of ground water flow, the distance could be shorter. In areas where the environment is less efficient in reducing the leachate concentration, greater distance would be required in order to provide sufficient travel time for attenuation of leachates.

Hydrogeologic Environments of South Central Wisconsin

Physical factors controlling the environments

Three factors which directly determine the effect of a landfill site on water resources have been used for classification of hydrogeologic environments: (1) the extent and character of surficial deposits, (2) the position of the site in the ground water flow system, and (3) depth to water table.

(1) Surficial deposits, including soils and unconsolidated sediments, control the access of leachates to aquifers, and affect the transportation and attenuation of leachates. Highly permeable materials, such as clean sands and gravels, allow relatively easy transport of leachates from the site and offer little attenuation. Materials with low permeability (silts and clays) will retard the movement of leachates and will reduce the concentration of leachates within a relatively short distance. Materials of low permeability will, in many cases, confine the leachates to a limited zone and virtually eliminate the leakage into aquifers.

Permeability of earth materials should be high enough to allow infiltration of leachates so that they will not spread horizontally and create springs and seeps around the landfill (toe leaching); but it should be low enough to retard sufficiently the movement of leachates and to provide time for their attenuation to an acceptable level before they reach the ground water aquifer. The ideal range of permeability is indicated in Table 4.

Approximately two-thirds of the study area is covered by the surficial deposits of glacial origin which exhibit the variability typical of such deposits. Great variations in permeability and thickness can be found even in relatively short distances. Most of this area is covered by glacial till of ground moraine, terminal moraines and drumlins which compose generally favorable conditions for landfilling. However, sand and gravel lenses with higher permeability are often interbedded in the till. Sandier and more permeable sediments of outwash plains and kettle moraines are less common and occur primarily in Rock and Walworth Counties. Sand gravel layers are also in alluvial deposits of well-developed stream valleys, especially those of the Sugar and Rock Rivers.

The western one-third of the area is covered by only a thin layer of soils and weathered and disintegrated bedrock material which in places can reach up to 25 ft. Bedrock outcrops are frequent and bedrock formations are near the surface (within 6 ft). Stream channels are mostly narrow and the main alluvial deposits (mostly sandy) are limited to major streams that had well-developed preglacial valleys, such as the Wisconsin, Baraboo and Pecatonica Rivers.

(2) Position of a site within a ground water flow system controls the distribution of that portion of leachates which reaches the aquifer. The greatest effect is in the direction of ground water flow. Then the distance to the nearest point of water use plays an important role.

If a landfill is located in a ground water recharge area, where the ground water gradient is downward, the leachates may be introduced into aquifers and eventually spread for a long distance, depending on the character of aquifer.

Leachates from a landfill located in a ground water discharge area, where ground water flow is upward may eventually migrate laterally, but would be confined to a limited zone close to the top of the zone of saturation. Therefore, they are unlikely to reach an aquifer. On the other hand, the leachates could reach surface water because ground water discharge areas usually border streams, lakes and swamps.

Ground water recharge areas are

represented by uplands; ground water discharge areas are in lowlands. Determination of the ground water flow systems within the area is beyond the scope of this report. Because of the varied topography, ground water flow is likely to be a composite of many local flow systems. Ground water flow pattern is also affected by heavy pumping, such as in the Madison area, and locally by the cone of the depression of individual high capacity wells.

(3) Depth to water table is controlled by the configuration of terrain, frequency and intensity of precipitation and permeability of earth materials. The water table lies closer to the surface in relatively impermeable materials and in lowlands. It is deeper in relatively permeable materials (coarse sands) and beneath topographic elevations (upland areas).

Depth to water table varies generally throughout south central Wisconsin from 0 to 150 ft below the surface. There are many places where a landfill can be located such that it would not intersect the ground water table. Areas where a landfill would be in direct contact with water table (that is approximately within 10 ft of the surface) are along the major streams, lakes and swamps.

If a landfill is so located that no portion of it intercepts ground water, the leaching is limited because it is influenced only by precipitation infiltrating through the landfill surface. The unsaturated portion of unconsolidated sediments provides then natural protection, the degree of which depends upon their thickness and nature. Leaching is most active in areas where landfill intersects the ground water table. Then the environment does not provide natural protection and engineering techniques must be used to control the production and migration of leachates.

It has been shown in several studies (Hughes et al. 1971) that a ground water mound forms below a landfill that is located in materials with low permeability. A mound develops because water can infiltrate more easily through the cover of the fill than through the sides or bottom of the fill. Then the original pattern of ground water gradient is changed. Ground water can no longer contribute to the production of leachates which again result only from infiltration through the landfill surface. However, ground water mounds are unlikely to be present under the landfills situated in permeable materials, such as sands and gravels.

Classification of hydrogeologic environments in south central Wisconsin

On the basis of the factors described above, the following hydrogeologic environments can be found in south central Wisconsin, as listed in Table 5. This information along with examples of the environments in Appendix A may serve as a guide for the selection of landfill sites and to the problems that might be expected in that type of environment.

Hydrogeologic environments with similar geologic conditions can be grouped into three basic categories:

I. Bedrock at or near the surface
II. Glaciated area
III. Alluvial fill deposits

The character of earth material and the position of the site in the ground water flow system have been used for subdivision of hydrogeologic environments into 10 groups. Within the groups further subdivision is based upon the depth to water table.

CATEGORY I.

Group 1a.

Thin cover (less than 5 ft) over carbonate rocks–recharge area–deep water table.

Pollution potential: ground water–high; surface water–low to high.

Occurrence: upland areas, usually deeply dissected, or upland slopes.

Example: site no. 48 and 35.

Group 1b.

Thin cover (less than 5 ft) over sandstones–recharge area–deep water table.

Pollution potential: ground water–moderate to high; surface water–low.

Occurrence: upland areas or upland slopes.

Example: site no. 50, 44 and 30.

Group 2.

Thin cover over bedrock (less than 6 ft)–discharge area–variable water table.

Pollution potential: ground water–high, but limited to small zone; surface water–high.

Occurrence: valley floors.

Example: site no. 32.

Solid waste disposal in Category I sites should be limited to ground disposal so that the excavation does not disturb the protective soil cover. Movement of leachates in subsurface bedrock will be fast, especially where fractured and fissured. Requires thorough investigation before the siting of a landfill.

CATEGORY II.

Group 3.

Low permeability materials–recharge area–deep water table.

Pollution potential: ground water–moderate; surface water–low.

Occurrence: till plains, morainal uplands.

Example: site no. 34.

Movement of leachates through the

TABLE 4. Permeability and Flow Characteristics of Soil Classes (after Todd 1959:53 and Hughes 1972:4).

cm/sec	10^2	10	1	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-7}	10^{-8}	10^{-9}
SOIL CLASS	Clean gravel		Clean sands; mixtures of clean sands and gravels			←Ideal Range→ Very fine sands; silts; mixtures of sand, silt and clay; glacial till; stratified clays; etc.				Unweathered clays		
FLOW CHARACTER.	Good aquifers					Poor aquifers				Impervious		
gal/day/ft^2	10^6	10^5	10^4	10^3	10^2	10	1	10^{-1}	10^{-2}	10^{-3}	10^{-4}	

TABLE 5. Classification of Hydrogeologic Environments in South Central Wisconsin

Pollution potential: H–high; M–moderate; L–low; ground water / surface water

General Character	I. Bedrock at or near the Surface (Soils thin or absent)		II. Glaciated Area (Soils generally more than 30 ft; heterogeneous)		III. Alluvial Fill Deposits (Thick soils exceeding 100 ft; stratified; homogeneous)		Water table	Position in ground water flow
Permeability of material	Over Rocks With Linear Openings	Over Rocks With Pores	High	Low	High	Low		
	Group 2	H/H					Deep	Discharge Zone
			H/M-H Group 8	M/L-H Group 4	H/H Group 9		Shallow	Discharge Zone
				L-M/L Group 5	M-H/L-M Group 10		Deep	Lateral Part
							Shallow	Lateral Part
	H/M-H Group 1a	H/L Group 1b	M-H/L Group 6	M/L Group 3			Deep	Recharge Zone
			H/L Group 7				Shallow	Recharge Zone

base and sides of the fill will be slow and the capacity of surrounding material to attenuate the leachates will be high. Refuse disposal for sites with shallow water table should be limited to ground disposal only. Pollution potential of these sites will depend on the depth to and character of bedrock. If the bedrock is a shale or fine, undisturbed sandstone, landfill operation might be permissable in reasonable distance from points of water use.

Group 4.

Low permeability materials–discharge area–shallow water table.

Pollution potential: ground water–moderate; surface water–moderate to high.

Occurrence: morainal lowlands, lake plains.

Example: site no. 16 and 9.

Movement of leachates will be slow and the affected area will be confined to a limited zone close to the water table. Leachates are unlikely to reach underlying aquifers. The material will provide attenuation of leachates to some extent before they reach the surface water.

Group 5.

Low permeability materials–lateral part of flow–deep water table.

Pollution potential: ground water–low to moderate; surface water–low.

Occurrence: morainal uplands.

Example: site no. 12.

Movement of leachates out of the landfill will be slow and they are unlikely to reach the underlying aquifers. The capacity of material is sufficient for attenuation of leachates to an acceptable level before they reach the point of water use.

Group 6.

High permeability materials–recharge area–deep water table.

Pollution potential: ground water–moderate to high; surface water–low.

Occurrence: gravel deposits in morainal uplands, outwash plains.

Example: site no. 55 and 26.

Movement of leachates will be relatively easy and the capacity of the material is not sufficient for completely safe disposal. Movement is downward and leachates are likely to reach deeper aquifers (site no. 26). Pollution potential will depend on the depth to and character of bedrock aquifers. The material is not efficient in attenuating leachates unless a long travel distance is available for at least partial attenuation (site no. 55).

Group 7.

High permeability materials–recharge area–shallow water table.

Pollution potential: ground water-high; surface water–low to moderate.

Occurrence: upland morainal slopes, outwash plains, stream terraces.

Example: site no. 11 and 25.

This environment very seldom offers natural protection if the landfill intersects the ground water table. Design of a landfill will require investigation and engineering techniques. If the landfill does not intersect the water table, the same applies as for Group 6.

Group 8.

High permeability materials—discharge area—shallow water table.

Pollution potential: ground water—high, but limited; surface water—moderate to high.

Occurrence: valley flats adjacent to streams, kettle moraines, outwash plains.

Example: site no. 61 and 29.

Movement of leachates will be upward so that they are unlikely to reach deeper aquifers. Leachates will be attenuated to some extent before they reach the surface water, depending upon the distance. Stream flow should be sufficient to further reduce leachate concentration by dilution so that they will not produce noticeable effects.

CATEGORY III.

Group 9.

High permeability materials—discharge area—shallow water table.

Pollution potential: ground water—high but limited; surface water—high.

Occurrence: valley flats of streams with well-developed preglacial valleys.

Example: site no. 43.

Principles of leachate movement are the same as for Group 8.

Group 10.

High permeability materials—lateral part of flow or recharge area—deep water table.

Pollution potential: ground water—moderate to high; surface water—low to moderate.

Occurrence: valley flats away from streams, outwash valleys.

Example: site no. 47.

Movement of leachates will be horizontal and relatively fast. Long travel distance would be required for attenuation of leachates because of low efficiency of material. Leachates are unlikely to reach a deeper aquifer, and they will be attenuated to a substantial degree before they reach the surface water.

Examples of hydrogeologic environments

Hydrogeologic environments defined in the previous section are exemplified by 17 sites selected from 62 inspected sites (they are referred to as selected sites). The description of selected sites is in Appendix A and includes a geologic cross section of the site (exaggerated 10 times) with schematic flow system, location, topography, drainage, soils, surface geology, bedrock geology, ground water conditions, pollution potential of water resources, compliance with state location requirements, rating, recommendations for improvement and number of corresponding hydrogeologic environment.

