Preliminary Evaluation of the Potential Impact on Ground Water and Surface Water of Six Landfills in Sussex County, Delaware

December 1982
PRELIMINARY EVALUATION OF THE
POTENTIAL IMPACT ON GROUND WATER AND SURFACE WATER
OF SIX LANDFILLS IN SUSSEX COUNTY, DELAWARE

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DECEMBER 1982

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SECTION 1

INTRODUCTION

1.1 BACKGROUND

Six landfills are located in Sussex County, Delaware. Presently two landfills, Bridgeville and Stockley, are still open and operating. The remaining four landfills are closed and presently operating as transfer stations. A previous study by Roy F. Weston, Inc. (WESTON) in 1980 described the hydrogeologic setting, ground-water quality and hydrogeologic controls and contaminants movement for each of the six landfills. The major portion of the study consisted of the installation and sampling of five monitor wells around each landfill. The study indicated that, generally, ground-water levels under the six landfills are quite shallow, and that contaminants, in the form of leachate, are found, to various extents, beneath each landfill. Ground-water quality at the six landfills, is monitored through a program of quarterly sampling and analysis of ground water from each of the landfill monitor wells.

1.2 PURPOSE AND SCOPE

As a result of the previous study and the continuing monitoring of ground-water quality in the monitor wells, the Delaware Department of Natural Resources and Environmental Control (DNREC) required Sussex County to evaluate each landfill's potential impact on the ground water in the vicinity of the landfills, and on any surface water receiving ground-water discharge from the landfill areas. Sussex County retained WESTON to conduct the evaluation of the potential impacts of the landfills. The principal objectives of the study were as follows:
• Estimate the leachate production at each landfill caused by precipitation and ground-water underflow

• Identify the location of surface water receiving ground-water discharge from each landfill

• Estimate the percentage of contaminated ground water expected to discharge to the surface water

• Estimate the changes in the water quality of the receiving surface water

• Estimate the size and shape of the zone of contaminant attenuation downgradient of each of the landfills

• Locate all domestic, production and irrigation wells within a one-mile radius of each site

• Locate possible future water development as anticipated by County planners.

1.3 LEACHATE GENERATION AND MOVEMENT

Leachate is liquid which has percolated through solid waste and has extracted dissolved or suspended materials from it. Whenever water comes in direct contact with solid waste, leachate will be produced. There are many materials in solid waste which are readily soluble in
in water. Other water soluble materials are generated as products of the biological degradation of the solid waste. Still other materials become soluble through the action of leachate upon the them. The quality of leachate from landfills, containing domestic refuse, is dependent on variables such as the composition, sorting, degree of compaction, moisture content, temperature and age of the refuse. Also affecting leachate quality is the amount of water entering the landfill from precipitation or ground water inflow. Generally, the more water that flows through the solid waste, the more pollutants will be leached out. Leachate-enriched ground water is characterized by the enhanced concentration of dissolved organic and inorganic substances.

The principal mode of leachate generation is through the infiltration of a portion of the precipitation that annually falls on a landfill. However, in some cases leachate is also generated by direct contact with ground water flowing through the bottom of a landfill. Once the moisture in a landfill reaches field capacity, that is, liquid has filled all the available voids in the refuse, vertical migration of the leachate occurs. The leachate will move downward until the water table is reached; then the leachate enters the ground-water flow system and begins to move downgradient in the direction of ground-water flow.

Once in the ground water, leachate begins to be renovated. The various renovation processes are dispersion/diffusion, biological assimilation, biological and/or chemical oxidation, chemical precipitation, adsorption and ion exchange.
SECTION 2

HYDROGEOLOGY

2.1 GENERAL GEOLOGY

The geology of Sussex County has been described in detail by others (Anderson, et al., 1948; Sundstrom and Pickett, 1970). In summary, Sussex County is underlain by beds of unconsolidated sediments consisting of sand, gravel and clay which thicken as they gently dip towards the southeast. The thickness of these sediments ranges from approximately 4,200 feet in the northeastern portion of the County to 7,800 feet in the southeast.

2.2 GROUND WATER

Ground-water is the sole source of water supply in the County. The uppermost aquifer, the water table aquifer, is the most heavily used in the County. The water table aquifer provides water to municipalities, industries, households and farms. It also provides base flow to streams and recharge to the artesian aquifers located beneath it.

The aquifer consists of fine to coarse-grained sands and gravels that cover the entire County. These Pleistocene Age sediments have been subdivided into several units, but, for hydrologic purposes, are considered to act as a single unit.
The depth to water in the water table aquifer, as indicated by water level measurements in the landfills' monitor wells, ranges from one foot to 20 feet below ground. The seasonal range in the depth to groundwater has been reported as being zero to 15 feet.

According to Sundstrom and Pickett (1969) saturated thickness of the water table aquifer ranges from 40 to 194 feet. Johnston, in his 1976 study of four drainage basins in Sussex County, found that local variability in the saturated thickness ranged from 38 to 92 feet.

The hydraulic characteristics of the aquifer are generally based on sparse data from field tests of pumping wells. These tests are usually of such short duration (one or 2 days) that only a small area of the aquifer is sampled, and are not necessarily representative of a regional aquifer.

Johnston (1976) analyzed the long-term recession of groundwater levels and base flow of streams. His determinations of aquifer characteristics are considered representative of the aquifer characteristics of the water table aquifer in Sussex County and were used in this study. Johnston found that the transmissivity of the aquifer ranged from 22,440 gpd/ft (gallons per day per foot) to 164,560 gpd/ft and averaged approximately 60,000 gpd/ft. He determined the storage coefficient of the aquifer to be 0.15 which is typical of the type of permeable sand aquifer that is found in Sussex County. The aquifer characteristics are the primary determining factor in leachate migration once the leachate enters the ground water.
Johnston also determined the rate of recharge, due to precipitation, for several drainage basins in Sussex County. Recharge rates ranged from 15 to 16 inches per year. These rates were based on data from a 10-year period when the average annual precipitation was slightly lower than the long-term precipitation. As such, the recharge rates have been revised upward for the purposes of this study and are in the range of 17 to 18 inches per year. One inch of recharge per acre is equal to 27,153 gallons.
3.1 GENERAL PROCEDURES

The primary goal of this study was to determine the potential impact on ground and surface waters of leachate emanating from the six landfills in Sussex County. Towards this goal, the available site data and regional data pertaining to aquifer characteristics, precipitation and recharge rates and water quality were utilized. It should be noted though that rigorous determinations of leachate movement and dispersion in the ground water, as described by various mathematical models, require extensive data covering several years of leachate movement. These data are required in order to test the models and make adjustments to them. These approaches are suited for advanced stages of contaminant studies and for long-term formal studies, but not for preliminary stages or where data are scarce, as in the present case. Every effort was made to insure that all available data was accurately utilized. Where assumptions were made in lieu of specific data, the assumptions are based on regional data or accepted hydrogeologic principles, and are conservative; that is, "worst case" conditions are assumed. The estimates of leachate production and extent are maximum "worst case" estimates. Actual leachate volumes may be less than those calculated.
3.2 LEACHATE PRODUCTION

Potential leachate production was determined by the following formula:

\[ V_R = A \times R \times C \]

where:
- \( V_R \) = Volume of leachate in gallons per year
- \( A \) = Area of the landfill underlain by refuse, in acres
- \( R \) = Recharge in inches of water
- \( C \) = Conversion factor:
  one acre-inch = 27,153 gallons.

Recharge rates varied from 17 inches per year to 18 inches per year based upon ground-water runoff figures determined by Johnston (1976) As an example:

**Landfill No. 3 - Angola**

- \( A = 45 \) acres
- \( R = 18 \) inches/year
- \( C = 27,153 \) gallons/acre-inch.

45 acres x 18 in/yr x 27,153 gal/ac-in = 21,993,930 gal/yr.

The potential leachate production at Angola, due to recharge, would be 21,993,930 gal/yr or 60,257 gpd (gallons per day).

For those landfills where the water table perennially intercepts a portion of the refuse, leachate production is a combination of recharge and ground-water interaction with the leachate. As an example, it is known that at Angola, a portion of the refuse is situated in the water table.
Leachate production due to ground-water inflow is described by the equation:

\[ V_{GW} = \frac{K \cdot I \cdot A}{K} \]

- \( V_{GW} \) = Volume of leachate-bearing ground water in gpd
- \( K \) = Hydraulic conductivity in gpd/ft\(^2\)
- \( I \) = Hydraulic gradient, determined from water level data
- \( A \) = Cross sectional area of the flow path, which is determined by the width of the landfill across the ground-water flow path times the average saturated thickness of refuse.

For Angola:

\[ A = 1,200 \text{ ft} \times 4 \text{ ft} = 4,800 \text{ ft}^2 \]

\[ I = 0.002 \]

\[ K = \text{Average transmissivity (60,000 gpd/ft) divided by the saturated thickness of the aquifer (assume 100 ft)} = 600 \text{ gpd/ft}^2 \]

Therefore:

\[ V_{GW} = \frac{600 \text{ gpd/ft}^2 \times 0.002 \times 4,800 \text{ ft}^2}{100} = 5,760 \text{ gpd} \]

Total leachate production, due to a combination of recharge and ground-water inflow, at Angola would, therefore, equal 60,257 gpd + 5,760 gpd = 66,017.

The following general assumptions were made for the current study:
- All recharge coming in contact with refuse will produce leachate.

- That leachate is produced uniformly throughout the year. Although, in reality, leachate production will vary seasonally, being greater during wet periods and less in dry periods.

- That leachate was being produced from the entire area, now underlain by refuse, within two years of the start of operations. Reports indicate that the average field capacity (field capacity is defined as the maximum moisture content which soil or refuse can retain without producing continuous downward percolation) of refuse is approximately 1.8 inches/ft. The average refuse thickness, in the 6 landfills, is approximately 12 feet, so field capacity would be reached in 1.2 to 2 years. In actuality, studies indicate that full leachate production may not occur until several years after the refuse is emplaced.

- The ground-water velocity calculated for each site does not take into account sediment porosity. Although this results in minimum values for velocity, it was considered as the best estimate for the rate of ground-water movement. Porosity data is almost non-existent for sediments in the County and textbook estimates of porosity are too variable for accurate use.

Using the equations given above, the potential leachate production of each landfill was calculated. The results
of the calculations are summarized in Table 3-1. The potential leachate production is large, but when compared to the total annual ground-water recharge for the entire County (in excess of 295 billion gallons per year), the leachate amounts to approximately 0.004 percent of the total recharge.

3.3 SURFACE WATER RECEIVING GROUND-WATER DISCHARGE

Topographic maps were used in conjunction with ground-water elevation data and site inspections to determine the ground-water flow direction. The locations of surface water bodies that potentially may be affected by leachate enhanced ground-water discharge were then identified. Estimates of the percentage of leachate-contaminated ground water discharging to the surface water were made using the known aquifer characteristics and standard ground-water flow equations.

