UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

GROUND-WATER FLOW AND POLLUTION AT A WELL FIELD, OLEAN, NEW YORK

Open-File Report 76-397

Prepared in cooperation with
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Albany, New York
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CONVERSION FACTORS AND ABBREVIATIONS

The following factors may be used to convert English units of measurement to the International System of Units (metric system).

Multiply	by	To obtain
degrees Fahrenheit (°F)	(°F-32)5/9	degrees Celsius (°C)
feet	0.3048	metres
feet squared per second	.0929	metres squared per second
gallons per minute	.0631	litres per second
miles	1.609	kilometres
million gallons per day	.0438	cubic metres per second
square miles	2.590	square kilometres
--	--	milligrams per litre (mg/l)

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By

Allan D. Randall

ABSTRACT

Major valleys near Olean, New York contain sand and gravel that constitute an important aquifer. At North Olean, the aquifer is about 80 feet thick, but the upper part is less permeable than the lower part and locally contains clay lenses that restrict downward flow of water. Under natural conditions, ground water would flow south or southwest beneath much of Olean. During the 1970's, ground-water withdrawal at North Olean created a cone of depression as deep as 30 feet, which captured all precipitation infiltrating locally plus ground-water underflow beneath Olean Creek and some water from Olean Creek and other streams.

Ground water near the well field has been polluted by petroleum, hexavalent chromium and, most recently, nitrogen compounds. The apparent source of the nitrogen compounds is near land surface in a small area nearly 2,000 feet southwest of the center of the well field. From 1970 to 1974, concentrations of ammonia plus nitrate have regularly exceeded 2,000 milligrams per litre as nitrogen in water from three test wells. All of the nitrogen-bearing water flows toward the center of the well field and is eventually withdrawn by wells. A thermal anomaly, with ground-water temperatures as much as 17°F above the regional normal, approximately coincides with the nitrogen anomaly, but the variety and complexity of possible causes of the thermal anomaly make it difficult to interpret temperature differences in terms of sources of pollution or changes in the rate of pollution.

If all pumping near North Olean were to cease, 4 to 8 months might be required to fill the cone of depression; thereafter the polluted water would move gradually to the south or southwest at a rate of roughly 4,500 feet in 12 years. However, different patterns of migration would result if some production wells remained in use or if new large-capacity wells were constructed at locations presently unforeseen.

Introduction

From September 1970 through October 1975, the U.S. Geological Survey investigated and monitored ground-water pollution at a well field in Olean, N.Y., as part of a jointly financed cooperative water-resources program with the New York State Department of Environmental Conservation. The investigation included making an inventory of all nearby wells, periodically measuring water levels and ground-water temperatures in accessible wells, drafting drilling specifications and supervising the drilling of five observation wells, reviewing chemical analyses and pumpage records furnished by others, and making related observations. The purpose of this summary of the behavior of ground water in the area is to answer some of the questions raised during the investigation. This summary draws to some extent on results of investigations by Frimpter (completed 1968, published 1974) and by Hydro Systems, Inc. (1975); their reports are included in the list of references.

Brief descriptions of wells in which water levels were measured repeatedly by the Geological Survey, and the water-level and temperature measurements through April 1971, are included as tables 1-2 and figures 1-2. Subsequent measurements of water level and temperature (at least bimonthly through October 1974 and once in October 1975) are on file with the U.S. Geological Survey in Albany, N.Y. More complete records of some of these wells are tabulated by Frimpter (1974). Records of additional observation wells drilled in 1974 are summarized in table 3 and presented in full by Hydro Systems, Inc. (1975).

Where and how does ground water occur near Olean?

In simple terms, one may think of two flat-bottomed valleys, each at least three-fourths of a mile wide and many miles long, roughly perpendicular and joining at Olean. The valleys are carved in shale bedrock that is so poorly permeable that only small amounts of ground water flow through it along tiny fractures. The bottoms of the valleys, however, are filled with loose (unconsolidated) sediment 150 to 300 feet thick, most of which was deposited by streams flowing from melting glaciers about 14,000 years ago and which, except in the uppermost few feet, is saturated with ground water. These deposits, particularly in the top 80 feet, include much sandy gravel and sand through which ground water can flow readily. From a regional viewpoint, this sand and gravel may be considered as a single aquifer (body of water-yielding deposits) that is present everywhere beneath the valley floors. It is the only potential source of large supplies of fresh ground water near Olean. Many of the industrial and municipal wells finished in it have each been pumped at several hundred gallons per minute. However, some layers of sand and gravel are silty and therefore less permeable than others, and scattered layers of silt and clay form local barriers to ground-water flow; thus detailed study often reveals fairly distinct aquifer subunits that have significance from a local viewpoint. Frimpter (1974) describes in some detail the occurrence and behavior of ground water in the bedrock (p. 22-23) and in the unconsolidated sand and gravel of the Allegheny River valley (p. 34-39).

What is the normal pattern of ground-water flow in the sand and gravel aquifer near Olean?

Under natural conditions, major streams such as Olean Creek and Allegheny River act as ground-water drains at most times and places. In each valley, ground water generally flows slowly both downvalley and toward the major stream, and eventually seeps into the stream channel. Infiltration of precipitation on the valley floor and seepage from channels of tributaries where they enter major valleys (Ku and others, 1975) are the principal natural sources of ground-water replenishment. Where the unconsolidated deposits are highly permeable, the water-table gradient is low and slopes nearly parallel to the major stream; where the deposits are less permeable, the gradient is steeper and slopes more toward the stream. In either case, the water table normally merges with the stream surface.

Under natural conditions, that is, with no significant pumping from wells, ground water would probably flow south or southwest beneath much of the city of Olean, as sketched in figure 3. The hypothetical contours in figure 3 were drawn using altitudes of the water surface known at three points along major streams on September 2, 1970. The altitudes are typical of summer low-water conditions and are virtually unaffected by current pumping. The contours are also generally concordant with:

1) average gradient of the Allegheny River according to the topographic map;
2) depth to water in several wells in Olean and Allegany on different dates before 1968, as reported by the well owners (Frimpter, 1974, table 4), and land-surface altitude estimated from the topographic map;
3) an area of high transmissivity around a well field at North Olean, as interpreted by Hydro Systems, Inc. (1975, appendix II).
4) an area of moderately low transmissivity northeast of Allegany village, as interpreted by Frimpter (1974, fig. 10D).

According to the interpretation in figure 3, under natural conditions ground water beneath North Olean and the nearby well field would flow away from Olean Creek toward the more distant Allegheny River. Highly permeable sand and gravel underlies much of this locality, so a large natural water-table mound is unlikely. Furthermore, reported water levels in several wells in this locality prior to late 1966, when Felmont Oil Corp. began to use the well field at North Olean, generally indicate water-table altitudes of 1,404 to 1,411 feet, which are below the September 1970 level of Olean Creek and therefore suggest ground-water flow from Olean Creek toward the well-field area. Specific dates and wells for which water levels have been reported are:

a) 1924-25--four wells drilled for Socony-Vacuum (previous owner of property now occupied by Felmont Oil Corp. and Agway, Inc.), from driller's records.
b) August 1966--Felmont production wells 1-6 prior to use, from driller's records.
c) Eight dates from 1944-57--dug well owned by city of Olean just west of Buffalo Street and north of Erie Railroad, from owner's records; spirit levels by owner. (Water levels as high as 1,414 feet were recorded, but only in March and (or) during floods in nearby Two Mile Creek).
d) 1958--driven well on Connell Street, measurement remembered by owner (Marcus, fig. 5).
e) 1955--well on Buffalo street, measurement remembered by owner (A. Hoffman, fig. 5). (Water level reported about 1,430 feet altitude; this well is close to the side of the valley and may be finished in bedrock and (or) beneath clay or till, which could explain a high water level.)