The horizontal distance of cross sections is 3 miles, which represents approximately half the width of a small drainage basin. The vertical distance is 500 feet, which represents approximately half the width of the saturated zone in the area.

SELECTION OF A LANDFILL SITE

Criteria for Siting of Sanitary Landfills

One of the tasks of the study was to examine general criteria used for selection of landfills throughout the United States and evaluate their applicability for the conditions in south central Wisconsin. Landfill practices in 21 of the states in the United States were compiled and summarized in a survey done by Zanoni (1971). According to that survey, there are only few states which have included some sort of criteria for selection of landfills into their codes or standards. Only one state (California) classifies disposal sites into three categories on the basis of physical factors and also limits the type of wastes which may be disposed of in each category of disposal sites.

The unwillingness to include specific criteria in the regulations in a form of numbers and distances is understandable if one considers the fact that arbitrarily selected distances required for all cases can be more dangerous than no number at all. A specific distance of well from a landfill given in regulations can lead one to believe that all wells located at the selected distances from a source of contamination are safe. Or, that landfill located such that its base is within selected distance from the water table or is underlain by a required thickness of unconsolidated sediments cannot cause any pollution problems.

One should not forget to look at the criteria as a guide or concept rather than a regulation. They have to be looked at as a set of parameters which aid in the selection of a landfill site—and not as a safety device which prevents pollution. Conditions vary from place to place and so do the criteria. Criteria used in one case cannot be applied in another one without thorough examination and adjustment to particular conditions. For this reason, no specific values for individual criteria have been recommended in this study. The values given serve only as an example of the optimal range which can be expected in ideal conditions. The study was aimed to determine which criteria are useful for the selection of a landfill site in south central Wisconsin, to describe their characteristics, to discuss what combinations of selected criteria constitute a good site, and to explain the consequences of a poorly located site.

It is probably not possible to establish a reasonable set of rules or regulations that would control all factors affecting the production and migration of leachate from landfill. Of course, it is possible to include in the state regulations or standards a set of distances selected on the basis of experience with existing sites. Then, it is necessary to allow some flexibility with regard to the application of these specific rules to each case because of the variability of physical factors involved. In addition, a complete review of existing rules should be undertaken periodically, together with a systematic clean-up of old regulations.

A more effective, more realistic and more meaningful approach is to request an early review of each proposed site. The importance of investigation of a specific site is obvious. The extent and the level of investigation will, of course, vary accordingly to the extent of operation and local conditions. Different phases of investigation and methods used for them are described later. Moreover, at the end of this section is a guide for establishing a tentatively acceptable site or obviously unsuitable site, which the local municipalities and local officials can use with the help of local environmental agents, in the evaluation before they decide to call upon professional services for investigation of a proposed site.

Criteria for the Selection of a Site in South Central Wisconsin

Despite the complexity of the physical environment, there are degrees of similarities in many respects that allow classification of sites, and allow also the selection of criteria for their location.

Set of Criteria

Controlling factors in selection of criteria are basic principles of ground water flow and properties of earth materials. The following set of criteria can provide a basis for preliminary evaluation of a site and its pollution potential. (Asterisks * designate variable factors, the importance of which depends upon the character of other factors.)

(1) Type of unconsolidated sediments.
Favorable: glacial till, windblown silt (loess), fluviatile silts and clays.
Acceptable: sand mixed with silt.
Unfavorable: clean sand and gravel, heavy clays, deep organic soils.

(2) Thickness of unconsolidated sediments.*
Favorable: 25-30 ft below the base of the fill.
Acceptable: 10-25 ft.
Unfavorable: less than 10 ft.
For the sites with unfavorable or acceptable thickness, the suitability has to be considered in combination with the character of material and type of bedrock.

(3) Depth to water table.
Favorable: deep, 25-50 ft.
Acceptable: intermediate, 10-25 ft.
Unfavorable: less than 10 ft (requires engineering solution).

(4) Position of the site in the ground water flow.*
Favorable: downstream of the water supply sources.
Acceptable: normal to flow lines.
Unfavorable: upstream of the water supply sources.
Suitability of less favorably located sites can be evaluated in combination with other factors, such as distance of water supply source, thickness of unconsolidated sediments, and depth to water table.

(5) Type of bedrock.
Favorable: shale, compact crystalline rock.
Acceptable: fine undisturbed sandstone or massive, compact dolomite not fissured.
Unfavorable: permeable sandstones, fissured carbonate rocks.

(6) Topography
Favorable: gently rolling or flat uplands.
Acceptable: dry flat lowlands away from streams, gentle slopes, shallow highway borrow pits.
Unfavorable (requires engineering solution): steep gullies and ravines, deep pits, wet lowlands, floodplains, depressions subjected to ponding.

It should be noted again that these criteria are to be taken rather as a guide, and not as a rule, and weighted for each case individually. Some values might seem rather high. But suitable conditions can be found in many places of south central Wisconsin. Hence it is possible to set up the criteria on the conservative side.

Classification of Sites

By combination of the criteria, the following rating system can be used for classification of sites in south central Wisconsin:

Class I. Good site–located in the environment which offers sufficient natural protection to water resources. Such a site can accommodate any type of waste material. This includes:

(1) Adequate separation from ground water aquifers by relatively impermeable formations through which no leachate can pass. Such conditions are rare in south central Wisconsin.

(2) Adequate protection of underlying aquifers by thick layers of low permeability materials (deep glacial till) with deep water table. Parameters of the site are such that the amount of leachate released is acceptable in that particular environment.

Other characteristics of good site:
–adequate distance from water supply source,
–good surface drainage restricted to the site,
–area protected from flooding and surface runoff.

Operational requirements and economic factors:

Factor	Characteristics of a Good Site
access	easy from major road
proximity of suitable cover material	available in sufficient quantities on spot or very close; easily workable (sandy silt loam) fast draining
proximity to waste sources	close to the community to be served
size	adequate to handle given volume of waste for a long term operation
land use	unused land: future improvement and increased value

Class II. Acceptable site—located in conditions where one or another factor is unfavorable but outweighed by favorable characteristics of other factors. Examples:

(1) Sand and gravel deposits, located in lateral part of the ground water flow, with deep water table which provides a long travel distance. Water supply source at a sufficient distance.

(2) Sand layers in a discharge area.

(3) Sand layers underlain by low permeability bedrock formation.

(4) Glacial till insufficiently thick but underlain by low permeability bedrock formation.

(5) Carbonate rocks in bedrock overlain by glacial till of sufficient thickness or by silt and clay residuum.

(6) High water table in thick glacial deposits of low permeability in lateral part of the ground water flow.

Class III. Poor site—located in the environment which offers little or no protection to water resources. Examples:

(1) Very shallow ground water.

(2) Floodplains, or wetlands.

(3) Sand and gravel pits.

Such a site can be used only for disposal of inert solid waste; or it must be developed using engineering techniques for the protection of the environment.

Investigation of a Site

Before a landfill site can be properly designed, the environment of the site must be known in order to determine if the landfill is to fit that particular environment. The investigation of a sanitary landfill site might require several steps, or phases.

(1) **Preliminary investigation**—is done in order to determine, for planning purposes, the general areas within which sanitary landfill sites might be acceptable, and to eliminate obviously unsuitable places. This preliminary evaluation does not necessarily require services of a hydrogeologist. Advice can be rendered by local representatives of state or federal agencies. The evaluation is based on existing material, land-use maps, highway maps, aerial photographs, topographic maps, soil maps and geologic maps. It is supplemented by field inspection of potential sites, concentrating on relief characteristics, possible flooding zones, and indications of ground water conditions.

(2) **Reconnaissance**—the objective is to determine the feasibility of a potential site for landfilling and to formulate a tentative design. The result is a general evaluation based on information listed under step 1, available literature, data from previous borings and wells, and on field-checking and mapping. This level of investigation requires the services of a professional hydrogeologist. Generally, relatively little expense will be involved. In some cases, however, where the existing data are inadequate, it may be necessary to make soil borings and water-level determinations. The borings should be proposed in such a way that they may be useful in the subsequent phases of the investigation.

(3) **Detailed investigation**—the objective is to gather data necessary for design of a site. The investigative procedures require usually a team of professionals and may include a full range of geologic methods, field measurements, test drilling and sampling. The result is the determination of the geologic framework and water levels, delineation of the ground water flow system, and evaluation of the potential impact of waste disposal on the environment. The actual impact should be then monitored during and after the use of a site.

(4) **Operational investigation**—is a special phase conducted in existing landfills where the impact of landfilling could not be, or was not, fully established before the site was put into use; or in sites developed in unfavorable physical conditions by the use of engineering techniques. The services of a professional hydrogeologist are required for proposal, supervision and periodical evaluation of monitoring.

Guidelines for Evaluation of a Site

A **preliminary evaluation** of a prospective area for a landfill site may be made by a nongeologist. A tentatively acceptable site may be established or an obviously unsuitable one may be rejected by evaluating important physical factors. These factors can be divided into two groups: (1) visible factors which can be assessed simply by the inspection of a proposed site (Table 6), and (2) obscured factors which can either be evaluated with the help of a professional or obtained from existing published or unpublished material (Table 7). Also evaluated should be physical factors influencing economic considerations listed earlier. In many cases the conditions will be far from the ideal. Therefore, it is necessary to use common sense for determining the optimal conditions feasible from both the physical and economic point of view.

Sources of information for the complete site evaluation may be divided into two broad categories: first, material already available in libraries and files; second, new information which must be gathered.

(1) There is a variety of useful information gathered by various agencies for various purposes: maps, borings, monitoring and reports. The Wisconsin Geological Survey, 1815 University Avenue, Madison, has most of this information on file, or it can advise where to obtain it.

Information useful especially for preliminary investigation of a site can be obtained free from local informators such as experienced well drillers, resource agents, employees of state and federal agencies.

Topographic maps (available at the U.S. Geological Survey) can show the slopes in a given area as well as the overall topography—hills, valleys, plains, lowlands, and streams, wetlands, roads, etc. Also, ground water recharge zones and discharge zones can be derived from these maps as well as a preliminary estimate of the position of a site within the ground water flow system.

Soil maps are available at the U.S. Soil Conservation Service offices or at local County Agricultural Agents. These maps are detailed and show the thickness and texture of soils, character of subsoils and substrata, drainage conditions, infiltration rate and areas having similar ranges in slope. In addition to maps, interpretative sheets are available for each soil type giving engineering properties of soils and their limitation for various land uses.

Geologic maps show types, characteristics and thicknesses of subsurface rocks, as well as geologic structure and main features of the area. They are usually accompanied by cross sections.

Aerial photographs indicate general topography and show land use (urban areas, homes, industrial buildings, roads, watercourses, dry runs) and also some geologic features (outcrops).

Special maps may include ground water maps (showing depth to water, potentiometric surface, direction of flow, water quality parameters), engineering geology maps (showing properties of materials, such as permeability, infiltration capacity, density) and land-use maps.

Several maps can be developed as a series of overlays and used together for construction of a land suitability map for landfilling. Such a map is a good guide for selection of tentative areas for land disposal. It can show areas having a high probability of favorable site characteristics, areas generally unfavorable for landfilling and areas where more field work will be needed to locate the site. Land suitability map is a useful tool in the hands of a professional who realizes its limitations. It cannot be given for public use because of the danger of its misinterpretation in the sense that the map in no way replaces the need for onsite investigation. It does reduce, however, the number of sites to be studied in detail.

Borings are useful sources of information on the thickness and character of surficial deposits, as well as on type of bedrock, wherever it is encountered. There are several kinds of borings which may be used for preliminary determination of what materials are most likely to be present at the site. Soil borings give information on the physical properties of the uppermost layer of earth materials. They are usually not readily available because the boring logs are on file in private organizations. Logs of test borings for highway location give the same information and they are on file at the Division of Highways, Department of Transportation, Hill Farms Office Building.

