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ABSTRACT

COMPUTER-LINKED TERRANE ANALYSIS FOR LANDFILL WASTE-DISPOSAL SITE SELECTION

By

Christine M. Iversen

Recent demands for landfill site locations in central Michigan have emphasized the need for a rapid, unbiased method of identifying suitable disposal tracts. One of the Michigan counties involved in the search for landfill sites is Clinton County, which has funded several studies to locate suitable areas. Methods for selection of landfill sites have involved a search for available land, followed by on-site evaluation to determine the geologic suitability for waste disposal. To a lesser extent sites have been selected through regional reconnaissance followed by on-site evaluation.

The technique used in this study is advantageous because it aids in initial reconnaissance by finding potential sites that are geologically compatible with the specified land use. The technique of Tilmann et al. (1974) is applied to the selection of landfill sites in Clinton County. The criteria used in site selection include: (1) Natural Drainage, (2) Water Holding Capacity, (3) Infiltration Capacity,

(4) Slope, (5) Depth of Water Table, (6) Forested Areas, (7) Urban Areas, (8) Flood plains, and (9) Water Bodies.

Several weightings of the criteria are evaluated to locate those tracts that appear suitable for landfill use regardless of the relative importances assigned to the respective criteria by the land use planners and to locate areas that are either unacceptable or conditionally acceptable. Field evaluation of selected sites will be used to demonstrate the efficacy of this technique. Comparisons will be made between the sites selected in this study and those proposed in the landfill-location studies funded by Clinton County.

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LANDFILL WASTE-DISPOSAL SITE
SELECTION

By

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DEDICATION

I wish to dedicate this thesis to my husband, Bill whose encouragement and support made the research and writing possible, and who quietly tolerated me and many cold, late dinners while I was busy on this paper.

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INTRODUCTION

This paper illustrates a rapid and flexible method for determining site selection for sanitary landfills based on soils and geologic conditions. This technique, described by Tilmann et al. (1974), is a variation of derivative mapping (McHarg, 1969). The benefit of this technique is that a number of alternative, geologic, site-selection policies (value judgements as to the importances of various geologic variables in determining site selection suitability) can be tested to illustrate the sensitivity of the land to variations in site selection criteria. The method is used to locate suitable landfill sites in Clinton County, Michigan.

Sanitary landfilling is a method of solid-waste disposal whereby refuse is spread into thin layers, compacted into the smallest practical volume and covered each day with a layer of soil, unconsolidated earth material, to prevent scattering. No burning is allowed at a sanitary landfill site (Brunner and Keller, 1972). Most solid waste disposed of in a sanitary landfill degrades chemically and biologically to produce solid, liquid, and gaseous products. The metals are oxidized, organic and inorganic refuse are metabolized by aerobic and anaerobic microorganisms. Food

wastes degrade rapidly, while other materials such as glass, rubber and plastics resist decomposition.

Some of the factors that influence degradation include characteristic physical, chemical, and biological properties of the waste material, along with the availability of oxygen, temperature, microbe population and moisture within the fill. If surface or ground water moves through solid waste it can produce leachate, a solution that contains dissolved and fine-grained, suspended, solid material and microbial waste products (Brunner and Keller, 1972). This leachate can leave the fill either by the surface through the cover material, or as percolate through the rocks and soils of the adjacent and underlying material. Through observance of geologically sound principles and engineering design, the production of leachate and its movement can be minimized so that it will not cause a water pollution problem.

Soils and subsurface material that underly and surround a landfill site can attenuate the contaminants by ion exchange, filtration, absorption, complexing, precipitation and biodegradation (Brunner and Keller, 1972). Contaminants are more attenuated in the unsaturated zone than in the saturated zone, because there is sufficient oxygen for waste oxidation, a large surface area of ion exchange, and a large and diverse population for soil microbes. In the saturated zone, anaerobic conditions usually prevail and

leachate travel is governed mainly by soil permeability and hydraulic gradient. Leachate does not rapidly mix with the ground water, but it closely follows the movement of the ground water.

The distance contaminants travel in ground water depends on soil composition, soil permeability and the type of contaminant. Permeable substrates such as sand and gravel, will allow infiltration of large quantities of liquid into the ground with little attenuation, while sediments of low permeability such as clays, will allow less infiltration with greater attenuation of leachate (Hughes, 1972). Therefore, the type of soil can determine to a great extent what will happen to the leachate when it enters the ground.

More than 90% of the nation's solid waste is directly disposed of on the land, and the majority is disposed of in a very unsatisfactory manner (Brunner and Keller, 1972). Solid waste collected in urban areas of the United States in 1920 amounted to 2.75 lbs./capita/day, in 1970 over 5 lbs/capita/day were collected, and by 1980 a figure of 8 lbs/capita/day is expected (Brunner and Keller, 1972). The 1968 National Solid Waste Survey indicated that only 6% of the land disposal operations and 25% of incinerator facilities were considered adequate to meet today's demands. With the need for improvement of these facilities more land must

be allocated for the disposal of refuse. At the same time, geologically sound principles (Michigan Department of Natural Resources, Geological Survey Division, 1974), must be used for the selection of that land to protect the environment.

PREVIOUS STUDIES

To date, landfill sites in Michigan have been selected mainly by the availability of land, proximity to transportation and only secondarily on geologic data (Commonwealth Association, Inc., 1970; Tri-County Regional Planning Commission, 1971). Only after a specific site is chosen is a geologist consulted to evaluate that particular area. Many studies have been done, e.g., (Hughes, et al., 1971) on the effects of established landfills on the environment and on the engineering techniques that must be used to sustain and modify a site once chosen.

Regional studies to determine sites for landfills have been attempted, but few are based primarily upon the geologic aspects of the land. Again, most are based upon economic, transportation, or zoning considerations (Commonwealth Associates, Inc., 1970; Tri County Regional Planning Commission, 1971). The reason so few regional studies based on geologic data have been attempted are many fold: First, much of the relevant, geologic data needed for regional evaluation is not available, or in a format useable for this type of study; second, methods of processing the many criteria involved in regional studies are lacking; third, the expense of regional studies for one specific purpose

(e. g., landfills) is often prohibitive; and fourth, no single agency is charged with conducting these types of evaluations. The data are derived from geologic surveys, the U.S.D.A., the Soil Conservation Service, health departments, and so forth. This represents a multi-agency effort with no clear cut authority. Thus, many criteria from many different sources must be looked at simultaneously. These criteria (factors) include soil permeability, continuity of clay layers, depth of the water table, and so forth. The process of factor compilation includes tedious assembly of well-log data, months of work and, finally site visitation. This process is especially difficult in complicated glacial terrane where good data can be scarce. Consequently, the results are at best only approximations.

A number of applicable studies have been developed in recent years in the area of land-use. Leopold and his associates (Leopold, 1968, 1969; Leopold et al., 1971) were among the first to develop a system whereby broad areas of land could be evaluated using geologic and geomorphic criteria for specific land-use functions. However, this technique requires site visitation. Thus, the number of possible sites considered is limited because of the time and expense involved in visitation of potential sites.

McHarg (1969) has popularized a technique that has become widespread in the development of land-use planning maps.

This technique, derivative mapping, includes preparation of acetate overlays for particular physical, cultural, or economic factors being studied. The least desirable regions with respect to each factor are shaded in the darkest color and the optimum areas left the lightest. By superimposing all the factor overlays, the darkest portions on the composite map represent the least desirable areas and the lightest, the most desirable. Relative importance of each factor overlay can be fixed by selection of overlay color density. This technique is limited in that only a small number of factors can be manipulated owing to the number of acetate overlays that can effectively be used. Also, alternative weightings can not be evaluated without preparation of new overlays. Since many factors must be considered when studying landfills, this technique has its drawbacks. The technique is rapid, but each initial factor overlay must be worked out on a base map. This involves the initial problem of compiling data for a specific criterion. Updating these maps would be difficult and the final map can only include one set of weighting of the factors.

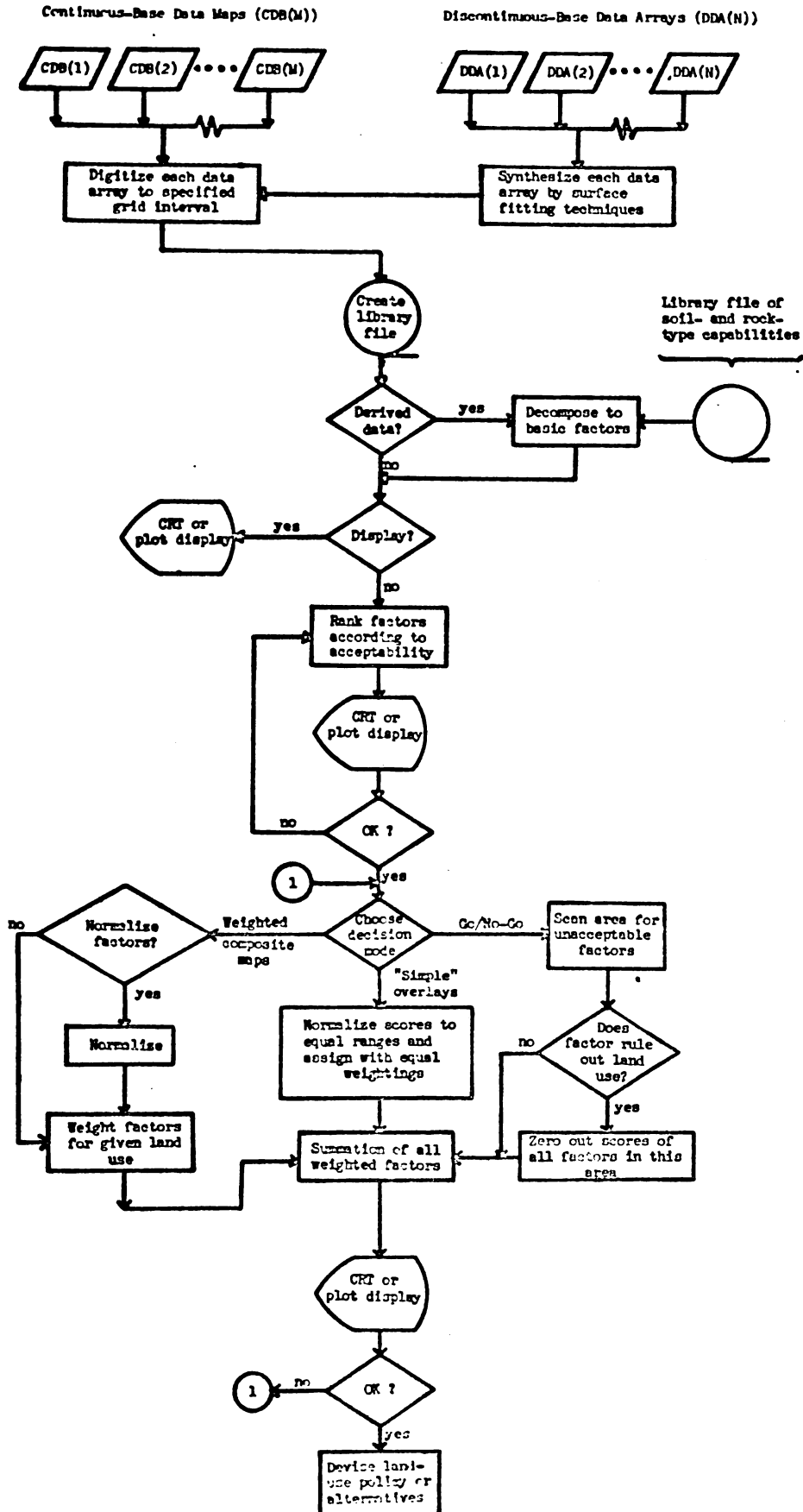
The Alabama Geological Survey (1971), the Bureau of Geology, Florida (1972) and others have conducted regional surveys using modifications of the McHarg technique and evaluated land by its physical characteristics for specific land-use purposes. Landfill sites are included in these

maps. However, alternative evaluations cannot be tested using this method.

