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The Hydrogeology of Bonnie Castle and Dustin Lakes and Its Relationship to Groundwater Contamination from the KL Avenue Landfill, Kalamazoo County, Michigan

Joseph S. Hobin
Western Michigan University

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THE HYDROGEOLOGY OF BONNIE CASTLE AND DUSTIN LAKES AND ITS
RELATIONSHIP TO GROUNDWATER CONTAMINATION FROM THE KL
AVENUE LANDFILL, KALAMAZOO COUNTY, MICHIGAN

by

Joseph S. Hobin

A Thesis
Submitted to the
Faculty of The Graduate College
in partial fulfillment of the
requirements for the
Degree of Master of Science
Department of Geology

Western Michigan University
Kalamazoo, Michigan
June 1993

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The objectives of this investigation were to explain the hydrogeology of Bonnie Castle and Dustin Lakes and to assess the water quality of the lake environments with respect to possible impact from the KL Avenue Landfill.

The surface water/groundwater relationship was determined by the installation of mini-piezometer nests and seepage meters at selected study stations along the shoreline of each lake. Field data were augmented with groundwater and surface water chemical analyses, lake depth profiles and geologic cross-sections.

The result of this research was the characterization of Bonnie Castle Lake as a perched recharge lake and Dustin Lake as a flow through lake. Laboratory analysis of seven selected chemical parameters performed on groundwater and surface water samples collected during the summer of 1985 indicated that the lake environments did not appear to have been adversely impacted from landfill contaminants.
ACKNOWLEDGEMENTS

I am grateful to many people whose guidance, advice, and information were indispensable in completion of this project.

My appreciation goes to my committee members, Dr. Richard Passero, Chairman, Dr. John Grace, and Dr. W. Thomas Straw. Their guidance, interest, patience and friendship will always be remembered.

I would also like to thank fellow graduate students Neal Carey and Gerard Martin and the lake area residents, especially the Snow family, the Meyers family and Rheta Selnar.

I would like to dedicate this thesis to my parents, Robert and Mary Hobin whose love and sacrifices gave me the peace of mind and assistance to complete my education. I shall repay them by following their example with my own children.

Lastly, I want to thank my wife, Yolanda for her love and patience throughout it all.

Joseph S. Hobin
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The hydrogeology of Bonnie Castle and Dustin Lakes and its relationship to groundwater contamination from the KL Avenue Landfill, Kalamazoo County, Michigan

Hobin, Joseph Stephen, M.S.
Western Michigan University, 1993
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CHAPTER I

INTRODUCTION

This thesis is one component of an ongoing investigation and monitoring program concerning the impact on the local environment from the now closed KL Avenue Landfill, hereinafter referred to as the KL Landfill. The thesis deals with the hydrogeology and water quality of the groundwater and two bodies of surface water, Bonnie Castle Lake and Dustin Lake in the KL Landfill area.

The primary objective of the study was to determine the hydrogeologic relationships, recharge, discharge or flow through between the lakes and the groundwater. Mini-Piezometers, seepage meters, water chemistry data, geologic-cross sections, lake depth profiles, well logs and flow nets were used as a basis for understanding the hydrogeologic nature of the lakes.

A secondary objective of the study was to determine whether the lakes' water quality has been impacted from the KL Landfill, and if not, whether that possibility exists in the future. Surface water and groundwater samples were collected and analyzed for seven chemical parameters; pH, specific conductance, hardness, iron, chloride, nitrate and chromium. Relating each lake's water chemistry to the wa-
ter chemistry of the landfill's contaminant plume gave indication of whether the lake has been impacted by the KL Landfill's leachate.

Geographical Location

The KL Landfill is located in section 21, T.2S., R.12 W., Oshtemo Township, Kalamazoo County, Michigan (Figure 1). It is about seven miles west of the City of Kalamazoo, one-half mile east of the intersection of KL Avenue and South 4th Street and one-half mile south of the junction of Almena Drive and West Main Street (M-43).

Bonnie Castle Lake is located about 300 feet northeast of the KL Landfill and 1500 feet south of West Main Street in the southeast 1/4 of section 16 and the northeast 1/2 of section 21, T.2S., R.12 W. Dustin Lake is located about one mile west of the KL Landfill, and 1.6 miles southwest of Bonnie Castle Lake between Almena Drive and KL Avenue, in the northwest 1/4 of section 20, T2., R.12 W.

Land Use

In general, land use in the area surrounding the study site is agricultural and suburban residential. Large tracts of woodlands consist of deciduous and coniferous trees interspersed among scrub vegetation.

In addition to the KL Landfill, there are several other near-vicinity potential sources of contamination. M-43
Figure 1. Location of the KL Landfill Site, Oshtemo Township, Kalamazoo County.

and KL Avenue border the study area to the north and south respectively. Surface runoff of de-icing salt and other road contaminants have been shown to elevate levels of chloride, sodium, lead and organic contaminants in soil, surface water and groundwater. Agriculture yields nutrient fertilizers, biocides and leachate from animal feed lots to the surface water and groundwater. Thus, elevated levels of nitrates, phosphates and organic contaminants may occur in the local water supply.

Topography

The study site is located on the inner ridge of the northeast trending Kalamazoo Moraine. The area exhibits the classical knob and kettle morainal topography. Relief is variable, ranging from tens of feet to more than 140 feet.

The topography of the KL Landfill includes a few small hills and three closed depressions with the elevation ranging from 955 to 980 feet above mean sea level (MSL). The area northeast of the landfill slopes down to a closed depression containing Bonnie Castle Lake at an elevation of 960 feet above MSL. The highest point in the study area is near the intersection of West KL Avenue and South 4th Street where the elevation is 990 feet above MSL. West of South 4th Street elevations decrease rather sharply to Dustin Lake at 850 feet above MSL.
Climate

In a hydrogeologic study the importance of climate should not be understated. Surface water and groundwater resources, the use of road salt, contamination from landfill leachate, agricultural productivity, seasonal turnover in lakes, fluctuations of lake levels, dilution of subsurface contaminant plumes, amount of surface runoff and several other factors are, in large part, controlled by climate.

Kalamazoo County is located at 42 degrees north latitude in the interior of the North American continent resulting in strong seasonal variations in temperature. The climate in the area is modified by Lake Michigan. Generally, the effect of prevailing westerly winds across Lake Michigan causes a moderation in temperature declines in the fall and increases in the spring, and an increase in the total annual precipitation.

Climatic records collected since 1867 at the Kalamazoo State Hospital Weather Station are considered to be representative of the county. Records indicate that the average annual temperature is 49.7 degrees (F). Mean monthly temperatures range from 24.7 degrees (F) in January to 74.0 degrees (F) in July.

Annual precipitation at the Kalamazoo State Hospital Weather Station averaged about 34.3 inches a year from 1940
to 1969. However, more recent years have had slightly higher totals. About two-thirds of the annual precipitation falls between May and September, which are the five warmest months of the year. The average seasonal snowfall in Kalamazoo County is 69.7 inches. The mean lake evaporation for southwest Michigan is 30 to 32 inches per year (Water Information Center Inc., 1955).

Monthly means of temperatures and precipitation for the duration of the study period are given in table 1. These figures were recorded by the Michigan Weather Station at the Kalamazoo State Hospital.

Table 1

Temperatures and Precipitation From 1/85 to 9/85 for Kalamazoo County, Michigan

<table>
<thead>
<tr>
<th>Month</th>
<th>Year</th>
<th>Average Temperature</th>
<th>Average Precipitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>1985</td>
<td>20.9 F</td>
<td>4.13&quot;</td>
</tr>
<tr>
<td>February</td>
<td>1985</td>
<td>25.7 F</td>
<td>3.80&quot;</td>
</tr>
<tr>
<td>March</td>
<td>1985</td>
<td>41.0 F</td>
<td>3.42&quot;</td>
</tr>
<tr>
<td>April</td>
<td>1985</td>
<td>55.0 F</td>
<td>4.03&quot;</td>
</tr>
<tr>
<td>May</td>
<td>1985</td>
<td>64.3 F</td>
<td>2.52&quot;</td>
</tr>
<tr>
<td>June</td>
<td>1985</td>
<td>65.0 F</td>
<td>2.12&quot;</td>
</tr>
<tr>
<td>July</td>
<td>1985</td>
<td>72.7 F</td>
<td>4.11&quot;</td>
</tr>
<tr>
<td>August</td>
<td>1985</td>
<td>68.1 F</td>
<td>3.96&quot;</td>
</tr>
<tr>
<td>September</td>
<td>1985</td>
<td>64.2 F</td>
<td>3.03&quot;</td>
</tr>
</tbody>
</table>

History of KL Landfill

The KL Landfill originated as the Oshtemo Township dump in the early 1960's. Prior to 1965, solid waste was simply discarded on the original 23 acre site. Following
1965, all landfill operators were required to cover dumps with at least six inches of soil at the end of each day of operation.

Because of the higher operational costs incurred by regulatory requirements, and the need for a large, county-wide disposal site, Kalamazoo County entered into a "Sanitary Landfill Agreement" with Osthemo Township. Under the agreement the county would assume control of the landfill, along with expanding the original 23 acres to a total of 87 acres, as shown in Figure 2.

To maximize the lifespan of the landfill, a new contractor was hired in 1970. The new contractor employed the "trench-area" method of waste disposal, whereby trenches were dug, filled with refuse, and the refuse was compacted by the weight of heavy bulldozers. In accordance with regulatory requirements, the soil removed to form the trench was used as a cover material at the end of the day.

During the early and mid-1970's, the KL Landfill was considered a model landfill operation. Other Michigan counties interested in upgrading or developing their own landfills were given tours of the KL Landfill in order to view what was considered a first class landfill operation.

In the late seventies, plans to again enlarge the KL Landfill were underway. Due in large part to the proposed expansion, a small opposition group of local citizens was formed. The Kalamazoo Gazette reported that leachate from
Figure 2. Map Showing Acreage of the KL Avenue Landfill Site.

the KL Landfill was seeping into Bonnie Castle Lake and the citizens group demanded an early closure of the Landfill.

During the years from 1976 to 1978 the State of Michigan monitored and reviewed the landfill for possible violations and landfill induced pollution. In April of 1979, several local residential wells were shown to contain various volatile hydrocarbons and the State ordered the immediate closure of the KL Landfill. In addition, the state ordered the County to prepare a plan for closing and stabilizing the landfill. The primary goal of this plan was to cover the landfill, thus minimizing precipitation infiltration.