3.4 ESTIMATE OF CHANGES IN WATER QUALITY

Estimates of the changes in both ground and surface water quality were made, based upon the aquifer characteristics and ground-water quality data collected by WESTON over the past two years. Also, one upgradient and one downgradient sample of surface water in the vicinity of each landfill was collected and analyzed for the following:

- Chloride
- Chemical Oxygen Demand
- Soluble Iron
- Soluble Manganese
- Ammonia-Nitrogen
- pH
- Specific Conductance
- Total Dissolved Solids
- Total Organic Carbon.
Table 3-1

Summary of Leachate Production

<table>
<thead>
<tr>
<th>Landfill</th>
<th>Refuse Area (acres)</th>
<th>Recharge (in/yr)</th>
<th>Groundwater Inflow (gpd)</th>
<th>Leachate Volume gal/yr</th>
<th>Leachate Volume gpd</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 1 - Bridgeville</td>
<td>52</td>
<td>17</td>
<td>--</td>
<td>24,003,252</td>
<td>65,762</td>
</tr>
<tr>
<td>No. 2 - Stockley</td>
<td>64</td>
<td>18</td>
<td>--</td>
<td>31,280,256</td>
<td>85,699</td>
</tr>
<tr>
<td>No. 3 - Angola</td>
<td>45</td>
<td>18</td>
<td>5,760</td>
<td>24,096,205</td>
<td>66,017</td>
</tr>
<tr>
<td>No. 4 - Anderson Crossroads</td>
<td>42</td>
<td>18</td>
<td>--</td>
<td>20,527,668</td>
<td>56,240</td>
</tr>
<tr>
<td>No. 5 - Laurel</td>
<td>32</td>
<td>17</td>
<td>1,608</td>
<td>15,358,152</td>
<td>42,077</td>
</tr>
<tr>
<td>No. 6 - Omar</td>
<td>18</td>
<td>18</td>
<td>--</td>
<td>8,797,572</td>
<td>24,103</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td></td>
<td></td>
<td>124,063,105</td>
<td>339,898</td>
</tr>
</tbody>
</table>
3.5 **ESTIMATE OF THE SIZE AND SHAPE OF THE LEACHATE PLUMES**

The aquifer characteristics were used to determine groundwater migration rates, the literature was searched for case studies of landfills in similar settings and a previous resistivity survey study at Angola Landfill was reviewed. Preliminary estimates of the extent of the leachate plumes were then made.

3.6 **LOCATION OF WELLS AND FUTURE WATER DEVELOPMENT IN THE VICINITY OF THE LANDFILLS**

The location of wells within a one-mile radius of the landfills was essentially determined during WESTON's previous study and updated with available information supplied by Sussex County. The State of Delaware had no well record or permit system prior to 1967. Discussions were held with the County planners to determine the future trends for groundwater development.

In general, it was noted that the actual population increase in the County exceeded projections. The projected population for 1980 was over 91,000, while the actual population in 1980 was over 98,000. The population of the County reached 100,000 in 1982, a figure that was projected for 1990. The major areas of population growth were in the recreational areas of the coast and inland bays. These areas account for most of the increase in population in the County. It was found that the inland, urban and rural areas, away from the recreational areas, generally followed the predicted population trends.
4.1 SITE DESCRIPTIONS

Landfill No. 3, Angola, is presented first in the site analysis, since it has more data available for comparison of the estimates of leachate generation and water quality with actual conditions.

Landfill No. 3 is located near Angola, west of Route 24 (Figure 4-1). The site covers an area of 53 acres (approximately 45 acres underlain by refuse) and was in operation from 29 December 1969 to 30 June 1980. The site is currently a transfer station. The average thickness of the refuse is estimated to be 12 feet. The site is underlain by highly permeable sand and the water table ranges from 4 to 9 feet below ground. A portion of the refuse is perennially in direct contact with the water table. The potential rate of leachate generation, through a combination of recharge and groundwater inflow, is on the order of 66,017 gpd. Landfill No. 3 has had additional monitor wells installed since WESTON's initial study and a preliminary resistivity survey has also been conducted at the site.

As indicated by water level measurements in the monitor wells, the general ground-water flow direction is towards the south-southeast, and the average ground-water gradient is 0.002.
Estimated Surveyed Surface = Water Sample Point
Estimated Leachate Plume — — —
Surveyed Leachate Plume
Upstream
Downstream
Private Well
Groundwater Flow Direction

FIGURE 4-1 LANDFILL #3 — SITE LOCATION

LEGEND
- Estimated Leachate Plume
- Surveyed Leachate Plume
- Surface Water Sample Point
  U — Upstream
  D — Downstream
  • — Private Well
  — Groundwater Flow Direction
4.2 SURFACE WATER RECEIVING GROUND-WATER DISCHARGE

As indicated on Figure 4-1, Chapel Branch is the downgradient surface water body that is receiving ground-water discharge from the vicinity of the landfill. Chapel Branch is approximately 300 feet southwest of the landfill at its closest approach.

In order to estimate the percentage of leachate that may be entering Chapel Branch, the ground-water velocity must be known. An estimate of ground-water velocity was made by multiplying the permeability \( K = 600 \text{ gpd/ft}^2 = 80 \text{ ft/day} \) times the gradient \( 0.002 \). This is called the Darcy velocity and equals 0.16 ft/day or 58.4 ft/yr. Given the ground-water velocity and using 11 years as the time leachate has been in production, leachate should have migrated 642 feet downgradient from the edge of the landfill. This would indicate that Chapel Branch is receiving leachate-contaminated ground water. Figure 4-2 shows the location of monitor wells around the site and the typical water table configuration.

Based upon the average ground-water gradient of 0.002, it was estimated that approximately less than 2 feet of the water table is above the level of Chapel Branch. Based on water quality data, from the monitor wells, it appears that most of the leachate is found in the upper 20 to 30 feet of the aquifer. It was assumed that the upper five feet of the aquifer would contribute ground-water discharge to the stream.

Based upon the ground-water contours, and landfill orientation, the cross sectional length of 1,200 feet for refuse perpendicular to the ground-water flow
path was determined. Multiplying the cross-sectional length by 30 feet (thickness of leachate contamination) results in a cross-sectional area through which leachate passes, of 36,000 ft$^2$. Using the equation, $V_{GW} = KIA$ where:

$$V_{GW} = \text{Volume of leachate-contaminated ground water}$$

$K = \text{Permeability in gpd/ft}^2$

$I = \text{Ground-water gradient}$

$A = \text{Cross-sectional area of flow, in ft}^2$.

$$V_{GW} = 600 \text{ gpd/ft}^2 \times 0.002 \times 36,000 \text{ ft} = 43,600 \text{ gpd flowing towards Chapel Branch. If the upper 5 feet of contaminated water enters Chapel Branch, then approximately 17 percent or 7,344 gpd of the leachate-contaminated ground water is discharging to Chapel Branch. Although, in reality, the actual discharge to Chapel Branch will be less than 7,344 gpd, since Chapel Branch is not strictly perpendicular to the ground-water flow. The remainder of the leachate would continue flowing downgradient as underflow beneath the stream.}

4.3 CHANGES IN WATER QUALITY

Changes in the quality of ground water and surface waters, due to leachate contamination were assessed. Figure 4-1 shows the location of the surface water samples which were collected in October 1982. The samples were collected approximately 3,000 feet upstream and downstream of the landfill. Table 4-1 lists results of the water quality analyses and, for comparison, the results of analyses for selected monitor wells. The well locations are shown on Figure 4-2. The results from Well P-1 are representative of background ground-water quality, while the results from Well AS-3 should reflect fresh leachate.
### Table 4-1

**Water Quality Data Summary**

**Landfill No. 3 - Angola**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>PL (20 ft)</th>
<th>AS-3 (20 ft)</th>
<th>P4C (20 ft)</th>
<th>P4B (50 ft)</th>
<th>P4A (92 ft)</th>
<th>P5C (20 ft)</th>
<th>P2C (20 ft)</th>
<th>Up Stream</th>
<th>Down Stream</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chloride</td>
<td>12.4</td>
<td>1420</td>
<td>111.4</td>
<td>11.4</td>
<td>6.3</td>
<td>14.3</td>
<td>12.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chemical Oxygen Demand</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>91.2</td>
<td>18.7</td>
</tr>
<tr>
<td>Iron</td>
<td>0.14</td>
<td>14.3</td>
<td>10.4</td>
<td>0.12</td>
<td>0.05</td>
<td>ND</td>
<td>ND</td>
<td>0.10</td>
<td>0.27</td>
</tr>
<tr>
<td>Manganese</td>
<td>0.05</td>
<td>0.2</td>
<td>0.67</td>
<td>0.05</td>
<td>ND</td>
<td>0.16</td>
<td>0.07</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>Ammonia-Nitrogen</td>
<td>ND</td>
<td>&lt;0.01</td>
<td>0.15</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>pH</td>
<td>5.0</td>
<td>7.7</td>
<td>6.6</td>
<td>6.2</td>
<td>5.8</td>
<td>4.6</td>
<td>4.0</td>
<td>6.6</td>
<td>5.6</td>
</tr>
<tr>
<td>Specific Conductance</td>
<td>90</td>
<td>&gt;5000</td>
<td>750</td>
<td>65</td>
<td>55</td>
<td>270</td>
<td>195</td>
<td>80</td>
<td>90</td>
</tr>
<tr>
<td>Total Dissolved Solids</td>
<td>77</td>
<td>4390</td>
<td>936</td>
<td>56</td>
<td>61</td>
<td>188</td>
<td>146</td>
<td>125</td>
<td>80</td>
</tr>
<tr>
<td>Total Organic Carbon</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>17</td>
<td>9</td>
</tr>
</tbody>
</table>

**NOTE:** All concentrations are given in milligrams/liter (mg/l), except for pH which is in pH units, and specific conductance which is in micromhos/cm. AS-3 penetrates refuse.

1: Since well AS-3 is sampled annually, the data in the table are from samples collected July 1982, all other samples were collected October 1982.

N.D.: Not detected.

*: Well depth.
There is little difference in water quality, with the exceptions of a slight increase in iron and a decrease in pH, between the upstream surface water sample and the downstream sample. In addition, significant renovation of the leachate-contaminated ground water takes place within a distance of 500 feet between Well AS-3 and P-4C. There are reductions in the concentrations of chloride and total dissolved solids (TDS) on the order of 92 percent and 79 percent, respectively, between AS-3 and P-4C. Chloride and TDS are generally good contaminant tracers. Chloride is particularly effective as a contaminant tracer since it is a conservative ion; that is, it does not appreciably interact with other chemical species in ground water or the sediment.

Wells P-5C and P-2C are within 400 feet and 600 feet, respectively, of the landfill. The water quality in these wells generally meet drinking water standards. The pH of the water in the two wells is low as compared with the other wells around the landfill, especially since the leachate in Well AS-3 has a pH of 7.7. The low pH appears to be restricted to the upper 20 feet of the aquifer adjacent to the P-5 and P-2 well clusters, since the water quality records indicate that the deeper "A" and "B" wells of each cluster, which range in depth from 60 to 100 feet, have pH on the order of 5.9 to 6.6.

Leachate migration studies done on two landfills on Long Island, New York, by Kimmel and Braids (1980) suggest that leachate-contaminated ground water has
a higher density than the native water and would tend to sink through the aquifer. Density differences would be expected between leachate-contaminated ground water and fresh ground water at Angola given the high concentrations of parameters found in Well AS-3. A review of the chemical data from Well AD-1, which is 50 feet deep and located on the southern edge of the landfill, indicates that there is evidence of leachate, at depth, in the well; but, the concentrations of chloride and TDS in AD-1 are 17 percent and 23 percent respectively, of the concentrations of chloride and TDS found in Well AS-3.