The computer-linked terrane analysis method (Figure 1) (Tilman et al., 1974) to be used in this paper improves on the McHarg method. Primarily, it differs in the way the data are assimilated and finally displayed. The method allows rapid manipulation of numerous factors simultaneously, and facilitates the output and display of data in varied and readily useable formats. It can test many alternatives and weightings of factors. Weightings can be changed to identify land for different uses. Thus, by shortening the time involved in identifying potential sites and by obtaining a useable output, this type of study is easily performed and is more readily available to planners, county commissioners and the general public.

Since this technique is flexible, potentially optimum sites can be identified using different weightings. By comparing these different weightings, land can be identified that is likely to be geologically best for landfill sites, regardless of the weightings chosen by the planner. This has never before been done.

Figure 1.--Schematic diagram of the computer-linked terrane analysis method from Tilmann et al. (1974).



LOCATION AND SETTING

Clinton County is located in the south-central portion of Michigan's Lower Peninsula (Figure 2). The county is predominantly flat to gently rolling farm land dotted with several small cities.

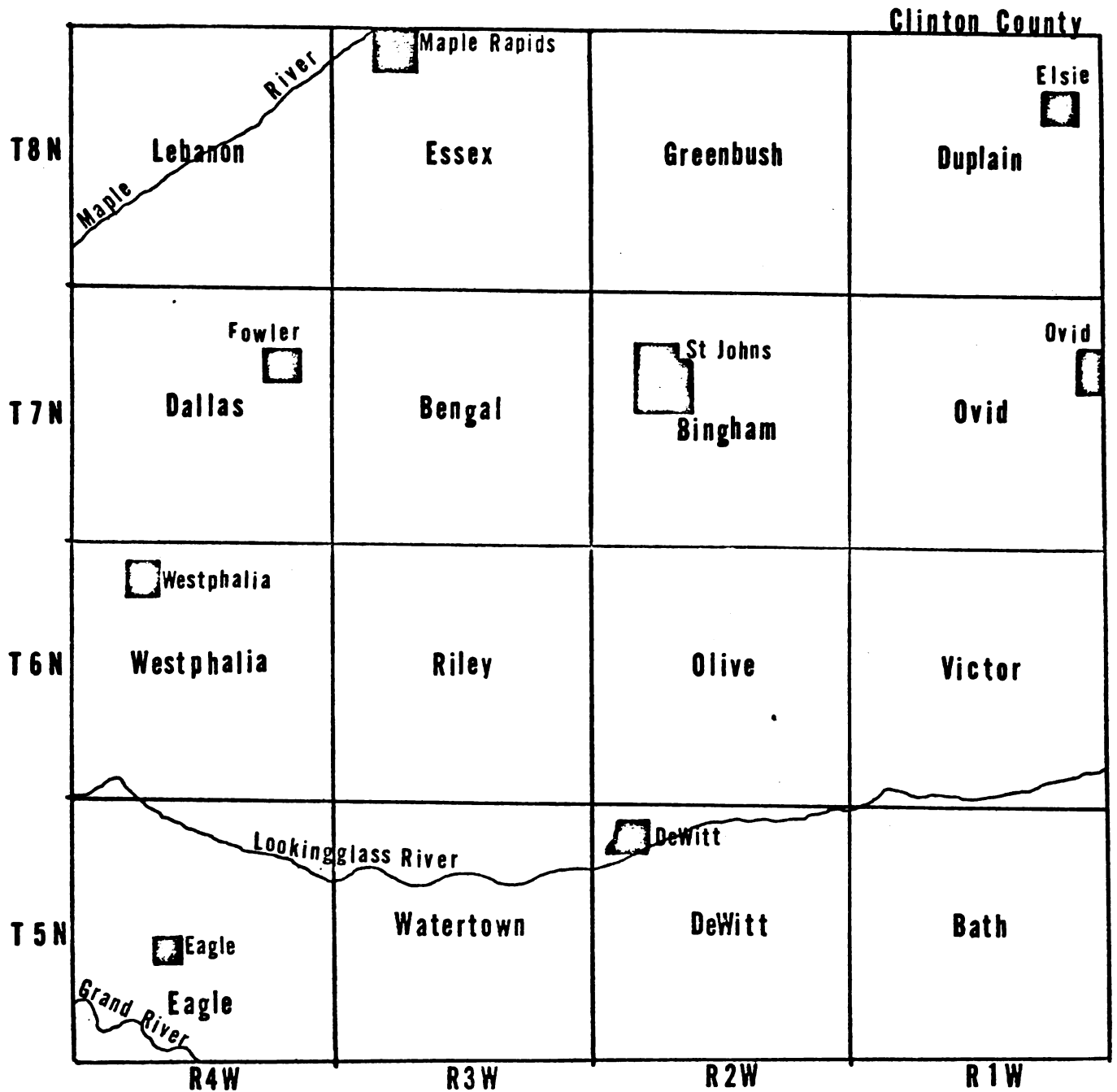
Three major rivers traverse Clinton County (Figure 3), the Grand, the Maple and the Lookingglass. The largest, the Grand River flows through the southwestern part of the county. Lowland areas on this river are mainly swamps and marshes. Just above Maple Rapids the Maple River is the scene of a wildlife flooding project. The Lookingglass River has a small discharge, especially during periods of dry weather. It is mainly used for aesthetic and recreational purposes.

Figure 2.--Map of Michigan showing location of Clinton County,
Michigan.



Figure 3.--Map of Clinton County, displaying townships,
cities and major rivers.

Location Map



1 Mile

GEOLOGIC HISTORY

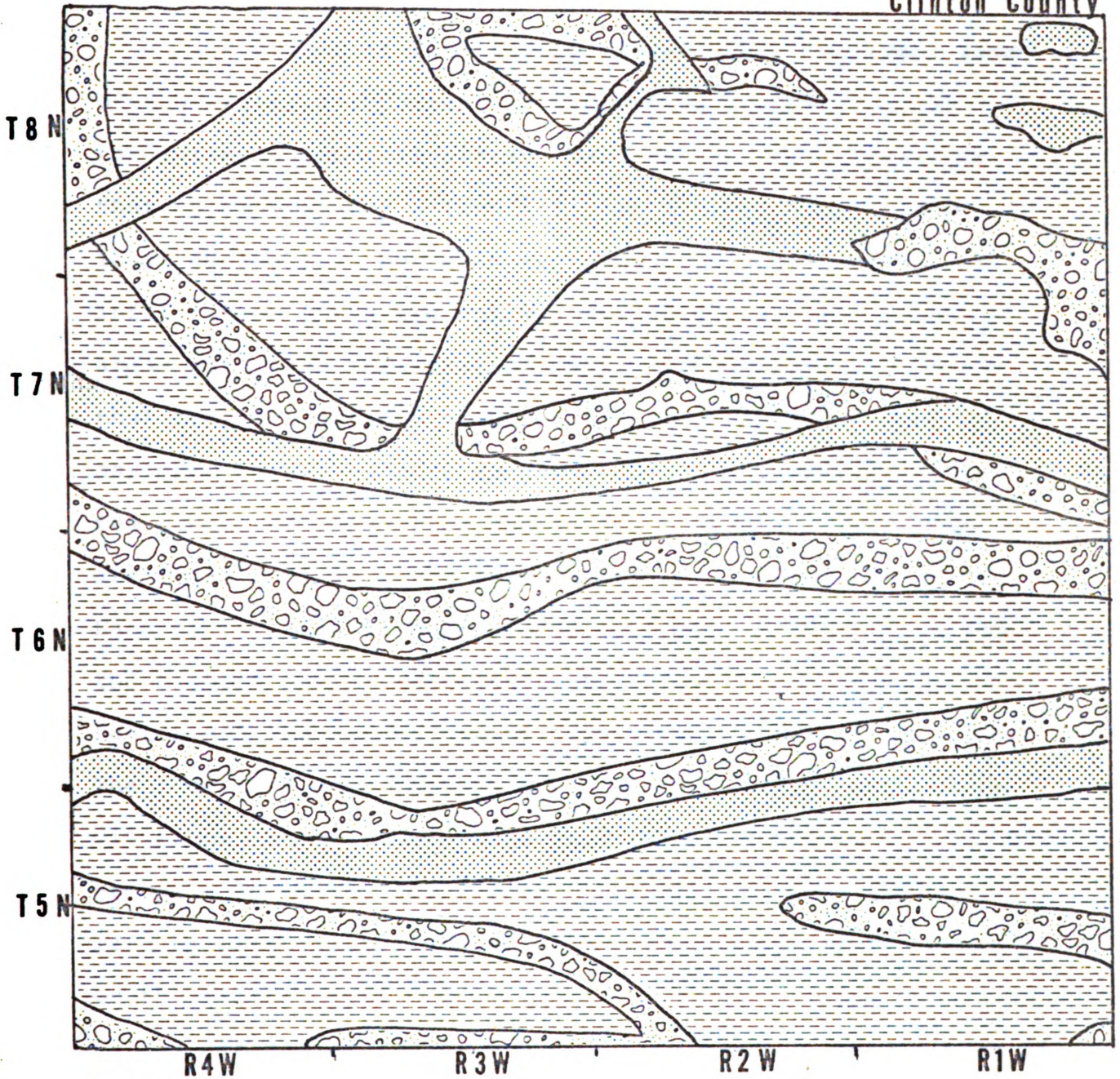
Clinton County is underlain by glacial drift consisting of unconsolidated clay, silt, sand and gravel. The drift rests upon Paleozoic bedrock composed of limestone, shale, sandstone, salt and gypsum. Generally the drift is thickest (about 250 feet) in the northwestern part of the county and thinnest in the southern part, where in places it is within 50 feet of the surface.

The glacial deposits in Clinton County (Figure 4) consist of three main types: (1) till, which consist of poorly-sorted clays, silts, gravel and boulders directly deposited from melting ice; (2) outwash, which is characterized by well-sorted silt, sand and gravel deposits from glacial meltwater; and (3) minor glacial-lake deposits of silt, sand and clay. The regions characterized by till deposits consist of subparallel east-west trending recession-al moraines and intermorainal till plains (Vanlier, et al., 1974).

Figure 4.--Generalized surficial geologic map of Clinton County,
Michigan (after Helen Martin, 1955).

Generalized Glacial Map

Clinton County



1 Mile

Legend:

- Outwash
- Moraine
- Till Plain

PROCEDURE

A number of factors are chosen which represent some of the criteria important in evaluating potential areas for suitable landfill sites. Each factor has a condition that is optimal for a landfill site and one that is the least desirable. For example, areas characterized by low infiltration rates are optimal for landfill sites, whereas areas with high infiltration rates are undesirable. Areas that meet the optimum requirements for each factor are assigned higher numbers ranging from 3 to 5, depending on the number of categories chosen for ranking. Areas that are least desirable for each factor receive a score of 1. Each factor then is represented by a set of numbers whereby the highest number represents the optimal condition for that factor and the lowest number, the least desirable condition. The scores of some factors are only broken down into three divisions, while others were subdivided into four or five groups. To weight all factors the same the data are normalized by proportionalization to a common range after assembly of the factor maps.