Valuable information can be obtained from the logs of *water wells* drilled in the area. Since 1935, well drillers have been obliged to submit drilling reports on DNR forms. Besides the thickness and character of unconsolidated sediments and type of bedrock, well drillers' reports give information on water levels and water yields. Extensive files of well drillers' reports, arranged by county, are maintained by the Private Water Supply Section of the Division of Environmental Protection in Madison. Many of the wells, especially those with high yield, have been geologically documented. These well logs are on file at the Wisconsin Geological Survey in Madison. Local information can be obtained from local well drillers.

Several agencies carry on *monitoring programs* of various factors. The U.S. Weather Bureau is in charge of meteorologic observations. The data include air temperature and precipitation and are published monthly and in annual summaries.

Stage, discharge and content of

TABLE 6. Evaluation of Visible Factors

Factor	Ideal Conditions	Unacceptable
Location	Upland; highway clay borrow pit; clay pit	Wet lowland; floodplain; deep pit or quarry; sand and gravel pit
Relief	Flat or gently rolling plain; low slope (up to 10%)	Plain adjacent to steep slope; deep gullies; steep slope (over 25%)
Drainage	Fast draining materials; dry surface	Heavy clayey or organic mat.; areas subjected to ponding
Surface water distance:	Valley flats or stream terraces away from stream; more than 1,000 ft of lake* more than 300 ft of a stream*	Valley flats close to stream; likelihood of flooding; closer than 50 ft to any surface water body
Ground water	No indication of high water table	Indication of high water table: seepage, spring, marsh, phreatophytic vegetation
Water supply source distance	More than 1,000 ft	Less than 100 ft
Public facilities–distances:		
fed. funded road	More than 1,000 ft*	Less than 30 ft
public park	More than 1,000 ft*	Less than 50 ft
Private residence	More than 1,000 ft	Less than 100 ft

*Distance required by the DNR Standards. Written permission has to be obtained if less than distance indicated.

TABLE 7. Evaluation of Obscured Factors

Factor	Ideal Conditions	Unacceptable
Soils– Depth	Deep (over 40 inches)	Very shallow (less than 10 inches)
Texture	Medium (silt to loam)	Very fine clay
Drainage	Well to moderately well	Very poorly
Inf. rate	Moderate (0.63-2.0 inch/hr)	Very slow (less than .06) or very rapid (over 20.0 inch/hr)
Org. matter	Low (1.0%)	Very high (over 8%)
Slope	Gently sloping to sloping (2-12%)	Very steep (over 25%)
Subsoils– Permeability	Low (10^{-3}-10^{-7} cm/sec): Mixtures of sand, silt and clay; glacial till; fine sands; silts	High (over 10^{-1} cm/sec): Clean sands and gravels; or very low (less than 10^{-8} cm/sec): heavy clays
Bedrock–Depth	Over 30 ft	At or near the surface
Character	Shale; very fine undisturbed sandstone	Fissured or fractured carbonate rocks
Ground water– Depth to aquifers	Over 50 ft	Less than 10 ft
	Tapped by deep bedrock wells; covered by thick impermeable layers	Wells tapping shallow aquifer; aquifer with thin cover
Direction of flow with respect to water use point	Toward the site	Away from the site

streams, lakes and reservoirs have been measured daily by the U.S. Geological Survey since 1913. The data are regularly published in U.S.G.S. Water-Supply Papers and Water Resources Data for Wisconsin.

Systematic observation of ground water levels is made on more than 40 observation wells in the study area. The monitoring network is maintained by the U.S. Geological Survey and data are also published in Water Supply Papers. Summaries of water level trends have been published in Wisconsin Geological Survey Information Bulletins 4, 9 and 21. In addition, 6 springs are monitored in Dane County.

U.S. Geological Survey in cooperation with other state agencies also maintains monitoring stations for water quality of both surface and ground water. Information can be obtained at the Madison office of the U.S.G.S. Water Resources Division, 1815 University Avenue.

(2) Sometimes it is difficult to obtain necessary information, especially on ground water, without field work. The amount and type of additional data to be gathered will depend on the hydrogeology and the design of the particular landfill. Some of the methods and techniques that can be used in gathering new information are described below.

Field inspection and mapping can be used to supplement geologic information gained from maps and photographs. Character of unconsolidated sediments and bedrock formations can be checked in sand and gravel pits, quarries, road cuts, diggings and excavations, and at natural outcrops.

Water table can be measured in abandoned wells or estimated from the water levels in nearby swamps, deep excavations and old quarries. Surface water is also a good indicator of ground water if checked in different seasons of the year. Intermittent streams occur and disappear depending on water table fluctuations. Measurement of a stream flow at low stage (late in the summer) gives the estimate of ground water discharge in the area. There are various other surface features indicating the ground water occurrence, such as springs, seeps, seepage ponds, marshes, and vegetation.

Field tests are used for determining the infiltration rate, effective porosity and permeability. These methods and procedures are described in the literature of soil science and ground water hydrology.

Table 8 . Information Needed for Solid Waste Management

A. PHYSICAL FACTORS

Topography		Land forms	2
		General slopes	2
		Relief of terrain	1
		Position of the site	1
Climate		Precipitation	2
		Snowfall	2
		Frost depth	1
		Temperature	3
		Evapotranspiration	3
Soils		Depth	1
		Slope	1
		Drainage characteristics	2
		Texture	1
		Infiltration rate	1
		Saturation	2
		Organic matter	2
Geology	Unconsolidated Sediments	Composition	1
		Thickness	1
		Permeability	1
		Aquifers	1
		Sand and gravel deposits	2
		Peat and muck deposits	1
	Bedrock	Depth of overburden	1
		Outcrops	1
		Type	2
		Structural characteristics	1
		Permeability	1
		Aquifers	1
Water resources	Surface water	Streams	2
		Lakes and impoundments	2
		Drainage areas	3
		Drainage patterns	2
		Surface runoff	1
		Floodprone areas	1
		Low flow of streams	3
		Natural quality	2
	Ground water	Availability	1
		Depth to water table	1
		Water table fluctuations	1
		Direction of flow	1
		Flow system	1
		Springs, seeps, swamps	2
		Natural quality	2

B. OTHER FACTORS

Operational and economic considerations	Proximity of waste sources	1
	Size of the site	1
	Proximity of suitable cover material	1
	Characteristics of cover material	1
	Access to the site	2
	Site facilities	2
	Engineering modifications	2
Location of public facilities	Water-supply sources	1
	Major roads & communic.	2
	Parks	2
	Residential areas	2
	Power- and other lines	2
	Sewage treatment plants	3
	Solid waste disposal sites	2
Regulations	State regulations & requirements	1
	Land use type	2
	Zoning	3
	Conflict in land uses	1
Socio-political considerat.	Public acceptance	1
	Acquisition of land	2
	Governmental and jurisdictional considerations	1
Other		

AN EXAMPLE OF THE IMPORTANCE RATING OF INFORMATION

1 Primary importance
2 Secondary importance
3 Indirectly related

Special method, though rather expensive, is a *geophysical survey* which can be used for determining the depth to bedrock and depth to water table (for example: seismic survey or electric logging).

Borings are a necessary part of any more advanced level of investigation for evaluation of the character and extent of soils and unconsolidated sediments underlying the proposed site, and for water level determinations. Shallow soil borings can be drilled by engineering firms; for deeper borings it is necessary to contract a water-well driller.

Sampling is an inevitable part of any field work. Representative samples of soils can be taken by a split-spoon sampler. Undisturbed samples, such as those obtained from cores, are used for laboratory determination of permeability.

Ground water quality is determined by chemical analyses of samples taken from borings, pumping tests, nearby domestic wells or surface streams at base flow. The sampling bottles must be washed several times by the sampled water and tightly capped after filling. For a representative sample, the volume of water in borings should be pumped out at least once and the tap from domestic wells should be open for several minutes before taking a sample in order not to take the water

Table 9 . Evaluation of Environmental Impact of Landfilling

	Proposed activities and resulting processes which may cause environmental impact
Modification of Natural Regime	Modification of natural habitat and vegetation
	Alternation of ground cover
	Alternation of drainage pattern
	Alternation of ground water recharge
	Alternation of ground water flow system
Land Alternation	Paving
	Grading
	Excavations
	Erosion and surface runoff control
	Landscaping
Traffic Changes	Communication
	Transportation
Operational Activities	Transportation of refuse and cover material
	Noise, dust and flying material
	Site facilities
	Engineering modifications
	Compaction and cover
Resulting Processes	Introduction of foreign elements into environment
	Decomposition of refuse
	Stabilization of the fill (subsidence)
	Gas production and migration
	Leachate production and migration
Other	

	Existing characteristics of the environment which may be affected by landfilling
Physical Characteristics	Soils
	Land forms
	Surface water
	Ground water
	Surface water quality
	Ground water quality
	Ground water recharge
	Air quality
	Climate
	Vegetation
Natural Processes	Surface runoff
	Erosion
	Sedimentation and siltation
	Stability of slopes
Land Use	Open space
	Residential
	Commercial
	Industrial
	Agricultural
Recreation, Aesthetics	Scenic view
	Park
	Playground
	Water based recreation
	Hunting
Man-Made Facilities	Structures and buildings
	Transportation network
	Utility networks and facilities
Cultural Status	Health and safety
	Population density
	Employment
Ecological Relationships	Natural habitat (fish, game, etc.)
	Eutrophication
	Disease-insect vectors
	Dust and flying material
	Noise level
	Other

(Source: U. S. G. S. Circular 645)

standing in casing or pipes. Samples for biological analyses should be taken in bottles provided by the State Laboratory of Hygiene.

Monitoring of ground water levels is done by shallow well points either installed in borings or set 5 to 10 feet below the water table so that they can encompass seasonal fluctuations. Usually, a standpipe of small diameter, 1/4-1/2 inch is used. The annulus of the well point should be backfilled with permeable material in the section below the water table and with material of low permeability above the water table (Hughes 1972).

But the well points determine only the horizontal component of flow (ground water elevation). In order to define the ground water flow system, both the horizontal and the vertical component of the flow must be measured. The vertical component is measured in a piezometer, by measuring the ground water pressure at a specific depth below the water table. It may consist of a well point attached to a standpipe with a seal in the annulus between the standpipe and the wall of the boring just above the screen, so that it shows the head of the interval between the base of the seal and the bottom of the boring. The vertical component of ground water flow is then determined from the relative water levels in a shallow well point and a deeper piezometer, both of which can be installed in the same boring.

The information needed for the evaluation of a site is listed in Table 8. The importance of information can be examined by the evaluation of factors limiting solid waste management to a specific solid waste disposal project objectives and goals. The factors that directly or indirectly relate to the project can be compiled into a simple check list which indicates the information needed for the evaluation of the site. Also, the importance of information can be established by assigning a weighted value to each factor related to the site. This indicates which bits of information are more important than others in evaluating the proposed site. An example of range of factors that may be considered and their possible rating for a site is in Table 8.

Evaluation of the Environmental Impact of Landfilling

Suggested procedure for evaluating environmental impact is to compile a checklist or reminder of all proposed actions and of all possible impacts on the environment that may relate to those actions. The actions which are likely to be involved in a solid waste disposal project are listed in the left column of Table 9, and the characteristics of the environment which may be affected by the project are listed in the right column. The table is by no means a complete list or universal rule. It is merely intended to show the possible range of actions and impacts.

People who are faced with the evaluation and preparation of environmental impact statements may use the table as a guide for compiling their own lists of actions and impacts. After compiling a list of proposed actions, each action should be taken individually and checked against all environmental characteristics in terms of possible impact. The evaluation should include not only the site proper but also the surrounding area and facilities in a larger area if relevant. This relatively simple procedure serves as a reminder of the variety of interactions that might be involved in the project and it also reveals the most significant impacts which might influence the future of the project at the very beginning. However, such a list alone cannot replace a full environmental impact report written in compliance with DNR regulations.