Some of the reported measurements may be imprecise; some may not reflect the natural water table if there were significant pumping nearby at the time, and in a, b, and e, some estimated or recently measured land-surface altitudes may not accurately represent the altitude at the top of the well many years earlier when water levels were measured. However, the consistency of the data suggests that such potential errors are not serious and thus supports the interpretation of southwestward flow shown in figure 3.

How has the well field at North Olean changed the pattern of ground-water flow?

The Felmont Oil Corp. operates seven production wells at North Olean; each was originally capable of yielding 1,000 gallons per minute. Locations of these wells, numbered 1-6 and 8, are shown in figures 4, 5, and 6.

When all seven wells are in operation, which has often been the case, pumpage has been about 9 million gallons per day, as estimated by Felmont Oil Corp. from daily measurements of head and pump-rating curves. Allowing for rough estimates of pumpage from several smaller production wells nearby that serve other industries (also shown in figs. 4-6), it is estimated that total ground-water withdrawal from this locality has often been as much as 10 million gallons per day during the years 1970-75. As a result, water levels in wells near the center of the well field have been lowered 25 to 30 feet below the inferred natural level. Because of this cone of depression, ground water flows toward the center of the well field from all directions to replace the water pumped. The cone of depression is illustrated in figures 5 and 6 by flow nets for August 1971 and July 1972. The flow nets represent the potentiometric surface for the principal aquifer, an imaginary surface defined by the water levels measured in wells finished 45 to 80 feet below land surface. Water levels in August 1971 were among the lowest measured in the years 1970-75; water levels in July 1972, less than a month after a major flood and a 2-week shutdown of the well field, were the highest measured.

New information on earth materials and water levels provided by test wells 15-19, drilled in 1971, suggested that the top 80 feet of unconsolidated deposits near the well field is made up of two units. The upper unit is 40-50 feet thick and consists of moderately silty gravel with occasional lenses of clay and thin lenses of clean, permeable gravel. The lower unit consists of clean, sandy, highly permeable gravel that constitutes the principal aquifer. Further test drilling in 1974 enabled Hydro Systems, Inc. to refine this concept; it now appears that beneath a substantial area west of the center of the well field (fig. 7), some part of the depth interval from 30 to 50 feet contains several thin overlapping lenses of clay or silty clay interbedded with silty fine sand or silty gravel. These clay lenses undoubtedly retard downward flow of water and are partly or solely responsible for a water-table mound in much of the area above them, at least during 1970-75, when the potentiometric surface of the principal aquifer was depressed far below its natural level. Four wells finished in gravel above or interbedded with the clay have water levels several feet higher than those in adjacent deeper wells finished in the principal aquifer (table 3). Other evidence suggesting a mound is summarized in figure 7. Although the gravel above the clay was not reported as yielding water in the logs of several wells, it may have been saturated at the base but too silty to permit appreciable seepage into holes extending only a few feet below the water table. Perhaps a similar clay layer is present near Dresser-Clark's Lincoln Ave. plant (fig. 5), where in the spring the water table (indicated by temporary flooding of plant cellars) is several feet higher than water levels in wells tapping the principal aquifer (tables 1 and 2).

When pumping depresses water levels in a sand-and-gravel aquifer below the surface of a river crossing the aquifer, water from the river seeps into the ground. This process, termed "induced infiltration," may permit nearby wells to be pumped continuously at much larger rates than would otherwise be possible (MacNish and others, 1969). It is certain that the cone of depression caused by the well field at North Olean extends northeastward beyond Olean Creek; water levels in an Olean City test well near the Erie-Lackawanna Railroad just east of Olean Creek (figs. 5, 6) were nearly 5 feet below creek level in August 1974 and September 1975. However, it is not at all certain how much induced infiltration may result, nor where it may occur. The city test well is finished in gravel at a depth of 100 feet but penetrates clay from 11 to 65 feet, which presumably prevents creek water from seeping down to the gravel aquifer in this immediate locality. Temperature measurements in a well at the Dresser-Clark plant on Lincoln Ave. strongly suggest that induced infiltration from Olean Creek reaches that well: a regular temperature change from 40°F in April 1971 (fig. 1) to 66°F in August 1971 was measured at a depth of 60 feet in that well. However, the two Felmont Oil Corp. production wells closest to Olean Creek fluctuate very little in temperature, as shown below.

Date	Well 4	Well 5
Sept. 1, 1970	49.3 °F	51.0 °F
Oct. 21, 1970	49.4	51.1
Feb. 17, 1971	49.9	51.0
Apr. 15, 1971	50.4	51.5
June 16, 1971	50.0	50.9
Aug. 12, 1971	50.9	51.2

Furthermore, a set of streamflow measurements in September 1971 showed no loss of water over a 1 1/2-mile reach of Olean Creek from the city line to Main Street. In any case, the flow nets (figs. 5, 6) show that a substantial part of the water pumped from the well field comes from the valley of Olean Creek; it must include ground water flowing through the sand and gravel beneath the creek and is probably augmented by induced infiltration from the creek itself, but the proportion and pattern of induced infiltration is not presently clear and deserves further study.

Ground-water levels close to the Allegheny River have not been measured, but quite possibly the head in unconsolidated deposits beneath or bordering the river has been lowered below river level in at least part of the reach from the mouth of Olean Creek to the Allegany town line. If so, some part of the water moving toward the well field at North Olean is derived from the Allegheny River.

Recharge in the form of direct infiltration of precipitation is another source of ground water. On the basis of unpublished studies by the U.S. Geological Survey in the Susquehanna River basin, recharge from precipitation on the valley floor is estimated to average 1.2 million gallons per day per square mile. The well field at North Olean encompasses only a small area, but the total area within its cone of depression between Allegheny River, Olean Creek, and the bedrock wall of the valley may be nearly 2 square miles. A smaller source of recharge, seepage loss from natural flow of Two Mile Creek and its tributary in Johnson Hollow, is estimated to average 0.7 million gallons per day and occurs chiefly where these streams enter the valley and chiefly during periods of high water in the winter and spring.

Below Johnson Street, Two Mile Creek carries several million gallons per day of heated water discharged by Felmont Oil Corp. and Agway Inc., and some of this heated water also recharges the well field. However, seepage loss from small streams winding across a flood plain usually is limited by extensive silt deposits beneath the channel, and observations at two points along Two Mile Creek revealed quite poorly permeable channel-bottom sediment. A pair of streamflow measurements on August 6, 1969 indicated a net loss of at least 0.8 million gallons per day between Johnson Street and West State Street, but no effort was made to ascertain whether industrial discharge was steady or variable prior to measurement. Temperature profiles in well 17, on the bank of Two Mile Creek, indicate that there must be warm water in sandy gravel and fine sand between depths of 16 and 35 feet (above the profiles in fig. 1), but the well penetrates clay from 35 to 60 feet through which heat probably moves rather slowly by conduction to the deeper aquifer. Ground water southeast of Two Mile Creek (wells 7, and 10, fig. 1, also well 8) is 1° or 2°F warmer than ground water north or west of the creek (well 11 and bottom of well 17), which could be explained if a small proportion of very warm (85°F) seepage from the creek has mixed with ground water flowing toward the well field.