To assign factor scores to a region, a grid system is superimposed on the basic data maps. Basic data maps can

include any areally distributed information relevant to the land use of interest. For landfill site reconnaissance soils maps are excellent as a data base because factors such as permeability, porosity, slope, and nutrient absorption capacity can be directly inferred from standard soils classification. Soils maps (Johnsgard, et al., 1942) in conjunction with aerial photographs (U.S. Soil Conservation Service) and U.S.G.S. topographic maps were used in this study as sources of factors. At each node on the grid system a factor rank is assigned. Soil types identified at the corners and center of each section in the county are considered representative of the soils in the section. These five points divide each section such that factor resolution is on a 160 acre grid. Therefore, tracts smaller than 160 acres are not necessarily identified in this reconnaissance.

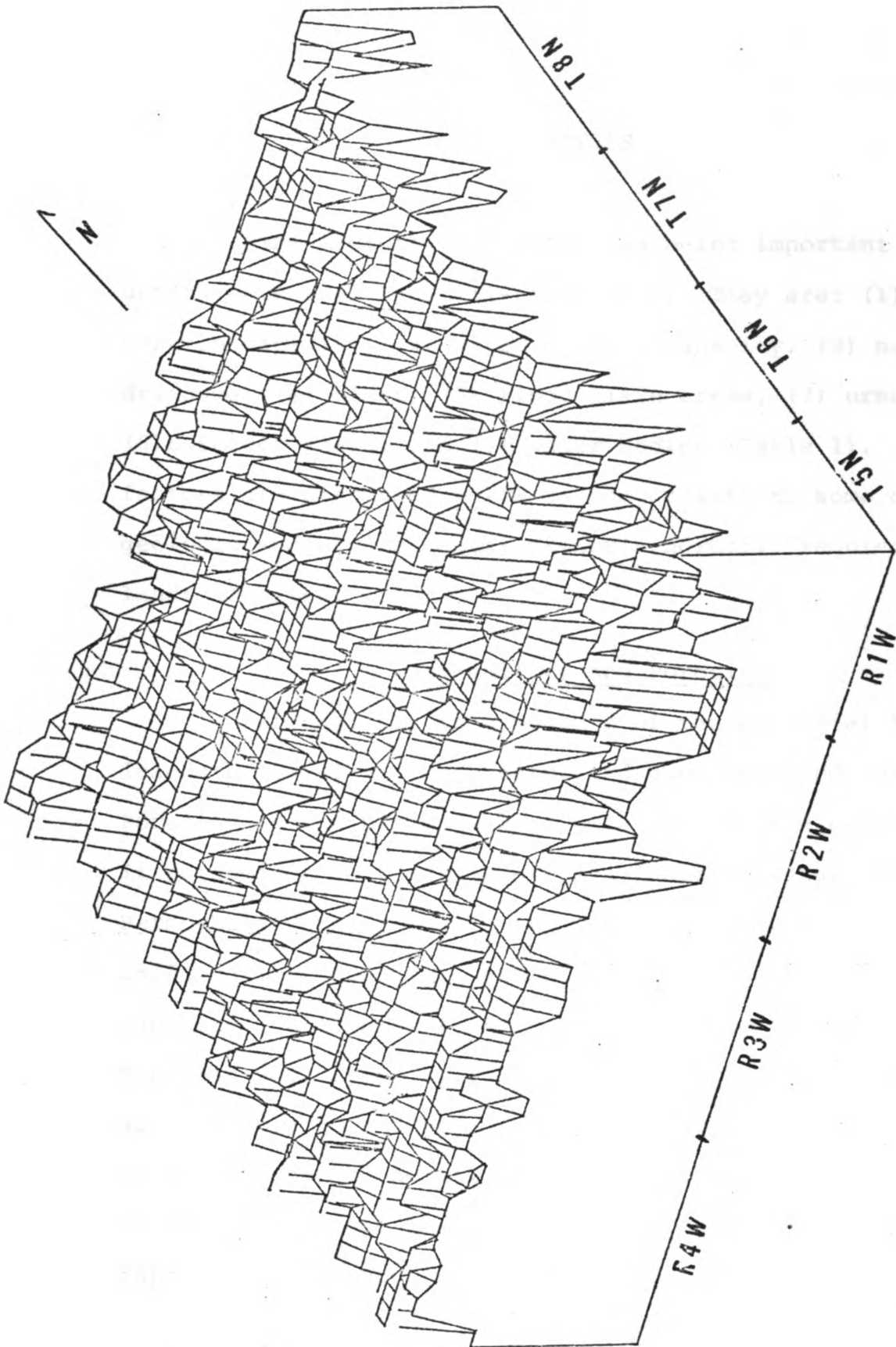
The construction of a map of potential landfill sites requires that the factor maps compiled from the basic data maps be compared simultaneously. This comparison of multiple factors is easily executed using the computer-linked terrane analysis (CLTA) technique described by Tilmann et al., (1974) (Figure 1). After scores are assigned to each factor, the planner makes a decision as to how important each factor is relative to the other factors. For example, in landfills permeability and porosity are several times more critical to site suitability than is nutrient absorption capacity.

The CLTA routine (Figure 1) allows this relative importance to be included by adjusting the scores, by a multiplication of the factors by weightings that reflect the planner's perception of the importance of the various factors. Since there is some question as to the relative importance of the factors, various combinations of weightings are chosen for use in CLTA. These weightings and combinations are discussed in a subsequent section.

After weighting, the computer sums the weighted factor scores at each node. If the area at a node represents the least desirable condition, a minimal, summed score results. If the sum is a maximum value, the area in the vicinity of the node is potentially optimal for landfill use. One method of presentation is the three dimensional, perspective map (Figure 5) where the high areas represent the optimum sites and the low areas the least desirable. These factor sums can also be machine contoured. Those areas within the highest contours are potentially the most desirable for landfill sites, and those within the lowest contours, potentially the least desirable sites. Alternative contour maps stressing different factors may be constructed in this manner to reflect the various weighting conditions. For comparison of alternative maps, the scores in each map are proportionalized to give equal maxima and minima.

The individual factors and scores assigned to each factor are discussed below.

Figure 5.--Three dimensional, perspective method of displaying alternatives after weightings and proportionalization. Highest areas represent potentially optimal sites for landfills, lowest areas the least desirable sites. Map is of Clinton County, for site-selection criteria alternative three.



CLINTON COUNTY LANDFILL. ALTERNATIVE 3

FACTORS

Nine factors were chosen as being important in evaluating potential landfill-site areas. They are: (1) infiltration capacity, (2) water holding capacity, (3) natural drainage, (4) slope, (5) flood plain areas, (7) urban areas, (8)forester areas, and (9) water bodies (Table 1). The factors are discussed below as they relate to some of the geologic and environmental criteria normally required of landfill sites.

Permeability and Porosity

Permeability is a measure of the potential for leachate travel in the unsaturated and saturated zones. Porosity is the percentage of pore spaces in a material. It determines what spaces are available to retain water. Permeability and porosity are represented by the factors Infiltration Capacity, Natural Drainage and Water Holding Capacity. All three factors have been identified for Michigan soil types by Schneider and Erickson (1972) and are reliable to a depth of 60 inches below the surface. In the absence of actual permeability and porosity data, it is felt that these factors will suffice for the sake of rapid reconnaissance.

Infiltration capacity is that feature of the soil that enables it to transmit water or air (Schneider and Erickson, 1972) and is expressed in inches per hour. Soil texture and structure affect infiltration rates. The portions of sand, silt and clay influence the rate of water movement through the soil profile. Infiltration capacity is generally the smallest in clayed soils. If the infiltration rate is slow, less water and leachate can leave the fill site. This minimizes contamination of ground- and surface-water supplies. Thus, areas with the slowest infiltration rates are optimum and receive a maximum factor score (Table 1).

Natural drainage as determined by Schneider and Erickson (1972) applies to the rate at which soils transmit water after saturation. The soil is tested for drainage with no artificial tiles or open ditches present. Five levels of natural drainage are assigned ranks ranging from very poorly drained to well drained soils. It is imperative to have soils that are poorly drained in proximity to a landfill. Water at the surface will therefore not readily seep through the soil and produce leachate that can enter ground- or surface-water supplies. The highest scores based on natural drainage are given to the more poorly drained soils (Table 1).

Schneider and Erickson (1972) determined water holding capacity values after a soil was wetted sufficiently to cause drainage below five feet. The soil was then allowed

to drain to an equilibrium state, and the retained moisture measured. Water holding capacity is also known as "field capacity". This factor is, then, related to the arrangement and size of pores, to the manner of interconnection of pores and to particle size. Clays have a higher water retention because of their small pore size than do coarse textured sands and gravels with large pores. Therefore, a soil with a very high water holding capacity is best for a landfill site because it retains water and retards transmission of leachate. Coarse-grained materials allow water to infiltrate into the areas surrounding the landfill. Lateral migration into the refuse can allow leachate to enter the ground water. As shown by the rankings in Table 1, a very high water holding capacity is optimal for landfill sites and a very low one is the least acceptable.

The type of material used to cover the refuse after each day's work must also be considered. This cover material is usually obtained by excavation at the site and must be subject to the same criteria as the substrate. Therefore, the factors infiltration capacity, natural drainage, and water holding capacity have dual importances in selection of landfill sites. Even though excavation and recompaction change the porosity and permeability of the cover material, soils with low permeability and high water holding capacity

Table 1.--Factor-Level Assignments.

Factors	Level (Score)	Comments
Infiltration Capacity ¹	1	Very rapid (greater than 10.00 inches per hour)
	2	Rapid (2.50 to 10.00 inches per hour)
	3	Moderate (0.80 to 2.50 inches per hour)
	4	Slow (0.20 to 0.80 inches per hour)
Natural Drainage ¹	1	Well drained
	2	Moderately well drained
	3	Somewhat poorly drained
	4	Poorly drained
	5	Very poorly drained
Water Holding Capacity ¹	1	Very low (less than 10 in.)
	2	Low (10 to 13 in.)
	3	Medium (13 to 18 in.)
	4	High (18 to 23 in.)
	5	Very high (Greater than 23 in.)
Depth to Water Table ¹	1	0 to 24 inches
	2	24 to 120 inches
	3	Over 60 inches
Water Bodies	1	Open water (lakes, swamps and streams)
	2	Intermittant streams
	3	Man-made drains
	4	No water present on the land
Flood plains	1	Land on flood plain
	4	Land <u>not</u> on flood plain
Urban Areas	1	within boundaries of an urbanized area
	4	<u>Not</u> within urbanized areas
Forested Areas	1	Forested land
	2	"scrub" land
	3	open land
Slopes ¹	1	6 to 12%
	2	0 to 2%
	3	2 to 6%

¹Based on data from Schneider and Erickson (1972).

act as a good cover material when the landfill is to be abandoned. Also, when revegetating an area, the soil should contain adequate nutrients and have a high moisture storage capacity.

Hydrologic Factors

Proximity of water to the surface throughout the year is an important factor to be considered when choosing a landfill site. If refuse is within or close to ground- or surface-water supplies, leachate can be transported away from the landfill. Depth to the water table, location of surface-water bodies and the location of flood plains are important criteria in the consideration of landfill sites.

Since contaminants in the unsaturated zone are attenuated more than in the zone of saturation, it is imperative that landfills be isolated from ground- and surface-water supplies. Also, flooding by surface and/or ground water encourages the formation of leachate, interferes with the design of the fill and promotes bacterial contamination of adjacent waters. Depth to the water table is then an important factor to consider when choosing a landfill site. Schneider and Erickson (1972) divided water table ranges for soils in Michigan into three categories: (1) over 60 inches to the water table, (2) soils characterized by a yearly fluctuation of 24 to 120 inches, and (3) water saturation very near or at the surface, that is, between 0 and 24 inches.