SUMMARY AND RECOMMENDATIONS

Generally, the physical environment of south central Wisconsin offers good natural protection against undesirable effects of landfilling. Landfills can be constructed in almost any of the hydrogeologic environments in south central Wisconsin, provided that a suitable design is used for each particular environment. Where the natural conditions are inadequate for protection, engineering techniques must be used as an alternative.

There is a possibility that each community would find a suitable site for disposal of its wastes with sufficient capacity for natural renovation. However, these places are unevenly distributed and will require, in most cases, preliminary evaluation of designated areas, or in some cases investigation of physical conditions. Potential sites are not so plentiful in the Driftless Area and they are also limited in size. However, the demand for sites there is much less because of low population.

Existing sites generally seem to meet state standards. DNR inspection is very effective in enforcing these standards. However, additional subsurface information may be necessary to document ground water conditions around the landfill sites.

In this study, field inspection was intentionally concentrated on sites having the locations rated as questionable in the preliminary selection. Therefore, the overall picture is somewhat distorted in favor of less suitable places. This is reflected in the rating of selected sites. From the 17 selected sites, only one can be rated as good, seven sites were found acceptable, two acceptable with limitations and seven sites were found poorly located.

The use of abandoned sand and gravel pits or quarries for sanitary landfills requires special attention. Most sand and gravel pits and dolomite or limestone quarries make poor landfill sites because these materials are usually good aquifers. The materials have high permeabilities, allow relatively unrestricted movement of leachates from the sites and are much less efficient in attenuating dissolved solids. Large-scale gravel pits or quarries with deep excavations are especially poor sites. The bottom of the excavation is usually very close to the water table and the site offers little natural protection. The use of such sites (such as nos. 23, 38 and 43) should be approved for all types of wastes only if detailed hydrogeologic investigations prove their safety. Otherwise, they may be used for disposal of inert solid waste only. Good sites can be found in gravel pits containing a high percentage of clay, in highway borrow pits with mixed material or in clay pits. Disposal on ground may be also acceptable in shallow sand pits where the mining operations were limited only to removing the material from the hilly part and no excavations were involved (such as site no. 34).

Protection of water resources against undesirable effects of landfilling can be improved by the more stringent requirements for submitting proper material before approval of a site; by including the description of ground water conditions in DNR Inspection Reports; by requesting hydrogeologic investigation where necessary (making such investigation obligatory for disposal sites in sand and gravel pits); and by requiring ground water monitoring where needed.

Wisconsin was one of the first states to require information on physical factors of a site by the law. The State Solid Waste Disposal Standards NR 51.10 (adopted in 1969) required, among other things, a report on geological formations and ground water elevations to a depth at least 10 ft below proposed excavation and lowest elevation of the site. This depth was later increased in revised standards NR 151.12 (effective July 1, 1973) to 15 ft. Although the requirements of the revised standards are much more extensive than those of the 1969 standards, it may be necessary to modify them slightly in the future in order to control the increasing pressure of competing land uses on the quality of the environment.

It is recommended in a future revision of standards more specific data be required. The total set of information on physical factors should include as minimum:

—map or aerial photograph;
—plot plan of the site;
—a separate report indicating:

(1) results of soil borings,
(2) soil properties,
(3) character of subsoils,
(4) description of unconsolidated sediments to a depth of at least 25 feet below the lowest elevation of the excavation, or to bedrock, whichever occurs first,
(5) description of bedrock formations, if applicable, to a depth of at least 25 feet below the lowest elevation of the excavation,
(6) determination of ground water elevations to a depth of at least 25 feet below the proposed lowest excavation of the site,
(7) description of all features indicating occurrence of high water table (such as seasonal ponding, marshes, intermittent streams, seepage, springs) or possibility of flooding.
(8) information on ground water quality obtained from several soil borings constructed as observation wells.

Most of the information can be obtained by subsurface investigations. Municipalities, or private proprietors, can avoid the unnecessary cost of investigations of unacceptable sites by simple preliminary evaluation of a prospective site. This evaluation, described in the section on Selection of a Landfill Site, will either establish tentative acceptability or indicate an obviously unsuitable site. Only after the tentative acceptability is established will subsurface investigations be arranged.

It is further recommended that the DNR continue to support and enhance the idea of areawide and countywide solid waste disposal. Most of the communities are not aware of the economic benefits of this approach. Economic advantages of cooperative management of solid waste have been discussed, using the case of Sauk County, in a University of Wisconsin Extension report (Porter et al. 1972). This publication is also useful in that it describes solid waste management in planning terms and indicates the steps in an investigation of county option for people with little planning experience.

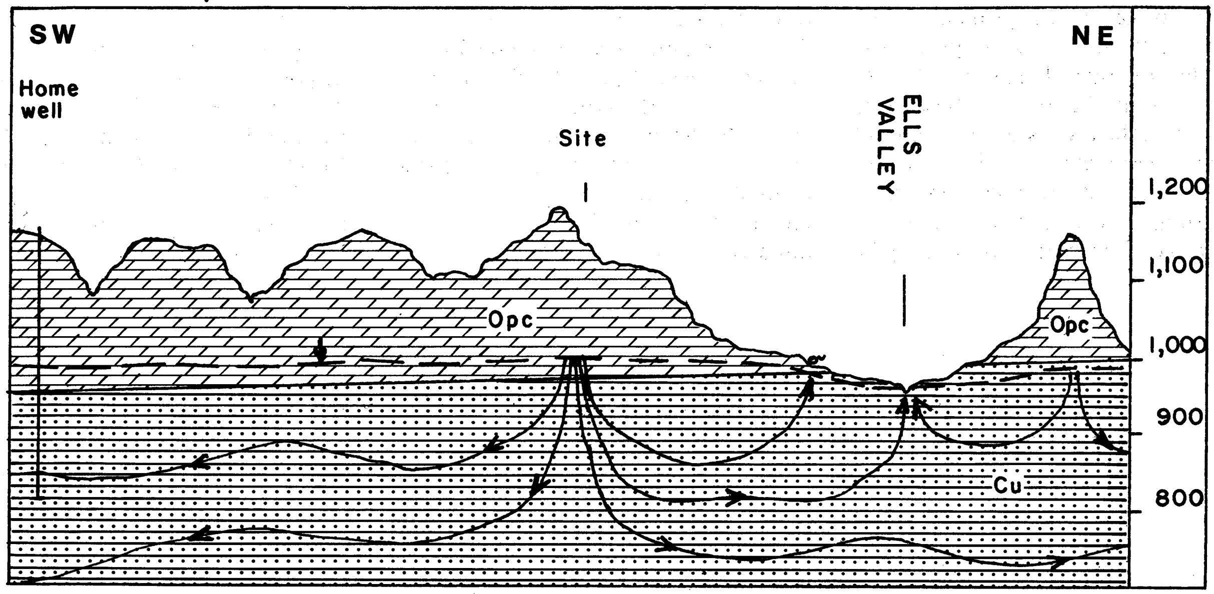
There is a growing recognition of the necessity to plan and manage solid wastes on area or county basis. Sauk, Green and Dane Counties are currently considering such an approach. Special attention should be given to problem areas.

Furthermore, DNR should initiate and encourage research and demonstration projects on ground water problems related to landfill operations, especially of their long-term effects. Very little is known in Wisconsin about the effect of sanitary landfills on the environment, and on water quality in particular. There are only few studies dealing with potential ground water pollution from landfills in Wisconsin. The best documented one is the study of two sites in the City of Madison (Kaufman 1970). The degree of concern that should be given to the potential danger of ground water pollution is unknown. This could be estimated on the basis of out-state studies (such as Hughes et al. 1971) which, of course, cannot be directly applied to the state's problems. Also the studies were conducted for a relatively short period of time and they may be therefore inadequate to establish the magnitude of the problem. The real effect can be documented only by a long-term experimental study. Should such a study be initiated, it would be the first of its kind in solid waste disposal research in the United States. The City of Madison has several sites suitable for such a study.

We have to live with the fact that the volume of solid waste will increase in the near future regardless of what action will be taken for its reduction. Land will be required for solid waste disposal because sanitary landfilling is likely to be the major method of disposal in the near future and the ultimate method for disposal of the remains from other methods in years to come. And for that, adequate planning is necessary, based on sound knowledge of the physical environment.

APPENDIX: DESCRIPTION OF SELECTED SITES

CATEGORY I, GROUP Ia



Topography: dissected upland
Drainage basin: principal–Wisconsin R., major–Baraboo R., local–Hill Point Creek
Soils: silty;very thin cover (less than 5 ft)
Surface geology: clayey residuum from shales and carbonate rocks (about 20 ft)
Bedrock geology: Ordovician Prairie du Chien dolomite
Ground water: major aquifer–Cambrian sandstones
water table–deep, 120-150 ft
position in flow–recharge area

Pollution potential: ground water–low to high depending on character of surficial deposits;
surface water–moderate (surface runoff)
Location requirements: does not comply–surface runoff; slopes
Rating: site acceptable with limitations
Recommendations: prevent surface runoff; soil borings; disposal on ground permissible if soil borings prove the existence of protective soil cover

Legend to the Cross Sections

Geologic formations

- glacial deposits (undiff.) (Quarternary System)
- S — Niagara Dolomite (Silurian System)
- Om — Maquoketa Shale (Ordovician System
- Opg — Platteville-Galena Dolomite (Ordovician System)
- Osp — St. Peter Sandstone (Ordovician System)
- Opc — Prairie du Chien Dolomite (Ordovician System)
- Cu — Cambrian sandstones (undiff.) (Cambrian System)
- PC — Precambrian rocks (undifferentiated)

Other symbols

- water table
- generalized ground water flow
- fault line
- spring

All cross sections of landfill sites are exaggerated approximately 10 times.