Other sources of ground-water recharge--leaks in city or industrial water mains and sewers, or seepage through the bedrock walls of the valley into the sand and gravel--are probably of minor importance as sources of water pumped from the well field.

What substances have polluted ground water near the well field?

Three pollutants have been recognized: petroleum, hexavalent chromium, and nitrogen compounds.

Frimpter (1974, p. 59) quotes an account of petroleum pollution in 1922 near an oil refinery in North Olean that occupied the site of the present well field. As of 1975, some petroleum remained as an oily film coating sediment grains above the water table, locally to depths as great as 40 feet (Hydro Systems, Inc., 1975, appendix I; also observation by the author); and a film of oil on the water surface was observed (U.S. Geological Survey personnel, Ithaca, N.Y.) in wells 9 and 14.

Frimpter also reports (1974, p. 60) that metal-plating solutions containing hexavalent chromium infiltrated to the ground water in a small area in Olean. Unpublished analyses by the U.S. Geological Survey indicate that water from Felmont production well 5 contained 26 mg/l hexavalent chromium in June 1967 and 2.5 mg/l in February 1971.

Pollution by nitrogen compounds has been monitored and investigated since 1970 by property owners and the New York State Department of Environmental Conservation. This problem is discussed in detail in the following section.

What is the nature and distribution of nitrogen compounds in the aquifer?

Water samples from production wells in the well field have been collected and analyzed daily for ammonia and nitrate by Felmont Oil Corp. from 1969 through 1975. Samples from observation wells have been analyzed periodically by Felmont Oil Corp. and by Agway Inc. (or CF Industries, a firm partly owned by Agway that has operated Agway's fertilizer plant since 1972). A few samples were analyzed by the New York State Department of Health and other laboratories. In general, ground water has contained less than 0.3 mg/l ammonia and 4 to 10 mg/l nitrate east of the well field, and less than 1 mg/l ammonia and 1-4 mg/l nitrate west of the well field. However, concentrations are much higher in an area southwest of wells 1 and 2. Water from well 18 has contained 6,000 mg/l ammonia and 10,000 mg/l nitrate (equivalent to 7,200 mg/l nitrogen as N) (table 4B; also Hydro Systems, Inc., 1975, figs. 22, 23.) From 1970 through 1974, concentrations of ammonia and nitrate have regularly exceeded 2,000 mg/l nitrogen as N in only three wells--3s, 16, and 18 (fig. 4). Although concentrations have declined irregularly from 1972 to 1974 throughout the area of nitrogen pollution, water from three wells (3s, 10s, 18) contained more than 1,500 mg/l nitrogen as N in 1974. (Hydro Systems, Inc., 1975, fig. 44-45). Analyses for nitrogen species other than ammonia and nitrate have rarely been made; samples from five wells were analyzed for urea by Agway in March 1971 and reported to contain 10 to 214 mg/l.

Throughout the area of nitrogen pollution, water samples obtained near the top of the zone of saturation contain more nitrogen than do samples from greater depth. This contrast in nitrogen concentration was found during the drilling of wells 16 and 18 (figure 2); in well 16, which is perforated at several depths, when pumps were operating above and below the seal at 55 feet in early 1972; and also in wells drilled for Hydro Systems, Inc. (1975, figs. 45-47), both within and beyond the limits of the clay layers shown in figure 7. Samples pumped from wells 16 and 18 late in 1972 (Hydro Systems, Inc., 1975, figs. 20-23) do not show this pattern, but downward flushing after extraordinary rainfall in June 1972 may be the reason. At any location, in general, water in the silty upper unit of the aquifer is derived from local infiltration and moves slowly downward and laterally, while water in the permeable lower unit is derived largely from sources farther from the well field and moves more rapidly laterally toward the center of the cone of depression. Near wells 16 and 18 the upper unit of the aquifer acts as a reservoir that stores polluted ground water and delays its downward percolation; when it reaches the zone of more rapid flow at the top of the top of the lower unit, it is carried off toward the center of the cone of depression.

An interpretation of the extent of nitrogen pollution is given in figure 8. The location of the area of highest concentration, the fact that concentration is highest near the top of the zone of saturation in this area, and the distribution of nitrogen downgradient toward production wells 1 and 2 (compare figs. 5 and 8) are evidence that the only important source(s) of nitrogen compounds in ground water near the well field is near land surface close to wells 16 and 18. (Figure 8 is not suitable for calculating rates of nitrogen movement because it obscures differences in concentration with depth and time, but if pollution were caused largely by periodic spills and leaks at different points, the contours in figure 8 would represent normal pollution distribution reasonably well.) A more detailed representation of conditions for October 1974, presented by Hydro Systems, Inc. (1975, figs. 40-48) as the basis for a chemical mass balance, leads to the same conclusion as to the source of nitrogen.

Under 1970-75 conditions, all of the nitrogen pollution is eventually captured by Felmont wells 1, 2, and, to a small extent, 6. Roughly 35 percent of the nitrogen pumped by these wells is from well 2, even though well 1 is almost directly between the apparent source and well 2. One way to explain the apparent bypassing of well 1 by some of the polluted ground water is to infer that east of well 1 the aquifer is more permeable to water moving northeast than to water moving northwest. Such anisotropic permeability is easily possible if the layers of sand and gravel are inclined as in a foreset structure and include a few silty layers. Consequently, as the plume of polluted water approaches the well field from the southwest, its eastern fringe would continue to flow northeastward past well 1 rather than curve to the northwest and converge on well 1. A second inference that would help explain the apparent bypassing is that there is eastward flow of polluted ground water above the clay layer(s) (Hydro Systems Inc., 1975, p. 18) in an area where flow in the principal aquifer is northeastward. This would tend to shift the body of nitrogen pollution eastward, after which it could move more directly downgradient toward well 2 through the principal aquifer. Both hypotheses also explain the moderately large ammonia concentration in wells 1s and 1d, and the increase in ammonia from 4 to 16 mg/l in well 6 when wells 2 and 3 were shut down for a few months in 1970. The very small nitrogen concentration of water from well 15 shows that there is no substantial secondary source of ammonia north of well 2.

The concentrations of ammonia and nitrate in water from wells 1 and 2 for 1970 through 1974 have been compiled by Felmont Oil Corp. (unpublished graphs) and Hydro Systems Inc. (1975, figs. 34-37). Except for fluctuations related to short-term changes in pumping rates, concentrations have remained fairly constant over these 5 years. Traveltime from near well 18 to well 1 has generally been less than 7 months (Hydro Systems, Inc., 1975, p. 27, p. 30; also personal calculations). Thus, although concentrations have declined at some observation wells over the years, nitrogen compounds must have continued to enter the permeable lower unit of the aquifer.