To keep refuse dry, the optimal condition is characterized by the situation where the water table is over 60 inches below the surface. Areas of maximum water-table depth are assigned ratings of three (Table 1). Regions with seasonally high water tables of between 24 and 120 inches are given scores of two, because this condition is better than having water at or near the surface continually. Areas with water saturation within 24 inches of the surface are rated one and are the least desirable sites.

To eliminate the possibility that a potential landfill site is located in open waters, such as lakes, rivers, or water-saturated areas such as swamps, the factor Water Bodies is included. The optimal condition, that no surface-water body is present, receives a score of four. Areas characterized by intermittent streams and man-made drains are less than optimal, but may present potential sites, if engineering modifications of the site are feasible. The areas where open water is present are scored one.

In guidelines (Michigan Department of Natural Resources, Geological Survey Division, 1974) soon to be adopted by the State of Michigan for evaluating data on proposed sanitary-landfill sites, the importance of flood plains is stressed. By definition, flood plains are the lands adjacent to river and stream channels and are covered with water at flood stage. A landfill covered with water at

any time of the year can allow seepage into the refuse and percolation of contaminated water into ground or surface water. Also, during the period of high water, cover material can be washed away and refuse, leachate and bacteria carried into the river.

There are few gaging stations on the three major rivers that traverse Clinton County and any direct determination of probable flood levels from existing data is not possible. Flood plains are approximated by choosing the area between the stream and the first major change in slope from the flood plain to upland. The optimal condition is no flood plain present (Table 1). These areas receive a score of four. Those areas on flood plain land scored one.

Socio-economic and Aesthetic Conditions

Zoning restrictions and population considerations are limiting to the development of landfill areas. The factors Urban Areas, Forested Areas and Slope are added for consideration (Table 1).

Even if there is a high potential for a landfill site within the boundaries of an urbanized area, it could not, at the present time, be justified within political considerations, such as zoning restrictions, public opinion, and future development plans. Clinton County is predominately rural and there is approximately one major population center

per township. Therefore, the optimum landfill sites have no urban development. These areas receive a rating of four. Those areas characterized by urban development are assigned a score of one.

Availability of land must be considered from the aesthetic and engineering points of view. Forested Areas and Slopes, represent this category. Aerial photographs (Soil Conservation Service, 1974) were used to differentiate between open land, "scrub" land (vegetation that consists mainly of small trees and shrubs), and forested areas. Open lands were chosen the most desirable (Table 1) for a landfill site. In this case, the least aesthetic damage is done to the environment, for no trees would have to be cut. These areas receive a rank of three. Forested areas are the least desirable condition. They have aesthetic qualities, lumber potential and harbor game and wildlife. Engineering difficulties include clearing trees at the site and access roads to the site. Those areas covered by forest land receive a ranking of one. "Scrub" land, then receives a two.

The three categories determined for slopes by Schneider and Erickson (1972) are (1) 0 to 2%, (2) 2 to 6%, and (3) 6 to 12%. The soils included in the 0 to 2% range possibly include either low, swampy land or the best farm land in the predominately agricultural Clinton County. There

is also a good possibility that this land may be on a flood plain and pose flood hazards and seepage into the ground water at times of high water levels. Land that has a 6 to 12% slope, not only requires greater engineering modifications than areas of less slope, but has aesthetic qualities and potential for hunting and wildlife refuges. These areas are ranked three. This leaves as the optimal condition (Table 1) the slope of 2 to 6%, which is not too hilly for engineering tasks, and avoids some of the possible constraints imposed by land with greater or less slope.

ALTERNATIVE MAPS (WEIGHTING)

Five alternatives in factor weighting were chosen (Table 2) for comparison of the sites selected after assigning different importances to the criteria. The five alternative weighting plans are significant for two reasons: first, the alternatives show the effect of various site selection criteria based upon the notion that some factors are more important than others, and second, the alternatives help evaluate the importance of a change in the weighting factors to identify areas sensitive to variations in use plans. All the alternatives were arbitrarily selected and reflect only a few of the combinations that are possibly suitable.

Alternative One

The first weighting alternative maximizes the importances of the factors Water Bodies, Urban Areas, and Flood Plains (Table 2) by assigning them higher weighting values. When multiplied by a large weighting value, emphasis is placed on the areas not within water bodies, urban areas, or flood plains. The other factors in this alternative represent a possible optimal use of the nine criteria. Infiltration Capacity and Depth to Water Table are emphasized to

conform with State site criteria (Michigan Department of Natural Resources, Geological Survey Division, 1974).

Figure 6 shows the result of summation of the weighted factors for alternative one.

TABLE 2.--Factors and Alternative Weightings¹

Factors	Alt. 1	Alt. 2	Alt. 3	Alt. 4	Alt. 5
Infiltration Capacity	3	1	3	<u>1</u>	<u>1</u>
Natural Drainage	2	1	<u>3</u>	<u>1</u>	<u>1</u>
Water Holding Capacity	1	1	1	1	1
Depth to Water Table	3	1	<u>4</u>	3	3
Water Bodies	4	1	4	4	<u>2</u>
Flood Plains	4	1	<u>2</u>	4	4
Urban Areas	4	1	4	4	4
Forested Areas	1	1	1	1	<u>3</u>
Slopes	1	1	1	1	1

¹Items underlined are those changed from alternative number one.

Alternative Two

In the second alternative (Table 2) all factors are normalized, meaning each factor is weighted with a value of one. This situation is comparable with the McHarg method (1970) of overlying sheets of acetate, one for each factor

considered. In this way all factors are equally important. Figure 7 shows the result of summation of factor scores using weighting alternative two.

Alternative Three

In this alternative factors are normalized to equal maxima prior to weighting. This alternative presents some considerations that can be made, if site modifications are acceptable and if constraints on the use of flood plains can be relaxed. The weighting for the factor Flood Plains is decreased from a weighting value of four in alternative one to a value of two. This reasoning implies that flood plain areas can be acceptable, if the depth of the water table (factor weighting raised to four) and the factor Natural Drainage (raised to a weighting of three) are suitable. Figure 8 shows the results of this weighting alternative.

Alternative Four

All factors in alternative four are normalized to equal maxima prior to weighting. This alternative is designed to indicate possible sites, if it is acceptable to structurally modify a site by underdraining, lining the sides of the fill, and generally developing a site with engineering techniques. If this is acceptable, then weighting values of the factors Infiltration Capacity and Natural Drainage, which

represent permeability, can be lowered. These two factors are then given weighting values of one, while the weighting values of all other factors remain the same as in alternative one. Figure 9 shows the results of summation of the weighted factors for alternative four.

Alternative Five

Socio-political constraints are considered in this alternative. All factors are again normalized to equal maxima prior to weighting. This alternative emphasized low quality forested land. Land near or in a water body is eliminated by increasing the weighting of the factor Water Bodies. Use of flood plains in this alternative is banned by law, and urban areas zoned are to exclude sanitary landfill use. Therefore, two factors, Flood Plains and Urbanized Areas retain the high weighting value of four. Thus, this alternative approximates the criteria used in conventional planning where zoning and land type are considered more initially important than geologic suitability. Figure 10 illustrates the results of this evaluation.

Figure 6.--Computer contour map of factors weighted using criteria established for alternative one. Factor sums proportionalized between one and thirty. Areas within the highest contours are potentially optimum sites for landfills, areas within the lowest contours, the least desirable.

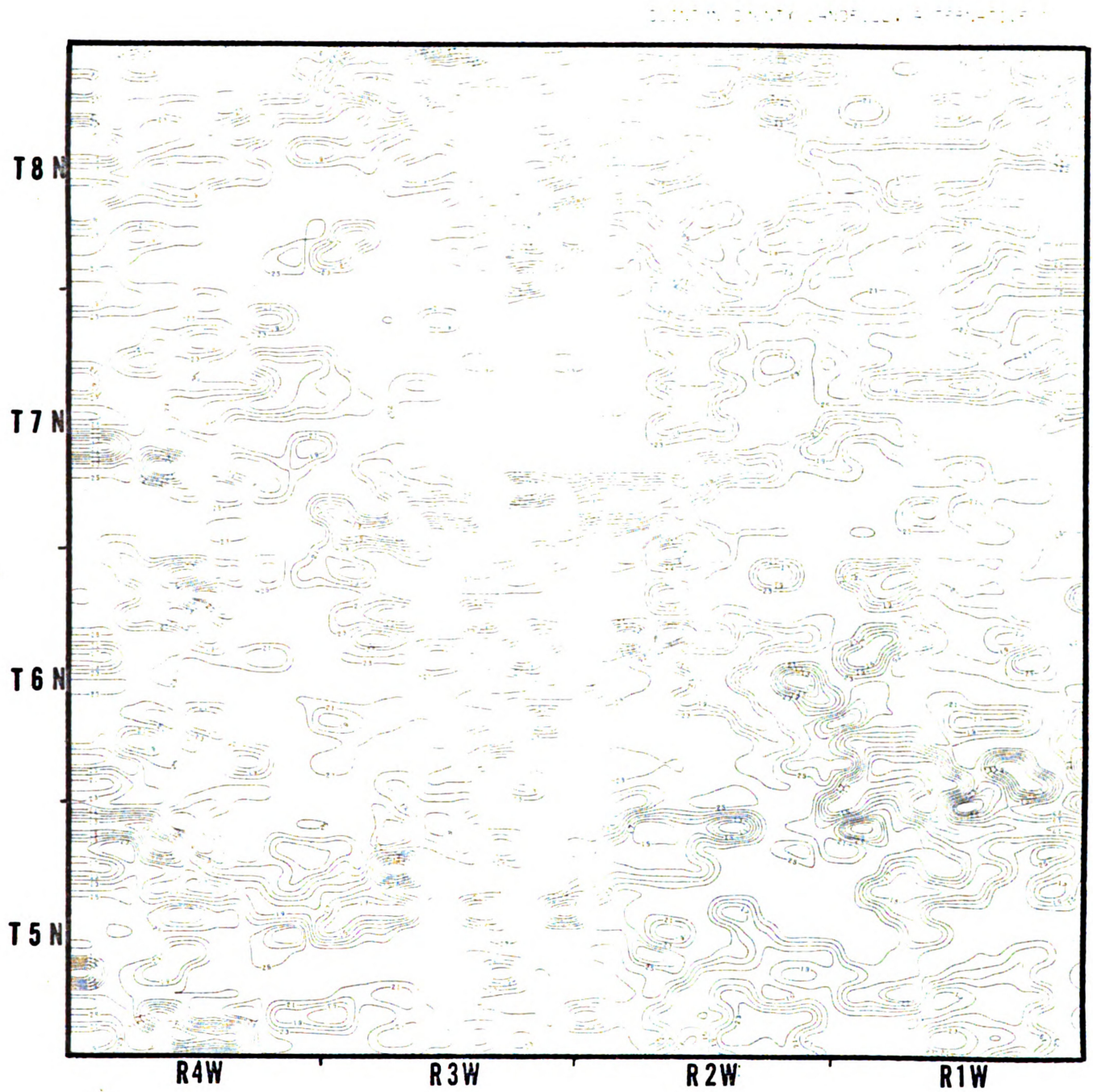


Figure 7.--Computer contour map of factors weighted using criteria established for alternative two. Factor scores are proportionalized between one and thirty. Areas within the highest contours are potentially optimum sites for landfills, areas within the lowest contours, the least desirable.