Scale

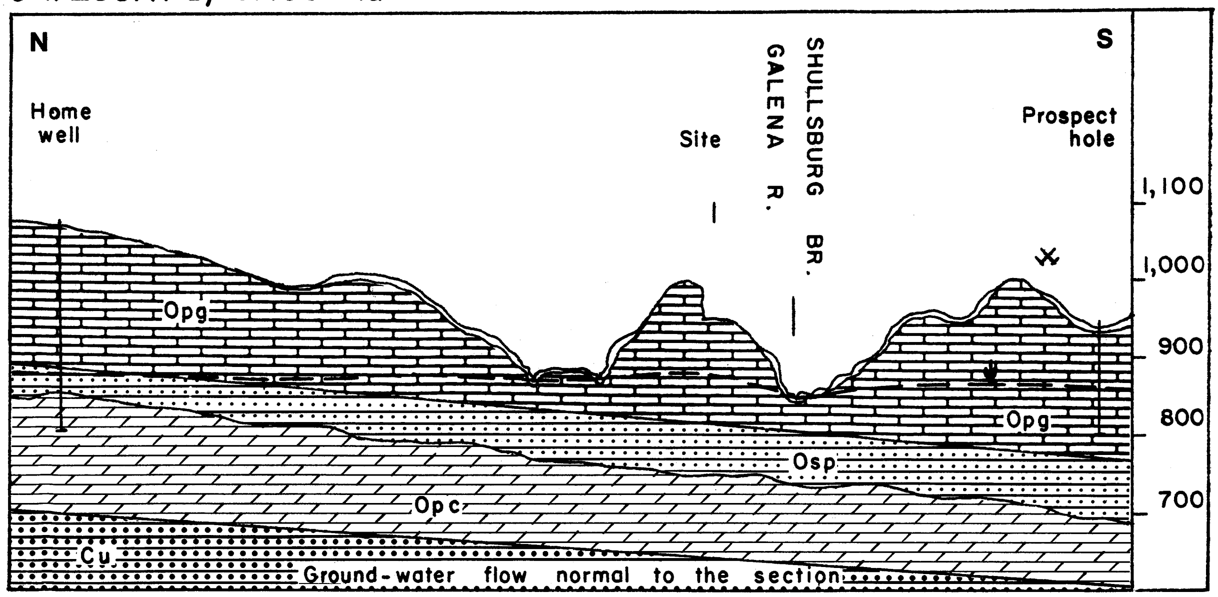
Horizontal
1 inch: 2,600 ft

Vertical
1 inch: 250 ft

0 2,000 4,000 ft
0 ½ 1 mile

1000
900
800
700
600
in feet above mean sea level

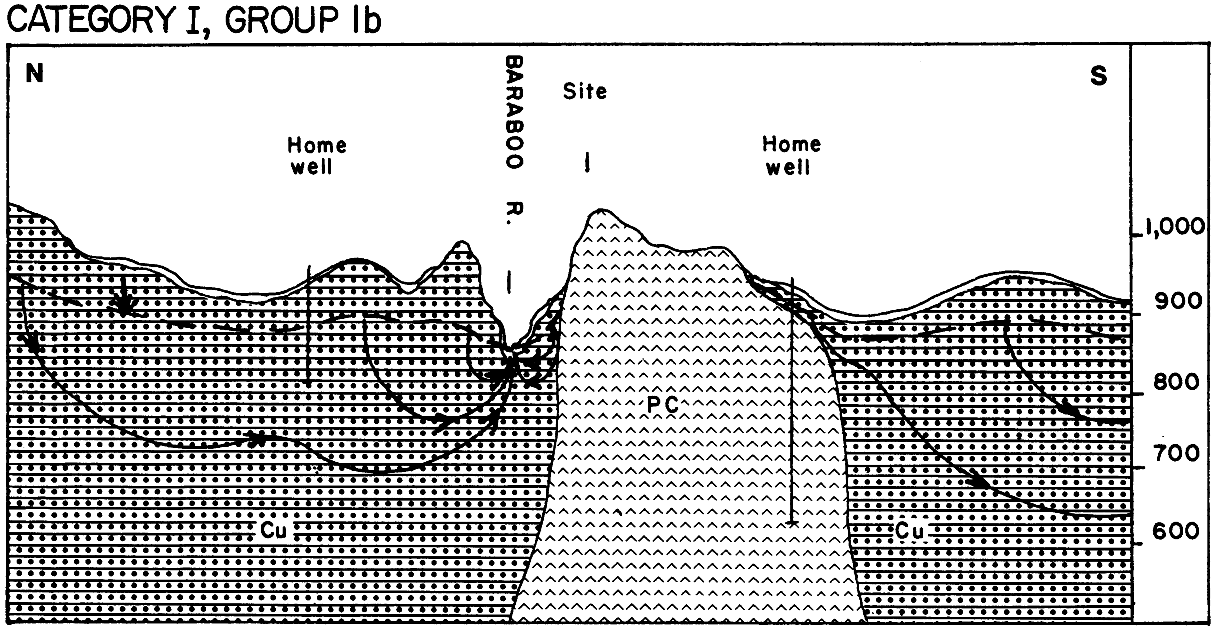
CATEGORY I, GROUP Ia



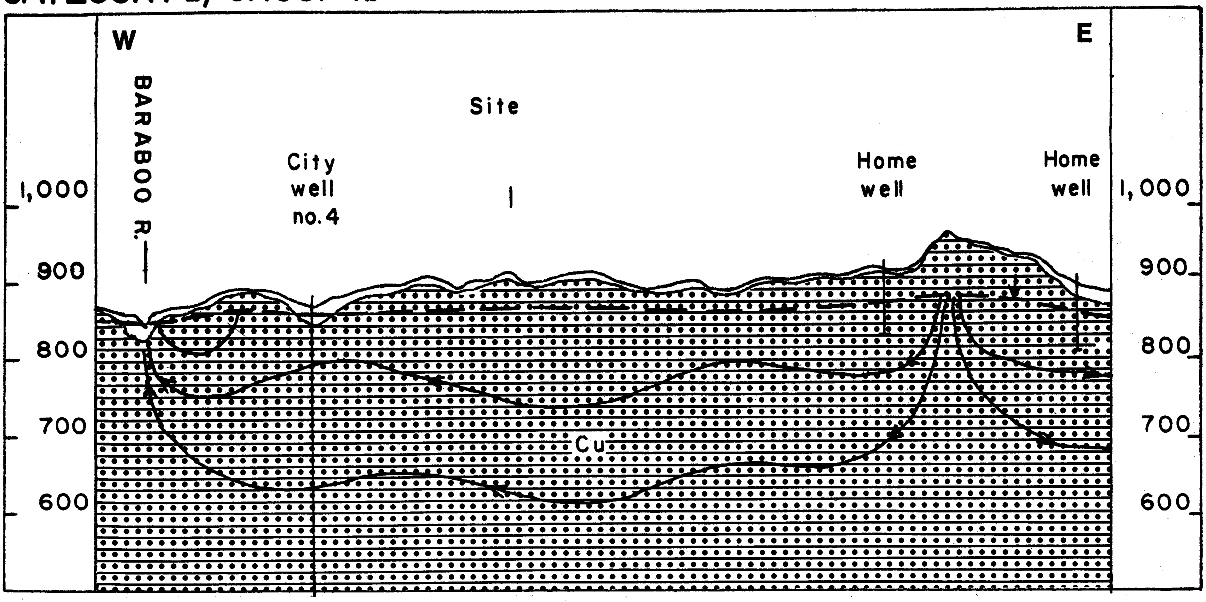
Topography: dissected relief, upland slope
Drainage basin: principal–Wisconsin R., local–Shullsburg Branch Galena. River.
Soils: thin cover (1-2 ft) removed; old quarry
Surface geology: residual deposits up to 10 ft (removed)
Bedrock geology: Galena–Platteville dolomite, Ordovician
Ground water: major aquifer–Cambrian– Ordovician complex
water table–deep, 150-200 ft
position in flow–local recharge area
Pollution potential: ground water–high
surface water–moderate to high
Location requirements: does not comply–steep slope, surface runoff
Rating: poor site
Recommendation: relocate

Topography: dissected relief, upland slope
Drainage basin: principal–Wisconsin R., local–Baraboo R.
Soils: thin cover (1-2 ft), clayey
Surface geology: no deposits
Bedrock geology: slope of Baraboo quartzite range, Precambrian; Cambrian sandstones.
Ground water: major aquifer–Cambrian sandstones
water table–deep, 200 ft.
position in flow–local recharge area
Pollution potential: ground water–high
surface water–low
Location requirements: does not comply–steep slope, surface runoff
Rating: poor site
Recommendations: relocate

CATEGORY I, GROUP Ib



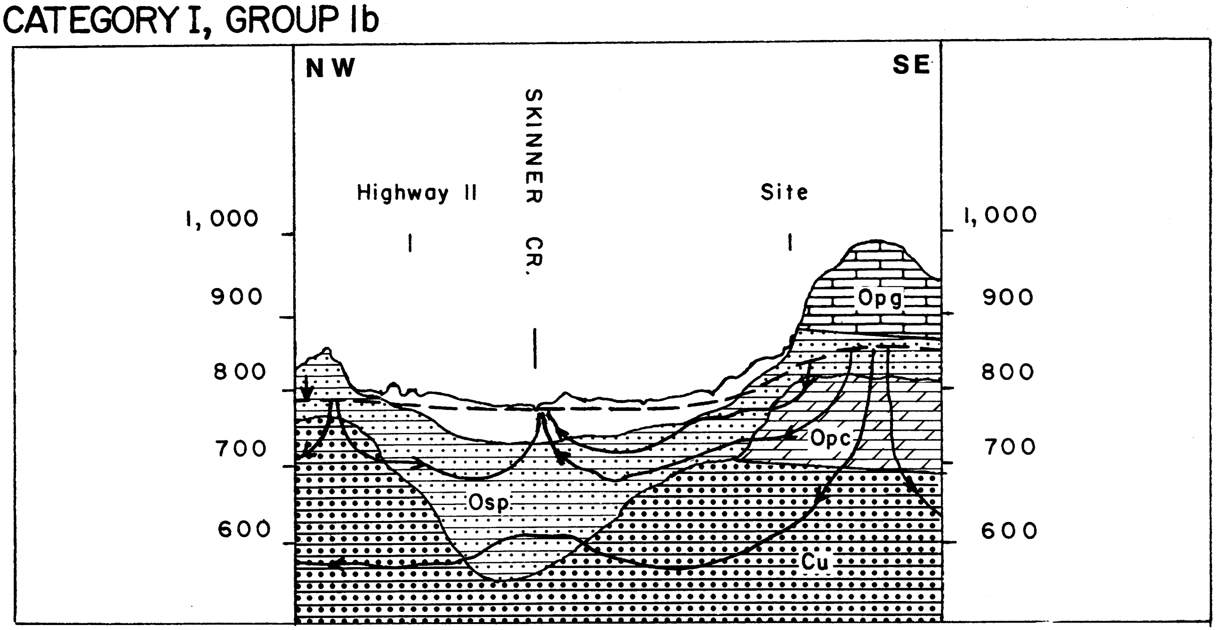
CATEGORY I, GROUP Ib



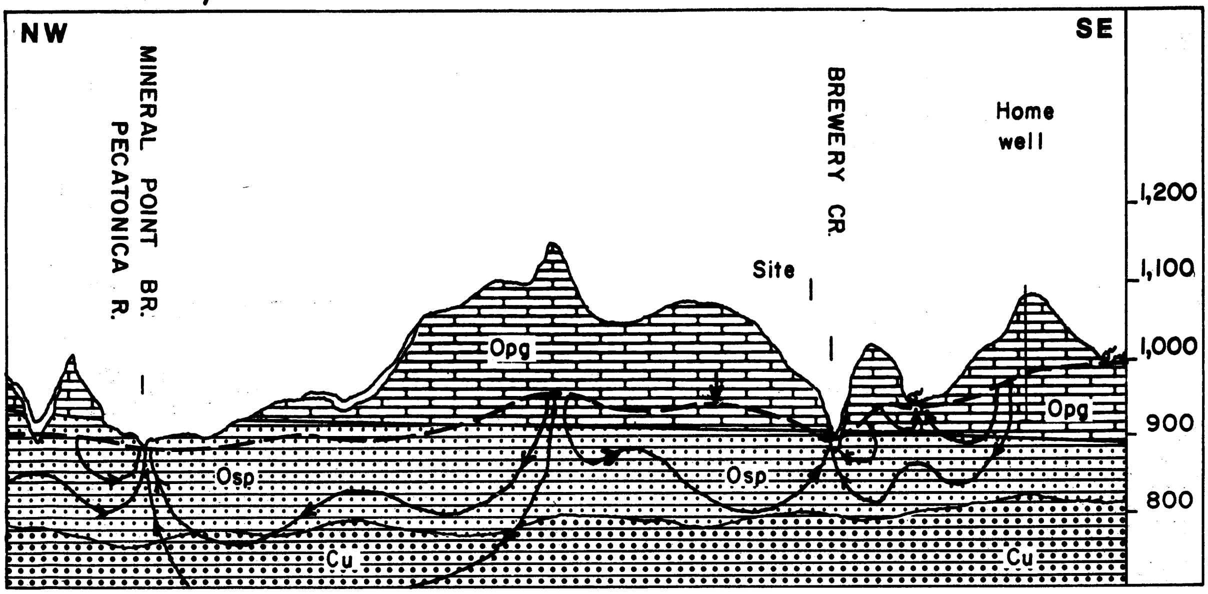
Topography: gently rolling upland
Drainage basin: principal–Wisconsin R., local–Baraboo R.
Soils: loamy and silty
Surface geology: sandy residuum 5-15 ft
Bedrock geology: Elk Mound sandstones, Cambrian
Ground water: major aquifer–Mt. Simon sandstone
water table–10-15 ft
position in flow – local recharge area, regional and lateral flow
Pollution potential: ground water–moderate (depending on character of sandstones)
surface water–low
Location requirements: in compliance
Rating: acceptable site
Recommendation: disposal on ground; do not remove protective soil cover