Downgradient of Well AS-2, in the P-4 well cluster, the shallow well, P-4C, (20 feet deep) shows evidence of dilute leachate; but, the deeper wells, P4-B (50 feet) and P-4A (92 feet) do not show any evidence of leachate. The water quality data indicate that the majority of the leachate has not penetrated to any considerable depth in the aquifer, that the highest concentrations of leachate are found adjacent to the landfill, and that no appreciable change in the nearby surface water quality has occurred.

Time vs. concentration plots were constructed for three indicator parameters: chloride (Cl), total dissolved solids (TDS), and ammonia nitrogen (NH₃-N). Chloride was selected, as mentioned earlier, because it does not appreciably interact with other chemical species. TDS was selected because it is a general indicator of the amount of dissolved constituents, and NH₃-N was selected because it is the major nitrogen species in leachate. The concentrations of the three parameters
plotted against time using all the available data (almost three years' worth). The plots represent the average concentrations, of each parameter, determined from the down-gradient wells. For comparison, the concentration of each parameter in the background well is also plotted (see Figures 4A, 4B and 4C). The plots of the indicator parameters at the Angola Landfill show an erratic, but general, decline in the leachate concentration, while the concentrations of the parameters in the background well have remained fairly constant. The data suggest that leachate production is decreasing at Angola, although whether this is a long-term trend or a transient occurrence cannot be stated with certainty at present.

4.4 EXTENT OF THE LEACHATE PLUME

The extent of the potential leachate plume was estimated based upon the available ground-water quality data and aquifer characteristics. Although there are equations for the calculation of the coefficient of dispersion, which will govern the spread of leachate, data is not available for the determination of a reasonable value for dispersion.

Based upon the aquifer characteristics it was earlier estimated that ground-water velocity was on the order of 0.16 ft/day or 58.4 ft/yr, and that in 11 years, the leachate would have migrated or longitudinally dispersed, approximately 642 feet downgradient. Kimmel and Braids (1980) and other studies indicate that in porous media, such as the sand beneath the landfill, the lateral or transverse dispersion is much less than the longitudinal dispersion. For the purpose of this study, lateral dispersion is estimated from changes in water quality in the
FIGURE 4-A LANDFILL #3 — CHLORIDE CONCENTRATION VS. TIME
FIGURE 4-B  LANDFILL #3 — TOTAL DISSOLVED SOLIDS CONCENTRATION VS. TIME
FIGURE 4-C  LANDFILL #3 — AMMONIA-NITROGEN CONCENTRATION VS. TIME
monitor wells across the landfill. Figure 4-1 shows the estimated extent of the leachate plume as the dashed line extending downgradient from the landfill.

A preliminary resistivity survey was conducted by WESTON in June 1980, along the downgradient side of Angola Landfill. The survey was conducted to determine the extent of the leachate plume leaving the landfill. Based on the ground-water velocity, the leachate plume should have extended 438 feet downgradient at the time of the survey (June 1980). The survey indicated that the farthest advance of the plume was in the southwest corner of the landfill where the plume extended approximately 350 feet downgradient. Whereas, the average extent of the leachate plume was 200 feet downgradient of the southern side of the landfill. Figure 4-3 shows the resistivity survey area and leachate plume in detail.

The variance in the shape and extent of the actual leachate plume from the estimated plume could be due to factors such as:

- Actual ground-water velocity may be lower than the calculated velocity

- Leachate production may not have started until several years after landfill operations commenced, with the older refuse cells, in the southwest corner of the landfill, producing leachate several years prior to the younger cells, thus accounting for the extent of the plume along the southwestern side of landfill.

- Actual leachate production may be lower than the estimated production rate.
Permeability may be locally variable, allowing leachate to move more rapidly from the southwestern side of the landfill.

Based upon estimated rates of movement and actual field data, the leachate plume from Landfill No. 3 near Angola is migrating in a south-southeasterly direction at rates ranging from 46 to 58 ft/yr. The leachate plume, at the present time, is located within 400 to 600 feet of the southern edge of the landfill. The predicted and actual extents of the leachate plume are roughly similar, with the actual extent being less than predicted.

4.5 WELL LOCATIONS AND FUTURE WATER SUPPLY DEVELOPMENT

Figure 4-1 shows the location of 53 domestic and agricultural wells within a one-mile radius of the landfill. None of the wells located downgradient of the landfill are presently in danger of contamination by leachate from the landfill.

The Comprehensive Development Plan for Sussex County, that was prepared in the late 1960’s, projected an increasing population of approximately 10,000 persons per decade, so that by 1990 the population of the County would be approximately 102,000. Discussions with Sussex County planners indicate that the actual growth trend has exceeded the projections by almost 50 percent. The population of the County reached 100,000 in 1982, with the majority of the increases occurring along the coastal areas and inland bays, which are prime recreational areas. The inland, rural and urban areas generally conformed to the population growth projections.
With the exception of a small housing development, about three-quarters of a mile southeast of the landfill, near Burton Pond, no significant increase in ground water use, in the vicinity of the landfill, are foreseen.
Section 5

Landfill No. 1 - Bridgeville

Landfill No. 1 is located near Coverdale Crossroads just south of Bridgeville, off County Road 594 (Figure 5-1). The site covers an area of 135 acres (approximately 52 acres underlain by refuse). Landfill operations began 1 October 1968 and the site is expected to close 30 June 1984.

The site is underlain by fine to coarse sand with gravel. The water table ranges in depth from 12 to 20 feet below ground surface. The average thickness of the refuse is estimated to be 12 feet. The bottom of the refuse is 4 to 6 feet above the water table.

The potential rate of leachate production, due to recharge is on the order of 65,762 gpd. Water level data from the 5 monitor wells on the site (Figure 5-2) suggests that a ground-water divide, trending north-south through Well BS-3, exists on the site. The general ground-water flow direction is south with components of flow towards the south-southwest and south-southeast. Based upon ground-water level data, the ground-water gradient ranges from 0.002 to 0.003.

5.2 Surface Water Receiving Ground-Water Discharge

A swampy area containing stagnant water and covering about 2 acres is located 150 to 200 feet south of the landfill boundary opposite the central portion of the site. If
FIGURE 5-1 LANDFILL #1 — SITE LOCATION

LEGEND
- Estimated Leachate Plume
- Surface Water Sample Point
  U — Upstream
  D — Downstream
  • — Private Well
- Groundwater Flow Direction

SCALE: 1N = 2000FT
Completed Area
Not in Contract
As of 12 Aug. 73

Legend

Ground Elevation

Property Corners

Area Used

Monitoring Wells

Groundwater Contours

Scale 1" = 475 ft.

FIGURE 5-2  LANDFILL #1 — MONITOR WELL LOCATIONS

AR100040
leachate is present, in the swamp, it is being masked by the stagnant water and natural decomposition of plant material. The nearest major surface-water body is the Nanticoke River located 2,000 feet west of the site (Figure 5-1).

Johnston (1976) indicated that the average transmissivity for the area was approximately 60,000 gpd/ft or 8,000 ft²/day. Using a saturated thickness for the aquifer of 110 feet, a permeability of 545 gpd/ft² or 73 ft/day was derived. The average ground-water velocity was calculated by multiplying the permeability by the ground-water gradient (0.003). The ground-water velocity in the vicinity of the landfill is 0.22 ft/day or 80 ft/yr. Assuming that leachate began entering the ground water 2 years after landfill operations began, the leachate plume should have migrated approximately 880 feet downgradient. Based upon the comparison of projected and actual leachate plumes at Landfill No. 3, Angola, and given similar aquifer characteristics, it is doubtful that leachate has migrated 880 feet. A value of 400 to 500 feet may be more appropriate for the length of the leachate plume at Landfill No. 1.

Given the ground-water velocity, distance to the river, and the fact that the Nanticoke River is not directly downgradient from the landfill, it is unlikely that leachate-contaminated ground water is discharging to the river.
5.3 CHANGES IN WATER QUALITY

Figure 5-1 shows the locations of the surface water samples that were collected in October 1982 from the Nanticoke River. Figure 5-2 shows the locations of the monitor wells that were used for the comparison of chemical parameters. The upstream and downstream surface water samples were collected approximately 3,000 feet and 1,500 feet, respectively, north and south of the landfill. Table 5-1 lists the results of the water quality analyses that were performed on the samples.

The results from Well BS-1 are representative of background water quality, while the results from Well BS-3 are representative of leachate contamination.

There is virtually no difference in water quality between the upstream and downstream surface water samples. The samples show no evidence of leachate. The chemical data from the monitor wells indicate that the highest concentrations of leachate are found in the vicinity of Wells BS-3 and BS-2. The moderate concentrations of leachate in BS-2 suggest that leachate production may not have reached full capacity in that portion of the landfill upgradient of the well. The similarity of the water quality in Wells BS-4 and BD-1 to background quality reinforces the ascertainment that no leachate is being discharged to the Nanticoke River. However, the slightly elevated values of chloride and TDS might suggest the first appearance of high density leachate sinking into the lower parts of the aquifer. It appears that the majority of the leachate is still confined to the upper 30 feet of the aquifer in the central portion of the site.
### Table 5-1

**Water Quality Data Summary**

**Landfill No. 1 - Bridgeville**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>BS-1 (30 ft)</th>
<th>BS-2 (30 ft)</th>
<th>BS-3 (37 ft)</th>
<th>BS-4 (30 ft)</th>
<th>B-1 (62 ft)</th>
<th>Upstream</th>
<th>Down Stream</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chloride</td>
<td>6.6</td>
<td>46.8</td>
<td>144.6</td>
<td>10.4</td>
<td>32.1</td>
<td>13.1</td>
<td>12.1</td>
</tr>
<tr>
<td>Chemical Oxygen Demand</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>41.4</td>
<td>41.2</td>
</tr>
<tr>
<td>Iron</td>
<td>0.10</td>
<td>66.3</td>
<td>155.0</td>
<td>0.29</td>
<td>0.55</td>
<td>0.08</td>
<td>0.06</td>
</tr>
<tr>
<td>Manganese</td>
<td>ND</td>
<td>1.84</td>
<td>0.8</td>
<td>ND</td>
<td>0.64</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>Ammonia-Nitrogen</td>
<td>ND</td>
<td>0.06</td>
<td>130</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>pH</td>
<td>5.1</td>
<td>5.9</td>
<td>6.7</td>
<td>5.2</td>
<td>5.9</td>
<td>6.7</td>
<td>6.8</td>
</tr>
<tr>
<td>Specific Conductance</td>
<td>55</td>
<td>600</td>
<td>2450</td>
<td>89</td>
<td>225</td>
<td>110</td>
<td>120</td>
</tr>
<tr>
<td>Total Dissolved Solids</td>
<td>51</td>
<td>594</td>
<td>2043</td>
<td>93</td>
<td>178</td>
<td>94</td>
<td>98</td>
</tr>
<tr>
<td>Total Organic Carbon</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>3</td>
<td>10</td>
</tr>
</tbody>
</table>

**NOTE:** All concentrations are given in milligrams/liter (mg/l), except for pH and specific conductance which are in pH units and micromhos/cm, respectively. Samples collected October 1982.

ND: Not detected.
*: Well depth
+: BS-3 adjacent to refuse cell.
In order to estimate long-term trends in water quality, the concentrations of three indicator parameters (Cl, TDS and NH$_3$-N) were plotted versus time. These plots are presented in Figures 5A, 5B and 5C. The plots are erratic with Cl showing an increase in concentration from November 1980 to May 1981 (possibly the result of a seasonal increase in recharge) then decreasing by approximately 50 percent in October 1982 and remaining relatively stable. TDS and NH$_3$-N show erratic, but generally increasing trends in concentration. While, except for a cyclic increase and decrease (February to October 1982) in NH$_3$-N and Cl, the background well has shown fairly constant concentrations of the indicator parameters. The data may suggest that leachate production has not reached full capacity and/or that the leachate plume beneath the landfill has not fully encompassed all of the downgradient monitor wells.