In general, nitrate has been 10 to 50 percent of total nitrogen in wells near the center of the area of pollution (including wells 1, Dresser-Clark 1, 2s, 2d, 12, 18, 18s, 3s, 3d, 9s, 11s), but only 0.3 to 5 percent of total nitrogen in wells on the fringes (1s, 1d, 7s, 7d, 13, 13s, 4s, 9, 6s, 6d). In well 2 and well 16 the nitrate percentage has been intermediate. Although data are sparse and (or) variable for many of these wells, the relative prominence of ammonia near the fringes of the plume is too consistent to be due to analytical error. It might reflect the distribution of nitrogen sources (leaks or spills); for example, a widespread, diffuse source of ammonia coupled with a more centralized source of ammonia plus nitrate. Alternatively, it might be due to chemical reduction underground. Denitrifying bacteria that convert nitrate to nitrogen gas require an oxygen-free environment; they were identified in water from Felmont production wells in 1970, and dissolved oxygen in the mixtures of polluted and unpolluted water produced by wells 1, 3, and 6 correlated inversely with nitrogen content (James White, St. Bonaventure Univ., oral commun., 1971.) Bacteria that convert ammonia to nitrate operate in oxygen-rich environments near land surface. Therefore, it could reasonably be inferred that below the water table, the principal effect of bacterial action is to reduce nitrate concentration and the nitrate/ammonia ratio with time and distance from the source. The relative abundance of nitrate in ground water of high total nitrogen concentration could also be explained by some other factor limiting denitrifying bacteria activity, such as possible depletion of the organic carbon required for bacterial metabolism long before large concentrations of nitrate can be reduced to nitrogen (T. Ehlke, U.S. Geological Survey, oral commun., 1975.) Effervescence or foaming in water samples has been noted only at well 18, suggesting that production of nitrogen gas is slow enough that its solubility of about 22 mg/l has not generally been exceeded.

What is the significance of ground-water temperatures?

Ground-water temperatures as high as 66°F (about 17°F above the regional normal) have been recorded near the Felmont well field (fig. 9). The thermal anomaly approximately coincides in areal extent with the nitrogen-pollution anomaly. The first data obtained after drilling additional test wells in 1971 (table 4A) suggested a linear relationship between temperature and nitrogen pollution (fig. 10) having the form

$$\log(\text{maximum T in } ^\circ\text{F} - 51^\circ\text{F}) = 0.3 \log(\text{ammonia} + \text{nitrate, mg/l as N}).$$

Maximum temperature for any particular well was selected within the depth interval 40-55 feet and at least 10 feet below the water level in order to eliminate any surface effects. A similar relationship is apparent for some subsequent dates and for the entire period of record (table 4B), but data scatter is sometimes large and the slope of the regression line varies, which suggests that other factors unrelated to nitrogen concentration influence temperature.

Four factors that may contribute to the thermal anomaly have been proposed:

(1) Leaks. Leaks of warm polluted water, or of warm unpolluted water coincident with sources of nitrogen, could explain the observed correlation. Leaks in one sump and in city water lines, and several spills during transfer of (presumably warm) fluids, are known to have occurred, and there may have been significant leakage from lined ponds west of well 9 between July 1974 and July 1975 (John Beecher, N.Y. State Department of Environmental Conservation, written commun., November 1975). However, the generally poor correlation between periodic changes in temperature and in nitrogen content at any particular well argues against leaks as a major factor.

(2) Chemical reactions. Bacteria release heat as they convert ammonia to nitrate and eventually to nitrogen. Preliminary calculations (John Turk, U.S. Geological Survey, written commun., 1975) suggest that oxidation of ammonia ultimately to nitrogen gas and water would release about 83 kilocalories per mole of ammonia. Presumably, most of the heat would be generated when ammonia is oxidized to nitrate at shallow depths (near or above the water table) where oxygen is present; subsequent conversion of nitrate to nitrogen below the water table releases less energy and, as previously explained, seems to be proceeding slowly. If 1,000 mg/l of the ammonia dissolved in subsurface water were completely converted, the heat released would raise the temperature of the water 11°F (6°C), ignoring heat loss to the environment. Thus, this process might be significant; however, no effort to estimate heat generation and loss at this site has been made by the Geological Survey.

(3) Infiltration from streams. Water-surface temperature in streams such as Olean Creek reaches a peak near 80°F in late summer and drops close to 32°F in winter. Where ground water consists largely of infiltration from streams, it will exhibit a corresponding seasonal temperature cycle, as in well 2 at Dresser-Clark's Lincoln Ave. plant (fig. 1); however, the peaks are subdued and delayed in proportion to the distance and velocity of underground travel. Hydro Systems, Inc. (1975, appendix III) used a linear heat-transfer computer model to show that under conditions thought to be typical of the aquifer in Olean, induced infiltration migrating from Olean Creek should have an annual temperature fluctuation of about 5°F upon reaching the west side of the well field, and they noted quasi-seasonal fluctuations in the historical record of temperatures in several wells. However, the historical fluctuations vary in date and in magnitude from year to year, do not decrease with distance of travel from Olean Creek, and are entirely above 49°F, the estimated natural mean. As previously noted, water from Felmont production wells closest to Olean Creek fluctuates little in temperature. Thus, induced infiltration from Olean Creek is probably not a significant influence on the observed temperature anomaly, which is southwest of the well field. Conditions are different in Two Mile Creek; most of its flow is industrial cooling-water discharge, so temperatures are unusually high year-round (85°F October 1, 1974 near well 11). Infiltration and (or) heat conduction from this source may explain why water in unpolluted wells southeast of the creek such as 7, 10 (fig. 9), and 8 has temperatures 1° to 2°F higher than that in well 11, west of the creek, but does not explain the principal anomaly near wells 12, 16, and 18.

(4) Effect of heated structures. The insulation provided by large heated buildings has a marked tendency to raise shallow ground-water temperatures, as illustrated by temperature profiles for the Hysol well (fig. 1) located beneath a large factory. Except for Dresser-Clark (Buffalo St.) well 1, wells within the temperature anomaly are not near large heated buildings; however, several cylindrical storage tanks near well 18 have contained fluids ranging from 135° to 300°F (Hydro Systems, Inc., 1975, appendix III). Perhaps heat loss from these tanks has raised ground-water temperatures significantly, although the facts below seem to require some other explanation:

a) the highest water temperature recorded in well 18, 66°F, occurred in September 1973, 2 years after fluid temperatures in the largest nearby tank were reduced from 250° to 135°F;
b) water in well 16 has had a temperature as high as 61°F (table 4), and yet it is upgradient from all tanks;
c) when Hydro Systems, Inc. (1975, Appendix III) used a numerical model to simulate heat conduction from some of these tanks, preliminary calculations apparently suggested that unless the shallow sediments were saturated, temperatures would rise less than 1°F a few tens of feet from the tanks.

As noted by Hydro Systems, Inc., the variety and complexity of possible causes of elevated temperatures makes it difficult to interpret this easily measured parameter to identify sources or changes in nitrogen pollution. Nevertheless, some apparent relationships (such as shown in fig. 10) are striking, and it may be noticed that in October 1974 and 1975, temperatures (fig. 9) were substantially below peak values measured 1 to 3 years previously in wells 12, 16, and 18, as was nitrogen content (Hydro Systems, Inc. 1975; also Felmont Oil Corp. and N.Y. State Department of Environmental Conservation, written communs. 1974, 1975).