Topography: hillslope above flat alluvial plain
Drainage basin: principal–Rock R., major–Pecatonica R., local–Skinner Creek
Soils: thin cover over carbonate rocks; silty-sandy
Surface geology: no deposits on the hillslope, sandy drift (5-40 ft) on the plain
Bedrock geology: contact between Galena–Platteville dolomite and St. Peter sandstone, Ordovician
Ground water: major aquifer–Cambrian sandstones
water table–40-70 ft
position in flow–local and regional recharge area
Pollution potential: ground water–high
surface water–low
Location requirements: in compliance
Rating: acceptable site (if in sufficient distance to water wells)
Recommendation: periodical checking of water quality in wells NW of the site

CATEGORY I, GROUP Ib



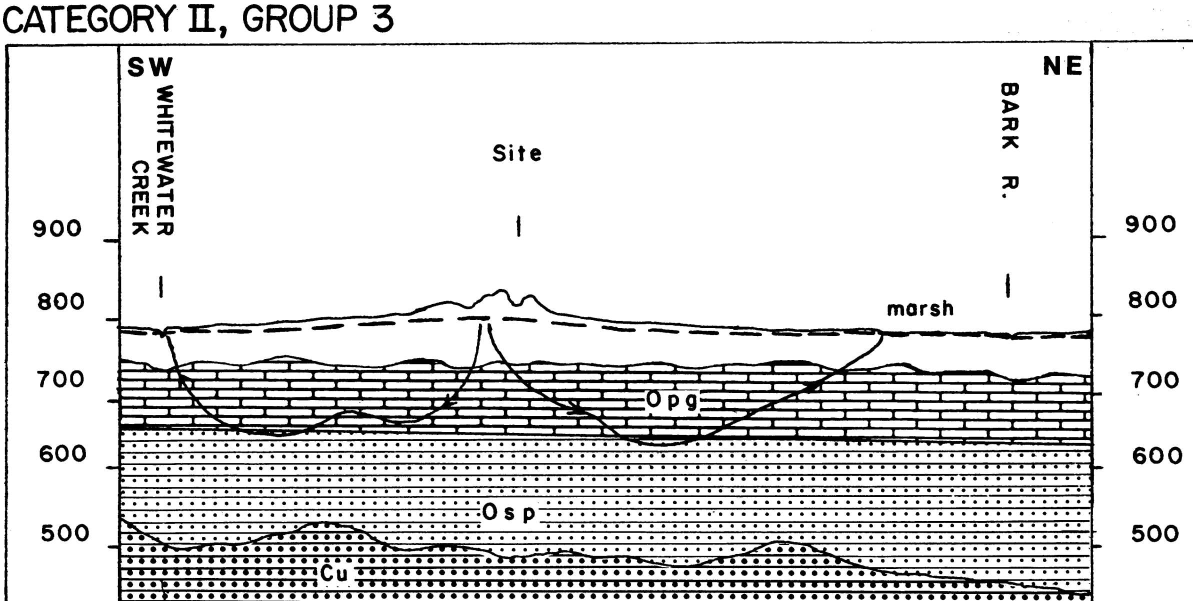
CATEGORY I, GROUP 2



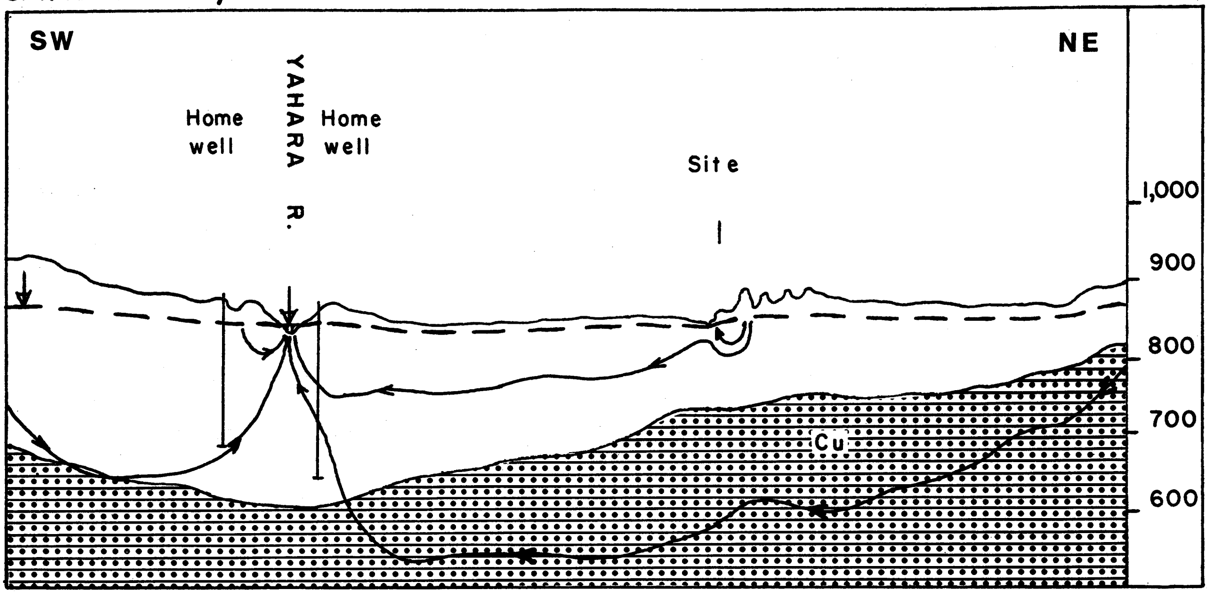
Topography: dissected upland; edge above the deep valley
Drainage basin: principal–Rock R., major–Pecatonica R., local–Brewery Creek
Soils: silty (very thin cover)
Surface geology: thin clayey residuum
Bedrock geology: edge of Ordovician Galena–Platteville dolomite over Osp
Ground water: major aquifer–St. Peter sandstone
water table–deep, over 50 ft
position in flow–local discharge area
Pollution potential: ground water–low to high, but limited; surface water–high
Location requirements: no protection against surface runoff
Rating: poor site

Topography: gently rolling; gravel pit on small hill
Drainage basin: major–Rock R., local–Bark R. and Whitewater Cr.
Soils: removed by gravel pit operation
Surface geology: sand and gravel pockets in glacial till (80 ft)
Bedrock geology: Ordovician Galena–Platteville dolomite
Ground water: major aquifer–Ogp dolomite
water table–moderate, approx. 25 ft
position in flow–local recharge area
Pollution potential: ground water–moderate to low
surface water–low
Location requirements: in compliance
Rating: acceptable site
Recommendations: disposal on ground, not in trench

CATEGORY II, GROUP 3



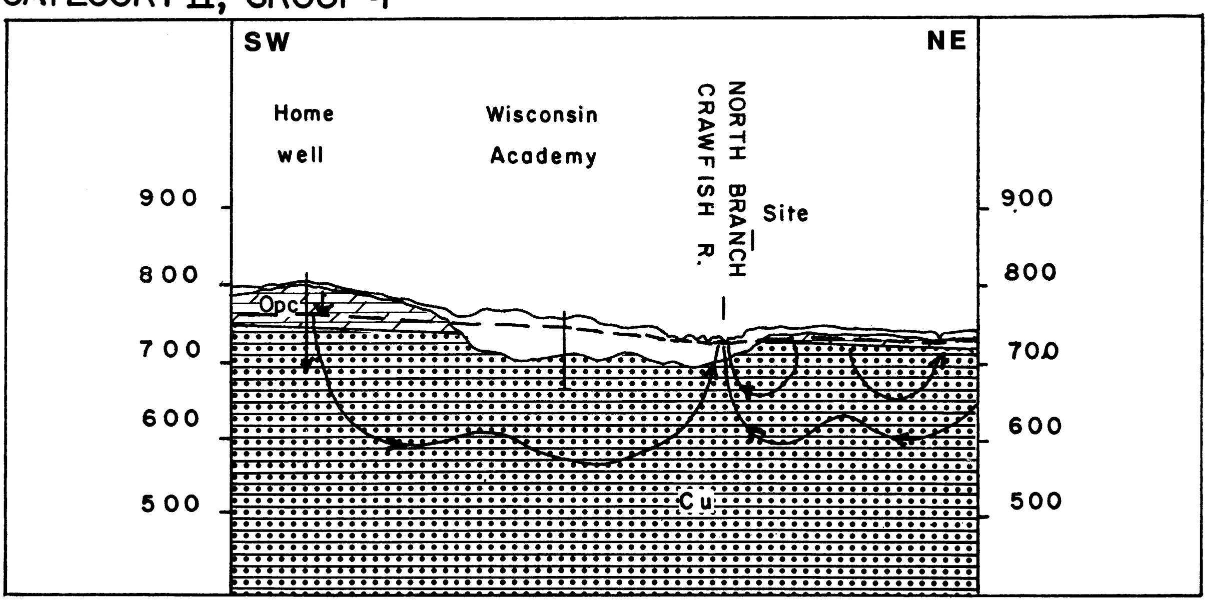
CATEGORY II, GROUP 4



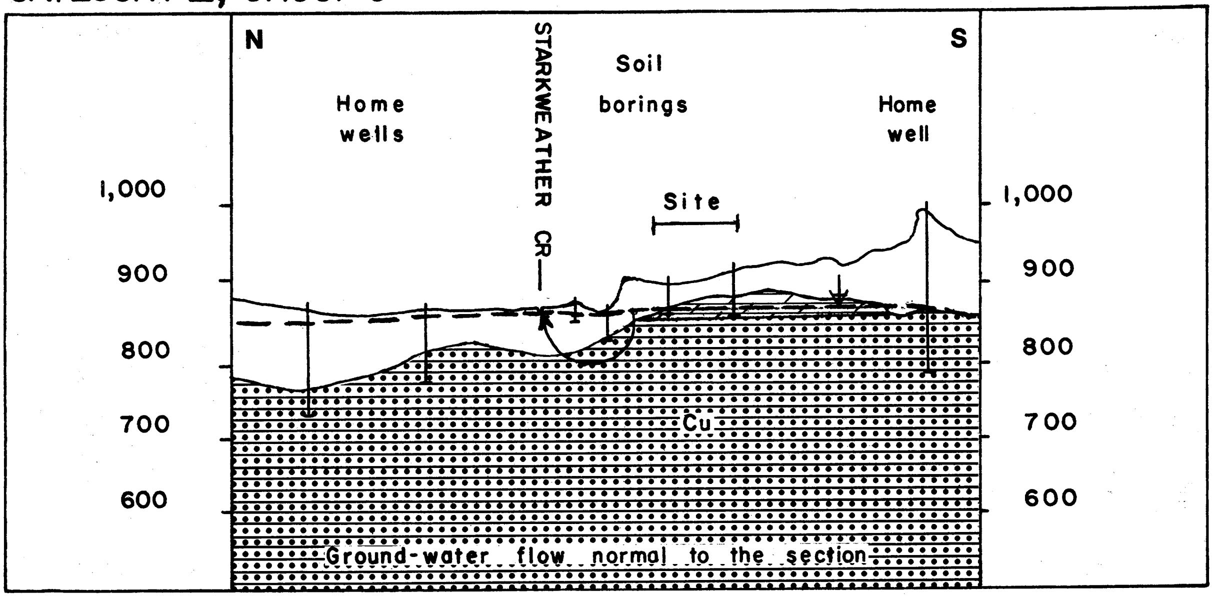
Topography: end of the flat adjacent to the valley
Drainage basin: principal–Rock R., major–Yahara R.
Soils: silty loam soils of low permeability
Surface geology: thick glacial till (over 100 ft)
Bedrock geology: Cambrian sandstones
Ground water: major aquifer–Cambrian sandstones
water table–3-5 ft
position in flow–local discharge zone; regional lateral flow
Pollution potential: ground water–moderate to high
surface water–low to high
Location requirements: too close to wetland
Rating: acceptable if the base of the fill does not intersect water table
Recommendations: only disposal on ground; farther from wetland