Several close out plans were studied and in February 1980, a decision was made. The proposed plan consisted of several measures, the most important of which was the application of bentonite clay to the landfill's surface. Bentonite is applied in a granular form and mixed with the existing cover materials. Upon becoming wet, it swells to retard water percolation. Other measures included planting vegetative ground cover to help stabilize an upper two feet of the landfill surface, construction of drainage channels to direct runoff and prevent soil erosion, and installing nine gas vents to allow the expected accumulation of methane to escape. The entire closeout plan took three months to complete at a cost of approximately $105,000.

In the spring of 1980, shortly after the completion of
the KL Landfill Closeout Plan, the County initiated a monitoring program. The monitoring program was designed to evaluate the effectiveness of the Closeout Plan by monitoring groundwater quality, surface water quality, landfill methane production, and landfill surface erosion. At that time, it was envisioned that the monitoring program would continue through 1986.

The monitoring program included the following:

1. The installation of 14 monitoring wells to form, with existing residential wells, a network of sampling sites for groundwater quality, subsurface plume analysis and evaluation of the plume over time.

2. The installation of seven methane gas monitoring systems on the landfill site.

Significance of Study

This study is significant because it increases our understanding of each lake's position in a groundwater flow system possibly impacted from the KL Landfill. In addition, it examines the comparison of two lakes having different hydrologic settings within the same groundwater flow system in a humid, temperate, glacially modified environment.
CHAPTER II
REGIONAL GEOLOGY

Bedrock Geology

Kalamazoo Township is located on the southwestern flank of the Michigan structural basin. Within the study area, the bedrock is overlain by up to 600 feet of Pleistocene glacial deposits. Below the glacial sediments lies the early Mississippian Coldwater Shale (Shah, 1972).

The Coldwater Shale dips gently to the northeast and consists of about 900 to 1,000 feet of soft gray shales (Shah, 1972). The shale is relatively impermeable and functions as an aquiclude in this region except locally where a lime facies produces small amounts of water. The Coldwater Shale formation overlies approximately 550 feet of the late Devonian Ellsworth and Antrim Shales (Straw, 1976) which also function as aquicludes.

The bedrock topography in Oshtemo Township ranges from less than 300 feet to more than 850 feet above MSL. This relatively high relief is due to erosion by streams during interglacial periods and by ice modifications from the Wisconsinan glacial advance, approximately 20,000 years before the present (Shah, 1972).

A major bedrock ridge trends southwest from sections
Figure 3. Bedrock Topography Map of Oshtemo Township, Kalamazoo County.

18 and 19 through sections 3 and 4 (Figure 3). A bedrock valley extends to the southwest 1/4 of section 22, and passes under the KL Landfill (Wilkins & Wheaton, 1981). The bedrock topography appears to have had a strong control on the deposition of the glacial drift. Stream valleys eroded into the Coldwater formation served as channels for both glacial ice and proglacial meltwater streams.

Glacial Geology

The bedrock in Kalamazoo County is covered with glacial drift deposited during the Pleistocene Epoch. The thickest deposits of glacial drift occur where the Kalamazoo Moraine overlies pre-Pleistocene bedrock valleys, which is the case in the area of the KL Landfill.

Glacially deposited sediments are principally clastics, ranging from fine clays to boulders. The distribution and sorting of these sediments is largely dependent on their mode of deposition. The primary divisions of glacial drift sediments are till or nonstratified drift and stratified drift (Flint, 1971).

Till is a heterogeneous sediment deposited directly by the melting glacial ice. Till may be primarily clay, primarily boulders, or any combination of these and the sizes in between (Flint, 1971). Moraines, such as the Kalamazoo Moraine, are essentially accumulations of till and outwash deposited at the ice margin while the glacier was at a
Stratified drift or washed drift in comparison to till is well sorted. Stratified drift is divided into two major subgroups, ice-contact drift and proglacial sediments (Flint, 1971). Ice-contact drift is material washed from the ice by meltwater and deposited upon or adjacent to the ice. Examples of these deposits are kames and eskers. Proglacial sediments are deposited beyond the ice front, they are carried by meltwater streams, and consist mainly of sorted sands and gravels called outwash. Proglacial sediments laid down in standing bodies of water such as kettle lakes are called glaciolacustrine sediments and are typically clays.

Three of the above types of glacial sediments, till, outwash and glaciolacustrine clay occur in the subsurface drift of the study area, as shown in Figures 4 and 5.

The KL Landfill is located on the crest of the recessional Inner Kalamazoo Moraine, which trends from the southwest to the northeast across the northwest quarter of Kalamazoo County, as shown in Figure 5. This morainal ridge consists of till with interlayered outwash. The moraine was laid down by the Lake Michigan Ice Lobe during a stand still in its retreats and readvances as the lobe withdrew to the northwest. Locally, in the vicinity of the KL Landfill, the morainal ridge's ice contact material was incised by meltwater streams emanating from the ice front.
Figure 4. Glacial Geology Map of Kalamazoo County.

Figure 5. Glacial Landforms of Kalamazoo County.

as it melted back to the northwest toward Lake Michigan. The above description of local glaciation, deglaciation and geomorphology was based mainly on work done by Lovan (1977), Straw (1976), and Shah (1972).

In Osthemo Township this deposition resulted in 100 to 600 feet of glacial drift. The glacial drift consists of a heterogenous mix of interspersed discontinuous layers of till, outwash, glacial lake bed sediments, and proglacial stream deposits, overlying the relatively high relief surface of the Coldwater Shale bedrock (Figure 3).

Bonnie Castle Lake, adjacent to the landfill, is also on the morainal crest. It is considered a kettle lake. The lake was formed when a detached ice block was left by the glacier as it withdrew to the northwest. The ice block was buried by outwash from the meltwater streams. After a time the ice block melted, leaving in its place a depression. The formation of kettle lakes is depicted in Figure 6. According to the Wilkins and Wheaton report of 1981, the lithological units underlying the 300 foot distance between the KL Landfill and Bonnie Castle Lake is composed of approximately 25 feet of sand and gravel underlain by approximately 50 feet of clay.

Dustin Lake located one mile due west of the KL Landfill is also a kettle lake. Wilkins and Wheaton in 1980 investigated the glacially deposited sediments lying between the KL Landfill and Dustin Lake by use of gamma ray
logs, drillers' records, split-spoon samples, and well cuttings. They were able to recognize eight distinct units. These units are listed below as follows, from top to bottom:

Unit 1. A till (clay, sand and gravel) unit that is exposed at the surface over much of the area. The unit is discontinuous locally, it ranges in thickness from 0 to 30 feet.

Unit 2. A zone of interbedded outwash and clay-rich sediments that range in thickness from 20 to 58 feet.

Unit 3. A clay-rich unit (till) that is apparently discontinuous, it ranges in thickness from being completely absent to 60 feet.

Unit 4a. A thick (105 to 145 feet) zone composed of glacial outwash, with a discontinuous middle clay-rich unit (till) that ranges from 5 to 23 feet thick. The outwash materials in this zone function as the shallow aquifer in this area. The unit seems to be a single, continuous hydrologic entity.

Unit 4b. A bed of lake clay, composed dominantly of silt and clay, it ranges in thickness from 5 to 10 feet.

Unit 4c. A unit of outwash, which ranges in thickness from 30 to 70 feet.

Unit 5. A thick (37 to 178 feet) zone of glacial till composed of clay, sand, gravel, and boulders.

Unit 6. A zone of glacial outwash that lies on the
bedrock surface. It ranges in thickness from 10 to 30 feet.

Unit 4a. at an approximate depth of 130 feet consists of outwash and functions as the shallow aquifer. It was this aquifer, which in April of 1979 first gave evidence of the KL Landfill induced contamination. Unit 6 at an approximate depth of 400 feet also consists of outwash, it was this deep aquifer which was tapped to replace the polluted wells lying in the uppermost aquifer. Unit 4b and Unit 5 which lie at respective depths of approximately 150 and 200 feet, are both composed of till and hence act as aquicludes. It was due to the presence of these two low conductivity till layers that the lower aquifer remained uncontaminated and useful.
Figure 6. Origin of Glacial Landforms in Kalamazoo County.

CHAPTER III

REVIEW OF PERTINENT LITERATURE

Groundwater Flow

The following discussion of groundwater flow is based primarily on the works of Davis and DeWiest (1966), Fetter (1980) and Freeze and Cherry (1979).

Under ordinary circumstances groundwater flow is from areas of recharge, usually topographic highs, towards areas of discharge, which are commonly topographic lows. Normally, the water table is at some depth below the surface in recharge areas, and at or near the surface in discharge areas. The symmetry of this described system creates vertical boundaries beneath valleys and ridges across which there is no flow, these boundaries are referred to as groundwater divides.

Topography and the basin depth-to-width ratio can create complex systems of groundwater flow. Where local relief is slight, such as on a flat rolling plain, only regional groundwater flow systems will develop. Hilly topography (such as is encountered in the study area) can produce a series of groundwater flow systems: local, intermediate and regional. Groundwater flow in a local system has the recharge area at a topographic high and its discharge
area at an adjacent topographic low. Deeper flow occurs in an intermediate system, with one or more local systems located between its primary recharge and discharge areas. A regional flow system lies at the bottom of the basin, with groundwater flow beneath its entire area.

Water Quality

The following discussion of water quality is based primarily on the works of White, Hem and Waring (1963), Back (1960), Cherry, Gillham and Pickens (1975), Kemmer (1979), Freeze and Cherry (1979), and Fetter (1980).

Precipitation reaching the earth is composed of only small amounts of dissolved solutes, as this water percolates underground it tends to progress towards a chemical equilibrium by reacting with the soil and rock. Thus, ordinarily, higher concentrations of dissolved constituents are found in groundwater than in surface water. The chemistry of natural groundwater is controlled by the lithology of the deposits through which the water flows, and by the direction of the flow path within the geologic framework. The flow path is determined by the hydraulic gradient, permeability of the sediments and the boundaries of the hydrologic system (Back, 1960). Where an excess of soluble material exists the dissolved content of the water will increase and the chemical system moves closer to equilibrium, as the flow path continues. Once chemical equilibrium is
attained, groundwater chemistry is relatively constant over time, due in large part to the comparatively low groundwater flow rates. In steady state groundwater domains, in an absence of aquifer contamination, the water chemistry remains essentially constant at a point (Fetter, 1980).

In the last few decades much of the focus in groundwater studies has changed from problems of groundwater sup­ply to the more complicated problem of groundwater quality. The introduction of contaminants into water supplies has been shown to be related to rainfall, the geological nature of the watershed or underground aquifer, and the activities of nature and the human population (Kemmer, 1979). Land­fill leachate can contain very high concentrations of inor­ganic and organic materials. The volume of leachate pro­duced is a function of the amount of water percolating through the refuse, thus humid climates produce more leach­ate than arid climates (Fetter, 1980).