What would happen to the nitrogen-bearing ground water if pumping from wells were to cease?

If all production wells at North Olean were shut down simultaneously, the present flow pattern would persist for a few months. Ground water would continue to flow toward the center of the well field, but at decreasing rates as the cone of depression filled. A graphic calculation based on the Theis equation (Ferris and others, 1962, p. 94), using transmissivity of 0.18 feet squared per second and coefficient of storage of 0.015 (adapted from Hydro Systems, Inc., 1975, fig. II-1), and using field data for August 12, 1971 (fig. 5), suggests that more than 4 months would be required to fill the cone of depression. This estimate does not consider local recharge, which would speed the process, nor the occurrence of a larger coefficient of storage that should be expected as the water table rises through gravelly deposits that had been unsaturated for many months or years, which would slow the process. Four to 8 months is probably a reasonable estimate of the range in time that might be required to fill the cone of depression; the shorter time could be expected if the shutdown occurred during the winter or early spring, when recharge is greatest. A more precise estimate of time required to fill the cone could be prepared using a digital model of the well field, such as the one described by Hydro Systems, Inc. (1975).

After the cone of depression is eliminated, the polluted water would move slowly to the south or southwest. Figure 3 suggests that if there were a return to natural conditions, the zone of polluted water would migrate toward St. Francis Hospital. A calculation of water velocity using Darcy's law, a porosity of 0.3, transmissivity of 0.18 foot squared per second (averaged from Hydro Systems, Inc., 1975, fig. II-1), and gradient from figure 3 herein, suggests that it would take 12 years for the first arrival of the plume of polluted water at the intersection of 19th Street and West State Street. The flow lines in figure 3 could, however, be shifted to indicate flow due south, or southwest more nearly parallel to Two Mile Creek, by making some reasonable assumptions as to relative transmissivity and water levels that can neither be proved nor disproved at present.

Figure 3 is actually of limited value as a means of predicting future rate and direction of travel of polluted water, assuming cessation of pumping from the Felmont wells at North Olean, because the aquifer could be tapped at almost any point by new, large-capacity wells. In this event, flow lines would shift dramatically toward the new wells. For example, if the present industrial wells near the Felmont well field were to continue in operation, the travel rate of polluted water rate would be slower than predicted above, whereas if new wells were installed near St. Francis Hospital, the rate would increase.

What would happen to the nitrogen-bearing ground water if pumping from wells were to cease?

If all production wells at North Olean were shut down simultaneously, the present flow pattern would persist for a few months. Ground water would continue to flow toward the center of the well field, but at decreasing rates as the cone of depression filled. A graphic calculation based on the Theis equation (Ferris and others, 1962, p. 94), using transmissivity of 0.18 feet squared per second and coefficient of storage of 0.015 (adapted from Hydro Systems, Inc., 1975, fig. II-1), and using field data for August 12, 1971 (fig. 5), suggests that more than 4 months would be required to fill the cone of depression. This estimate does not consider local recharge, which would speed the process, nor the occurrence of a larger coefficient of storage that should be expected as the water table rises through gravelly deposits that had been unsaturated for many months or years, which would slow the process. Four to 8 months is probably a reasonable estimate of the range in time that might be required to fill the cone of depression; the shorter time could be expected if the shutdown occurred during the winter or early spring, when recharge is greatest. A more precise estimate of time required to fill the cone could be prepared using a digital model of the well field, such as the one described by Hydro Systems, Inc. (1975).

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A more versatile approach that would permit estimating future water-table configurations under various possible circumstances would be to construct a digital ground-water model of the area, extending farther south and west than the model described by Hydro Systems Inc (1975), with the Allegheny River as one boundary. For maximum model reliability, water-level altitudes would have to be determined in several wells south and west of well 11, and pumping test data obtained for any wells screened in sand or gravel in that area. Once the model is calibrated, any proposed arrangement of pumped wells and pumping rates could be simulated, and, from the resulting water-table map, the direction and rate of water movement could be estimated.

Would the nitrogen compounds be removed to any extent as the polluted ground water migrated through the aquifer?

The plume of polluted water that would begin to move southward under a return to natural conditions would be similar in size and shape to that shown on fig. 8. Its average concentration could be roughly estimated as twice the concentration of water pumped from well 1 at the time of shutdown, since comparison of fig. 8 and the flow nets (figs. 5, 6) suggest that about half the water reaching well 1 is polluted. A subsequent increase in concentration of the plume could be expected because it would, in part, move back under the area inferred to be the source of nitrogen compounds, and because the ratio of local recharge and vertical flushing in the polluted area to lateral flow beneath that area should be greater under nonpumping conditions than in 1975.

Undoubtedly the first arrival of nitrogen at any point downgradient would be delayed by ion exchange, the peak concentration would be lowered by diffusion, and the total amount would be reduced by bacterial conversion to nitrogen gas as the polluted water migrated. However, no attempt has been made to calculate the net effect of these factors that would reduce concentration with distance of travel, nor the increase in concentration postulated in the previous paragraph.

A case history on Long Island has documented subsurface movement of ammonia (Kimmel and Braids, 1974). Ground water was sampled near two large sanitary landfills resting on glacial outwash similar to that near Olean. The plumes of polluted water created during 27 and 41 years of operation could be traced 10,600 and 5,000 feet downgradient, respectively. Neither plume exhibited much lateral spread. Ammonia was about 90 mg/l near the landfill (the same order of magnitude as in the principal aquifer near Olean) and about 10 mg/l near the downgradient edge of the plumes. Nitrate was generally less than 1 mg/l throughout the plumes, probably limited by strongly reducing conditions and a favorable environment for denitrifying bacteria. However, nitrogen compounds were only 10 percent of cations in the Long Island plumes but they predominate at Olean, so the rate of attenuation at Olean may not closely resemble that recorded on Long Island.

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Table 1.--Water-level observation wells, Olean, New York