Topography: edge of the flat above valley floor
Drainage basin: principal–Rock R., major–Crawfish R., local–North Branch Crawfish R.
Soils: silty loam soils
Surface geology: thin glacial till, 15-30 ft
Bedrock geology: Cambrian sandstone with thin overlay of Ordovician dolomite
position in flow–discharge area
Ground water: major aquifer–Cambrian sandstone
water table–10 ft
position in flow–discharge area
Pollution potential: ground water–moderate
surface water–moderate
Location requirements: in compliance
Rating: acceptable site for ground disposal
Recommendations: no trenches

CATEGORY II, GROUP 4



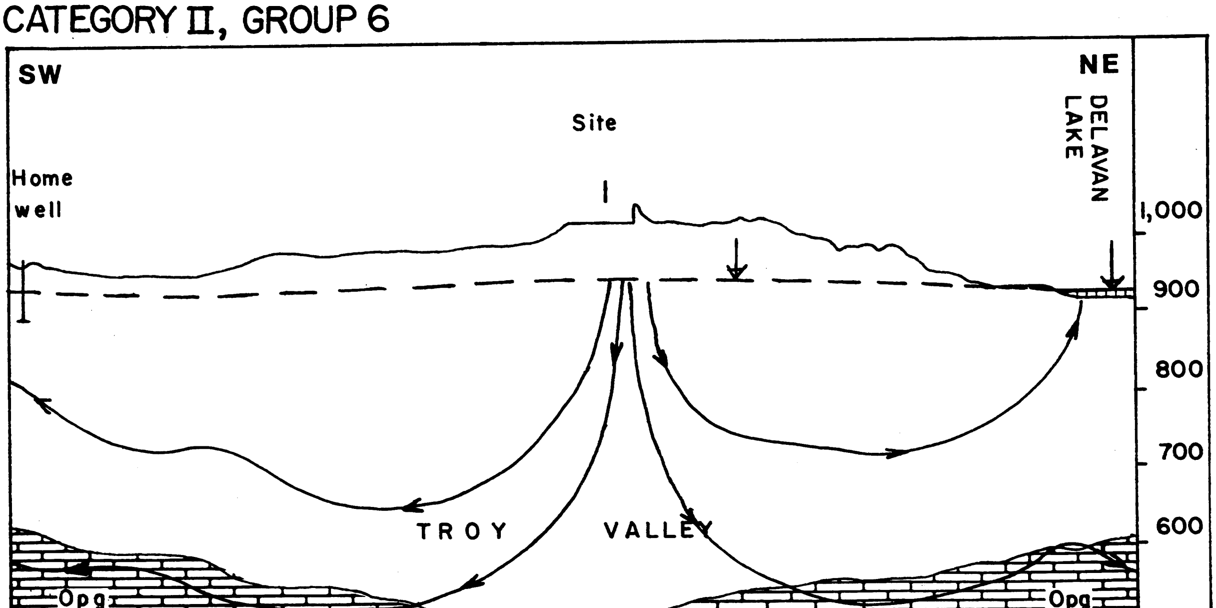
CATEGORY II, GROUP 5



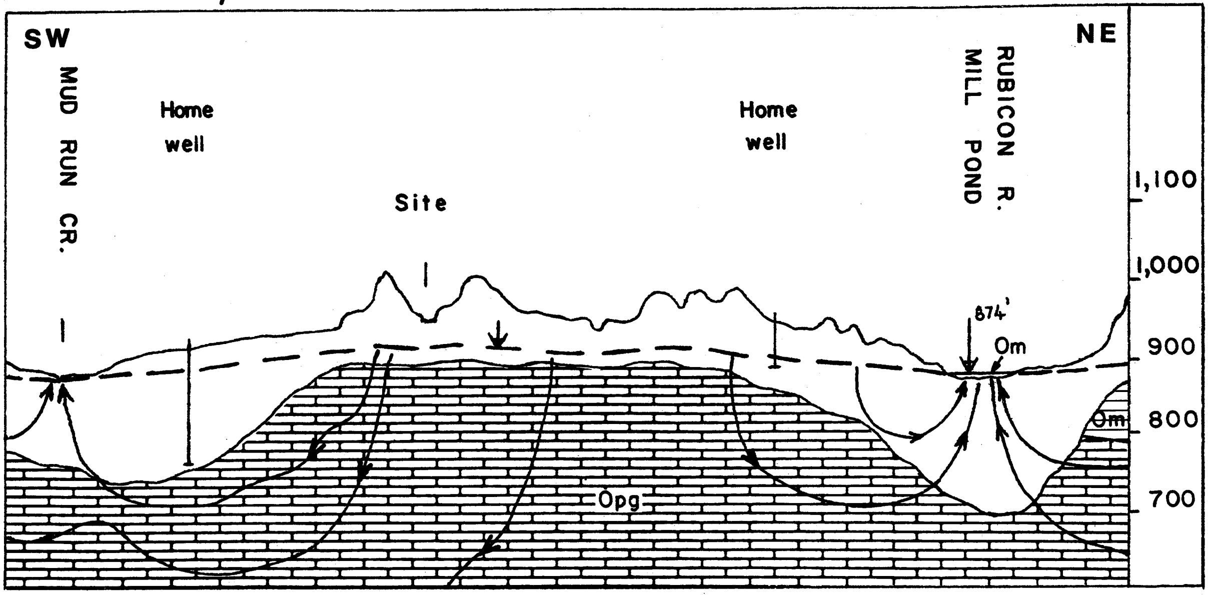
Topography: gently rolling upland
Drainage basin: principal–Rock R., major–Yahara R., local–Starkweather Creek
Soils: silty loam
Surface geology: till of ground moraine (35 ft)
Bedrock geology: Cambrian sandstone and Ordovician dolomite
Ground water: major aquifer–Cambrian sandstones
water table–50 ft
position in flow–lateral part of the flow
Pollution potential: ground water–low to moderate
surface water–low
Location requirements: in compliance
Rating: good site

Topography: gently rolling upland
Drainage basin: principal–Rock R., local–Turtle Cr. (Delavan Lake)
Soils: removed, gravel pit
Surface geology: thick outwash (over 400 ft) in Troy Valley covered by ground moraine till deposits
Bedrock geology: Ordovician carbonate rocks
Ground water: major aquifer–glacial drift
water table–80 ft
position in flow–recharge zone
Pollution potential: ground water–moderate
surface water–low
Location requirements: in compliance
Rating: acceptable site

CATEGORY II, GROUP 6



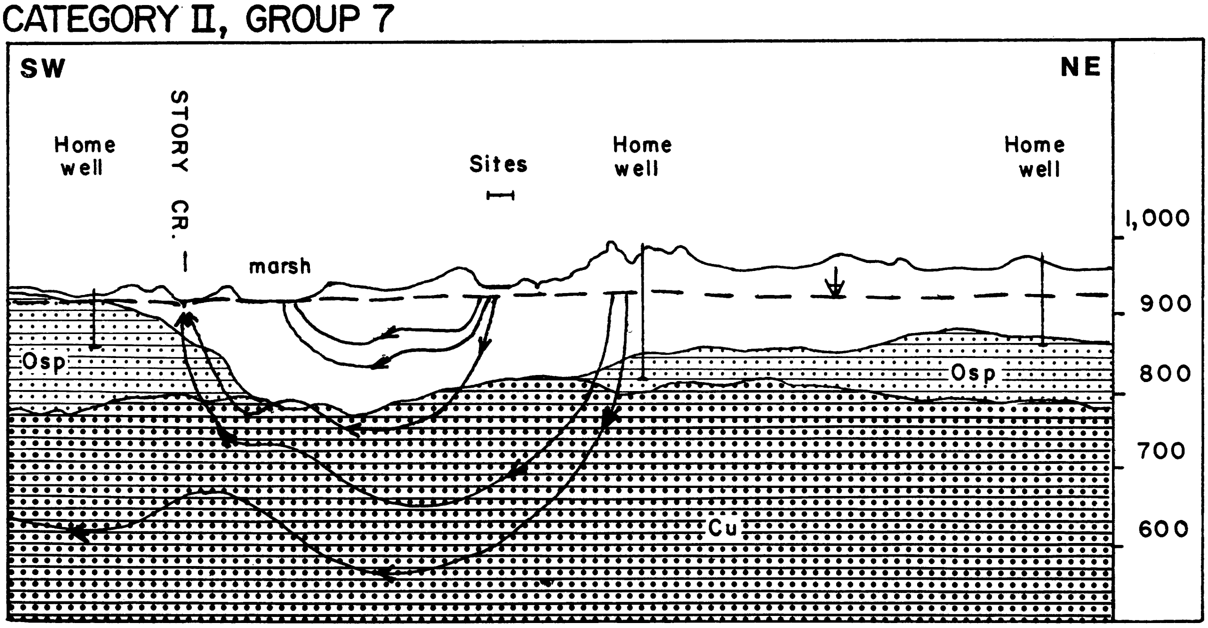
CATEGORY II, GROUP 6



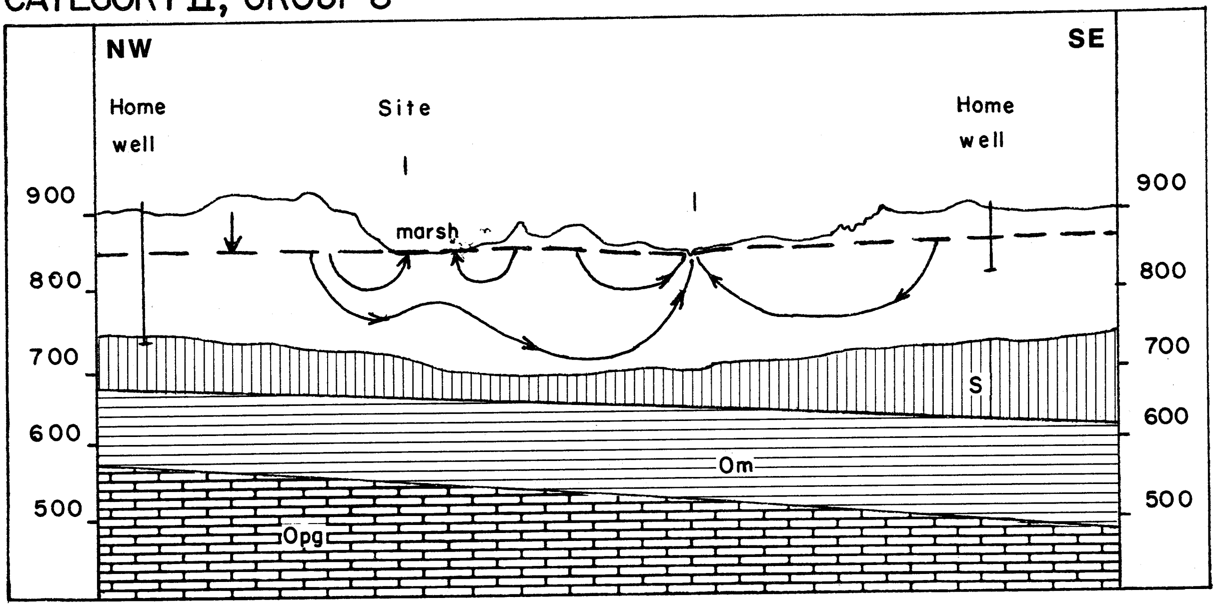
Topography: rolling upland
Drainage basin: major–Rock R., local–Rubicon R. and Mud Run Creek
Soils: removed, gravel pit
Surface geology: sandy till and outwash sand (50 ft)
Bedrock geology: Ordovician Galena–Platteville dolomite
Ground water: major aquifer–Ogp dolomite
water table–deep, 30-50 ft
position in flow–local and regional recharge area
Pollution potential: ground water–moderate to high
surface water–low
Location requirements: in compliance
Rating: acceptable with limitations
Recommendations: determine depth to bedrock and to water table below the site, character of unconsolidated sediments and bedrock
Note: Site operation may be approved if the thickness will be sufficient and unconsolidated sediments will have moderate permeability