CLINTON COUNTY LANDFILL ALTERNATIVE 2

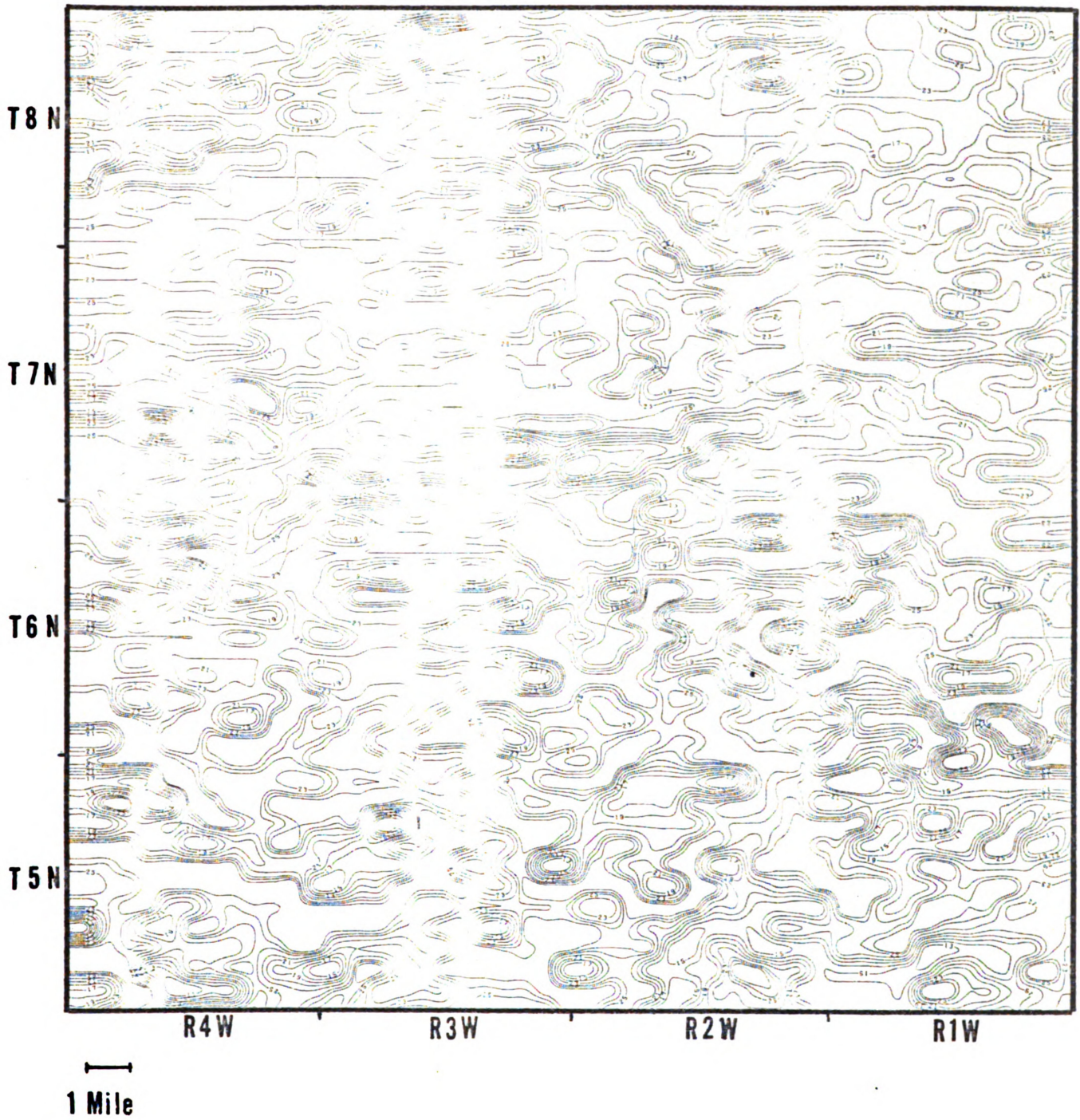
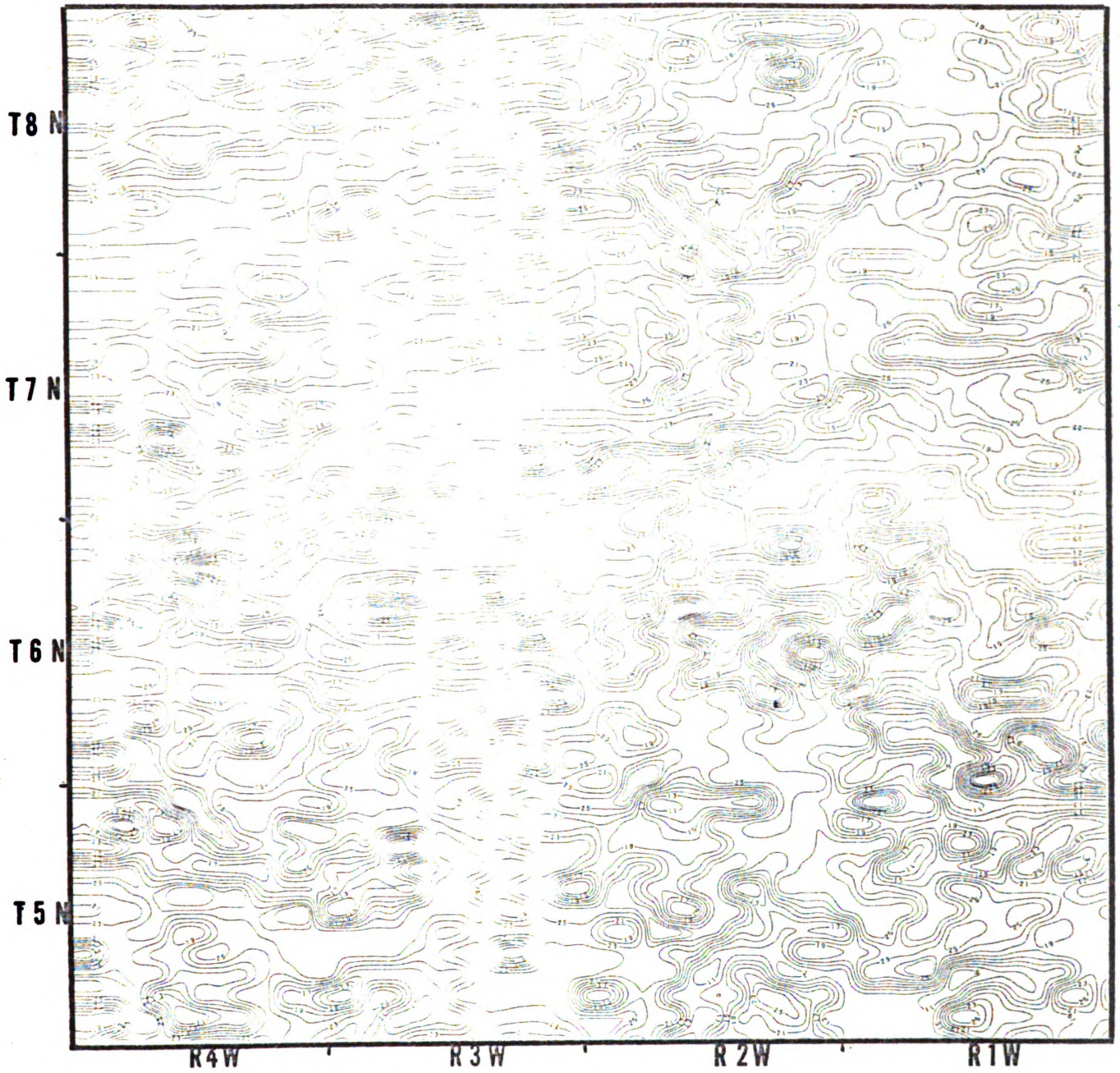


Figure 8.--Computer contour map of factors weighted using criteria established for alternative three. Factor scores are proportionalized between one and thirty. Areas within the highest contours are potentially optimum sites for landfills, areas within the lowest contours, the least desirable.

CLINTON COUNTY LANDFILL ALTERNATIVE 3



1 Mile

Figure 9.--Computer contour map of factors weighted using criteria established for alternative four. Factor scores are porportionalized between one and thirty. Areas within the highest contours are potentially optimum sites for landfills, areas within the lowest contours, the least desirable.