5.4 EXTENT OF THE LEACHATE PLUME

Based upon the aquifer characteristics, it was earlier estimated that ground-water velocity was on the order of 80 ft/yr and that the leachate plume may presently extend as much as 880 feet downgradient. However, chemical data from the monitor wells do not indicate a widespread zone of concentrated leachate and field data from Angola suggest that leachate production and migration may be slower than estimated. Still leachate is being produced and the ground-water elevation contours indicate that it can migrate away from the landfill. Based upon the assigned aquifer characteristics and taking into account the chemical data for the site, an estimation of leachate plume has been made and is shown on Figure 5-1, as the dashed line around the southern side of the landfill.
FIGURE 5-A LANDFILL #1 — CHLORIDE CONCENTRATION VS. TIME

FIGURE 5-B LANDFILL #1 — TOTAL DISSOLVED SOLIDS CONCENTRATION VS. TIME
FIGURE 5-C   LANDFILL #1 — AMMONIA-NITROGEN CONCENTRATION VS. TIME
5.5 WELL LOCATIONS AND FUTURE WATER SUPPLY DEVELOPMENT

Figure 5-1 shows the location of 55 domestic and agricultural water supply wells within a one-mile radius. None of the wells downgradient of the landfill are presently in danger of contamination by leachate from the landfill, with the possible exception of the chicken farm just south of the landfill.

The only planned development is a trailer park west of County Road 594, opposite the landfill. A total of 58 sites are planned for development with an average occupancy of 2.54 persons per site. Once completed, this development would increase the utilization of groundwater by approximately 15,000 gpd. Although the western side of County Road 594 does not appear to be in the flow path of the leachate, the exact location of the development and its wells will determine whether future pumping causes a shift in the leachate plume. No other significant development is planned for the foreseeable future in the vicinity of the landfill.
6.1 SITE DESCRIPTION

Landfill No. 2 is located east of Workman Corners just off State Highway 20, (Figure 6-1). The site covers an area of 109 acres, with approximately 64 acres underlain by refuse. Landfill operations began 23 December 1969 and the site is expected to close 30 June 1983.

The site is underlain by fine to coarse sand mixed with gravel, and occasional thin lenses of silt or clay. The water table ranges in depth from 4.5 to 14 ft below ground surface. The refuse is estimated to be 12 ft thick and it is suspected, based upon the refuse thickness that portions of the refuse may be in contact with ground-water. The extent of the contact is unknown since only one monitor well boring penetrated refuse and in that boring the refuse was found to be only 5 ft thick and located above the water table.

The potential rate of leachate production, due to recharge, is on the order of 85,699 gpd. Water level data from the five monitor wells (Figure 6-2) on the site indicate that the general ground-water flow direction is southeast. The ground-water gradient was calculated to be 0.002.

6.2 SURFACE WATER RECEIVING GROUND-WATER DISCHARGE

As indicated on Figure 6-1, Sheep Ditch is the surface water body immediately down gradient of the site that will receive ground-water discharge from the site. Sheep Ditch forms the
FIGURE 6-1 LANDFILL #2 — SITE LOCATION

LEGEND
- Estimated Leachate Plume
- Surface Water Sample Point
  U — Upstream
  D — Downstream
  • Private Well
- Groundwater Flow Direction

SCALE: 1 IN = 2000 FT
Ground-water velocity for the site was estimated to be 0.19 ft/day or 69 ft/yr, based upon a permeability of 97 ft/day and gradient of 0.002. Assuming 11 years for leachate production and migration, the leachate plume should extend approximately 760 ft down gradient. This would indicate that Sheep Ditch is receiving leachate contaminated groundwater.

In order to estimate the percentage of leachate-contaminated water that would discharge to Sheep Ditch, the volume of ground-water flowing under the landfill was determined. Based upon water level data and the configuration of the water table, it is estimated that Sheep Ditch would receive ground-water flow from the upper 5 ft of the water table. A review of the water quality data for the monitor wells on the site indicates that the majority of the leachate is found in the upper 20 to 25 ft of the aquifer.

Based upon the orientation of the landfill to the ground-water flow direction and the stream, a cross-sectional aquifer length of 2,400 ft was determined. The cross-sectional area of the contaminated portion of the aquifer was calculated to be:

\[ A = 2,400 \times 25 \text{ ft} = 60,000 \text{ ft}^2. \]

Using a permeability of 730 gpd/ft$^2$ (Johnston, 1976) and the groundwater gradient of 0.002, the volume of leachate-contaminated ground-water flowing from the landfill is:

\[ V_{GW} = 730 \text{ gpd}/\text{ft}^2 \times 0.002 \times 60,000 \text{ ft}^2 = 87,600 \text{ gpd}. \]
If the upper 5 ft of contaminated water enters Sheep Ditch, then approximately 20% or 17,520 gpd is discharging to the stream. The remainder of the leachate would continue flowing down gradient as underflow beneath the stream. Since the stream generally parallels the ground-water flow direction, the leachate may, eventually, discharge to Sheep Ditch farther down stream.

6.3 CHANGES IN WATER QUALITY

Figure 6-1 shows the locations of the upstream and downstream sampling points on Sheep Ditch, from which surface water samples were collected in October 1982. The upstream sample was collected just above Pole Dam Bridge approximately 100 ft west of the landfill. The downstream sample was collected approximately 8,000 ft east of the landfill, where Sheep Ditch flows under Route 113. Sampling closer to the landfill was precluded by the unwillingness of the homeowners in the area to allow the field crew to cross their property to get to the Ditch.

Table 6-1 lists the results of the analyses that were performed on the surface water samples. The table also lists the results of analyses of ground-water from the landfill monitor wells. The results from Well SS-1 are representative of the background ground-water quality, while the results from Wells SS-2 and SS-3 are indicative of leachate contamination.

The results of the surface water analyses indicate there is little difference in surface water quality upstream and downstream of the landfill. There is no evidence of leachate in the surface water. The estimate of the amount of leachate that
Table 6-1

Water Quality Data Summary

Landfill No. 2 - Stockley

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Groundwater</th>
<th>Surface Water</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SS-1 (20 ft)*</td>
<td>SS-2 (20 ft)*</td>
</tr>
<tr>
<td>Chloride</td>
<td>5.9</td>
<td>76.5</td>
</tr>
<tr>
<td>Chemical Oxygen Demand</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Iron</td>
<td>0.19</td>
<td>4.19</td>
</tr>
<tr>
<td>Manganese</td>
<td>0.05</td>
<td>0.9</td>
</tr>
<tr>
<td>Ammonia-Nitrogen</td>
<td>ND</td>
<td>510</td>
</tr>
<tr>
<td>pH</td>
<td>5.2</td>
<td>6.4</td>
</tr>
<tr>
<td>Specific Conductance</td>
<td>850</td>
<td>800</td>
</tr>
<tr>
<td>Total Dissolved Solids</td>
<td>462</td>
<td>1184</td>
</tr>
<tr>
<td>TOC</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

NOTE: All concentrations are given in milligrams/liter (mg/l), except for pH and specific conductance which are in pH units and micro MHOS/cm, respectively.

1: SS-2 and SS-4 are sampled annually the data for these wells are from samples collected July 1982, all the other samples were collected October 1982. SS-2 penetrates refuse.

N.D.: Not Detected.
* Well Depth.
Discharges to the Ditch may be too high, or complete renovation may occur, once leachate enters the Ditch, between the landfill and the downstream sample point. However, if leachate was actually discharging to the stream on the order of 17,520 gpd, then conservative ions, such as chloride should be present in high concentrations for some distance downstream.

The lack of evidence of leachate in Well SD-1, which is 50 ft deep and adjacent to Well SS-3, which is contaminated, indicates that leachate is only found in the upper 20 to 25 ft of the aquifer, and that the estimate of the time that leachate has been in production is too long. The leachate plume may be younger than originally estimated, the rate of migration may be slower than projected, or the leachate is being renovated.

Data available from monitor wells located east and south of the landfill, that were installed by Kidde Consultants, Inc., indicate that no leachate was found in the wells. This would indicate that the leachate is still essentially confined to the landfill or is being rapidly attenuated down gradient. Chemical data from the three Kidde monitor wells, nearest the landfill, (Wells 4, 7 and 8 on Figure 6-1), are presented in Table 6-2. The chemical data do not indicate the presence of any leachate and, except for slightly elevated manganese concentrations in Wells 4 and 8, meet the standards for potable water. The Kidde wells were installed in clusters of 3 wells per site. The wells in each cluster were generally at depths of 20, 60 and 120 feet. The analytical reports on the water quality in the wells provided, by Richardson Assoc., are for samples taken from the shallow wells, but it is not clear if the wells are 20 or 60 feet deep.

Concentration versus time plots for the indicator parameters Cl, TDS and NH₃-N are shown on Figures 6A, 6B and 6C. The plots for Cl and TDS show accelerating rates of concentration...
Table 6-2

Chemical Data Summary

Kidde Consultants, Inc. Wells

<table>
<thead>
<tr>
<th>Parameter</th>
<th>No. 4</th>
<th>No. 7</th>
<th>No. 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alkalinity</td>
<td>3.0</td>
<td>11</td>
<td>13</td>
</tr>
<tr>
<td>Arsenic</td>
<td>&lt;0.004</td>
<td>&lt;0.004</td>
<td>&lt;0.004</td>
</tr>
<tr>
<td>Chloride</td>
<td>15</td>
<td>16</td>
<td>7</td>
</tr>
<tr>
<td>Total Chromium</td>
<td>&lt;0.05</td>
<td>&lt;0.05</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Specific Conductance</td>
<td>120</td>
<td>100</td>
<td>61</td>
</tr>
<tr>
<td>Copper</td>
<td>&lt;0.05</td>
<td>&lt;0.05</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Hardness</td>
<td>38</td>
<td>21</td>
<td>11</td>
</tr>
<tr>
<td>Iron</td>
<td>0.08</td>
<td>&lt;0.05</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Lead</td>
<td>&lt;0.05</td>
<td>&lt;0.05</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Manganese</td>
<td>0.14</td>
<td>&lt;0.05</td>
<td>0.06</td>
</tr>
<tr>
<td>Mercury</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
</tr>
<tr>
<td>Nickel</td>
<td>&lt;0.05</td>
<td>&lt;0.05</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Ammonia Nitrogen</td>
<td>&lt;0.11</td>
<td>&lt;0.11</td>
<td>&lt;0.11</td>
</tr>
<tr>
<td>pH</td>
<td>5.5</td>
<td>5.9</td>
<td>6.3</td>
</tr>
<tr>
<td>Total Dissolved Solids</td>
<td>82</td>
<td>68</td>
<td>60</td>
</tr>
<tr>
<td>Selenium</td>
<td>&lt;0.004</td>
<td>&lt;0.004</td>
<td>&lt;0.004</td>
</tr>
<tr>
<td>Sulfate</td>
<td>15</td>
<td>&lt;5</td>
<td>&lt;5</td>
</tr>
<tr>
<td>Total Organic Carbon</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Chemical Oxygen Demand</td>
<td>&lt;5</td>
<td>&lt;5</td>
<td>5</td>
</tr>
<tr>
<td>Total Coliform</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;10</td>
</tr>
<tr>
<td>Phenol</td>
<td>&lt;0.004</td>
<td>&lt;0.004</td>
<td>0.004</td>
</tr>
<tr>
<td>BOD₅</td>
<td>&lt;2.4</td>
<td>&lt;2.4</td>
<td>&lt;2.4</td>
</tr>
</tbody>
</table>

NOTE: Samples collected 5/25/82, analyses performed by Edward H. Richardson Associates. All results given in mg/l, except pH, specific conductance and coliform which are given in pH units, micro NH₃OS/cm and colonies/100 ml, respectively.
FIGURE 6-A  LANDFILL #2 — CHLORIDE CONCENTRATION VS. TIME

FIGURE 6-B  LANDFILL #2 — TOTAL DISSOLVED SOLIDS CONCENTRATION VS. TIME
FIGURE 6-C  LANDFILL #2 — AMMONIA-NITROGEN CONCENTRATION VS. TIME
increase through time, while NH$_3$N fluctuates considerably in concentration, but, generally, does not indicate any increase in the average concentration. The background well shows some minor, possibly seasonal, fluctuations, but in general the concentrations of the indicator parameters are fairly stable through time.