Groundwater pollution may be defined as the artifi­cially induced degradation of natural groundwater quality. Groundwater is the transporting medium for the contaminant solutes, and attenuation of the contaminant solute by the subsurface material is the retarding mechanism. Pollutants in groundwater tend to be removed or reduced in concentra­tion with time and distance traveled. Attenuation of a solute in a groundwater flow system refers to the concentra­tion reduction that occurs due to the combined effects
of filtration, adsorption, ion exchange, chemical processes, microbiological decomposition and dilution. These processes over time, cause a natural decrease in both the size and concentration of a contaminant plume.

Filtration removes suspended particles, as well as precipitates formed by chemical reactions. Most filtration however, takes place between the ground surface and the top of the water table.

Adsorption can be significant in groundwater pollutant attenuation. Under certain conditions, ions attached to a solid surface may be exchanged for other ions in solution. This process is known as ion exchange. The surfaces of many solids, especially clays, have an electrical charge. The electrical charge may be satisfied by adsorbing a charged ion. The adsorption process depends on the type of pollutant and the chemical and physical properties of the solution and the aquifer materials. The presence of clay is a major factor.

Chemical processes, of which precipitation is one, can remove ions in solution and thus lower contaminant concentration. Oxidation and reduction can occur in the subsurface and change complex compounds to simpler less hazardous compounds. Volatilization and radioactive decay can also act to decrease chemical concentration over time in certain circumstances.

Fortunately, most pathogenic microorganisms undergo
microbiological decomposition and do not persist in soil. Field studies indicate that pathogens are largely removed by passage through as little as one meter of soil, provided reasonable amounts of silt and clay are present.

Pollutants in groundwater flow systems tend to become diluted in concentration due to hydrodynamic dispersion. Dilution is the most important attenuation mechanism for pollutants after they reach the water table (Todd, 1980). Hydrodynamic dispersion is the process by which groundwater containing a solute is diluted with uncontaminated groundwater as it moves through an aquifer (Fetter, 1980). This mixing produces a longitudinal and lateral extension of the contaminant, thus the volume increases and the concentration decreases with distance traveled. The spreading of the solute in the direction of bulk flow is known as longitudinal dispersion. Spreading in directions perpendicular to the flow is called transverse direction. Longitudinal dispersion is normally much stronger than lateral dispersion (Freeze and Cherry, 1979).

The movement of solute contaminants is essentially controlled by two main physical parameters, groundwater velocity and dispersion. Dispersion is essentially a microscopic phenomenon caused by a combination of molecular diffusion and hydrodynamic mixing occurring with laminar flow through porous media (Todd, 1980). The problem is to determine these parameters in the field. Once this is ac-
complished, determination of the plume's geometry may be possible.

Groundwater - Lake Water Interaction

Relatively recent field studies (Allred et al., 1971; Born et al., 1974, 1979; Lee, 1972; McBride and Pfannkuck, 1975) have demonstrated significant interchange between lakes and groundwater bodies. From these studies and others it appears that lakes, rather than being isolated from groundwater bodies by lake bottom sediments, are most often in close connection with them, and thus are integral parts of the groundwater flow systems.

Regime dominance is a descriptive term pertaining to the relative importance of groundwater in a total lake water budget. This criterion is based on the ratio of groundwater inflow or outflow to total inflow or outflow. Lakes can be classified in terms of their regime dominance as groundwater dominated or surface water dominated (Born et al., 1979).

There are three possible lake-groundwater interactions (Born et al., 1974). Lakes situated in groundwater recharge regions are known as recharge lakes, and contribute water through their bottoms to the groundwater. Lakes situated in groundwater discharge regions are known as discharge lakes, and gain water through their lake bottom from the groundwater. In areas with lateral groundwater
flow, lakes will often gain groundwater on one side and lose groundwater on the other side. Lakes such as this are known as flow-through lakes. In addition, some lakes are completely isolated from the groundwater. These are perched lakes. Perched lakes are important here because they are not uncommon in the glaciated northern mid-west.

McBride and Pfannkuck (1975) and Lee (1972) showed that seepage into or out of lakes tends to be concentrated near the shore, and decreases with increasing distance from the shore. In many cases the rate of decrease is exponential. In Lee's (1972) study of Lake Sallie, Minnesota, he noted that in this two kilometer wide lake, 50% of the discharge occurs within 17 meters of shore, 90% occurs within 60 meters of shore and 99% occurs within 120 meters of shore. It was shown that this holds true only where the diameter of the lake is at least roughly comparable to the thickness of the underlying permeable lake bottom sediments. When lakes have diameters much less than the thickness of the underlying bottom sediments, seepage into or out of the lake occurs throughout the entire lake bottom. The two lakes in this study have diameters greater than the thickness of their underlying permeable sediments, thus, it would be expected that seepage is concentrated in the near-shore shallow zone.
CHAPTER IV

INVESTIGATIVE METHODS

The purpose of this study is twofold. The primary objective is to define the hydrologic relationship of Bonnie Castle Lake and Dustin Lake to the groundwater. The second objective is to attempt to determine if either of these surface water bodies has been impacted by groundwater degraded by KL Landfill leachate.

Determination of Hydraulic Head

As shown in Figure 7, four study stations were established along the shoreline of each lake, stations 1, 2, 3 and 4 along Dustin Lake and stations 5, 6, 7 and 8 along Bonnie Castle Lake. The location of these study stations was assigned by proximity to the KL Landfill and to divide the shoreline into four approximately equally spaced station sites.

Station 2 on Dustin Lake was positioned to intercept the contaminant plume believed to be migrating due west from the KL Landfill (Wilkins & Wheaton, 1981). Station 6 on Bonnie Castle Lake was positioned close to the KL Landfill.

Each study station consisted of a "nest" of five mini-
Figure 7. Map Showing Location of Study Stations and Regional Groundwater Divide.

piezometers, hereafter referred to simply as piezometers. Piezometers can be used to determine hydraulic head (h), and thus the direction of groundwater flow. The piezometers used were modified from the design employed by Lee and Cherry (1978). A total of 40 piezometers were emplaced around the two lakes. Each piezometer consists of a 1/2 inch I.D. PVC (polyvinylchloride) pipe nine feet long. One end of each pipe was sealed with a tight fitting PVC cap. 44 1/2-inch I.D. holes were drilled in the bottom six inches of the pipe and wrapped with a fine nylon mesh netting to prevent fine sediments from entering the piezometer. Figure 8 illustrates the piezometer and piezometer nest design.

The five piezometers were installed along a line at distances of 5, 10, 15 and 20 feet into the lake. Another piezometer was emplaced on land, 10 feet up the bank.

Each piezometer was manually installed. A 10 foot long, 1 inch I.D., rigid steel pipe, with a loose fitting cap on one end, was hammered, with a pipe driver into the sediment to a distance of approximately six feet. At this point a piezometer was introduced into the steel pipe. The steel pipe was then slowly extracted leaving behind the cap, and the piezometer, screened at a depth of approximately six feet. To aid the sediment in closing around the piezometer the slow steel pipe extraction was followed by foot compaction of sediments around the piezometer.
To insure that the position of each piezometer remained fixed each one was sited and marked with a hand level to a permanent fixed point on land. Periodically, throughout the study, piezometers were checked to determine if the position had been altered. Only two incidences of piezometer movement were noted and corrected.

The piezometer nests as described above were installed in numerical order, station number 1 being emplaced February 21, 1985 and station number 8 being emplaced on March 9, 1985. At the time of installation the following readings were taken: the depth of the piezometer in the sediment, the length of the piezometer above the lake surface, the depth of the water at each individual piezometer and the initial hydraulic head reading.

Hydraulic head (h) was defined as the difference between the water level in the piezometer and the level of the lake surface. The water level within the non-transparent piezometer was determined by use of a conventional electrical tape. Each piezometer reads hydraulic head at that point in the saturated zone in which the piezometer is screened with the six inches of mesh covered 1/4 inch I.D. holes.

In terms of groundwater lake interactions there are three possible hydraulic head readings: positive hydraulic head, negative hydraulic head and equivalent hydraulic head. Positive hydraulic head is indicated when the water
Figure 8. Diagram Showing Piezometer Nest Configuration.
(Note: Figure Not to Scale)
level in the piezometer is higher than the surface of the lake. This is shown in Figure 9 as the lines within the piezometers indicating static water levels in feet above MSL. Positive hydraulic head means that the potential energy of the water increases with increasing depth. Consequently the groundwater is flowing upward and discharging into the lake. This is known as a discharge lake. Figure 9 is a flow net from Station 2, representing actual discharge conditions.

Negative hydraulic head is indicated when the water level in the piezometer is lower than the surface of the lake. This is shown in Figure 10 as the lines within the piezometers indicating static water levels in feet above MSL. Negative hydraulic head means that the potential energy of the water decreases with increasing depth. Consequently the lake water is flowing out of the lake and to the groundwater. This is known as a recharge lake. Figure 10 is the flow net from Station 8, representing actual recharge conditions. Equivalent hydraulic head is indicated when the water level in the piezometer is at the same level as the surface of the lake. Equivalent hydraulic head implies a static situation, one in which neither discharge or recharge is taking place at the time of the hydraulic head reading.

Head measurements to define each station along the lake as either a recharge, discharge or static condition
Figure 9. Diagram of Study Station #2, on Dustin Lake, Discharging Flow Net (Note: Figure Not to Scale)
Figure 10. Diagram of Study Station #8, on Bonnie Castle Lake, Recharging Flow Net
(Note: Figure Not to Scale)
were taken throughout the course of the study. From March 1985 through July 1985, hydraulic head readings from all 40 piezometers were taken on 12 dates. Four of these 12 readings took place on consecutive days after a significant rainfall to examine the effect of a major precipitation event on the lake's relationship to the groundwater. The summary and explanation of these findings will be presented in Chapter V.

**Determination of Seepage Flux**

In addition to the measurement of hydraulic head, seepage meter readings were also taken at each station. These readings would validate the interpretations based on the piezometer data as to the recharge-discharge nature of the lakes. Furthermore, the seepage meters permit determination of seepage flux and darcy velocity Q.

Seepage flux is the volume of water per unit time and per unit area of lake bottom entering or leaving the lake bottom. Seepage flux between the groundwater and the overlying surface water can be measured directly by covering an area of bottom sediment with an open bottomed container and measuring the time and change of water volume in a collection bag connected to that container (Lee, 1977).