CLINTON COUNTY, INDIANA, ALTERNATIVE 1

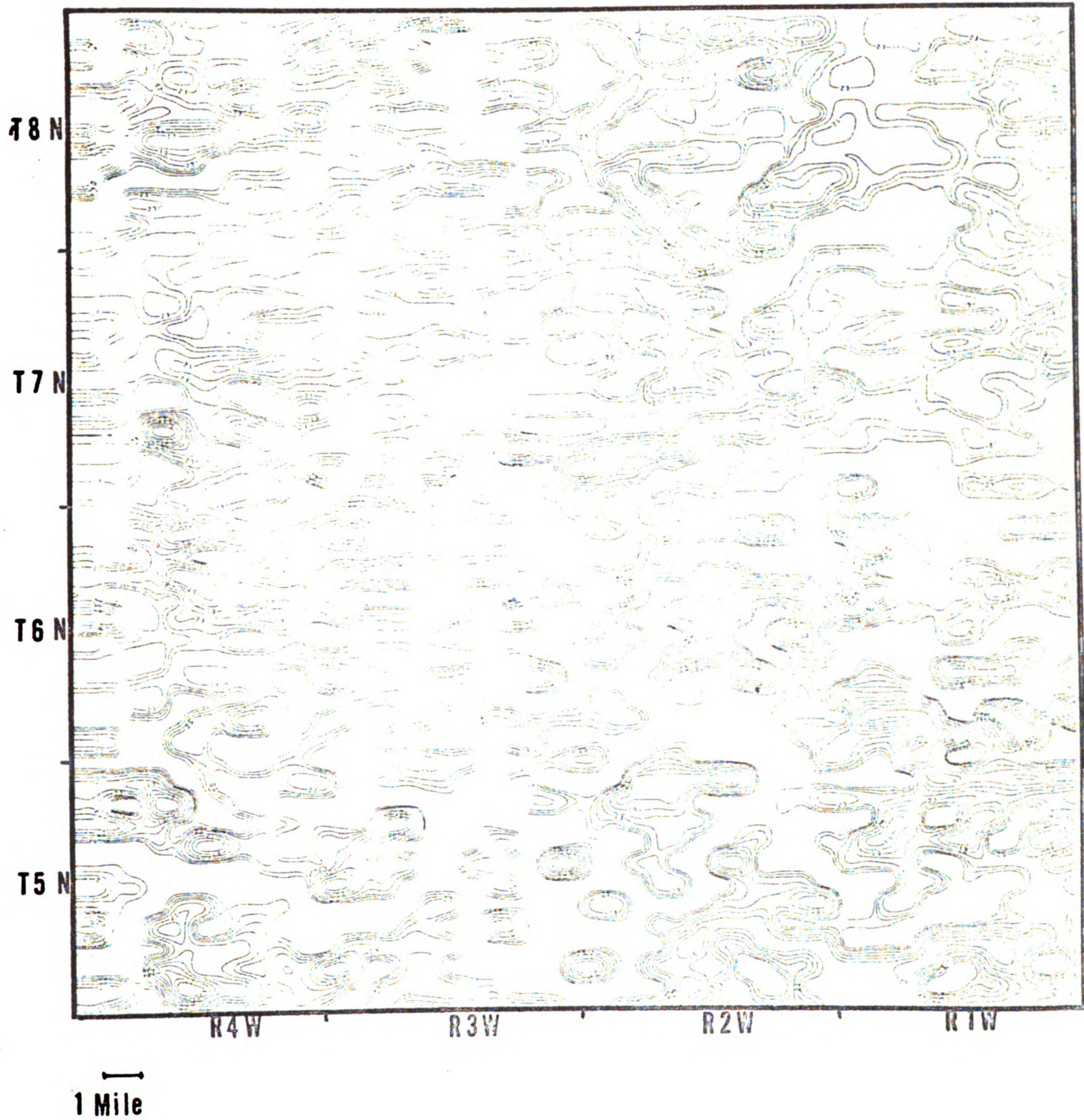
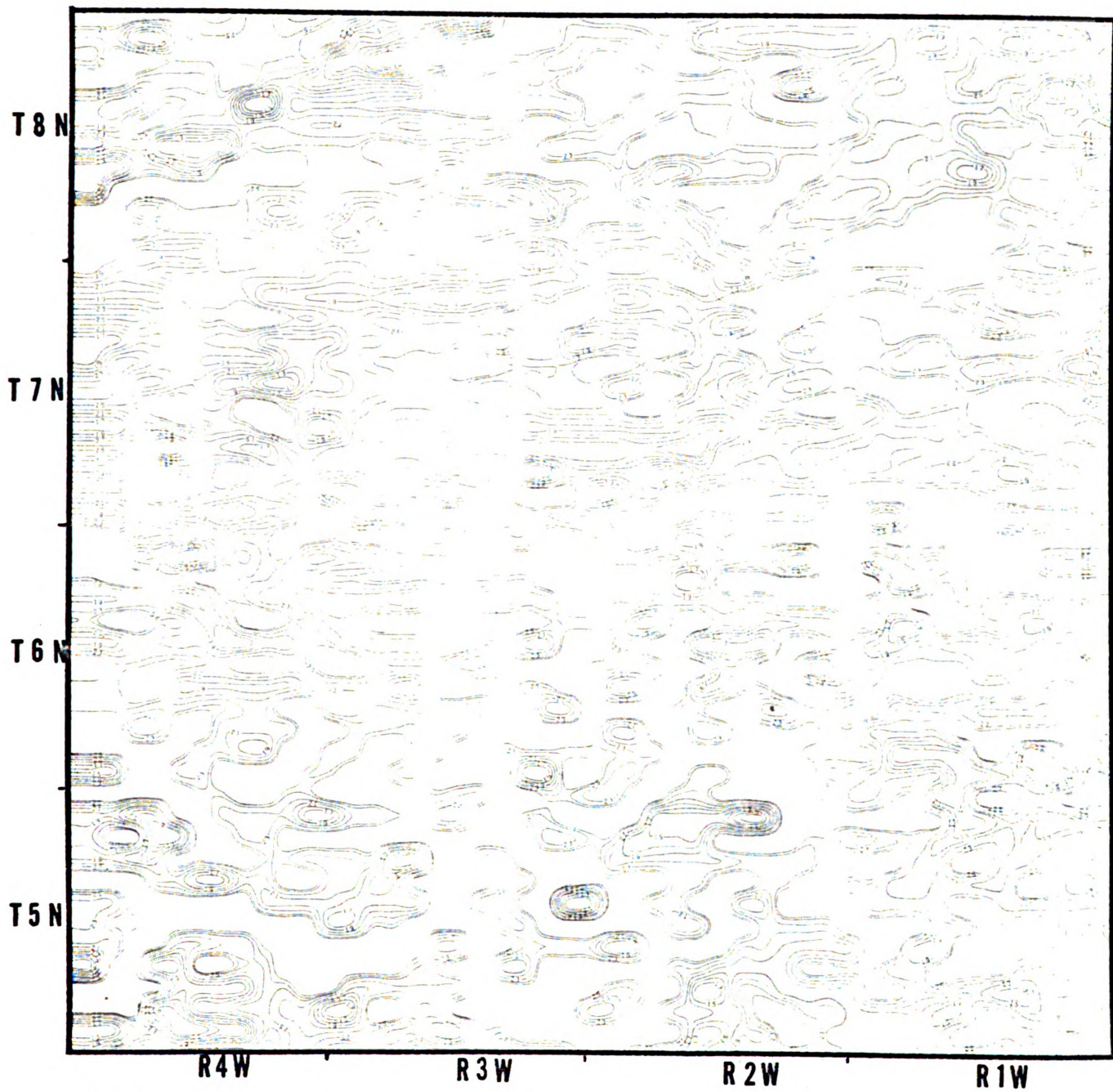


Figure 10.--Computer contour map of factors weighted using criteria established for alternative five. Factor scores are proportionalized between one and thirty. Areas within the highest contours are potentially optimum sites for landfills, areas within the lowest contours, the least desirable.

CLINTON COUNTY LANDFILL ALTERNATIVE 5



1 Mile

TABLE 3.--Normalized, factor sum frequency distribution.

Factor Sum	Alternative 1		Alternative 2		Alternative 3		Alternative 4		Alternative 5	
	%	cum. %	%	cum. %	%	cum. %	%	cum. %	%	cum. %
1	.08	.08	.08	.08	.08	.08	.08	.08	.17	.17
2	.08	.17	0.00	.08	0.00	.08	0.00	.08	0.00	.17
3	0.00	.17	0.00	.08	.08	.17	0.00	.08	0.00	.17
4	.08	.25	0.00	.08	0.00	.17	0.00	.08	.17	.33
5	0.00	.25	.08	.17	0.00	.17	0.00	.08	0.00	.33
6	0.00	.25	.08	.25	.08	.25	0.00	.08	0.00	.33
7	.33	.58	0.00	.25	.08	.33	.25	.33	.33	.67
8	0.00	.58	.79	1.04	.08	.42	.08	.42	.25	.92
9	.92	1.50	.25	1.29	1.37	1.79	.54	.96	.08	1.00
10	.67	2.17	0.00	1.29	.75	2.54	.17	1.12	1.42	2.42
11	1.04	3.21	.33	1.62	2.00	4.54	.17	1.29	.17	2.58
12	1.25	4.46	.50	2.12	.58	5.12	0.00	1.29	1.33	3.92
13	.96	5.41	.92	3.04	6.21	11.33	.33	1.62	1.08	5.00
14	.42	5.83	2.29	5.33	1.21	12.54	1.46	3.08	1.04	6.04
15	2.21	8.04	.33	5.66	2.50	15.04	1.25	4.33	.37	6.41
16	1.08	9.12	7.37	13.04	1.75	16.78	5.96	10.29	3.33	9.75
17	8.33	17.45	1.29	14.33	2.21	18.99	.83	11.12	1.67	11.41
18	4.08	21.53	2.17	16.49	8.50	27.49	2.04	13.16	1.92	13.33
19	1.33	22.87	2.04	18.53	3.96	31.45	1.25	14.41	7.91	21.24
20	5.25	28.11	1.12	19.74	10.54	41.98	1.71	16.12	2.21	23.45
21	2.42	30.53	9.20	28.95	5.66	47.65	2.96	19.08	4.08	27.53
22	4.62	35.15	3.83	32.78	3.08	50.73	4.83	23.91	5.16	32.69
23	8.37	43.52	14.70	47.48	15.62	66.35	9.75	33.65	13.49	46.19
24	16.20	59.73	1.83	49.31	9.00	75.34	7.87	41.52	.92	47.11
25	34.28	94.00	16.91	66.22	1.42	76.76	2.33	43.86	15.91	63.02
26	2.83	96.83	10.66	76.88	20.32	97.08	17.53	61.39	4.62	67.64
27	2.58	99.42	1.04	77.93	1.25	98.33	5.50	66.89	2.62	70.26
28	.37	99.79	21.70	99.63	1.46	99.79	9.12	76.01	8.66	78.93
29	0.00	99.79	.17	99.79	0.00	100.00	4.71	80.72	1.79	80.72
30	.21	100.00	.21	100.00	.21	100.00	19.28	100.00	19.28	100.00

RESULTS

All sums in the five, alternative contour maps are normalized between one and thirty so that comparisons can be made between alternatives. Those areas within the highest contour intervals are potentially optimum landfill site areas. Based upon the frequency distribution of scores (Table 3), areas with factor sums greater than 27 were chosen as potentially optimal in each case. Figure 11 compares those areas from each alternative map that received scores greater than 27. There are few acceptable sites (0.5% of area, Table 3) in alternative one, which is in accord with the strong emphasis on geologic suitability. Alternative two identifies many possible sites (22% area, Table 3). Alternative two is an approximation of the acetate-overlay technique, and does not differentiate between factors on the basis of relative importance. Alternatives 3 and 4 show the effect of loosening constraints with respect to geologic criteria. In alternative three few sites (approximately 1.5% of area, Table 3) are acceptable owing to the rigor of the criteria imposed through weighting. Alternative 4 is sufficiently less rigorous to allow 34% of the area (Table 3) to have scores greater than 27. Alternative 5 does not appear to be an efficient weighting

alternative. This is largely due to the fact that there are few areas where land types (e.g., forest type, flood plains, and urban areas) are completely acceptable.

All areas from the five alternatives that received scores greater than 27 were superimposed (Figure 11). Those sites that are unique to at least four alternatives were shaded in. It is important to note that there are only three areas that are acceptable regardless of the importance attached to the criteria. These areas are unique in that, for four of the five alternatives chosen in this study, there appear to be viable sites for a sanitary landfill regardless of how the selection is made.

The large area that is acceptable for four alternatives in Riley Township, T6N, R3W, (Figures 11 and 12). is taken as an example to evaluate the efficacy of the Computer-Linked Terrane Analysis technique. The evaluation consisted of a site visitation and compilation of subsurface data from water-well logs. Two cross sections through this potentially optimal area were constructed using the water-well logs (Figures 13 and 14). From these cross sections three very important features should be noticed: (1) the bedrock is the aquifer in the area and is not close to the surface, (2) there appears to be two continuous clay layers overlying this aquifer and protecting it from possible leachate contamination, if a landfill were to be placed on

this site, and (3) the static water levels on the wells are high suggesting a strong artesian head. This head can produce upward trending flow lines. If leachate did penetrate into the subsurface hydrostatic pressure, represented by these flow lines would tend to bring any leachate toward the surface, rather than carrying it downward into the aquifer. These three conditions strongly suggest a potentially optimal site.

The area was then field checked during the spring thaw. The soils are a loamy clay on a 2-6% slope. The land, now in farm use, was not flooded as was much of the surrounding low area. No engineering problems appeared evident.

The optimal sites identified on the composite diagram (Figure 11) can also be compared with two other studies done on Clinton County. These sites (Figure 15) were identified by Commonwealth and Associates (1970), and the other by the Tri-County Planning Commission (1971). In both studies potential sites for landfills were chosen mainly in accordance with zoning laws, administrative cost and transportation distance. As seen from Figure 15, the sites chosen by these two studies differ greatly from those chosen in this study using soils and geologic criteria.

Figure 11.--Alternative contour maps one through five, a through e, respectively, with areas that receive a factor sum of 27 or above shaded in. Section f is the composite of the five alternative maps with areas unique to at least four alternative maps shaded in.