Well identification	Latitude (° ′ ″)	Longitude (° ′ ″)	Well characteristics, in ft below land surface: Depth (m= measured by USGS)	Well characteristics, in ft below land surface: Openings through which water enters well	Measuring Point: Description	Measuring Point: Distance above (+) or below (-) land surface (LS), building floor (BF), or pump platform (PP)	Measuring Point: Altitude (spirit levels by Felmont Oil Co. except as noted) (ft above mean sea level)
Felmont 1	42 05 26	78 26 36	82	62-82	Vent hole, pump base	PP + 0.3	1429.22
2	42 05 29	78 26 32	73	53-73	Southwest vent hole	do.	1430.14
3	42 05 34	78 26 30	72	52-72	Northeast vent hole	do.	1433.17
4	42 05 31	78 26 23	72	52-72	Vent hole	do.	1431.54
5	42 05 27	78 26 21	67	47-67	do.	do.	1429.19
6	42 05 26	78 26 26	67	47-67	do.	do.	1429.44
7	42 05 24	78 26 45	74.9m	75	Top of casing, paint mark	LS + 1.1	1430.50
8	42 05 14	78 26 55	78	?-78	Northeast vent hole	PP + 0.43	1422.46
9	42 05 19	78 26 48	70	60-70	Top of casing, paint mark	LS + 1.2	1428.49
10	42 05 24	78 26 51	70.0m	60-70	do.	LS + 0.9	1427.01
11	42 05 06	78 27 09	70	60-70	do.	LS + 1.2	1418.48
12	42 05 19	78 26 42	76.0m	58-78	do.	LS + 0.4	h/1426.49
13	42 05 12	78 26 42	77.7m	63-78	do.	LS + 1.4	1426.56
14	42 05 37	78 26 29	60.7m	27-61	Base of steel recorder shelter	LS + 1.3	1434.96
State 15	42 05 31	78 26 33	69.0m	61-69	Top of casing, paint mark	LS + 1.3	1430.86
16	42 05 13	78 26 45	76.5m	f/50	do.	LS + 2.1	1427.55
				60-70	Top of tee on pump discharge	g/	
17	42 05 35	78 26 48	63.2m	64	Top of casing, paint mark	LS + 1.3	a/1424.12
18	42 05 18	78 26 45	75.2m	f/42	Top of coupling, paint mark	LS + 1.3	1427.13
				52-69	Top of tee on pump discharge	g/	
19	42 05 06	78 26 31	64.6m	65	Top of coupling	LS + 3.0	1429.04
Dresser-Clark, Buffalo St. (Clark Bros.) 1	42 05 23	78 26 37	62.1m	>52.5m	Top of casing, in pit	LS - 5.5	1421.73
A2			61	?	Top 1-in. plastic tube	LS + 4.9	1432.17
A4	42 05 24	78 26 29	56.4m	?	do.	LS + 3.0	1430.93
A6			58.6m	?	do.	LS + 2.4	1429.32
Dresser-Clark, Lincoln Ave. 1	42 05 14	78 26 11	81.8m	74-82	Top of 1-in. iron slab below pump	LS + 0.5	1425.26
2	42 05 12	78 26 10	72.9m	69-73	Top of casing, in pit	LS + 4.6	1420.77
Olean Electroplating	42 05 21	78 26 08	71	?	South vent hole	BF + 0.81	1430.20
Hysol 1	42 05 41	78 26 24	62.5m	?	Top of casing	BF - 0.18	1434.39
Marcus, Cornell St.	42 05 50	78 26 07	21.5m	31-34?	Pump base (pump removed)	LS + 3.3	1423.72
Vanderhorst Plant 2	42 05 29	78 26 48	191.6	80+	Top of 6-in.casing	LS + 0.35	c/1424.39
Bush Bros., Ave. A	42 05 27	78 27 02	?	?	Top of casing	BF + 0.4	a/ d/1417.07
Columbia Gas	42 04 53	78 27 02	40?	?	do.	BF + 1.0	1415.83
Bush Bros., Sullivan St.	42 04 55	78 27 25	57	?	do.	BF - 2.3+	b/ e/1419.2
City of Olean 14M Erie Street	42 05 54	78 25 47	100m	?	Top of coupling	LS + 1.4	1419.79
Erie-Lackawanna RR bridge, Olean Creek	42 05 53	78 25 52	--	--	Top of south rail, near west bank	--	1423.78
North Union St. bridge, Olean Creek,	42 05 18	78 25 48	--	--	Pavement, at grating near west curb 18 ft south of expansion joint near middle of bridge	--	1433.90
Allegheny River at sewage plant	42 04 19	78 27 09	--	--	Staff gage	--	Datum= 1401.2

a/ Spirit levels by contractor for New York Department of Transportation, adjusted -0.15 ft to match levels by Felmont Oil Co.
b/ Leveled with Brunton compass to building floor
c/ Measured when out of service.
d/ Well destroyed February 1971.
e/ Well buried and pumped since November 1970.
f/ Seal installed within casing has separated uppermost opening from those below for several periods during the years 1971-75.
g/ Has varied; each measurement is referenced to top of casing.
h/ 1429.45 since mid-1975.

Table 2.--Water levels measured by U.S. Geological Survey in idle wells, adjusted to date and hour shown

(MP, measuring point)

Date, Hour:	Sept. 2, 1970 9-11 a.m.		Oct. 21, 1970 8:30-11 a.m.		Dec. 16, 1970 5 p.m.		Feb. 2, 1971	Feb. 16, 1971 5 p.m.		April 15, 1971 4 p.m.	
Felmont wells pumped:	None		1-6, 8		1, 4-6, 8		1, 4-6, 8	1, 4-6, 8		1-6, 8	
	Depth (ft) below MP	Altitude (ft) above mean sea level	Depth (ft) below MP	Altitude (ft) above mean sea level	Depth (ft) below MP	Altitude (ft) above mean sea level	Depth (ft) below MP	Depth (ft) below MP	Altitude (ft) above mean sea level	Depth (ft) below MP	Altitude (ft) above mean sea level
Felmont 1	43.57	1385.65	a/46.0	1383	a/41	a/1388.2		40.92	1389.22		
2	44.75	1385.39	a/49.3	1381	40.57	1389.57		43.54	1389.63		
3	48.00	1385.17	a/50.4	1383	43.25	1389.92					
4	46.24	1385.30	a/48.2	1383	a/42.7	a/1388.8					
5	43.64	1385.55	a/45+	1384	a/40.5	a/1388.7					
6	43.99	1385.45	a/46.4	1383	a/41	a/1388.4					
7	44.23	1386.27	44.93	1385.57	39.38	1391.12	38.97	40.03	1390.47	40.81	1389.69
8	34.46	1387.97	a/36?	1387?							
9	40.87	1387.62	40.27	1388.22	35.55	1392.94		36.97	1391.52	36.46	1392.03
10	39.93	1387.08	39.30	1387.71	34.39	1392.62	34.42+	35.45	1391.56	35.38	1391.63
11	29.73	1388.75	28.37	1390.11	24.09	1394.39		25.71	1392.77	24.48	1394.00
12	39.52	1386.97	39.58	1386.91	34.44	1392.05		35.47	1391.02	35.55	1390.94
13	39.32	1387.24	38.41	1388.15	33.50	1393.06		34.70	1391.86	34.29	1392.27
14	49.70	1385.26	d/51.73	1383.23	44.71	1390.25		44.94	1390.02	47.54	1387.42
State 15								b/41.56	b/1389.30	44.35	1386.51
16										35.23	1392.32
17										32.47	1391.65
18										29.89	1397.24
19										35.72	1393.32
Dresser-Clark No. Buffalo St. (Clark Bros.) 1	36.29	1385.44	38.14	1383.59	33.12	1389.61		32.68	1389.05	33.91	1387.82
A2	c/46.25	1385.92	48.39	1383.78	42.21	1389.96				44.05	1388.12
A4	c/44.99	1385.94	47.04	1383.89	40.88	1390.05		41.37	1389.56	42.63	1388.30
A6	c/43.12	1386.20	44.39	1384.93	38.51	1390.81		39.07	1390.25	40.02	1389.30
Dresser-Clark, Lincoln Ave. 1								31.04	1394.22	e/ --	
2								26.39	1394.38	26.60	1394.17
Water level 200 ft E or W with 1 and 2 pumping (est.)									1393.50		1394.0
Hysol 1	c/50.23	1384.34	c/51.28	1383.29	44.00	1390.39		44.25	1390.14	46.39	1388.00
Marcus, Cornell St.			16.36	1407.36	15.97	1407.75		17.08	1406.64	15.38	1408.34
Vanderhorst Plant 2							32.16	33.20	1391.19	33.69	1390.70
Bush Bros., Ave. A							23.58	b/24.62	b/1392.45		
Columbia Gas								19.4+	1396.6	15.85	1399.98
Bush Bros., Sullivan St.			21.49	1397.7							
River Stage											
Olean Creek, Erie-Lackawanna RR bridge	20.65	1412.13	d/19.3	1413.5						18.1	1414.7
No. Union St. bridge	23.71	1410.19								21.1	1412.8
Allegheny River at sewage plant		1400.62									

a/ Estimated water level near well, from air-line measurements with pump running or 1 minute after pump shut off briefly.
b/ Adjusted from measurement more than 24 hours from time shown.
c/ Less than 24 hours from time shown, not adjusted.
d/ Less than 48 hours from time shown, not adjusted.
e/ No measurement because well was being pumped.