Two of these devices, known as seepage meters, were designed with modifications from the seepage meter described by Lee (1977). A clean, 30-gallon, metal barrel, 73
cm in height, was cut in half yielding two end sections. The top of each end section had a small bore tube adapter welded onto it. The adapter serves as a connection for the plastic water volume collection bag. The seepage meter is pushed slowly into the lake bottom sediments. It is important that the seepage meter be embedded at least three inches into the lake bottom to insure a good seal and thus a closed system. It is also important that the entire collection bag be submerged to maintain the same piezometric head in the seepage meter as in the lake water. The seepage meter and its proper placement is illustrated in Figure 11.

Once the seepage meter is correctly installed on the lake bottom, the time is noted and the collection bag with a known volume of water and no air is connected. After several hours, the bag is removed, and its volume gained or lost is noted. In a discharge situation any water that seeps upward through the area of lake bottom covered by the seepage meter will be trapped and water will be forced into the collection bag. In a recharge situation any water that seeps downward through the area of lake bottom covered by the seepage meter will cause water to be lost from the collection bag, since the system is closed.

Seepage flux is arrived at by calculating the volume change per hour and multiplying that value by a factor of 2.6 to convert the area covered by the seepage meter (0.170
Figure 11. Diagram Showing Operation of Seepage Meters.
m²) into square meters. Seepage flux is thus expressed as cm³/hr/m².

The Darcy velocity (Q) is calculated from the relation:

\[ Q = 0.043 \frac{V}{t} \]

where V is the volume of water (ml) entering or leaving the collection bag, and t is the elapsed time in minutes. The Darcy velocity is expressed as micrometers per second (1 um/s = 8.64 cm/day). The factor 0.043 converts units of time, volume, and area covered by the seepage meter (0.170 m²) to equivalent units of velocity (um/s).

A seepage meter was emplaced at each station, and over the course of the investigation a minimum of five seepage flux readings were taken. In all cases the resulting data remained consistent for each station, and it confirmed the findings observed with the piezometer's hydraulic head measurements.

**Soil Sampling**

To better evaluate the hydrogeology of the two lakes, eight soil borings were taken. A soil boring two inches in diameter and approximately six feet deep was advanced at each study station. All samples were collected with a six-inch bucket auger. As each bucket sample was removed it was placed in a zip lock plastic bag, assigned a field classification, and marked as to its collection depth.
The eight soil cores were brought back to the laboratory and examined by the author. In general appearance, color, and texture the four cores of each lake were very similar. An upper fine, organic rich, dark brown-black sandy soil ranged from approximately 17 to 24 inches in depth. The lower material consisted of a coarser light brown-yellow sandy soil which existed below the upper material to a depth of approximately 72 inches.

Two soil cores from each lake were chosen as representative of the lake bottom sediments. These four cores were subjected to an investigation, which included grain-size analysis by mechanical and hydrometer methods to classify the soils according to the U.S. Department of Agriculture Textural Classification (see Figure 12).

Station 2 core was chosen from Dustin Lake because it was the eastern most station and the closest Dustin Lake station to the KL Landfill. The second core chosen for study was from Station 4, the western most Dustin Lake Station. The Station 6 core was chosen from Bonnie Castle Lake because it was the western most Bonnie Castle station and the closest station to the KL Landfill. The fourth core chosen for study was from station eight, the eastern most Bonnie Castle station. Eight separate analyses were run including the four previously-mentioned upper soil layers from each station and the four bottom soil layers from each station.
Grain-size analysis is an attempt to determine the relative proportions of the different grain sizes which make up a given soil mass. This procedure is a commonly used method for soil classification (Bowles, 1970). Each of the eight samples were oven dried at a temperature of 130 degrees fahrenheit for 48 hours. Then a representative split sample was ground up with a mortar and pestle and weighed into manageable sample sizes ranging from 221 to 488 grams. After weighing, each soil sample was dry sieved through the #4, #10, #20, #40, #60, #100, and #200 U.S. Standard Mesh Sieves. Sieving was done by placing the stack of sieves in a mechanical sieve shaker (Ro-Tap) for ten minutes. The fines which passed through the #200 sieve were weighed and set aside to be used in the hydrometer analysis.

After shaking, the weight of soil remaining on each sieve was obtained. The percent retained on each sieve was determined by dividing the weight retained on each sieve by the initial sample weight. The percent passing was determined by subtracting the percent retained on each sieve as a cumulative procedure. The data from the above procedure were coupled with the hydrometer analysis data to plot a grain-size gradation curve for each sample (Appendix A).

The fine material which passed through the #200 sieve was the soil included in the hydrometer analysis. This procedure utilizes the relationship among the velocity of fall
of spheres in a fluid, the diameter of the sphere, the unit weights of the sphere and of the fluid, and the viscosity of the fluid as expressed by Stokes, (ca. 1851).

Each of the eight fine soil samples was mixed with 125cc of four percent calgon solution and allowed to stand for 16 hours. The solution was then poured into a graduated cylinder and enough deionized water added to bring the volume to 1000 ml. The calgon solution was added to prevent flocculation of clay and silt particles. After carefully agitating the sample for one minute, hydrometer readings and temperatures were taken at elapsed times of 1, 2, 3, and 4 minutes with a standard 152H hydrometer. This procedure was repeated until two sets of readings were in agreement. Then hydrometer and temperature readings were taken at 8, 15, and 30 minutes, and 1, 2, 4, 8, 16, 24, 48, and 96 hours.

From each grain-size gradation curve a coefficient of uniformity was calculated. The coefficient of uniformity (Cu = D60/D10) characterizes the distribution of particles in a soil sample. A uniform or well-sorted soil has a low Cu value, while a poorly-sorted soil has a high Cu value. D60 is the particle size diameter at the 60th percentile as observed on the grain size gradation curves. The Cu values for each station's soil core segment are listed in Table 2. Refer to Appendix A for the grain size gradation curves.
Sand—2.0 to 0.05 mm. diameter
Silt—0.05 to 0.002 mm. diameter
Clay—smaller than 0.002 mm. diameter

Figure 12. U.S. Department of Agriculture Textural Classification Chart.

Source: U.S. Department of Agriculture
Table 2

Grain Size Percentages and Coefficients of Uniformity

<table>
<thead>
<tr>
<th>Study Station</th>
<th>Core</th>
<th>Sand</th>
<th>Silt</th>
<th>Clay</th>
<th>Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>upper</td>
<td>88%</td>
<td>9%</td>
<td>3%</td>
<td>4.3</td>
</tr>
<tr>
<td>2</td>
<td>lower</td>
<td>81%</td>
<td>16%</td>
<td>3%</td>
<td>4.8</td>
</tr>
<tr>
<td>4</td>
<td>upper</td>
<td>91%</td>
<td>7%</td>
<td>2%</td>
<td>3.6</td>
</tr>
<tr>
<td>4</td>
<td>lower</td>
<td>96%</td>
<td>3%</td>
<td>1%</td>
<td>2.2</td>
</tr>
<tr>
<td>6</td>
<td>upper</td>
<td>87%</td>
<td>10%</td>
<td>3%</td>
<td>4.4</td>
</tr>
<tr>
<td>6</td>
<td>lower</td>
<td>95%</td>
<td>4%</td>
<td>1%</td>
<td>4.2</td>
</tr>
<tr>
<td>8</td>
<td>upper</td>
<td>93%</td>
<td>6%</td>
<td>1%</td>
<td>3.7</td>
</tr>
<tr>
<td>8</td>
<td>lower</td>
<td>97%</td>
<td>3%</td>
<td>0%</td>
<td>3.3</td>
</tr>
</tbody>
</table>

Water Sampling

Groundwater samples were collected from piezometers to determine whether or not the water chemistry would substantiate the interpretations as to the recharge-discharge nature of each lake, to determine if the landfill has impacted either of the lakes and to get an estimate of the lake's current water quality. Seven water quality parameters were obtained: pH, specific conductance, hardness, iron, chloride, nitrate and chromium.

The water quality analysis work was done in the summer of 1985. During the period between July 13 and September 25, 1985, from three to six separate chemical analyses for each chemical parameter was performed by the author. Ten separate areas were tested. Analytical testing was performed on groundwater from each of the eight stations and
surface water from each lake.

On the morning of a "sampling day" all the piezometers were purged of at least three times their volume of water to obtain representative groundwater samples. Purging was done with a small manual hand pump connected to a length of flexible plastic tubing, which was introduced into the piezometer. Each station had its own designated, marked length of tubing to prevent cross-contamination of samples between stations. Samples were collected in new, clean, 75cc glass bottles with tight fitting, plastic, screw on style caps. Each bottle was permanently marked for either its assigned study station or lake. The groundwater samples were acquired by introducing the station's flexible plastic tube into the piezometer. The exposed end was then clamped tightly and the water filled tubing extracted. This method of groundwater sampling has no effect on pH due to negative pressure by vacuum pumping. Lake water samples were taken from the middle area of each lake at a depth of at least five feet below the lake surface.

Field measurement of pH, specific conductance and temperature was performed on each lake or station's water sample promptly after it was obtained. For the five remaining analytical parameters, the sample was first filtered through 0.45 micron filter paper. The samples were preserved according to the Standard Methods outlined in the United States Environmental Protection Agency's (EPA's)
1974 "Methods for Chemical Analysis of Water and Wastes."

Table 3 lists the preservation techniques employed.

Table 3
Preservation Techniques

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Preservation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chloride</td>
<td>None required</td>
</tr>
<tr>
<td>Nitrate</td>
<td>Cool to 4 degrees centigrade</td>
</tr>
<tr>
<td>Hardness</td>
<td>Cool 4 C/nitric acid to pH &lt;2 (.3% nitric acid)</td>
</tr>
<tr>
<td>Iron</td>
<td>Cool 4 C/nitric acid to pH &lt;2 (.3% nitric acid)</td>
</tr>
<tr>
<td>Chromium</td>
<td>Cool 4 C/nitric acid to pH &lt;2 (.3% nitric acid)</td>
</tr>
</tbody>
</table>

Once the sample was filtered and preserved it was put into a marked sample jar, that had been rinsed twice with some of the freshly collected sample. Care was also taken to insure that the bottle was completely full, with little or no air. All the sample bottles, except the chloride specimen, were immediately put into an ice filled cooler.

Chemical analyses were performed on the samples in the laboratory either that evening or early the next morning. Thus all analyses were performed within 24 hours of their collection. This was well within the maximum holding time for each parameter.

Chemical Analysis

Analysis was done on all seven chemical parameters by utilizing the following procedures as outlined in the APHA (American Public Health Association) Standards Methods, 16
Temperature was measured in the field promptly after sampling with a mercury filled centigrade thermometer.