6.4 EXTENT OF LEACHATE PLUME

The estimate of the ground-water velocity (69 ft/yr) would appear to be reasonable based upon the regional aquifer characteristics. Yet, surface water samples and down-gradient, off-site well samples, show no indication of leachate. It is assumed that leachate is migrating off-site, but that the leachate has not yet reached the Kidde wells, for which analytical results are available. Therefore, any off-site migration will be limited to within 300 feet of the southeast side of the landfill. The dashed line on Figure 6-1 shows the estimated extent of the leachate plume.

6.5 WELL LOCATION AND FUTURE WATER DEVELOPMENT

Figure 6-1 shows the locations of 39 domestic and agricultural water supply wells within one mile of Landfill No. 2. None of the wells are presently in danger of contamination from landfill leachate.

No significant increases in ground-water development are foreseen. According to the Sussex County planners, the Delaware Solid Waste Authority has an option on nearby land as a possible future landfill site.
SECTION 7

LANDFILL NO. 4 - ANDERSON CROSSROADS

7.1 SITE DESCRIPTION

Landfill No. 4 is located southwest of Anderson Crossroads just off County Route 216 (see Figure 7-1). The site covers an area of approximately 51 acres, with approximately 42 acres underlain by refuse. Landfill operations began 1 March 1970 and the site closed 29 January 1982. The site is presently operated as a transfer station.

The site is underlain by fine to coarse sand with gravel. The boring logs of the five monitor wells on the site indicate that thin lenses of silt or clay are occasionally present in the sand. The water table, beneath the site, ranges in depth from 9 to 17 feet below ground surface. According to the Site Plan of Operations, the approximate refuse thickness is 12 feet.

The potential rate of leachate production, due to recharge in on the order of 56,240 gpd. Water level data from the 5 on-site monitor wells indicate that the ground-water flow direction is southwest. The ground-water gradient was calculated to 0.005.

7.2 SURFACE WATER RECEIVING GROUND-WATER DISCHARGE

As indicated on Figure 7-1, a small tributary to Church Branch lies southwest of the landfill. At the time the ground water and surface water samples were collected in late October 1982, the tributary was dry as far as its
LEGEND
- Estimated Leachate Plume
- Surface Water Sample Point
- U — Upstream
- D — Downstream
- • Private Well
- Groundwater Flow Direction

SCALE: 1 IN = 2000 FT

FIGURE 7-1 LANDFILL #4 — SITE LOCATION
juncture with Church Branch. The tributary undoubtedly flows during the wetter portions of the year and may at that time receive leachate-contaminated ground-water discharge. For this study, Church Branch was considered as the stream likely to receive leachate.

Ground-water velocity for the site was estimated to be 0.4 ft/day or 146 ft/yr, based upon the ground-water gradient of 0.005 and a hydraulic conductivity of 80 ft/day (Johnston, 1976; Sundstrone and Pickett, 1969). Assuming 10 years for leachate generation and migration, the leachate plume should extend approximately 1,460 feet downgradient. This would suggest that Church Branch, which is approximately 700 to 900 feet downgradient of the landfill at its closest approach should be receiving leachate-contaminated ground-water discharge.

In order to estimate the percentage of leachate-contaminated ground water that would discharge to Church Branch, the volume of ground water flowing under the landfill was determined. Based upon the orientation of the landfill to the ground-water flow direction and the stream, a cross sectional aquifer length of 1,370 feet was determined. Water quality data indicate that the upper 20 to 25 feet of the aquifer contain the majority of the leachate. Therefore, the cross sectional area of flow for the leachate would be 1,270 x 25 feet = 34,250 feet². Using a permeability of 600 gpd/ft² times the ground-water gradient of 0.005, times the cross sectional area, a volume of flow of 102,750 gpd was determined. This would suggest that, if 56,240 gpd of leachate is actually being generated, the leachate entering the ground water...
beneath the site is being diluted by a factor of almost 2 to 1, by ground-water underflow. If it is assumed that the upper 5 feet of the aquifer could contribute discharge to Church Branch, then 20 percent or 20,550 gpd of leachate-contaminated water may be discharging to Church Branch.

7.3 CHANGES IN WATER QUALITY

Figure 7-1 shows the location of the upstream and downstream surface water sampling points on Church Branch. The surface water samples were collected in October 1982 during the quarterly landfill monitor well sampling program. The upstream sample point is approximately 7,400 feet south of the landfill, while the downstream sample point is approximately 100 feet downstream of the landfill.

Table 7-1 lists the results of the analyses that were performed on the surface water samples, along with the results from the analyses of the monitor well samples for comparison. Figure 7-2 shows the location of the landfill monitor wells and the general water table configuration. The analytical results from Well AXS-3 may be considered to represent background ground-water quality. The analytical results from Wells AXS-2 and AXS-4 are representative of leachate-contaminated ground water.

The results of the surface water analyses indicate that little, if any, leachate is reaching Church Branch. There were very slight increases in the concentrations of chloride, iron, manganese and ammonia nitrogen in the downstream sample when compared to the upstream sample, but the downstream sample, with the exception of manganese, still meets drinking water standards. The highest concentration of leachate in ground water was exhibited by Well AXS-4. Well AXS-4 is upgradient of the major portion of the
### Table 7-1

Water Quality Summary

Landfill No. 4 - Anderson Crossroads

<table>
<thead>
<tr>
<th>Parameter</th>
<th>AXS-3 (20 ft)</th>
<th>AXS-1 (25 ft)</th>
<th>AXS-2† (25 ft)</th>
<th>AXS-4† (20 ft)</th>
<th>AXD-1 (60 ft)</th>
<th>Upstream</th>
<th>Down Stream</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chloride</td>
<td>11.5</td>
<td>8.8</td>
<td>41.2</td>
<td>224.6</td>
<td>25.2</td>
<td>9.9</td>
<td>11.2</td>
</tr>
<tr>
<td>Chemical Oxygen Demand</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>72.9</td>
<td>43.4</td>
</tr>
<tr>
<td>Iron</td>
<td>1.73</td>
<td>0.09</td>
<td>10.1</td>
<td>184.0</td>
<td>1.83</td>
<td>ND</td>
<td>0.14</td>
</tr>
<tr>
<td>Manganese</td>
<td>0.3</td>
<td>0.07</td>
<td>1.61</td>
<td>18.7</td>
<td>13.1</td>
<td>ND</td>
<td>0.10</td>
</tr>
<tr>
<td>Ammonia-Nitrogen</td>
<td>ND</td>
<td>ND</td>
<td>0.37</td>
<td>0.17</td>
<td>0.5</td>
<td>ND</td>
<td>0.05</td>
</tr>
<tr>
<td>pH</td>
<td>6.1</td>
<td>5.4</td>
<td>6.2</td>
<td>4.8</td>
<td>6.9</td>
<td>6.5</td>
<td>6.7</td>
</tr>
<tr>
<td>Specific Conductance 1000</td>
<td>55</td>
<td>580</td>
<td>1600</td>
<td>300</td>
<td>120</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Total Dissolved Solids</td>
<td>92</td>
<td>62</td>
<td>381</td>
<td>1700</td>
<td>190</td>
<td>100</td>
<td>85</td>
</tr>
<tr>
<td>Total Organic Carbon</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>7</td>
<td>12</td>
</tr>
</tbody>
</table>

**NOTE:** All concentrations are given in milligrams/liter (mg/l), except for pH and specific conductance which are in pH units and micromhos/cm, respectively.

N.D.: Not detected.

*: Well depth.
†: Adjacent to refuse.
landfill and it would be expected to be relatively free of leachate, but in the latter stages of the landfill operation, refuse was emplaced in the vicinity of both Wells AXS-4 and AXS-3. Therefore, it is expected that these wells will show increasing concentrations of leachate. The deep well AXD-1 shows some parameters that are in excess of drinking water standards, but the concentrations of chemical constituents are essentially the same as they were in 1979 when the monitor wells were installed and are not considered to be due to leachate contamination. An old migrant camp, up-gradient of the landfill (Figure 7-1), may be a possible source of contaminants that would affect the ground-water quality on the northeastern side of the landfill.

Concentration versus time plots for the indicator parameters Cl, TDS and NH$_3$-N are shown on Figures 7A, 7B and 7C. The plots indicate that the average concentration of chlorides in the downgradient well has started to increase within the last year and that the concentration of TDS has increased by nearly an order of magnitude within the last year and a half. The concentrations of NH$_3$-N has remained fairly stable through time, although the background well showed higher concentrations of NH$_3$-N, for a period of time between October 1981 and July 1982, than the downgradient wells. As mentioned earlier, refuse emplaced nearby Well AXS-3 may be beginning to impact on water quality in the well. The plots suggest that leachate production has increased within the last two years and may not have been significant before that time.
FIGURE 7-A LANDFILL #4 — CHLORIDE CONCENTRATION VS. TIME

FIGURE 7-B LANDFILL #4 — TOTAL DISSOLVED SOLIDS CONCENTRATION VS. TIME
FIGURE 7-C LANDFILL #4 — AMMONIA-NITROGEN CONCENTRATION VS. TIME
7.4 EXTENT OF LEACHATE PLUME

Given a ground-water velocity estimate of 146 ft/yr, it would be expected that leachate should be found in Church Branch. Yet, the surface water samples do not indicate the presence of leachate. The ground-water samples indicate an increase in leachate concentration through time and suggest that high concentrations of leachate had not migrated from the landfill prior to 1979. Therefore, it is considered that the extent of the leachate plume is within 400 feet of the landfill. The dashed line of Figure 7-1 indicates the probable extent of the leachate plume.

7.5 WELL LOCATION AND FUTURE WATER DEVELOPMENT

Figures 7-1 shows the location of 85 domestic and agricultural water supply wells within one mile of Landfill No. 4. None of the wells are presently in danger of contamination from landfill leachate.

The County Planners indicate that possibly 20 home sites may be developed near the landfill in the near future. There is said to be the possibility of development along County Roads 216 (east side of the landfill) and 214 (north side of the landfill). These areas are not directly downgradient of the landfill, but are sufficiently close to the site that the possibility exists that extended pumping of any new wells, in the vicinity, may draw diluted leachate towards them. New development adjacent to the landfill may have to be restricted, unless the actual aquifer characteristics and extent of the leachate plume are determined and indicate that pumping of any new water supply wells, near the landfill, will not affect the shape of the leachate plume or its direction of migration.
8.1 SITE DESCRIPTION

Landfill No. 5 is located west of the Laurel Airport, between County Road 494 and Route 24 (Figure 8-1). The site covers 39 acres with approximately 32 acres underlain by refuse. Landfill operations began 11 May 1970, and the site was closed 11 August 1979. The site is presently operated as a transfer station.