Table 3.--Water levels measured by U.S. Geological Survey in idle wells, September 6-7, 1975
(MP, measuring point)

	Water level				Water level	
Well a/	Depth below MP (ft)	Altitude (ft above mean sea level)	Well b/	Depth of well below land surface (ft) c/	Depth below MP (ft)	Altitude (ft above mean sea level)
1	Pumped		Agway 1s	48	47.75	1383.52
2	do.		1d	68	48.50	1383.51
3	do.		2s	51	44.61	1384.67
4	do.		2d	80	44.62	1384.74
5	do.		3s	43	39.00	1388.59
6	do.		3d	74	39.58	1388.14
7	44.47	1386.03	4s	41		
8	Pumped		4d	75	38.67	1388.46
9	40.54	1387.95	5s	50	49.57	1383.61
10	39.35	1387.66	5d	67	49.45	1383.61
11	29.07	1389.41	6s	46	33.44	1396.51
12	42.43	1387.02	6d	70	44.67	1385.79
13	38.52	1388.04	7s	43	33.29	1395.19
14			7d	64	41.07	1387.34
15	47.40	1383.46	8s	42	40.37	1387.85
16	39.35	1388.20	9s	43	33.51	1396.14
17	35.80	1388.20	10s	44	40.93	1388.25
18 (above)	30.94	1396.19	11s	47	39.95	
18 (below)	40.58	1387.85	12s	46	39.74	
19	40.39	1388.65	13s	46	38.64	1388.16
Dresser-Clark 1			18s	45	38.64	1387.75
No. Buffalo St. (Clark Bros.)	37.51	1348.22				
City 14M	12.57	1407.22				
Olean Creek at Erie-Lackawanna RR bridge	20.85	1411.93				

a/ Wells 1-14, drilled for Felmont Oil Corp.
Wells 15-19, drilled for State of New York

b/ Wells 1s-18s, drilled for Agway, Inc.

c/ Reported by Hydro Systems, Inc.
Casing depth equals well depth, no perforations
Add about 1 foot for well depth below MP
For complete records and logs see Hydro Systems, Inc. (1975)

Table 4.--Nitrogen content and maximum temperatures in observation wells

Well	A. Mid-March 1971				B. Maximum consistent values for period of record 1960-75 a/			
	NH_3 (mg/l)	NO_3 (mg/l)	$NH_3 + NO_3$ as N (mg/l)	Maximum temperature °F b/	NH_3 (mg/l)	NO_3 (mg/l)	$NH_3 + NO_3$ as N (mg/l)	Maximum temperature °F b/
18	3,250	4,100	3,600	63	6,000	10,000	7,200	63
16	2,200	650	1,950	61	2,700	1,800	2,600	61
12	650	1,500	875	58.5	800	2,300	1,200	58.5
Dresser-Clark (Buffalo St) 1	350	230	340	55	350	200	330	56
13	95	2	78	53	145	10	120	53
9	25	1.5	21	54.5	42	4.2	35	56
7	1.4	1.5	1.4	52	2.5	4.0	3.0	53
10	0.8	1.5	1.0	52	1.8	4.0	2.5	52.5

a/ Maximum temperature on each date measured was determined according to footnote b/; temperatures listed are the second highest of record. Most of the ammonia and nitrate data were furnished by Felmont Oil Corp.; concentrations listed were exceeded by about 10 percent of data over period of record.

b/ Temperature listed is the highest temperature recorded in the interval 40-55 feet below land surface and 10 feet or more below the water surface. These limits were chosen to exclude surface effects.