Specific conductance was measured in the field at the time of each sampling, using the model EP-10 specific conductivity meter manufactured by Myron L. Company of Encinitas, California. This unit is a portable, single parameter instrument. The results are reported in micromhos/cm, with a calibrated unit precision of plus or minus 5%.

The procedural description for each of the following five chemical analyses is taken from Explanation of Hach Water Chemistry, 1st ed., (1976).

Total hardness in mg/l as calcium carbonate was determined in the laboratory using the EDTA titration method. In this procedure the water sample is first buffered to a pH of 10, where the analysis functions best. Calmagite, an organic dye is added as the indicator for the test. This dye will react with calcium and magnesium ions to give a red colored solution. As the titrant, EDTA (ethylenediaminetetraacetic acid), is added, the EDTA will react with all free calcium and magnesium ions present in the sample. The end point of the titration is noted by a color change from red to blue. The normality and volume of the EDTA titrant is then related to the hardness content to determine a final test result, expressed as mg/l as calcium carbonate.
The chloride concentration was determined in the laboratory using the Hach mercuric nitrate method. In this test diphenylcarbazone is the indicator and mercuric nitrate the titrant. Once all the chloride present in the sample is complexed by the mercuric ions, the excess mercuric ions combine with diphenylcarbazone to form a purple complex indicating the end point of the titration. The normality and volume of the mercuric nitrate is then related to determine the final chloride concentration in ppm (parts per million).

The concentrations of the four remaining chemical parameters (pH, nitrate, chromium and iron) were all determined using the colorimetric method. The instrument used was the Hach DC Operated Colorimeter, model DR-EL, manufactured by the Hach Chemical Company of Ames, Iowa. The instrument was calibrated with known standard solutions, 100% transmission solutions and 0% transmission blanks. The Hach Company reports a maximum deviation of plus or minus 2% for a calibrated Hach colorimeter. In colorimetry the absorbance of the solution is directly proportional to the concentration of the absorbing species (the solute) in that medium. This theoretical relationship is known as Beer's Law.

The pH was measured in the field, within sixty seconds of obtaining the sample. It is important to measure pH immediately after sampling to avoid changes caused by the ex-
cape of carbon dioxide from the water sample, when groundwater is exposed to the atmosphere carbon dioxide will escape and the pH will rise. The pH was measured colorimetrically with the Hach colorimeter. The pH of the sample was determined using a specific pH indicator or dye, this dye will react with or donate free hydrogen ions in the water sample until an equilibrium point is reached. At equilibrium the dye will take on a particular color, this color indicates sample pH. pH can be read directly from the pH meter scale in conventional units of hydrogen ion concentration.

The nitrate concentration in ppm was determined in the laboratory using the Hach low range cadmium reduction method. In this test, cadmium metal is used to reduce the nitrates to the nitrite form. The nitrite ions react with sulfanilic acid to produce an intermediate diazonium salt which forms an amber colored complex with chromotropic acid. The intensity of this amber color is in direct proportion to the nitrate concentration in the sample.

The concentration of hexavalent chromium was determined in the laboratory using the Hach 1,5-diphenylcarbohydrazide method. This test for total chromium employs a pretreatment with 1,5-diphenylcarbohydrazide which converts all the trivalent chromium present to the hexavalent form. This results in the formation of a pink colored complex. The intensity of this pink color is proportional to the
amount of hexavalent chromium in the sample. The measurement of the color intensity determines the concentration in ppm.

The concentration of iron was determined using the Hach 1,10-phenanthroline method. In this test, all forms of iron present in the sample are dissolved and reduced to the ferrous state in an acidic medium. The ferrous ions react with the 1,10-phenanthroline to form an orange colored complex. Because the reaction is directly proportional to the amount of dissolved iron present in the sample, a measurement of the color intensity of the complex determines the iron concentration of the sample in ppm.
CHAPTER V

ANALYSIS OF DATA

Regional Groundwater Flow System

A static water level map of the study area was prepared by Wilkins and Wheaton Testing Laboratory (1981), modified from Allen et al., (1972). It shows that the groundwater surface essentially mimics the regional surface topography. The established regional groundwater divide follows a line just east of the landfill and parallel to the northeast trending Kalamazoo Moraine (Figure 7).

In the study area, the water table decreases from an elevation of approximately 900 feet above MSL along the crest of the groundwater divide, to a low of approximately 750 feet above MSL beneath the Alamo Plain, about three miles northwest of the groundwater divide. It appears that the study area's regional groundwater flow is predominantly to the northwest away from the groundwater divide at a hydraulic gradient of approximately 30 to 50 feet per mile.

Within this regional groundwater flow system are smaller, local, groundwater flow systems. One of these smaller local systems is a radial groundwater flow pattern away from the topographically mounded KL Landfill.
Depth Profiles of Lakes

The lake depths were determined by siting a compass line between two stations and while rowing along that line determining the depth of the lake approximately every 20 feet. This procedure was carried out by the author and a member of the Geology Department. Lake depth was determined by lowering a length of incremented rope, weighted with a flat lying 25 lb. plate weight, which was allowed to come to rest on the lake floor.

The Dustin Lake depth profile is shown in Figure 13. Line A-A' is from station 2 to station 1 respectively. Line B-B' is from station 4 to station 3 respectively. The surface of Dustin Lake is 847 feet above MSL and its deepest point was determined to be approximately ten feet three inches. This point lies just to the west of the intersection of the two lines, A-A' and B-B'.

The Bonnie Castle Lake depth profile is shown in Figure 14. Line A-A' is from station 7 to station 5 respectively. Line B-B' is from station 6 to station 8 respectively. The surface of Bonnie Castle Lake is 917 feet above MSL and its deepest point was determined to be approximately 13 feet 11 inches. This point is approximately located at the midpoint of line A-A'.
Figure 13. Depth Profile of Dustin Lake.
Figure 14. Depth Profile of Bonnie Castle Lake.
Determination of Recharge/Discharge Relationships

From March, 1985 to July, 1985; twelve separate hydraulic head readings were taken at each study station. Since four of these twelve readings were taken after a major precipitation event and will be addressed in a future chapter, only the remaining eight readings will be taken into consideration here. These eight readings constitute what can be considered "typical indicators", since they are representative of times other than heavy rain periods.

The eight hydraulic head readings for both Dustin Lake and Bonnie Castle Lake are shown in Tables 4 and 5. The letter p stands for positive hydraulic head in inches, that is, the water level in the piezometer is so many inches above the lake surface. This indicates groundwater discharge. The letter n stands for negative hydraulic head in inches, that is, the water level in the piezometer is so many inches below the lake surface. This indicates groundwater recharge.

From Table 4, it is apparent that stations 2 and 3 are areas of groundwater discharge and stations 1 and 4 are areas of groundwater recharge. Therefore, it appears that Dustin Lake is a flow through lake. The groundwater is discharging or flowing into the lake on its eastern side and lake water is recharging or flowing to the groundwater on its western side.
Table 4

Hydraulic Head Data Sheet for Dustin Lake

<table>
<thead>
<tr>
<th>Station</th>
<th>3/10/85</th>
<th>3/16/85</th>
<th>3/21/85</th>
<th>4/15/85</th>
<th>5/2/85</th>
<th>6/22/85</th>
<th>7/21/85</th>
<th>7/27/85</th>
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</thead>
<tbody>
<tr>
<td>1*</td>
<td>10'</td>
<td>27.5&quot;</td>
<td>26.0&quot;</td>
<td>26.25&quot;</td>
<td>26.75&quot;</td>
<td>26.0&quot;</td>
<td>30.0&quot;</td>
<td>58.0&quot;</td>
<td>65.5&quot;</td>
</tr>
<tr>
<td></td>
<td>5'</td>
<td>n0.75&quot;</td>
<td>n0.75&quot;</td>
<td>n1.0&quot;</td>
<td>n1.0&quot;</td>
<td>n0.75&quot;</td>
<td>n1.0&quot;</td>
<td>n1.0&quot;</td>
<td>n1.0&quot;</td>
</tr>
<tr>
<td></td>
<td>10'</td>
<td>n1.0&quot;</td>
<td>n1.0&quot;</td>
<td>n1.0&quot;</td>
<td>n0.75&quot;</td>
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<td>n0.75&quot;</td>
<td>n0.62&quot;</td>
</tr>
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</tr>
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<td>even</td>
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<td>even</td>
<td>n0.12&quot;</td>
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<td>38.0&quot;</td>
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<td>37.0&quot;</td>
<td>34.75&quot;</td>
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<td>36.0&quot;</td>
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<td></td>
<td>5'</td>
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<td>p4.0&quot;</td>
<td>p4.75&quot;</td>
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<td>p6.5&quot;</td>
<td>p8.0&quot;</td>
<td>p8.25&quot;</td>
<td>p9.0&quot;</td>
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* Static water table in inches below ground surface.
Figure 7 shows a dotted line running essentially north-south across Dustin lake. This line is the estimated boundary between the eastern discharge area and the western recharge area. The location of the boundary between recharge and discharge was determined by a sequence of "hit or miss" lake shore piezometer placements between stations 1 and 3, and stations 2 and 4. When the hydraulic head read positive, the piezometer would be moved to the west. When the piezometer read negative it would be moved to the east. After six trials, equal hydraulic head was reached on both the north and south shore. The line joining these points is dotted since no hydraulic head readings were taken in the deeper portion of the lake and also because the actual position of this line changed slightly to the east and west throughout the course of the study.

From the data in Table 5, it is apparent that all four Bonnie Castle Lake stations are areas of groundwater recharge. Thus Bonnie Castle Lake is to be considered a recharge lake.

Neither lake was observed to have any surface water inlets or outlets. Dustin Lake receives water from groundwater discharge on its eastern end, surface runoff, and direct precipitation (Chapter I, annual precipitation of 34.3 inches per year). Dustin Lake loses water through groundwater recharge on its western end and evaporation (Chapter I, mean lake evaporation of 30 to 32 inches per year). Bon-
Table 5

Hydraulic Head Data Sheet for Bonnie Castle Lake

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* Static water table in inches below ground surface.
V-vandalized on 7/25/85.
nie Castle Lake gains water from surface runoff and direct precipitation, it loses water through groundwater recharge and evaporation. The two lakes exist because the volume of water they gain exceeds the volume of water they lose, through the means referenced above.

Also, data shown in Tables 4 and 5 are in general agreement with McBride and Pfannkuck (1975) and Lee (1972), in that seepage into or out of lakes tends to be concentrated near the shore and decreases with increasing distance from the shore. In all the averages from each station, there is a greater hydraulic head difference at the piezometer 5 feet from shore than at the piezometer 20 feet from shore, regardless of whether it is a discharge or recharge seepage area.