The site is underlain by permeable, fine to medium sand with gravel and occasional thin lenses of silt and clay. The water table ranges in depth from 6 to 12 feet below ground surface. Water level data from the five monitor wells (Figure 8-2) on the site indicate that the general ground-water flow direction is north. The ground-water gradient is 0.002.

The refuse is estimated to be 12 feet thick and it was evident from one of the monitor wells, well LS-1, that a portion of the refuse in the vicinity of that well is in contact with the water table. The potential rate of leachate production is 42,077 gpd, with 40,469 gpd attributed to recharge and 1,608 gpd attributed to ground-water inflow.
Big Mills Bridge

**LEGEND**
- Estimated Leachate Plume
- Surface Water Sample Point
- U — Upstream
- D — Downstream
- ● Private Well
- Groundwater Flow Direction

**FIGURE 8-1 LANDFILL #5 — SITE LOCATION**

SCALE: 1IN = 2000FT
FIGURE 8-2  LANDFILL #5 — MONITOR WELL LOCATIONS
8.2 SURFACE WATER RECEIVING GROUND-WATER DISCHARGE

Culver Ditch (west of the site) and Holly Ditch (east of the site) are the nearest surface water bodies that potentially may receive ground-water discharge from the vicinity of the landfill. During the field sampling, done in October 1982, these drainage ditches were found to be dry. Although, it is likely that during wetter portions of the year the ditches would contain flowing water.

The ground-water velocity for the site was estimated to be 0.15 ft/day, based upon a gradient of 0.002 and a hydraulic conductivity, or permeability of 73 ft/day (Johnston, 1976, Sundstrom and Pickett, 1969), or 53 ft/yr. Assuming 9 years for leachate production and migration, the leachate plume should extend approximately 477 feet downgradient. Since Culver Ditch and Holly Ditch were found to be dry as far as County Road 492, it is apparent that ground-water discharge to the ditches is intermittent. Also, the ditches flow generally parallel to the ground-water flow direction, so that leachate will enter the ditches through lateral dispersion which occurs at a much slower rate than longitudinal dispersion, or down gradient flow.

Assuming a worst case, that the portion of Culver Ditch nearest the landfill receives ground-water discharge 6 months out of the year and that the upper 5 feet of the aquifer will provide discharge to the Ditch, then the percentage of leachate-contaminated ground-water can be estimated. Assuming flow perpendicular to the Ditch through a cross-sectional length of the landfill (closest to the ditch) of 1,140 ft and an average contaminated aquifer thickness of 35 feet then the
cross-sectional area of flow is 39,900 ft\(^2\). The potential discharge is then equal to the permeability 72 ft/day or 546 gpd/ft\(^2\) times the gradient, 0.002, times the cross-sectional area. This results in a potential ground-water flow of 43,571 gpd. If the upper 5 feet provide the discharge to the ditch then 14\% or 6,100 gpd of leachate-contaminated water may enter the Ditch. This is a worst case estimate and does not appear to actually happen. Since the ground-water elevation contours, shown on Figure 8-2, do not indicate any ground-water mound beneath the site there is little or no likelihood of lateral flow towards the Ditch, and, as mentioned earlier, lateral dispersion of the leachate plume would be much slower than the downgradient dispersion, it is probable that, at worst, only a small fraction of the potential leachate-contaminated discharge may reach the ditch. Given the ground-water flow rate, leachate would not be expected to discharge to the Ditch down gradient of the landfill for some years (10 to 30) to come.

8.3 CHANGES IN WATER QUALITY

Figure 8-1 shows the location of the surface water sample points. Since there was no surface water directly up gradient of the landfill, samples were collected from Culver Ditch and Holly Ditch where surface flow was evident downgradient of the landfill. The surface water samples were collected approximately 5,500 downgradient of the landfill in October 1982, during the regular quarterly monitor well sampling period.

Table 8-1 lists the results of the analyses performed on the surface water samples. The table also lists the results of analyses performed on the landfill monitor wells. The results from Well LS-4 are considered to be generally representative of background ground-water quality, even though the well is
## Table 8-1

**Water Quality Data Summary**

*Landfill No. 5 - Laurel*

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Ground Water</th>
<th>Surface Water</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LS-1&lt;sup&gt;1&lt;/sup&gt; (35 ft)</td>
<td>LS-2 (30 ft)</td>
</tr>
<tr>
<td>Chloride</td>
<td>32.7</td>
<td>129.7</td>
</tr>
<tr>
<td>Chemical Oxygen Demand</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Iron</td>
<td>0.05</td>
<td>63.0</td>
</tr>
<tr>
<td>Manganese</td>
<td>0.58</td>
<td>1.46</td>
</tr>
<tr>
<td>Ammonia Nitrogen</td>
<td>5.6</td>
<td>0.79</td>
</tr>
<tr>
<td>pH</td>
<td>6.4</td>
<td>6.1</td>
</tr>
<tr>
<td>Specific Conductance</td>
<td>360</td>
<td>920</td>
</tr>
<tr>
<td>Total Dissolved Solids</td>
<td>192</td>
<td>678</td>
</tr>
<tr>
<td>Total Organic Carbon</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

**NOTE:** All concentrations are given in milligrams/liter (mg/l), except for pH and specific conductance which are in pH units and micro-mhos/cm, respectively.

1: Well LS-1 and Well LS-3 are sampled annually. The data in the above table for these wells are from samples collected July 1982. All other samples were collected October 1982. LS-1 and LS-3 penetrate refuse.

ND: Not Detected.

*: Well Depth.
downgradient of the refuse cells and will eventually be contaminated. The ground-water quality in Wells LS-1, LS-2 and LS-3 is representative of leachate in ground water.

The results of the surface water analyses indicate no direct evidence of leachate in the surface water, as would be expected given the distance of the samples from the landfill. The sample from Culver Ditch has slightly higher concentrations of most of the parameters tested than did the sample from Holly Ditch. It is likely that these results reflect the quality of the ground-water discharging locally to the ditches, which is affected by local conditions, such as the swamp areas from which the samples were collected, and are not associated with the landfill.

The monitor wells generally indicate that leachate has penetrated the aquifer to depths of 35 feet. Although the deep Well LD-1 has elevated values of all the parameters tested, when compared to Well LS-4, which is adjacent to Well LD-1, it is questionable whether the results are indicative of leachate penetration to depth. Well LD-1 is 50 feet deep, while LS-4 is 30 feet deep; if a leachate plume were spreading through the area then Well LS-4 should show indications of leachate prior to or simultaneously with Well LD-1. Possible explanations for the difference in water between the two wells are: refuse may have been emplaced in close proximity to Well LD-1 and the pumping of the well for sampling purposes may result in leachate being drawn into it, or the well may intercept a slug of high density leachate which has sunk into the aquifer. Given the relatively small difference in depth between the wells, a high density leachate plume would have to be very small in order to miss Well LS-4 and enter Well LD-1. It is likely that leachate from nearby refuse is being drawn into the well as the result of sample pumping.
The concentrations for three indicator parameters, Cl, TDS, and NH$_3$-N were plotted through time and shown on Figures 8A, 8B and 8C. On the average, Cl and TDS show slight increasing concentration trends. The trend for NH$_3$-N is erratic, but on the whole, the average concentration of NH$_3$-N in the downgradient wells does not appear to increase significantly. The background well, LS-4, showed a concentration of NH$_3$-N in October 1982 that exceeded the average of the downgradient wells, which suggests that leachate may be beginning to reach the well. However, succeeding samples from Well LS-4 indicate that the NH$_3$-N concentration has decreased to below the downgradient average. In general, the plots suggest that leachate production may not have reached its maximum volume or concentration as yet.

8.4 EXTENT OF LEACHATE PLUME

The dashed line on Figure 8-1 shows the estimated extent of the leachate plume. This is based upon the estimated groundwater velocity in the vicinity of the site. Therefore, the leachate plume may extend 400 to 500 feet downgradient of the landfill, although Well LS-4 does not show high concentrations of leachate under the northern end of the landfill, Well LD-1, adjacent to LS-4, appears to be contaminated. So, in the absence of off-site groundwater quality data, a distance of 500 feet downgradient is assumed for the edge of the plume.

8.5 WELL LOCATION AND FUTURE WATER DEVELOPMENT

Figure 8-1 shows the location of 59 domestic and agricultural water supply wells within one mile of Landfill No. 5. With the exception of the wells north and west of the landfill which appear to be near the estimated edge of the leachate plume, no wells are in danger of contamination by landfill leachate. It is doubtful that the leachate plume extends
FIGURE 8-A LANDFILL #5 — CHLORIDE CONCENTRATION VS. TIME

Average of Downgradient Wells

Background Well

FIGURE 8-B LANDFILL #5 — TOTAL DISSOLVED SOLIDS CONCENTRATION VS. TIME

Average of Downgradient Wells

Background Well
Average of Downgradient Wells

Background Well

FIGURE 8-C  LANDFILL #5 — AMMONIA-NITROGEN CONCENTRATION VS. TIME
as far as is estimated, so it may be several years before the
domestic wells north and west of the landfill are actually in
danger of contamination.

Discussions with the County planners indicate that three single-
home lots just west of County Road 497, approximately 4,000
feet west of the landfill, and one single lot, approximately
three-quarter of a mile east of Landfill No. 5, on the south
side of Route 24, were developed in 1982, but no new large
scale development is foreseen for the area.
9.1 SITE DESCRIPTION

Landfill No. 6 is located east of Omar, off County Road 373 (Figure 9-1). The site covers 97 acres with approximately 18 acres covered by refuse, only the acreage used for refuse disposal is shown on Figure 9-1. Landfill operations began on 20 April 1971 and the site was closed on 9 February 1980. The site is currently operated as a transfer station.

The site is underlain by permeable, fine to medium sand. There is a layer of dark gray, silty clay beneath the site, generally encountered 7 to 10 feet below ground, that ranges in thickness from 0.75 to 4 feet. If continuous, this clay layer would limit the downward migration of leachate. The ground water ranged in depth beneath the site from 1 to 7 feet below ground. The approximate thickness of the refuse is 12 feet. The refuse was spread over the original ground surface, rather than buried in cells, due to the shallow ground-water table.

Ground-water level data from the 5 monitor wells on the site indicate that the ground-water flow direction is towards the southeast. The ground-water gradient is 0.006. Figure 9-2 shows the location of the monitor wells and the ground-water table configuration.
LEGEND

- Estimated Leachate Plume
- Surface Water Sample Point
- U — Upstream
- D — Downstream
- • Private Well
- ← Groundwater Flow Direction

SCALE: 1 IN = 2000 FT

FIGURE 9-1 LANDFILL #6 — SITE LOCATION
Leachate production, due to recharge, is estimated to be 24,103 gpd.

9.2 SURFACE WATER RECEIVING GROUND-WATER DISCHARGE

The area marked as a borrow pit on Figure 9-2 is a shallow pond, that intercepts the water table, and is downgradient of a portion of the landfill. This pond can be expected to receive leachate migrating from a portion of the refuse, and the presence of leachate in the pond has been observed in the past. Just to the east of the pond, and flowing northeast along the eastern side of the landfill, is a small stream, Blackwater Creek, that is known to receive leachate.