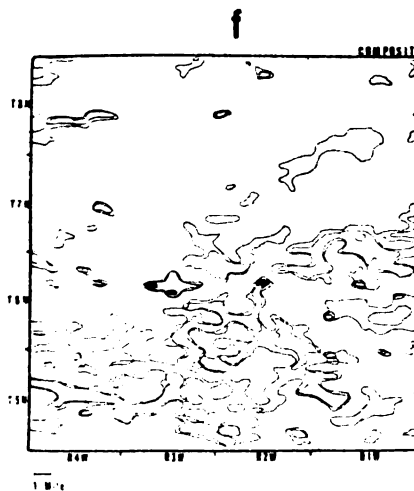
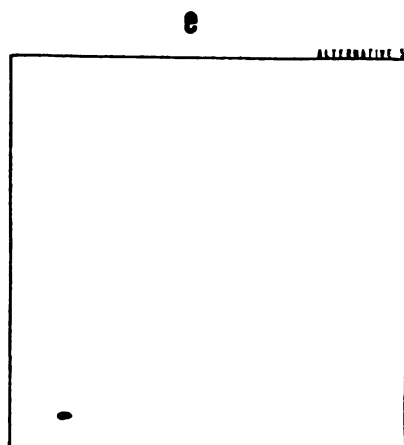
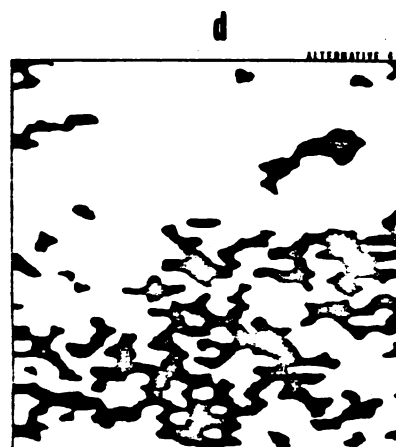
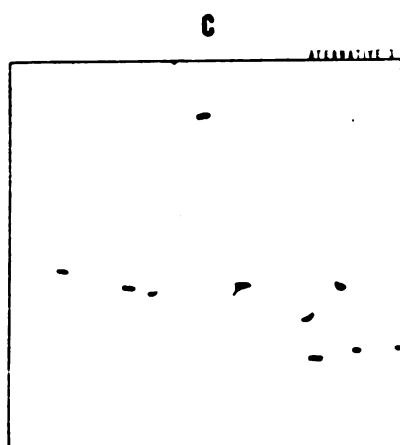
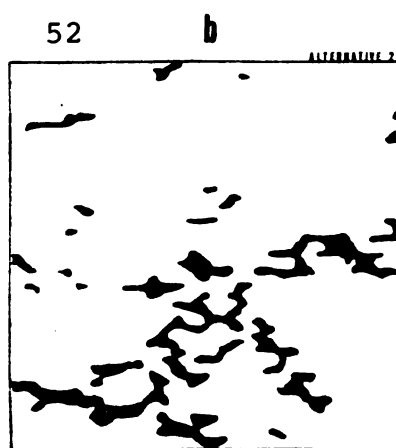
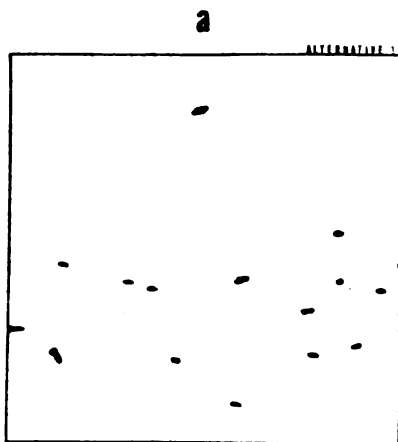
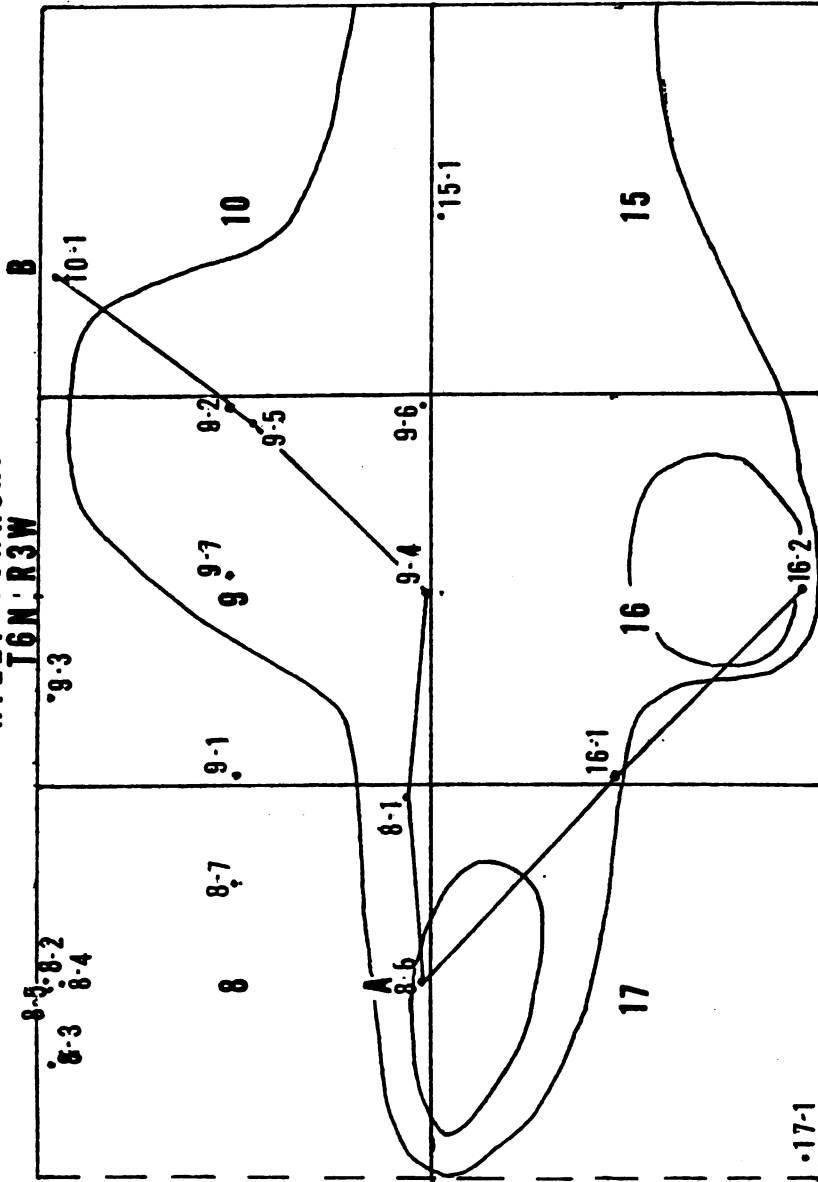


Figure 12.--Location of one potentially optimal area in Riley Township showing locations of plotted water well logs and the two lines of cross section.

CLINTON COUNTY
RILEY TOWNSHIP
T6N R3W



8-6 Well Log Number
A—C Cross Section

Optimum areas
selected from
composite map
17 Section Number

DISCUSSION OF THE METHOD

The rapidity of execution, flexibility and the contoured output are the main advantages to this technique. Because this technique is fast, it can be more readily used than conventional methods. The easy to read visual output can be more readily used by planners, commissioners, and lay people interested in township planning.

This technique is limited only by the availability of data. Five of the nine factors considered are determined from soils data which only considers the first 60 inches of ground. In many cases it is true that shallow soil horizons are indicative of the earth at a depth of many feet. However, in the glaciated regions of the northern United States, it can also be true that the first 60 inches of soil may be totally different from what lies below. Landfills should be judged in part upon the water-table range, which are determined from water-well logs from the area, and upon the distribution of clay layers at depth. By trend-surface analysis, point data, such as data derived from well logs, can be included in factor derivation (Tilman, et al., 1974). A thorough study should include all such data as factors. By using this quick method, then checking

optimum sites against data collected from the potentially optimum sites, these aspects are considered. The final composite maps should be used to merely eliminate those sites which are undesirable allowing more time to be spent using traditional geological methods on those areas remaining.

To gain more precise information, the resolution of the grid should be smaller than 160 acres. Instead of each section corner and center, additional points in each section should also be digitized to give a resolution of at least 40 acres. This detail is possible and has been used by Tilmann et al., (1974) to study a portion of Roscommon County, Michigan.

One of the most important features of this method is the flexibility with which data can be viewed. Virtually any number of factor maps can be utilized and each factor weighted according to the particular need of the community. As more data becomes available there is only a minimum amount of difficulty involved in updating each factor map.

Figure 13.--Cross section A-C through an optimal area in Riley Township, Clinton County, Michigan (See Figure 12).
Legend: (1) gravel, (2) sand, (3) clay, (4) sand and gravel, (5) sand and clay, (6) clay and gravel, (7) bedrock; (8-6) well log number, (Δ) casing depth, () static water level, (- - -) land surface, and (—) correlation lines. Vertical exaggeration is 176X.

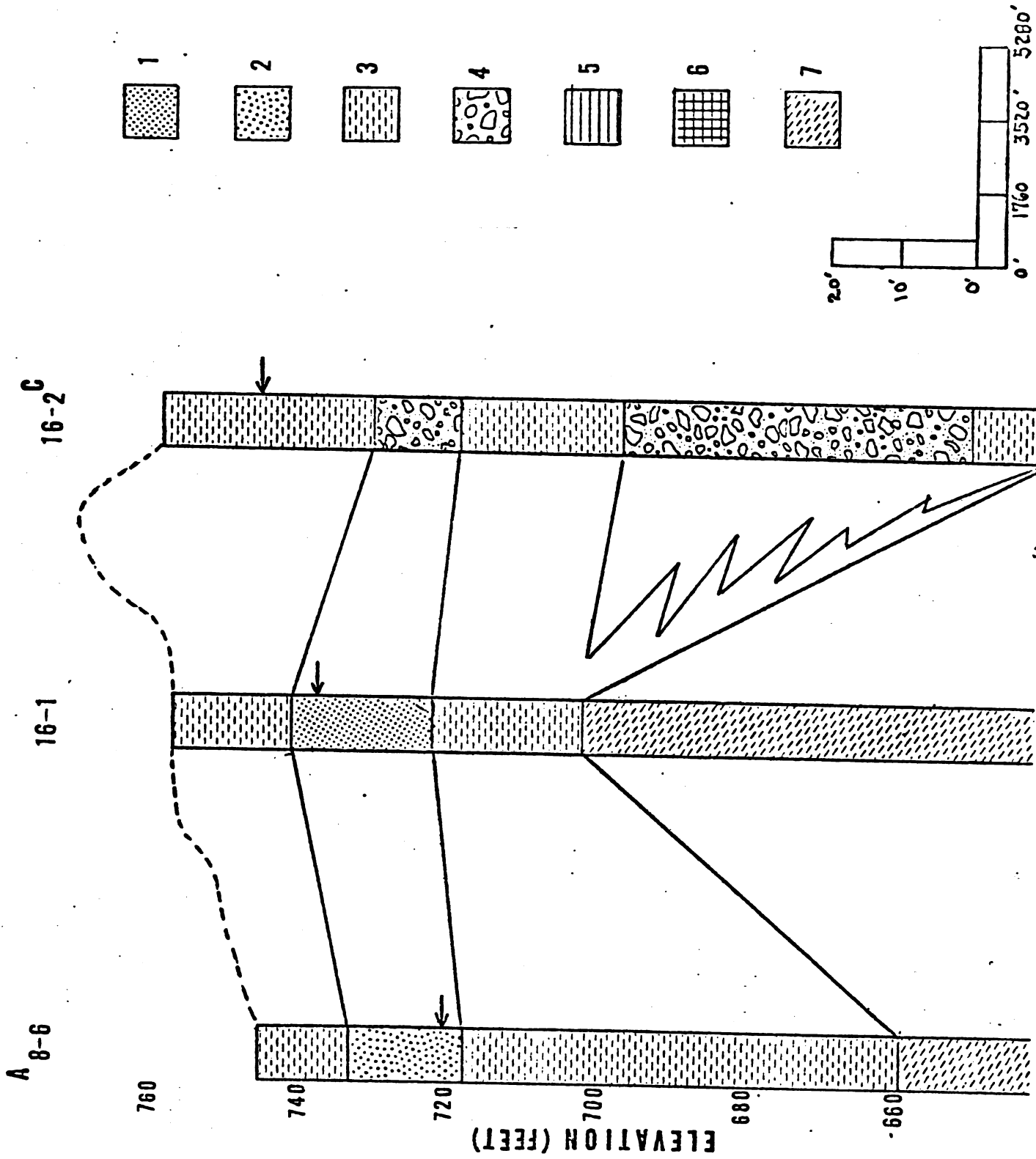


Figure 14.--Cross section A-B through an optimal area in Riley Township, Clinton County, Michigan (See Figure 12).
Legend: (1) gravel, (2) sand, (3) clay, (4) sand and gravel, (5) sand and clay, (6) clay and gravel, (7) bedrock; (8-6) well log number, (▲) casing depth, (←---) static water level, (- - -) land surface, and (——) correlation lines. Vertical exaggeration is 176X.