Calculation of Seepage Meter Parameters

Seepage meter readings were taken five separate times at each of the eight stations. The results of these seepage flux investigations, shown in Table 6 were consistent.

Data reveal that stations 2 and 3 on Dustin Lake show positive seepage flux (Table 6). Positive seepage flux occurs when groundwater is discharging into the lake, it is manifested by a seepage meter collection bag which gains water over time. The seepage volume and the Darcy velocity for station 2 are much greater and faster than the other seven stations. This corresponds with the comparatively
high hydraulic head measurements from that station (Table 4). Study stations 1 and 4 show negative seepage flux. Negative seepage flux occurs when lake water recharges through the lake bottom sediments to the groundwater. It is manifested by a seepage meter collection bag which loses water over time.

Thus, for Dustin Lake the seepage meter data validates the interpretation from the hydraulic head data. Dustin Lake is a flow through lake, with the groundwater discharging into the lake along the lake's eastern shore and the lake water recharging the groundwater along the lake's western shore.

An examination of Table 6 data reveals that stations 5, 6, 7, and 8 on Bonnie Castle Lake show negative seepage flux. Thus, Bonnie Castle Lake seepage meter data also validates the hydraulic head interpretations. Bonnie Castle Lake is a recharge lake, with the lake water percolating or recharging comparatively slowly through the lake bottom sediments to the groundwater.

Geologic Cross-Sections

Geologic cross-sections obtained from Wilkens and Wheaton (1981) were modified by the author. Figure 15 is an east-west cross-section through Dustin Lake. The slope on the water table surface is consistent with the interpretation that Dustin Lake is a flow through lake. At Dustin
## Table 6
Seepage Meter Data Sheet

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<th>Station</th>
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<td>5</td>
<td>recharge</td>
<td>16.5 outflow</td>
<td>3x10⁻⁷</td>
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Lake's eastern boundary, the water table elevation is slightly higher than the lake surface, thus a groundwater discharge situation would be expected. At Dustin Lake's western boundary, the water table elevation decreases dramatically in relation to the lake's surface suggesting a groundwater recharge situation. Thus Dustin Lake appears to be a flow-through lake.

Figure 16 is a southwest-northeast cross-section through Bonnie Castle Lake. The position of the static water table in relation to the lake is consistent with the
Figure 15. Geologic Cross-Section Through Dustin Lake.

interpretation that Bonnie Castle Lake is a perched recharge lake. From Figure 16, it can be observed that the static water table elevation beneath Bonnie Castle Lake is approximately 20 feet below the lake bottom. Thus, it would be expected that the lake water would percolate downward and recharge the groundwater. Of great importance is the presence of a clay layer between the lake bottom and the static water table. This clay with its expected low hydraulic conductivity may be responsible for the existence of Bonnie Castle Lake. It may prevent the lake water from rapidly percolating through to the static water table. Thus, Bonnie Castle Lake, appears to be a perched recharge lake.

Correlation of Hydrologic Data With a Precipitation Event

A rain gauge was installed at each of the lakes. On May 20, 1985, approximately 0.7 inches of rainfall was recorded. For four consecutive days following this precipitation event, hydraulic head readings were taken at each of the eight piezometer stations to determine what effect, if any, precipitation would have on each lake's relationship with the groundwater.

In general, the 0.7 inches of rain resulted in a temporary situation whereby the six stations that were normally areas of groundwater recharge (stations; 1, 4, 5, 6, 7 and 8) exhibited a trend of recharging less or even becoming
Figure 16. Geologic Cross-Section Through Bonnie Castle Lake.

for a time areas of groundwater discharge (Tables 7 and 8). This trend is especially evident for Bonnie Castle Lake. Piezometer stations 2 and 3, on Dustin Lake, which are the only Dustin Lake stations identified as groundwater discharge, show a trend of increased discharge.

As shown on Figure 9, the near shore static water level is higher in elevation than the lake surface in an area of groundwater discharge. As shown on Figure 10, the near shore static water level is lower in elevation than the lake surface in an area of groundwater recharge. A precipitation event would cause a temporary elevational increase in the static water level. Thus, depending on the static water level's elevational increase and the pre-precipitation relationship between the lake and adjacent groundwater, the groundwater would for a time, recharge less, discharge more or convert from a recharge to a discharge situation.

In conclusion, rainfall would be expected to cause an increase in the flow of groundwater into both lakes. This finding is particularly noteworthy for Station 6 which is lower in elevation and approximately 300 feet northeast of the KL Landfill. It presents the possibility of temporary, post precipitation, local groundwater flow from the Landfill to the southwest corner of Bonnie Castle Lake.
Table 7

Hydraulic Head as it is Affected by a Precipitation Event for Dustin Lake

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<tr>
<td>15'</td>
<td>n0.5&quot;</td>
<td>n0.12&quot;</td>
<td>n1.0&quot;</td>
<td>n0.5&quot;</td>
</tr>
<tr>
<td>20'</td>
<td>even</td>
<td>p0.12&quot;</td>
<td>n0.25&quot;</td>
<td>n0.37&quot;</td>
</tr>
</tbody>
</table>

*Static water table in inches below ground surface.

Soil Classification

The results of the mechanical grain size analyses and the hydrometer analyses described in Chapter IV were plotted. The data obtained from the plotted grain size distribution curves was compiled (Table 2, is a complete listing of grain size percentages and coefficient of uniformity (cu) for each designated study station soil column). The
Table 8

Hydraulic Head as it is Affected by a Precipitation Event for Bonnie Castle Lake

<table>
<thead>
<tr>
<th>Station</th>
<th>5/21/85</th>
<th>5/22/85</th>
<th>5/23/85</th>
<th>5/24/85</th>
</tr>
</thead>
<tbody>
<tr>
<td>5*-10'</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5'</td>
<td>23.5&quot;</td>
<td>24.25&quot;</td>
<td>24.0&quot;</td>
<td>24.0&quot;</td>
</tr>
<tr>
<td>10'</td>
<td>p0.25&quot;</td>
<td>p0.25&quot;</td>
<td>p0.25&quot;</td>
<td>p0.75&quot;</td>
</tr>
<tr>
<td>15'</td>
<td>even</td>
<td>n0.5&quot;</td>
<td>n0.75&quot;</td>
<td>n0.62&quot;</td>
</tr>
<tr>
<td>20'</td>
<td>p1.2&quot;</td>
<td>p1.5&quot;</td>
<td>p2.0&quot;</td>
<td>p1.2&quot;</td>
</tr>
<tr>
<td>6*-10'</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5'</td>
<td>25.0&quot;</td>
<td>26.25&quot;</td>
<td>26.25&quot;</td>
<td>25.5&quot;</td>
</tr>
<tr>
<td>10'</td>
<td>p0.75&quot;</td>
<td>p1.0&quot;</td>
<td>p0.75&quot;</td>
<td>p1.25&quot;</td>
</tr>
<tr>
<td>15'</td>
<td>even</td>
<td>even</td>
<td>n0.37&quot;</td>
<td>even</td>
</tr>
<tr>
<td>20'</td>
<td>p0.12&quot;</td>
<td>p0.75&quot;</td>
<td>p1.2&quot;</td>
<td>p0.75&quot;</td>
</tr>
<tr>
<td>7*-10'</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5'</td>
<td>34.5&quot;</td>
<td>34.0&quot;</td>
<td>34.25&quot;</td>
<td>34.5&quot;</td>
</tr>
<tr>
<td>10'</td>
<td>p1.2&quot;</td>
<td>p0.75&quot;</td>
<td>p1.0&quot;</td>
<td>p0.25&quot;</td>
</tr>
<tr>
<td>15'</td>
<td>n0.75&quot;</td>
<td>n0.25&quot;</td>
<td>n0.37&quot;</td>
<td>n0.5&quot;</td>
</tr>
<tr>
<td>20'</td>
<td>p0.5&quot;</td>
<td>p1.0&quot;</td>
<td>p1.0&quot;</td>
<td>p0.37&quot;</td>
</tr>
<tr>
<td>8*-10'</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5'</td>
<td>5.5&quot;</td>
<td>6.0&quot;</td>
<td>6.0&quot;</td>
<td>6.0&quot;</td>
</tr>
<tr>
<td>10'</td>
<td>p2.5&quot;</td>
<td>p2.75&quot;</td>
<td>p2.75&quot;</td>
<td>p2.75&quot;</td>
</tr>
<tr>
<td>15'</td>
<td>p1.0&quot;</td>
<td>p0.12&quot;</td>
<td>p0.37&quot;</td>
<td>even</td>
</tr>
<tr>
<td>20'</td>
<td>p1.7&quot;</td>
<td>p1.5&quot;</td>
<td>p1.1&quot;</td>
<td>p0.75&quot;</td>
</tr>
</tbody>
</table>

*Static water table in inches below ground surface.

Table 2 data were plotted on a USDA textural triangle (Figure 12) for purposes of soil classification.

The results of the USDA soil classification for each station's soil core are as follows:

1. The soil core from station 2 on Dustin Lake: 2.0' of grey, well-sorted sand over 4.0' of light brown-yellow, well-sorted, loamy sand.
<table>
<thead>
<tr>
<th>Units</th>
<th>pH</th>
<th>umho/cm</th>
<th>mg/l as CaCo₃</th>
<th>Iron</th>
<th>Chloride</th>
<th>Nitrate</th>
<th>Chromium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trials</td>
<td>6</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Dustin Lake</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>6.60</td>
<td>200</td>
<td>120</td>
<td>0.1</td>
<td>4.0</td>
<td>0.7</td>
<td>BDL</td>
</tr>
<tr>
<td>Station 1</td>
<td>6.30</td>
<td>240</td>
<td>221</td>
<td>0.1</td>
<td>4.0</td>
<td>0.7</td>
<td>BDL</td>
</tr>
<tr>
<td>Station 2</td>
<td>6.40</td>
<td>480</td>
<td>230</td>
<td>0.9</td>
<td>4.0</td>
<td>1.0</td>
<td>BDL</td>
</tr>
<tr>
<td>Station 3</td>
<td>6.40</td>
<td>720</td>
<td>310</td>
<td>0.6</td>
<td>3.4</td>
<td>0.9</td>
<td>BDL</td>
</tr>
<tr>
<td>Station 4</td>
<td>6.30</td>
<td>245</td>
<td>185</td>
<td>0.6</td>
<td>4.6</td>
<td>0.7</td>
<td>BDL</td>
</tr>
<tr>
<td>Bonnie Castle Lake</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>6.30</td>
<td>120</td>
<td>100</td>
<td>0.3</td>
<td>7.8</td>
<td>0.5</td>
<td>BDL</td>
</tr>
<tr>
<td>Station 5</td>
<td>6.25</td>
<td>260</td>
<td>120</td>
<td>7.5</td>
<td>8.4</td>
<td>0.8</td>
<td>BDL</td>
</tr>
<tr>
<td>Station 6</td>
<td>6.0</td>
<td>250</td>
<td>124</td>
<td>6.8</td>
<td>11.3</td>
<td>0.8</td>
<td>BDL</td>
</tr>
<tr>
<td>Station 7</td>
<td>6.30</td>
<td>250</td>
<td>100</td>
<td>6.8</td>
<td>9.1</td>
<td>0.9</td>
<td>BDL</td>
</tr>
<tr>
<td>Station 8</td>
<td>6.10</td>
<td>340</td>
<td>124</td>
<td>11.5</td>
<td>9.0</td>
<td>0.9</td>
<td>BDL</td>
</tr>
</tbody>
</table>