Ground-water velocity for the site was estimated to be 0.38 ft/day or 140 ft/year, based upon a hydraulic conductivity of 64 ft/day (Johnston, 1976; Sundstrom and Pickett, 1969) and a gradient of 0.006. Assuming 9 years for leachate production and migration, the leachate plume should extend approximately 1,260 feet downgradient from the landfill.

In order to estimate the percentage of leachate-contaminated ground water that would discharge to Blackwater Creek on the east side of the landfill, the volume of ground water flowing under the landfill was estimated. Based upon the orientation of the landfill and the Creek, a cross sectional length, of the aquifer perpendicular to the flow path, of 900 feet was determined. The cross-sectional depth of the most contaminated portion of the aquifer was estimated to be 15 to 20 feet, based upon water quality data from the monitor wells. Therefore, ground-water flow beneath the landfill is equal to the permeability, 64 ft/day or 479 gpd/ft², times the gradient, 0.006, times the cross-sectional area, 18,000 ft².
This results in a ground-water flow, beneath the landfill, of 51,732 gpd. Approximately, the upper 2 to 3 feet of the aquifer, beneath the landfill, is above the level of the Creek. For a worst case estimate, it is assumed that the upper 5 feet of the aquifer contribute to discharge to the Creek. Therefore, 25 percent, or 12,933 gpd of leachate-contaminated water would discharge to Blackwater Creek.

9.3 CHANGES IN WATER QUALITY

Figure 9-1 shows the locations of the upstream and downstream sampling points on Blackwater Creek. The upstream sample was collected approximately 200 feet south of County Road, approximately 200 feet upstream of the landfill. The downstream sample was collected on the north side of County Road 353, approximately 700 feet downstream from the landfill.

Table 9-1 lists the results of the analyses that were performed on the surface water samples collected in October 1982. The table also lists the results of analyses of ground-water samples collected from the landfill monitor wells, during the annual sampling period in July 1982. The results from Well OS-1 are considered to be representative of background water quality. The results from Wells OS-2 and OS-3 are representative of leachate in the groundwater.

The analyses of the surface water samples indicate that both upstream and downstream samples are above drinking water standards in regards to TDS and manganese, and that the downstream sample has approximately twice the Cl concentration of the upstream sample. These results suggest that Blackwater Creek is somewhat contaminated by
Table 9-1

Water Quality Data Summary

Landfill No. 6 - OMAR

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Ground Water(^1)</th>
<th>Surface Water</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OS-1 (20 ft) *</td>
<td></td>
</tr>
<tr>
<td></td>
<td>OS-2 (^+) (20 ft) *</td>
<td></td>
</tr>
<tr>
<td></td>
<td>OS-3 (^+) (20 ft) *</td>
<td></td>
</tr>
<tr>
<td></td>
<td>OS-4 (15 ft) *</td>
<td></td>
</tr>
<tr>
<td></td>
<td>OD-1 (50 ft) *</td>
<td></td>
</tr>
<tr>
<td>Chloride</td>
<td>65.8</td>
<td>39.3</td>
</tr>
<tr>
<td>Chemical Oxygen Demand</td>
<td>--</td>
<td>30</td>
</tr>
<tr>
<td>Iron</td>
<td>0.38</td>
<td>0.05</td>
</tr>
<tr>
<td>Manganese</td>
<td>0.04</td>
<td>0.10</td>
</tr>
<tr>
<td>Ammonia-Nitrogen</td>
<td>&lt;0.03</td>
<td>0.09</td>
</tr>
<tr>
<td>pH</td>
<td>4.6</td>
<td>6.2</td>
</tr>
<tr>
<td>Specific Conductance</td>
<td>280</td>
<td>390</td>
</tr>
<tr>
<td>Total Dissolved Solids</td>
<td>166</td>
<td>325</td>
</tr>
<tr>
<td>Total Organic Carbon</td>
<td>--</td>
<td>9</td>
</tr>
</tbody>
</table>

\(^1\) The wells at Landfill No. 6 are sampled semi-annually, the data in the table are from samples collected July 1982, the surface water samples were collected October 1982.

* Well depth.

\(^+\): Adjacent to refuse cells.

NOTE: All concentrations are given in milligrams/liter (mg/l), except for pH and specific conductance which are given in pH units and micromhos/cm, respectively.
other sources prior to its passing the landfill and that the addition of leachate from the landfill does not appreciably degrade the Creek. The results would also suggest that the actual amount of leachate-contaminated ground water that is discharged to the Creek is less than estimated; otherwise, if 12,933 gpd of leachate-contaminated ground water were entering the system then the downstream sample should show higher concentrations of the parameters tested than is the case.

The monitor well samples indicate that the highest concentrations of leachate are found under the central portion of the landfill, as indicated by Well OS-3. The relatively low concentrations of the parameters tested for in Well OS-4 would suggest that the width of the plume of highly degraded ground water does not extend across the entire downgradient side of the landfill. The results from Well OD-1 indicate that except for a high iron concentration, the deeper ground water at the site does not show any indication of leachate. The majority of the leachate appears to still be concentrated in the upper 15 to 20 feet of the aquifer.

The concentrations of selected indicator parameters, Cl, TDS and NH$_3$-N, were plotted versus time. These plots are shown on Figure 9A, 9B and 9C. The plots indicate that the average concentrations of Cl and NH$_3$-N have varied erratically, but have generally not increased, although the background well, OS-1, has shown a slight trend of increasing Cl concentration. Changes in concentration in the background well usually mirror changes in the average concentrations of the downgradient wells. This would suggest that the fluctuations in concentration
FIGURE 9-A  LANDFILL #6 — CHLORIDE CONCENTRATION VS. TIME

FIGURE 9-B  LANDFILL #6 — TOTAL DISSOLVED SOLIDS CONCENTRATION VS. TIME
FIGURE 9-C  LANDFILL #6 — AMMONIA-NITROGEN
CONCENTRATION VS. TIME
seen on the plots are the result of seasonal changes in the recharge rate, which would affect leachate production. The plot of TDS versus time indicates a slight trend toward increasing concentration, but this may be a regional effect since the TDS concentration in the background well also shows a slight increasing trend.

9.4 EXTENT OF LEACHATE PLUME

Earlier, the ground-water velocity was estimated to be 140 ft/yr and the possible extent of leachate plume downgradient was estimated to be 1,260 feet. It is known that some leachate does enter Blackwater Creek which borders the eastern side of the landfill, but apparently the leachate enters in such small quantities that it is renovated within 700 feet downstream of the landfill. This would also suggest that the leachate may be far more diluted, when it reaches Blackwater Creek, than is evident by the concentrations of chemical species in Well OS-3. Without actual wells downgradient of the landfill, it must be assumed that some, diluted leachate has migrated downgradient approximately 1,200 feet southeast of the landfill. Although, based on field data from landfills such as Angola and Stockey, where off-site wells are available for sampling, it appears that through a combination of factors such as lower than anticipated leachate production, or lower ground-water velocity, actual leachate movement is less than estimated. The dashed line of Figure 9-1 shows the estimated maximum extent of the leachate plume.
9.5 WELL LOCATION AND FUTURE WATER DEVELOPMENT

Figure 9-1 shows the location of 78 domestic and agricultural water supply wells within one mile of Landfill No. 6. None of the wells are presently in danger of contamination by landfill leachate.

Discussions with the County planners indicate that no large developments or significant increases in ground water use are expected in the foreseeable future.
CONCLUSIONS AND RECOMMENDATIONS

10.1 CONCLUSIONS

Each of Sussex County's 6 landfills, which are 11 to 13 years old, generate leachate to some extent. Leachate production rates and extent of the leachate plume at each landfill were estimated using existing site data from each landfill and average regional aquifer characteristics derived from available reports. In order to estimate leachate volumes and the extent of the leachate plumes, on a worst case basis, the following assumptions were made:

- All recharge coming in contact with the refuse will produce leachate; annual recharge ranges from 17 to 18 inches per year
- Leachate is produced uniformly throughout the year
- Leachate production started within two years of the start of landfill operations
- Leachate is produced from the entire landfill area currently underlain by refuse
The upper 5 feet of the aquifer contribute ground-water discharge to receiving surface water bodies near the landfill.

The highly permeable sediments typically found under the landfills will provide renovation for the leachate principally by dilution and dispersion.

At two landfills, Landfill No. 3-Angola and Landfill No. 2-Stockley, where predictions could be compared to actual field conditions, it was found that the extent of the leachate plumes was much less than predicted. Possible reasons for the differences between the estimated and actual extent of leachate migration, which may apply to all of the landfills are:

- Leachate production may not be as large or as seasonally continuous as estimated.
- Leachate production may not have started within two years of the opening of the landfills, but may have started later and at initially much smaller volumes.
- Recharge may be sufficiently rapid so as to minimize contact time with the refuse, resulting in less concentrated leachate.
- Aquifer characteristics, locally, may be lower than estimated, resulting in slower ground-water velocities and smaller leachate plumes than originally estimated.
- Ground-water flow may dilute leachate faster than originally estimated; this would also result in smaller leachate plumes.

- A smaller proportion of leachate-contaminated ground-water discharge reaches the surface water than originally estimated or underflows the streams altogether.

The general conclusions of the study are:

- Leachate generation and migration are less than estimated.

- Surface water contamination, in the vicinity of the landfills, is not taking place to any great extent.

- Ground-water flow is effectively reducing concentrations of leachate, by dilution and dispersion, generally within 500 feet of the landfills (Angola and Stockley as examples).

- Leachate is generally confined to the upper 20 to 40 feet of the aquifer.

- Under present conditions, no domestic wells are in danger of contamination, except for a domestic well downgradient of Landfill No. 1 - Bridgeville and a domestic well downgradient of Landfill No. 5 - Laurel, both
of which wells are near the estimated edge of the leachate plumes

- Although leachate is being diluted by ground-water under-flow and recharge downgradient, chemical data indicate that leachate production will continue

- There are erratic fluctuations in the long term trends of the concentrations of indicator parameters which suggest that leachate production is seasonal and responsive to variations in the rate of recharge

- Given the existing site conditions of highly permeable surface soils and sub-surface sediments, leachate migration will continue

10.1.1 Landfill No. 1 - Bridgeville

- Approximately 52 acres of the site are underlain by refuse. The landfill is 13 years old and still in operation

- Recharge to ground water, in the vicinity of the landfill, is on the order of 17 in/yr. The potential leachate production is estimated to be 65,762 gpd

- The water table, beneath the landfill, ranges in depth from 12 to 20 feet below ground water. Ground-water flow direction is generally south, with components of flow to the southwest and southeast. The ground-water gradient is 0.002 to 0.003 and the ground-water velocity is estimated to be 80 ft/yr, based upon an estimated permeability of 545 gpd/ft²
The potential extent of the leachate plume may be 880 feet downgradient, but may actually be on the order of 400 to 500 feet.

A small, swampy area several hundred feet downgradient shows no gross leachate contamination. The nearest major surface water body is the Nanticoke River which is approximately 2,000 feet west of the site and too far away to receive groundwater discharge from the site.

Surface water quality in the Nanticoke River has not been affected by the landfill.

The landfill monitor wells indicate that the concentration of leachate varies beneath the landfill and that the majority of the leachate is confined to the upper 30 feet of the aquifer.