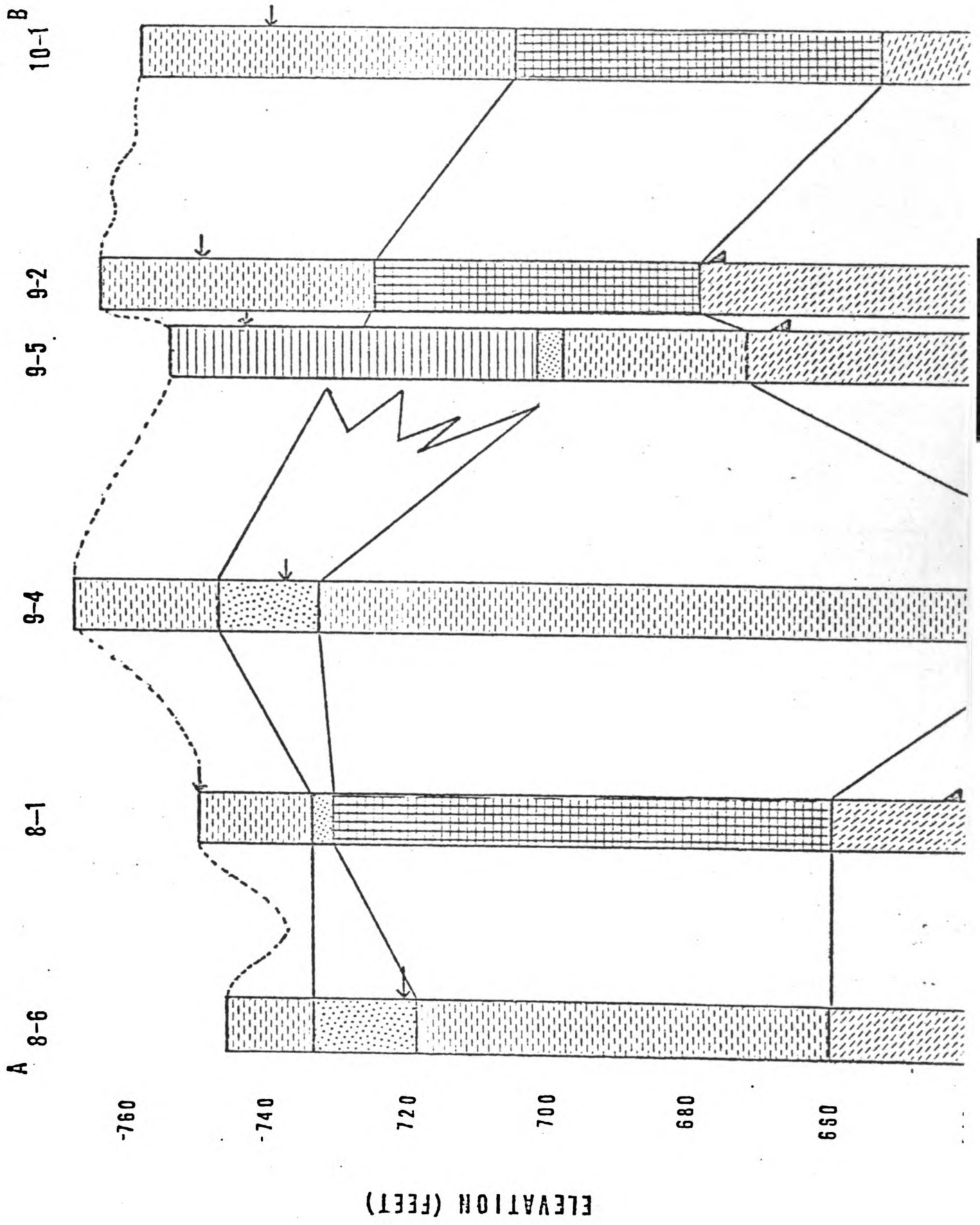
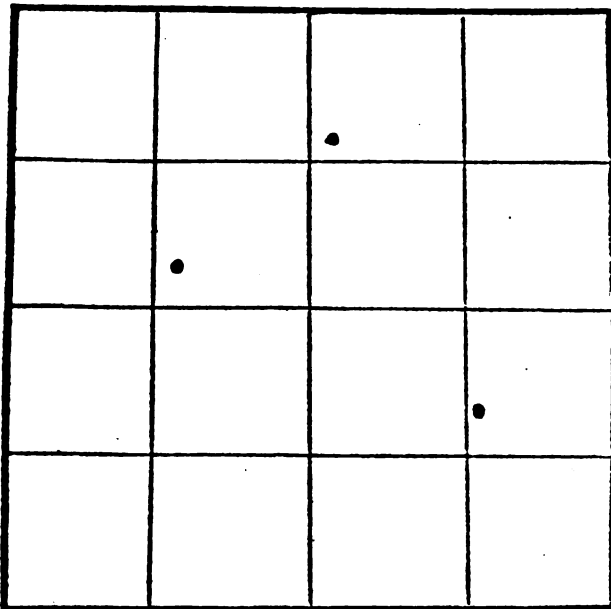
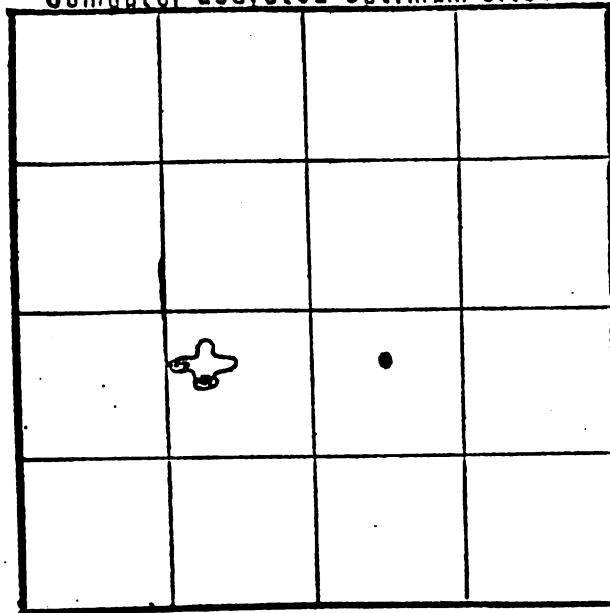


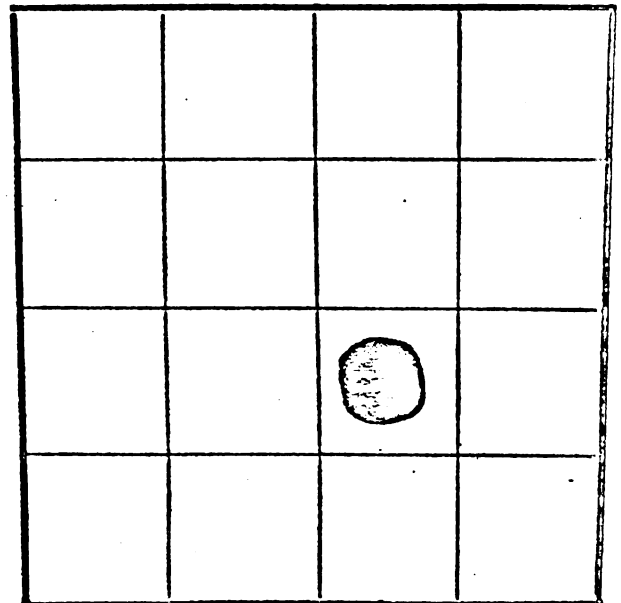
Figure 15.--Three maps of Clinton County: (1) showing the optimum sites derived by the computer assisted method, (1970) (2) sites selected by Commonwealth Associates, Inc., (1970), and (3) area chosen by the Tri-County Planning Commission, (1971).

Clinton County

Computer assisted optimum sites



Sites selected by Commonwealth Associates Inc. for the Clinton County Planning Commission



Area selected by the Tri-County Regional Planning Commission

SUMMARY

Using the computer-linked terrane analysis technique described by Tilmann, et al., (1974) important aspects of land-use planning are considered. (1) The generalized geology of an area seems to be reflected in the factor maps. The general geology of Clinton County is reflected on the computer maps by the same east-west trends representing moraines and intermorainal till plains seen on the generalized map of Clinton County (Figure 4). (2) The frequency distributions of score sums for each alternative help evaluate potentially optimum sites. The contours on the computer maps point to specific areas that are potentially optimal and the ones that are the least desirable. By precisely locating an area, well log and on-site data can be plotted allowing for a greater, in-depth study. (3) Factor weighting allows diversity in land-use planning. If one or two factors are more important than others in an area studies, they can each be evaluated or judged with respect to the others using alternative weightings. (4) It appears possible to obtain optimal land that is insensitive to various weightings using only a small number of alternatives. (5) The basic grid system allows resolution

corresponding to the data available. This technique is only as limited as the quality and resolution of the grid system and data used. It is valuable as a method of eliminating undesirable sites so that more time can be spent on reconnaissance of the remaining area even when only marginal data are available. (6) This technique allows for input from various interested sources. The outputs are easy to read so that it can be utilized more by those in planning and in the community. The technique is fast and flexible in that multiple factors can be weighted and many alternatives determined depending on the specific needs of the particular area. This allows for input from planners as well as interested citizens which allows for better rapport between planners and citizens, a situation that is rarely possible.

This technique is not viewed as a replacement of sound geologic reconnaissance and on-site evaluation, but rather as a tool in these processes. Since the technique indicates areas that are not suitable, as well as areas that appear to be suitable, more effective geologic evaluation can be concentrated on the more suitable areas. This method, then, perhaps, can be a mechanism by which sound geologic information can be incorporated into land-use planning and decision making.

RECOMMENDATIONS FOR FURTHER STUDIES

This paper represents only an initial, small-scale study in the realm of land-use planning. It only deals with one aspect of waste disposal, which is only one aspect of total land-use management. But, it is a beginning.

Heeding the recommendations and suggestions of this paper, the Computer-Linked Terrane Analysis Method should be attempted, not only for other forms of waste disposal, but for the many varied aspects of land-use planning as well. More regional, state-wide studies based on a total land-use plan for the state should be a long range goal. However, I recommend that this method not be used indiscriminately. The compilation of basic data maps should be performed by a trained geologist, for the results can only be as sound as the initial data sources and their interpretation.

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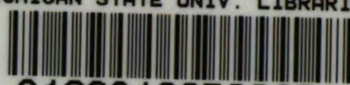
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