1) BDL = Below Instrument Detection Limit

2. The soil core from station 4 on Dustin Lake: 1.4' of dark brown, organic rich, well-sorted sand over 4.6' of light brown, well-sorted sand.
Table 10

General Water Quality in the Glacial Drift, Kalamazoo County
(From: Hydrogeology for Underground Injection Control in Michigan, 1981)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Number of Wells Sampled</th>
<th>Range</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrate (mg/L)</td>
<td>30</td>
<td>0.0 - 7.7</td>
<td>0.6</td>
</tr>
<tr>
<td>Chloride (mg/L)</td>
<td>30</td>
<td>1.0 - 95.0</td>
<td>13.0</td>
</tr>
<tr>
<td>Iron (mg/L)</td>
<td>30</td>
<td>0.0 - 3.3</td>
<td>1.1</td>
</tr>
</tbody>
</table>

Table 11

Selected Chemical Analyses of Groundwater, Kalamazoo County
(From Allen, et al., 1978)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Number of Wells Sampled</th>
<th>Range</th>
<th>Mean</th>
<th>Date of Sample</th>
<th>Depth of Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>6</td>
<td>7.2-7.5</td>
<td>7.5</td>
<td>6/62&amp;9/64</td>
<td>46'-60'</td>
</tr>
<tr>
<td>Specific Conductance</td>
<td>6</td>
<td>480-960</td>
<td>645</td>
<td>6/62&amp;9/64</td>
<td>46'-60'</td>
</tr>
<tr>
<td>Hardness (mg/L as CaCO₃)</td>
<td>6</td>
<td>230-490</td>
<td>331</td>
<td>6/62&amp;9/64</td>
<td>46'-60'</td>
</tr>
<tr>
<td>Nitrate (mg/L)</td>
<td>6</td>
<td>0.0-4.0</td>
<td>1.1</td>
<td>6/62&amp;9/64</td>
<td>46'-60'</td>
</tr>
<tr>
<td>Chloride (mg/L)</td>
<td>6</td>
<td>11.0-35.0</td>
<td>17.0</td>
<td>6/62&amp;9/64</td>
<td>46'-60'</td>
</tr>
</tbody>
</table>

3. The soil core from station 6 on Bonnie Castle Lake: 1.7' of dark brown, organic rich, well-sorted sand over 4.3' of light brown-yellow, well-sorted sand.

4. The soil core from station 8 on Bonnie Castle Lake: 1.8' of dark brown, organic rich, well-sorted sand.
Table 12
Selected Chemical Parameters From the KL Avenue Landfill Contaminant Plume From 1978 Through 1980 (Wilkins and Wheaton, 1981)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value or Range of Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>6.7 to 7.5</td>
</tr>
<tr>
<td>Specific Conductance (umhos/cm)</td>
<td>500 to 2100</td>
</tr>
<tr>
<td>Iron (mg/L)</td>
<td>17.3</td>
</tr>
<tr>
<td>Chloride (mg/L)</td>
<td>89 to 210</td>
</tr>
<tr>
<td>Nitrate (mg/L)</td>
<td>4</td>
</tr>
<tr>
<td>Chromium (mg/L)</td>
<td>0.018 to 0.19</td>
</tr>
</tbody>
</table>

over 4.2' of light brown-yellow, well-sorted sand.

From the above soil descriptions, it is apparent that in general, each lake has a sandy bottom and that the piezometers are screened in sand.
CHAPTER VI

EXPLANATION OF CHEMICAL PARAMETERS

pH

All pH values were determined by the Hach colorimetric method. This system is based on approved procedures as outlined by Standard Methods for the Examination of Water and Wastewater, published jointly by the American Public Health Association (APHA), the American Water Works Association (AWWA), and the Water Pollution Control Federation (WPCF).

The general range of groundwater pH for Kalamazoo County in the early 1960's was 7.2 to 7.5 (Table 11). The average pH range determined by the author for the summer of 1985 in the surface water and groundwater of Dustin Lake and Bonnie Castle Lake was 6.0 to 6.6 (Table 9).

Most natural waters range from pH 4 to pH 9. A basic groundwater pH may indicate the presence of carbonate or bicarbonate in the overburden sediments or bedrock. This is probably the case with thick deposits of calcareous glacial drift in the area local to Dustin Lake and Bonnie Castle Lake. The more acidic pH may be an indication that the natural buffering mechanism of the calcareous glacial deposits is less effective. The difference in the two pH rang-
es could also be explained by the fact that the above-referenced 1960 pH ranges are from groundwater sampled at a depth of between 46 and 60 feet. It would be expected that this groundwater traveled a longer subsurface flow path and would thus come in contact with a greater amount of naturally occurring carbonate. Additional considerations are the possibility of two different analytical techniques yielding somewhat different results and the increasing acid rain contribution.

The pH values give some support to the author's view of the lake water-groundwater relationships. Stations 2 and 3, the two areas of groundwater discharge, have the most basic pH values. This would be anticipated because of the calcareous glacial drift buffering action on the groundwater before it discharges into Dustin Lake. Furthermore, flow-through Dustin Lake water would be expected to be more basic than Bonnie Castle Lake water, which is not supplied by naturally buffered groundwater.

Specific Conductance

Specific Conductance is expressed in micromhos per centimeter, it is a measure of the ability of water to conduct an electric current due to the presence of dissolved ions. Normally, the amount of dissolved solids in milligrams per liter (mg/L) is approximately 65 percent of the total conductivity.
Distilled water has a low conductivity. Groundwater ordinarily has a higher conductivity due to exposure during subsurface migration to soluble materials and minerals in the geologic formation. Thus, conductivity measure is an accepted effective means of differentiating discharge groundwater from recharge groundwater and/or surface water.

The general range for Kalamazoo County groundwater conductivity is 480 to 960 micromhos per centimeter (Table 11). Stations 2 and 3, the two areas designated as groundwater discharge, have conductivity values within this range (see Table 9). The remaining six stations designated as groundwater recharge, have values less than 480 micromhos per centimeter. Flow-through Dustin Lake has a higher specific conductivity than Bonnie Castle Lake as expected since Bonnie Castle Lake appears to have little or no groundwater in-flow. Thus, interpretations based on specific conductance support the author's data.

Hardness

Total hardness values were determined using an APHA approved wet titration method. Hardness is expressed in units of mg/L as calcium carbonate (CaCO₃). Calcium and magnesium ions are the principal causes of hardness in natural waters, although iron, aluminum, manganese, strontium, zinc and hydrogen ions are capable of producing the same effect. Water with hardness values greater than 200 mg/L
is generally considered very hard.

Groundwater hardness for Kalamazoo County ranges between 230 and 490 mg/l (Table 11). This hardness is derived from the drainage and solution of the calcareous glacial deposits.

Hardness data supports the interpretation of Bonnie Castle Lake being a groundwater recharge lake with little or no groundwater in-flow (Table 9). The Bonnie Castle Lake groundwater hardness values are not consistent with groundwater hardness values for Kalamazoo County. Thus, the groundwater, being comparatively soft, would appear to be recharge water.

Dustin Lake groundwater hardness values on the other hand are higher. Stations 2 and 3 exhibit groundwater hardness values within the range of expected hardness values for Kalamazoo County as depicted in Table 11. Thus, the hardness from these stations lends support to the interpretation that groundwater discharge is taking place along Dustin Lake's eastern perimeter. Stations 1 and 4 have hardness values less than the expected values for Kalamazoo County groundwater. These hardness values reflect some mixing of recently discharged groundwater from the lake's eastern boundary and supports the author's interpretation of Dustin Lake being a flow-through lake.
Iron

Iron is a common, naturally occurring element, found in the rocks, soils and waters of the earth's crust. Groundwater which is devoid of oxygen may contain dissolved ferrous iron. When this groundwater is oxygenated the ferrous iron oxidizes to ferric iron and precipitates. Well-oxygenated surface waters normally contain almost no dissolved iron (Fetter, 1980).

The author's iron analyses (Table 9) for Dustin Lake and Bonnie Castle Lake waters agree with Fetter's above statement regarding well-oxygenated surface waters. In addition, the author's iron analyses for the Dustin Lake study stations are within the expected range for dissolved iron in Kalamazoo County groundwater (Table 10). However, the author's iron analyses for the Bonnie Castle Lake study stations exceed the expected range for Kalamazoo County groundwater. The source of the elevated dissolved iron concentrations identified in the Bonnie Castle Lake study station's water is unknown. The author's iron analyses do not substantiate or contradict the interpretation of the lake's lake water/groundwater relationship.

Chloride

The chloride anion is very soluble and mobile in groundwater flow systems. Chloride is often found to be a
major chemical constituent of naturally occurring groundwater. The chloride range is commonly less than 10 ppm in humid regions, but up to 1000 ppm in arid regions. The EPA maximum allowed secondary limit for chloride in drinking water is 250 ppm. This limit is based on taste, not on any known physiological hazards. Much of the chloride found in the environment today is not natural, being contributed through the activities of man. Numerous studies have shown that septic systems, application of salt to icy winter roads, agricultural activities and the percolation of landfill leachate raise the level of chloride concentration in natural waters. All of these activities were found to occur local to Bonnie Castle Lake and Dustin Lake.

Chloride values are comparatively low (Tables 9 and 10). As would be expected, the deeper sampling points (Table 10) reflect higher groundwater chloride concentrations.