Long term trends of selected chemical indicator parameters suggest that the leachate production has not reached full capacity.

There are 55 domestic and agricultural water supply wells within one mile of the site. Except for one well, downgradient of the landfill near the estimated edge of the leachate plume, no...
other wells have the potential for being contaminated by leachate

- A 58-unit trailer park has been proposed just west of the landfill. Although the general area does not appear susceptible to leachate contamination, the exact location of the new wells will have to be determined in order to determine if pumping will influence leachate movement.

10.1.2 Landfill No. 2 - Stockley

- Approximately 64 acres of the site are underlain by refuse. The landfill is 13 years old and still in operation.

- Recharge to ground water, in the area, is on the order of 17 in/yr. The potential leachate production rate is estimated to be 85,699 gpd.

- The water table, beneath the landfill, ranges in depth from 4.5 to 14 feet below ground surface. The ground-water flow direction is southeast. The ground-water gradient is 0.002 and the ground-water velocity is estimated to be 69 ft/yr based upon an estimated permeability of 730 gpd/ft².
The potential extent of the leachate plume may be 760 feet downgradient, although off-site wells within 300 feet of the landfill do not indicate any leachate contamination.

Sheep Ditch, flowing southeast, on the southern boundary of the landfill would be the surface water body receiving ground-water discharge.

The percentage of leachate-contaminated ground water potentially discharging to Sheep Ditch was estimated to be 20 percent, 17,520 gpd, of the ground-water flow.

Surface water quality data shows no evidence of leachate in Sheep Ditch 8,000 feet downstream. Off-site wells adjacent to the downgradient side of the landfill, show no evidence of leachate.

Landfill monitor wells indicate that the concentration of leachate varies beneath the landfill and that the majority of the leachate is found in the upper 25 feet of the aquifer.

Long-term trends of selected chemical indicator parameters suggest that the leachate production may not have reached full capacity.
• There are 39 domestic and agricultural water supply wells within one mile of the landfill. No wells are in danger of contamination by leachate.

• No significant increases in ground water use are foreseen for the area.

10.1.3 Landfill No. 3 - Angola

• Approximately 45 acres of the site are underlain by refuse. The landfill is 13 years old and was in operation between 29 December 1969 and 30 June 1980. The site is presently operated as a transfer station.

• Recharge to ground water, in the area, is on the order of 18 in/yr. The potential rate of leachate production is estimated to be 66,017 gpd, with 60,257 gpd of the total due to recharge and 5,760 gpd due to ground-water inflow.

• The water table, beneath the site, ranges in depth from 4 to 9 feet below ground surface. The ground-water flow direction southeast. The ground-water gradient is 0.002 and the ground-water velocity is estimated to be 58 ft/yr, based upon an estimated permeability of 600 gpd/ft$^2$. 


The potential extent of the leachate plume may be 640 feet downgradient, although a resistivity survey conducted at the site showed the plume to be 100 to 200 feet short of the predicted position at the time of the survey. The resistivity survey also showed that the greatest advance of the plume was found along the southwest corner of the landfill. This may suggest that a zone of increased permeability exists along the southwest side of the landfill, or that leachate from the older refuse cells, located in the southwest corner of the landfill, has advanced downgradient to the extent indicated by the survey while the younger refuse cells have lagged behind in leachate production.

Chapel Branch, flowing southeast, on the western and southern sides of the landfill would be the surface water body receiving ground-water discharge.

The percentage of leachate-contaminated ground water potentially discharging to Chapel Branch was estimated to be 17 percent, or 7,344 gpd, of the ground-water flow.

Surface water quality data shows no evidence of leachate in Chapel Branch 3,000 feet downstream.
• The landfill monitor wells indicate that leachate concentration varies and that the majority of leachate is found in the upper 30 feet of the aquifer.

• Off-site monitor well data indicate that the ground water within 400 to 600 feet downgradient of the landfill generally meets drinking water standards.

• Long-term trends of selected chemical indicator parameters suggest a decrease in leachate production. This data, though, is not conclusive.

• There are 53 domestic and agricultural water supply wells within one mile of the landfill. None of the wells are in danger of contamination by leachate.

• Except for a small, approximately 10-unit development three-quarters of a mile southeast of the landfill, no significant increases in ground water use are foreseen.

10.1.4 Landfill No. 4 - Anderson Crossroads

• Approximately 42 acres of the site are underlain by refuse. The landfill is 12.5 years old and was in operation between 1 March 1970 and 29 January 1982. The site is presently operated as a transfer station.

• Recharge to ground water, in this area, is on the order of 18 in/yr. The potential rate of leachate production is estimated to be 56,240 gpd.
• The water table, beneath the site, ranges in depth from 9 to 17 feet below ground surface. The ground-water flow direction is southwest. The ground-water gradient is 0.005 and the ground-water velocity is estimated to be 146 ft/yr, based upon an estimated permeability of 600 gpd/ft².

• The potential extent of the leachate plume may be 1,460 feet downgradient.

• Church Branch, flowing north, is within 700 to 900 feet downgradient of the western side of the landfill and is the surface water body that would be receiving ground-water discharge from the landfill. There is a tributary to Church Branch closer to the landfill, but during the current study the tributary was dry.

• The percentage of leachate-contaminated ground water potentially discharging to Church Branch was estimated to be 20 percent, or 20,550 gpd, of the ground-water flow.

• Surface water quality data shows little, if any, leachate is reaching Church Branch 100 feet downstream of the landfill.

• Landfill monitor wells indicate that the concentration of leachate under the landfill is very variable and that the majority of the leachate is found in the upper 25 feet of the aquifer.
• Long-term trends of selected chemical indicator parameters suggest that leachate production has increased within the last two years and may not have been significant before then.

• There are 85 domestic and agricultural water supply wells within one mile of the landfill. None of the wells are presently in danger of contamination by leachate.

• There is the possibility for the development of approximately 20 home sites along County Roads 214 and 216 in the vicinity of the landfill. No other significant increase in ground water use is foreseen.

10.1.5 Landfill No. 5 - Laurel

• Approximately 32 acres of the site are covered by refuse. The landfill is 12 years old and was in operation between 11 May 1970 and 11 August 1979. The site is presently operated as a transfer station.

• Recharge to ground water in the area is on the order of 17 in/yr. The potential rate of leachate production is 42,077 gpd, with 40,469 gpd of the total attributed to recharge and 1,608 gpd attributed to ground-water inflow.
- The water table, beneath the site, ranges in depth from 6 to 12 feet below ground surface. The ground-water flow direction is north. The ground-water gradient is 0.002 and the ground-water velocity is estimated to be 53 ft/yr, based upon an estimated permeability of 546 gpd/ft².

- The potential extent of the leachate plume may be 477 feet downgradient.

- The nearest surface water bodies that would receive ground-water discharge from the landfill, Culver Ditch and Holly Ditch, were dry within 5,500 feet of the landfill during the sampling period.

- The percentage of leachate-contaminated ground water potentially discharging to the nearest surface water body, Culver Ditch, was estimated to be 14 percent, or 6,100 gpd, of the ground-water flow.

- Surface water quality data shows no evidence of leachate in Culver Ditch or Holly Ditch 5,500 feet downstream of the landfill.

- Landfill monitor wells indicate that the concentration of leachate under the landfill varies and that the majority of the leachate is found in the upper 35 feet of the aquifer.
- Long-term trends of selected chemical indicator parameters suggest that leachate production has not reached full capacity.

- There are 59 domestic and agricultural water supply wells within one mile of the landfill. With the exception of two wells, which are near the estimated downgradient edge of the leachate plume, no other wells are in danger of contamination by leachate.

- No significant increase in ground water use is foreseen for the area.

10.1.6 Landfill No. 6 - Omar

- Approximately 18 acres of the site are underlain by refuse. The landfill is 11 years old and was in operation between 20 April 1971 and 9 February 1980. The site is presently operated as a transfer station.

- Recharge to ground water in the area is on the order of 18 in/yr. The potential rate of leachate production is 24,103 gpd.

- The water table, beneath the site, ranges in depth from one to 7 feet below ground; ground-water gradient is 0.0006 and the ground-water velocity is estimated to be 140 ft/yr, based upon an estimated permeability of 479 gpd/ft².
• The nearest surface water bodies that would receive ground-water discharge from the landfill are a shallow pond on the southeast corner of the site and Blackwater Creek, which flows north, along the eastern side of the site.

• The percentage of leachate-contaminated ground water potentially to Blackwater Creek was estimated to be 25 percent, or 12,933 gpd, of the ground-water flow.

• Blackwater Creek is known to receive leachate from the northeastern portion of the landfill. Surface water quality data shows little difference between the upstream and downstream samples of Blackwater Creek. This indicates that any leachate entering the Creek is renovated within 700 feet downstream of the landfill.

• Landfill monitor wells indicate that the concentrations of leachate under the landfill varies, and that the majority of the leachate is found in the upper 20 feet of the aquifer.

• Long-term trends of selected chemical indicator parameters suggest that leachate production is essentially stable.
There are 78 domestic and agricultural water supply wells within one mile of the landfill. None of the wells are presently in danger of contamination by leachate.

No significant increase in ground water use is foreseen for the area.

10.2 RECOMMENDATIONS

10.2.1 Landfill No. 1 - Bridgeville

- Conduct a resistivity survey along the southern boundary of the landfill to determine the actual extent of the leachate plume.

- The domestic well at the chicken farm, south of the landfill, should be sampled on the same schedules as the landfill monitor wells, in order to determine if leachate has reached the well.

- Grading and seeding of the landfill surface cover in order to reduce recharge and leachate production should be investigated.

10.2.2 Landfill No. 2 - Stockley

- Sample Kidde Consultants, Inc. Wells 4, 7 and 8 on the same schedule as the landfill monitor wells, in order to determine actual downgradient leachate movement and attenuation.
• Sample Sheep Ditch, close to the landfill, on the same schedule as the landfill monitor wells, in order to determine if leachate enters the stream on a seasonal basis.

• Conduct a resistivity survey along the southern and eastern boundaries of the landfill to determine the actual location of the leachate plume.

• Grading and seeding of the landfill surface cover in order to reduce recharge and leachate production should be investigated.

10.2.3 Landfill No. 3 - Angola

• Chapel Branch should be sampled, close to the landfill, on the same schedule as the landfill monitor wells, in order to determine if leachate enters the stream on a seasonal basis.

• Grading and seeding of the landfill surface cover in order to reduce recharge and leachate production should be investigated.

10.2.4 Landfill No. 4 - Anderson Crossroads

• Conduct a resistivity survey along the southwestern boundary of the landfill in order to determine the actual extent of the leachate plume.

• Grading and seeding of the landfill surface cover in order to reduce recharge and leachate production should be investigated.
10.2.5 Landfill No. 5 - Laurel

- The domestic wells north and west of the landfill should be monitored on the same schedule as the landfill monitor wells, in order to determine if leachate is reaching the wells.

- Conduct a resistivity survey along the northern boundary of the landfill to determine the actual extent of the leachate plume.

- Grading and seeding of the landfill surface cover in order to reduce recharge and leachate production should be investigated.

10.2.6 Landfill No. 6 - Omar

- Conduct a resistivity survey along the eastern side of Blackwater Creek to determine the actual extent of the leachate plume.

- Blackwater Creek should be sampled on the same schedule as the landfill monitor wells, in order to determine seasonal changes in leachate discharge.

- Grading and seeding of the landfill surface cover in order to reduce recharge and leachate production should be investigated.