Topography: rolling upland
Drainage basin: principal–Rock R., major–Sugar R., local–Story Creek
Soils: removed , gravel pit
Surface geology: sand and gravel layers in glacial deposits approx. 120 ft thick
Bedrock geology: Cambrian and Ordovician sandstones
Ground water: major aquifer–glacial deposits; Cambrian sandstones
water table–less than 10 ft
position in flow – local recharge zone, regional lateral flow
Pollution potential: ground water–high
surface water–low
Location requirements: in compliance
Rating: poor site
Recommendations: detailed investigation

CATEGORY II, GROUP 7



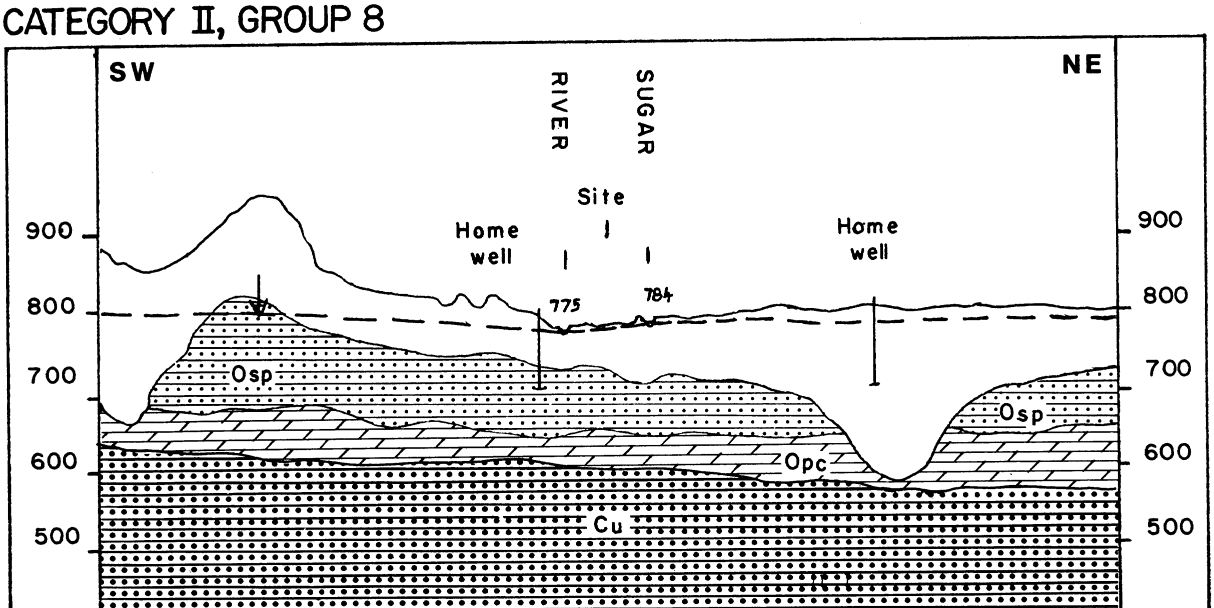
CATEGORY II, GROUP 8



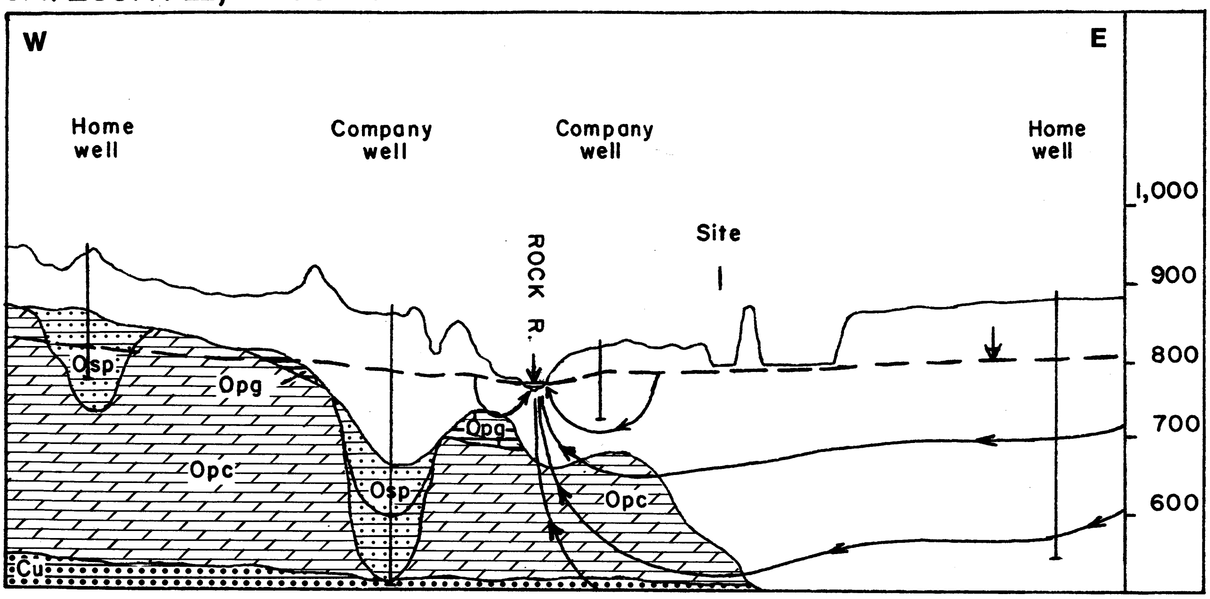
Topography: marshy lowland
Drainage basin: principal–Fox (Illinois) R., local–White R.
Soils: silty loam
Surface geology: thick glacial drift–150 ft; edge of outwash sand plain
Bedrock geology: Silurian–Niagara dolomite
Ground water: major aquifer–glacial deposits
water table–0-3 ft
position in flow–discharge zone
Pollution potential: ground water–high, but limited
surface water–high
Location requirements: located in marshy area connected with the stream
Rating: poor site
Recommendations: relocate to upland

Topography: river valley flat; subject to flooding
Drainage basin: principal–Rock R., local–Sugar R.
Soils: silty alluvial soils
Surface geology: alluvial fill; outwash deposits (about 100 ft)
Bedrock geology: Ordovician sandstone and dolomite
Ground water: major aquifer–glacial outwash and St. Peter sandstone
water table–5-10 ft or less
position in flow–*
Pollution potential: ground water–character will depend on ground water flow
surface water–high
Location requirements: very close to the river; on the island
Rating: poor site
Recommendations: relocate
Note: *Ground water flow system complicated due to different levels of the river; could not be determined without detailed investigation.

CATEGORY II, GROUP 8



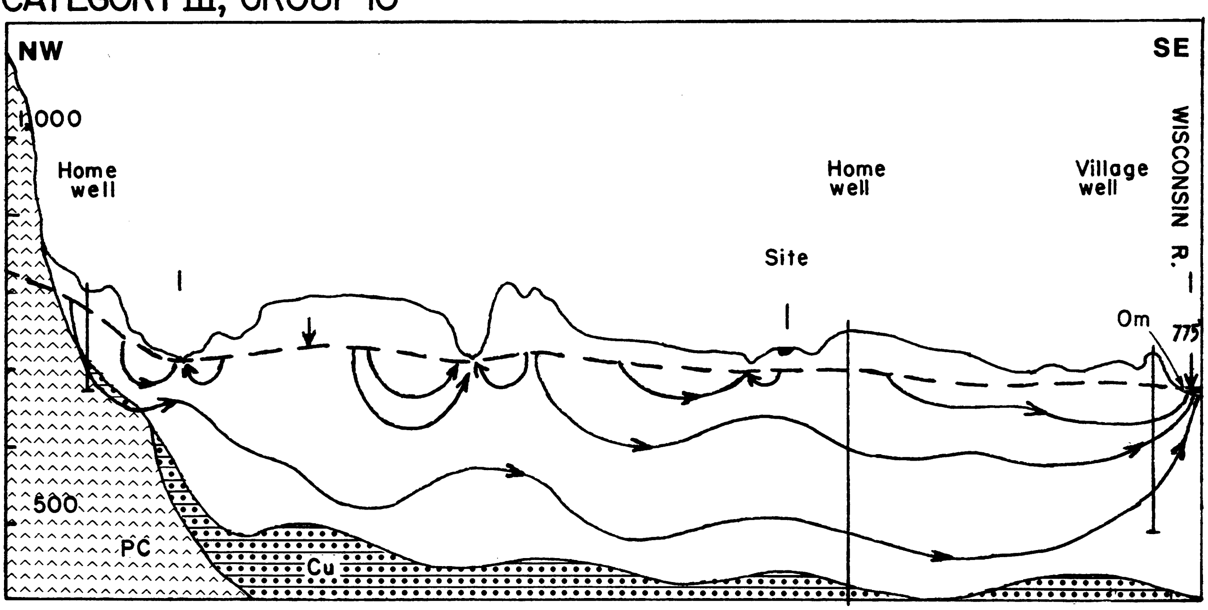
CATEGORY III, GROUP 9



Topography: gently sloping
Drainage basin: principal–Rock River
Soils: removed gravel pit
Surface geology: sand and gravel of outwash deposits (250 ft)
Bedrock geology: Ordovician dolomite; Cambrian sandstone
Ground water: major aquifer–outwash sand and gravel
water table–about 5 ft below the base of the pit
position in flow–transient zone between the lateral part of the flow and regional discharge area
Pollution potential: ground water–high
surface water–moderate
Location requirements: deep gravel pit unfavorable for disposal
Rating: poor site
Recommendations: detailed investigation; engineering modifications

Topography: flat plain in broad Wisconsin River valley
Drainage basin: principal–Wisconsin R., local–lower Wisconsin R.
Soils: sandy
Surface geology: thick alluvial deposits and glacial outwash (over 300 ft)
Bedrock geology: Cambrian sandstone
Ground water: major aquifer–glacial outwash
water table–30 ft
position in flow–lateral part of the flow
Pollution potential: ground water–moderate*
surface water–low
Location requirements: in compliance
Rating: acceptable site
Note: *requires longer distance to water supply sources

CATEGORY III, GROUP 10



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ACKNOWLEDGEMENTS

This report was prepared under a cooperative research agreement between the Wisconsin Department of Natural Resources (DNR) and the University of Wisconsin-Madison, and was supported by the Interagency Water Resources Research and Data Collection Program. Of much help were the results of previous studies and data which the author collected for a research project supported by the Environmental Protection Agency Research Fellowship, Grant 5-F1-WP-26, 495-02.

The author is grateful to Mr. E. D. Cann, Research Coordinator, DNR, for assistance given during the project; to Mr. T. A. Calabresa, of the same agency, for approval to use well drillers' reports; to the Wisconsin Geological and Natural History Survey for the use of material on file; to Mr. J. E. Kerrigan, Assistant Director, Water Resources Center, for suggestions in the initial phase of the study; to the staff of the Solid Waste Disposal Section of DNR for providing technical information on licensed sites; and to Messrs. J. J. Reinhardt, Chief of that Section, and D. A. Stephenson, Associate Professor of Geology, University of Wisconsin, for critical review of the manuscript.

Edited by Ruth L. Hine

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