The chloride values shown in Table 9 do little in the way of supporting or contradicting the author's perception of the lake water/groundwater relationship of the two lakes. However, in terms of evaluating the possible impact of landfill induced leachate seeping into the lakes, there is a conclusion to be drawn. According to Griffin et al. (1976), and Leckie et al. (1975), the representative range for chloride in landfill leachate is 300 to 3000 ppm. It would appear from the chloride analyses that as of the summer of 1985, no significant landfill leachate has migrated
into either Dustin Lake or Bonnie Castle Lake.

Nitrate

All nitrate values were determined by the colorimetric cadmium reduction method. According to the Freeze and Cherry (1979), the most common contaminant identified in groundwater is dissolved nitrogen in the form of nitrate (NO$_3$). This contaminant is becoming increasingly widespread because of agricultural activities and disposal of sewage on or beneath the land surface. Nitrate in naturally occurring groundwater, has an expected concentration range of 0.01 to 10.0 ppm. Potable water containing excessive amounts of nitrates can cause infant methemoglobinemia. For this reason, a maximum allowed limit for nitrate nitrogen of 10 ppm has been established for all public drinking water supplies. Tables 9 and 10 show that the author's determined values for nitrate fall within the expected range of nitrate for Kalamazoo County groundwater.

Nitrate values (Table 9) do not substantiate or contradict the interpretation of the lake water/groundwater relationship or the impact on the lakes from the KL Landfill contaminant plume. These results indicate that based on the nitrate levels for the summer of 1985, it appears the lakes had not been negatively impacted by individual sewage systems or local agriculture.
Chromium

Chromium may be present in water as either the hexavalent or trivalent form, although the trivalent form of chromium rarely occurs in water supplies. Because hexavalent chromium is a potential carcinogen, a systemic poison and very corrosive, the maximum allowed limit for potable water is set at 0.05 ppm by the U.S. Environmental Protection Agency. Chromium salts are used extensively in industrial processes and can enter the water supply through waste discharge from landfill disposal.

In 1978, before the closing of the KL Landfill, the average chromium concentration in groundwater samples from test wells at the landfill was 0.19 ppm. After the closing of the landfill in 1979, these same chromium concentrations decreased to 0.024 ppm in 1979, and 0.018 ppm in 1980. Background chromium concentrations for the KL Landfill area are generally inferred to be less than 0.001 ppm (Wilkins and Wheaton, 1981).

The author chose hexavalent chromium as a testing parameter to indicate the possible presence of the KL Landfill's contaminant plume around the two study lakes. Because of the low background level of 0.001 ppm, any observed significant concentration of chromium in the lake's surface water or groundwater would be considered an indicator of contaminant plume migration into the lake environ-
Data in Table 9 reveal that for the summer of 1985, chromium concentrations from the eight groundwater stations and two surface water stations were below the detection limit (BDL) of 0.5 ppm.
CHAPTER VII

INTERPRETATIONS AND CONCLUSIONS

Recharge/Discharge Characteristics of Bonnie Castle and Dustin Lakes

The data from the piezometers, seepage meters, water chemistry and geologic cross-sections indicate that Bonnie Castle Lake is a perched, groundwater recharge lake. There is a relatively slow flow of water from the lake through an underlying clay layer to the water table.

The data from the piezometers, seepage meters, water chemistry and geologic cross-sections indicate that Dustin Lake is a flow-through lake. Groundwater is discharging or flowing into the lake on its eastern side and lake water is recharging or flowing to the groundwater on its western side.

Lake Water Quality and Possible Contamination From the KL Avenue Landfill

1985 water quality parameters for groundwater and surface water at both Bonnie Castle Lake and Dustin Lake fall below the maximum allowed limits as set by the Environmental Protection Agency. Thus, for the chemical parameters tested, the lake environments can be considered to possess water of relatively good quality. Sampling for the
presence of chlorinated and non-chlorinated volatile organic compounds was not within the scope of this study. However, there are two minor exceptions to this. The pH values appear somewhat lower than would normally be expected and the relatively high average groundwater specific conductance encountered at Station 3. The specific conductance value of 720 umhos/cm, however, is within the expected range for Kalamazoo County groundwater.

It would appear, therefore, that the KL Landfill's contaminant plume has not impacted either of the lake environments.

Bonnie Castle Lake has been designated a perched groundwater recharge lake and thus would not be expected to have in-flowing groundwater contaminated or otherwise.

Dustin Lake has been designated a flow-through groundwater lake, which has groundwater discharge along its eastern boundary. According to Wilkins and Wheaton (1981), the KL Landfill plume is migrating west from the landfill towards the eastern shore of Dustin Lake. However, the 1984 groundwater chemistry, analyzed by KAR Laboratories, Inc. of Kalamazoo, from Monitoring Well 5 (MW-5, Figure 12), which is located approximately 400 feet east of Dustin Lake's eastern shore had a specific conductance of 340 umhos/cm, a chloride of 4 ppm and a non-detectable level of chromium. These parameter concentrations are in general agreement with the author's values. This may be taken as
an indication that the contaminant plume had not significantly impacted MW-5 or the eastern shore of Dustin Lake. It is expected that if the plume does enter the lake environment, it will have decreased in concentration such that its impact would most likely be relatively minimal.
CHAPTER VIII

RECOMMENDATIONS

A surface and groundwater monitoring program should be instituted. The monitoring emphasis should be to evaluate the presence of landfill induced contaminants in the lake environments. Particular attention should be placed on Dustin Lake. Dustin Lake's hydrogeology and location with respect to the suspected plume migration path make it susceptible to future landfill plume impact. Monitoring Well 5 should also be included in the monitoring program in that its location directly east of Dustin Lake would allow an early warning of impending landfill contamination discharge into the lake.

Although testing of total volatile organics were not within the scope of this study, it is recommended that the monitoring program include these analyses.

It is also recommended that additional post precipitation studies of Bonnie Castle Lake be performed. The preliminary investigation undertaken by the author suggests the possibility of groundwater influx into the lake after a precipitation event. This situation, a temporary reversal of the generally occurring surface water/groundwater
relationship may possibly allow groundwater containing landfill contaminants to migrate into the lake environment.
Appendix A

Grain Size Gradation Curves
## STUDY STATION 2  UPPER CORE

<table>
<thead>
<tr>
<th></th>
<th>Gravel</th>
<th>Sand</th>
<th>Fines</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Coarse to medium</td>
<td>Fine</td>
</tr>
<tr>
<td></td>
<td></td>
<td>U.S. standard sieve sizes</td>
<td></td>
</tr>
<tr>
<td>3/4 in.</td>
<td>30</td>
<td>20.10</td>
<td>20</td>
</tr>
<tr>
<td>1.00</td>
<td>4.75</td>
<td>3.15</td>
<td>2</td>
</tr>
</tbody>
</table>

**Grain diameter, mm**

**Percent finer**

© Mechanical Analysis

* Hydrometer Analysis
STUDY STATION 2  LOWER CORE

<table>
<thead>
<tr>
<th>Gravel</th>
<th>Sand</th>
<th>Fines</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coarse to medium</td>
<td>Fine</td>
</tr>
</tbody>
</table>

U.S. standard sieve sizes

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## STUDY STATION 4 UPPER CORE

<table>
<thead>
<tr>
<th>Gravel</th>
<th>Sand</th>
<th>Fines</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coarse to medium</td>
<td>Fine</td>
</tr>
</tbody>
</table>

### U.S. standard sieve sizes

<table>
<thead>
<tr>
<th>Grain diameter, mm</th>
<th>0.254</th>
<th>0.160</th>
<th>0.125</th>
<th>0.094</th>
<th>0.074</th>
<th>0.042</th>
<th>0.010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent finer</td>
<td>100</td>
<td>80</td>
<td>60</td>
<td>40</td>
<td>20</td>
<td>10</td>
<td>0</td>
</tr>
</tbody>
</table>

© Mechanical Analysis

X Hydrometer Analysis
<table>
<thead>
<tr>
<th>Gravel</th>
<th>Sand</th>
<th>Fines</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Grain diameter, mm

- 3/4 in.
- No. 4
- No. 10
- No. 20
- No. 40
- No. 60
- No. 80

<table>
<thead>
<tr>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
</tr>
<tr>
<td>60</td>
</tr>
<tr>
<td>40</td>
</tr>
<tr>
<td>20</td>
</tr>
<tr>
<td>10</td>
</tr>
<tr>
<td>0</td>
</tr>
</tbody>
</table>

- Mechanical Analysis
- X Hydrometer Analysis

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STUDY STATION 6  UPPER CORE

<table>
<thead>
<tr>
<th></th>
<th>Gravel</th>
<th>Sand</th>
<th>Fines</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coarse to medium</td>
<td>Fine</td>
<td>Silt</td>
</tr>
</tbody>
</table>

U.S. standard sieve sizes

- 0.478
- 0.200
- 0.125
- 0.074
- 0.042
- 0.035
- 0.014
- 0.005
- 0.001

Percent finer

Grain diameter, mm

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X Hydrometer Analysis

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STUDY STATION 6  LOWER CORE

<table>
<thead>
<tr>
<th>Gravel</th>
<th>Sand</th>
<th>Fines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse to medium</td>
<td>Fine</td>
<td>Silt</td>
</tr>
</tbody>
</table>

U.S. standard sieve sizes

[Graph showing grain diameter distribution with key notes: G Mechanical Analysis, X Hydrometer Analysis]
### STUDY STATION 8  UPPPER CORE

<table>
<thead>
<tr>
<th>Gravel</th>
<th>Sand</th>
<th>Fines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse to medium</td>
<td>Fine</td>
<td>Silt</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>U.S. standard sieve sizes</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/4 in.</td>
</tr>
</tbody>
</table>

#### Percent finer

- **Mechanical Analysis**
- **Hydrometer Analysis**

---

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<table>
<thead>
<tr>
<th>Gravel</th>
<th>Sand</th>
<th>Fines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse to medium</td>
<td>Fine</td>
<td>Silt</td>
</tr>
</tbody>
</table>

U.S. standard sieve sizes

- 3/4 in.
- No. 4
- No. 10
- No. 20
- No. 60
- No. 100
- No. 200

<table>
<thead>
<tr>
<th>Grain diameter, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.01</td>
</tr>
<tr>
<td>0.005</td>
</tr>
<tr>
<td>0.001</td>
</tr>
<tr>
<td>0.010</td>
</tr>
<tr>
<td>0.006</td>
</tr>
</tbody>
</table>

- Ø Mechanical Analysis
- X Hydrometer Analysis

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Straw, W.T. (1976). *Some Aspects of the Glacial Geology of the Kalamazoo Area.* North-Central Section of the Geological Society of America and Department of Geology, Western Michigan University, Kalamazoo, MI.


Regulations, Federal Register, 40, No. 248.