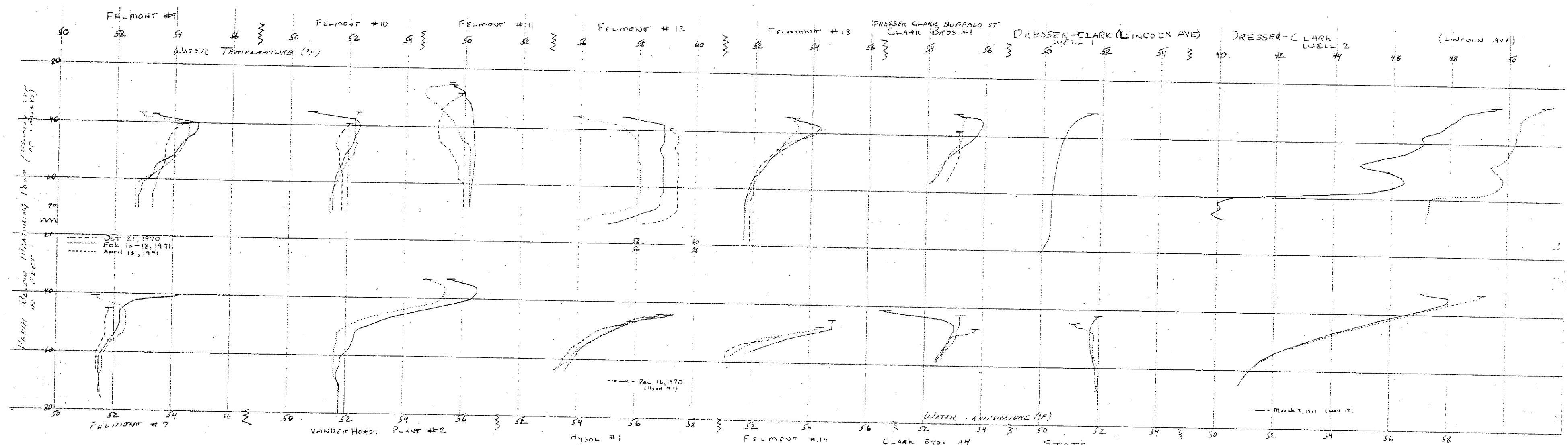


Figure 1.--Temperature profiles in wells, October 1970 - April 1971

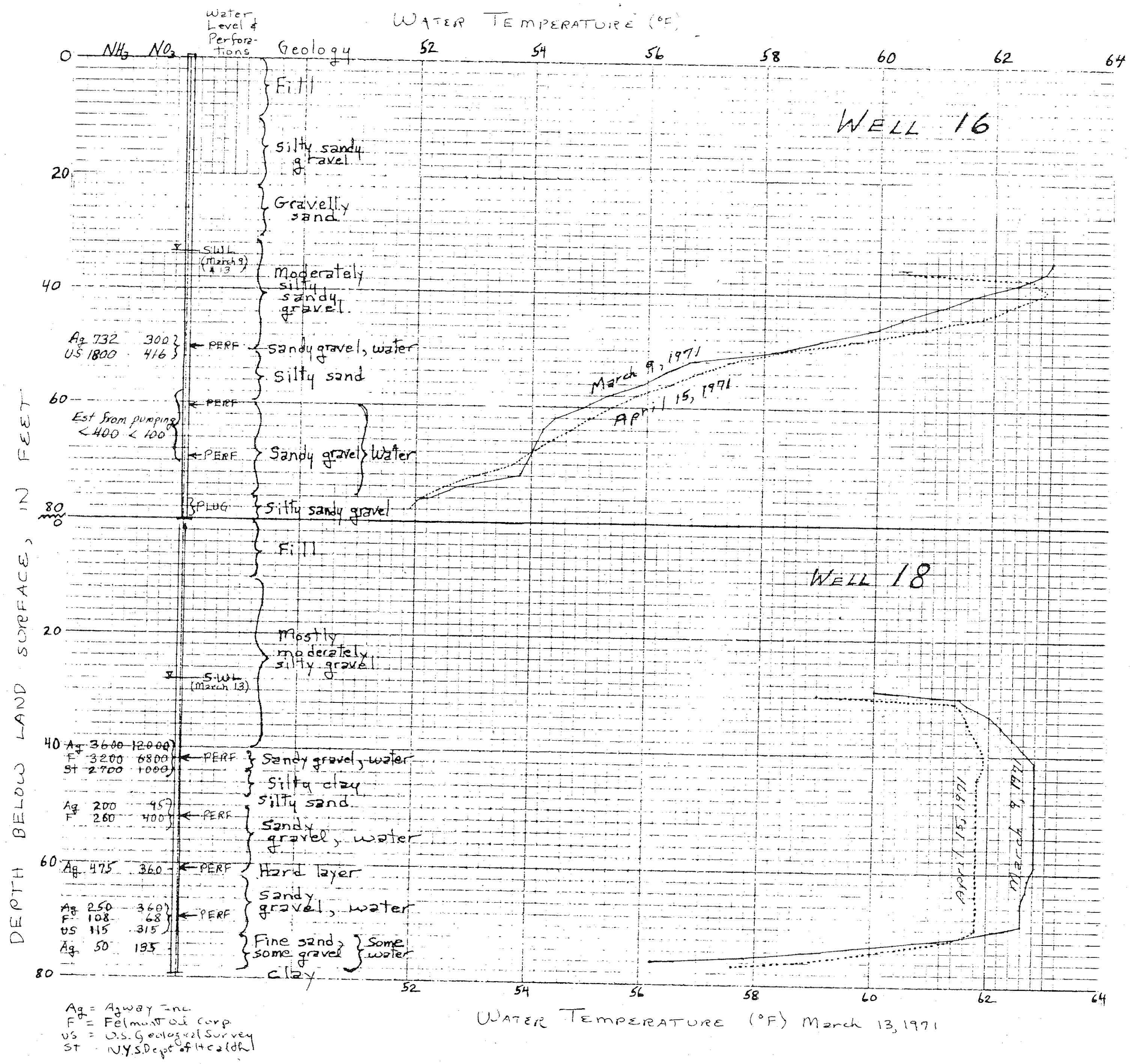


Figure 2.--Construction details and temperature profiles for March and April 1971, wells 16 and 18

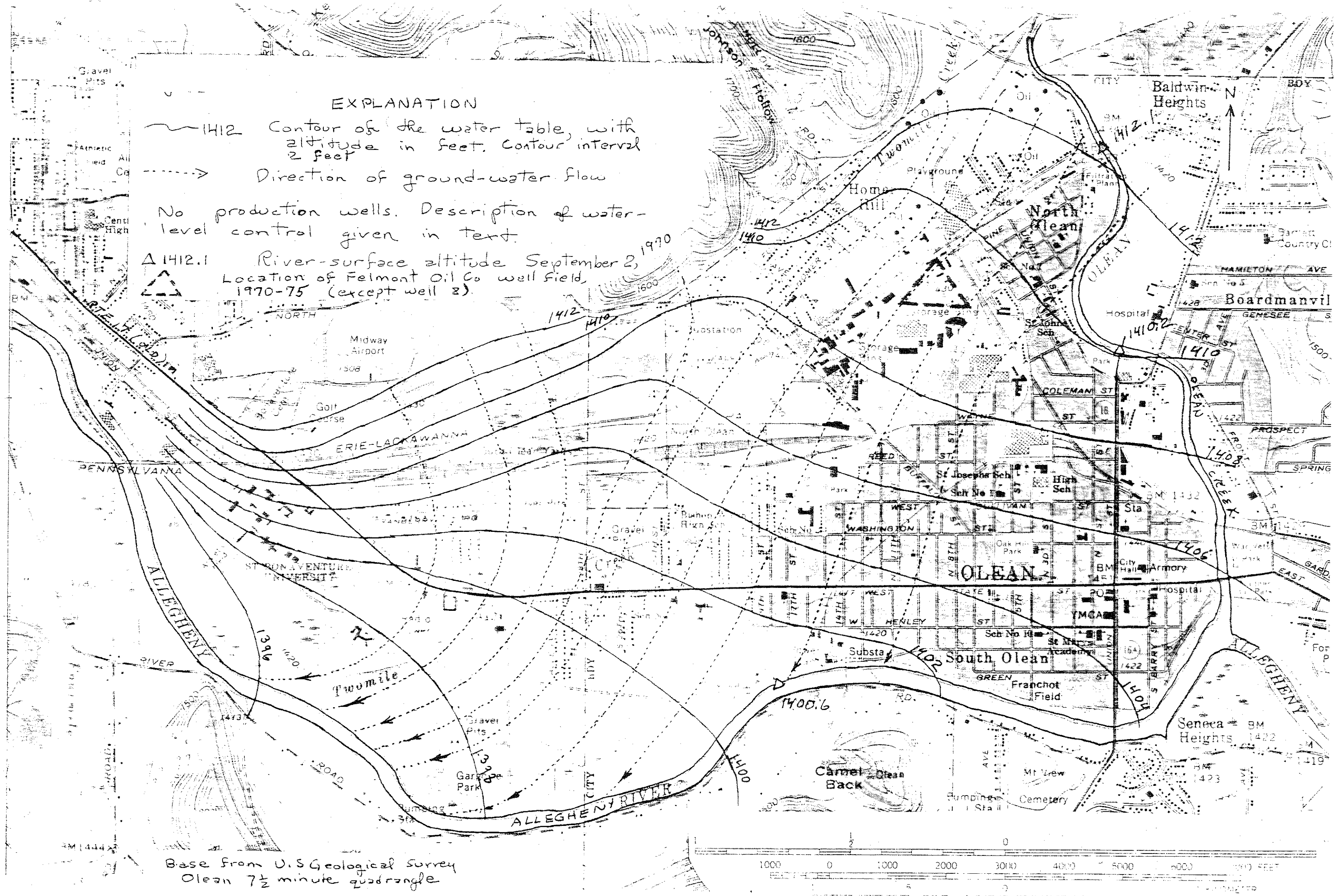


Figure 3.--Water levels under natural conditions

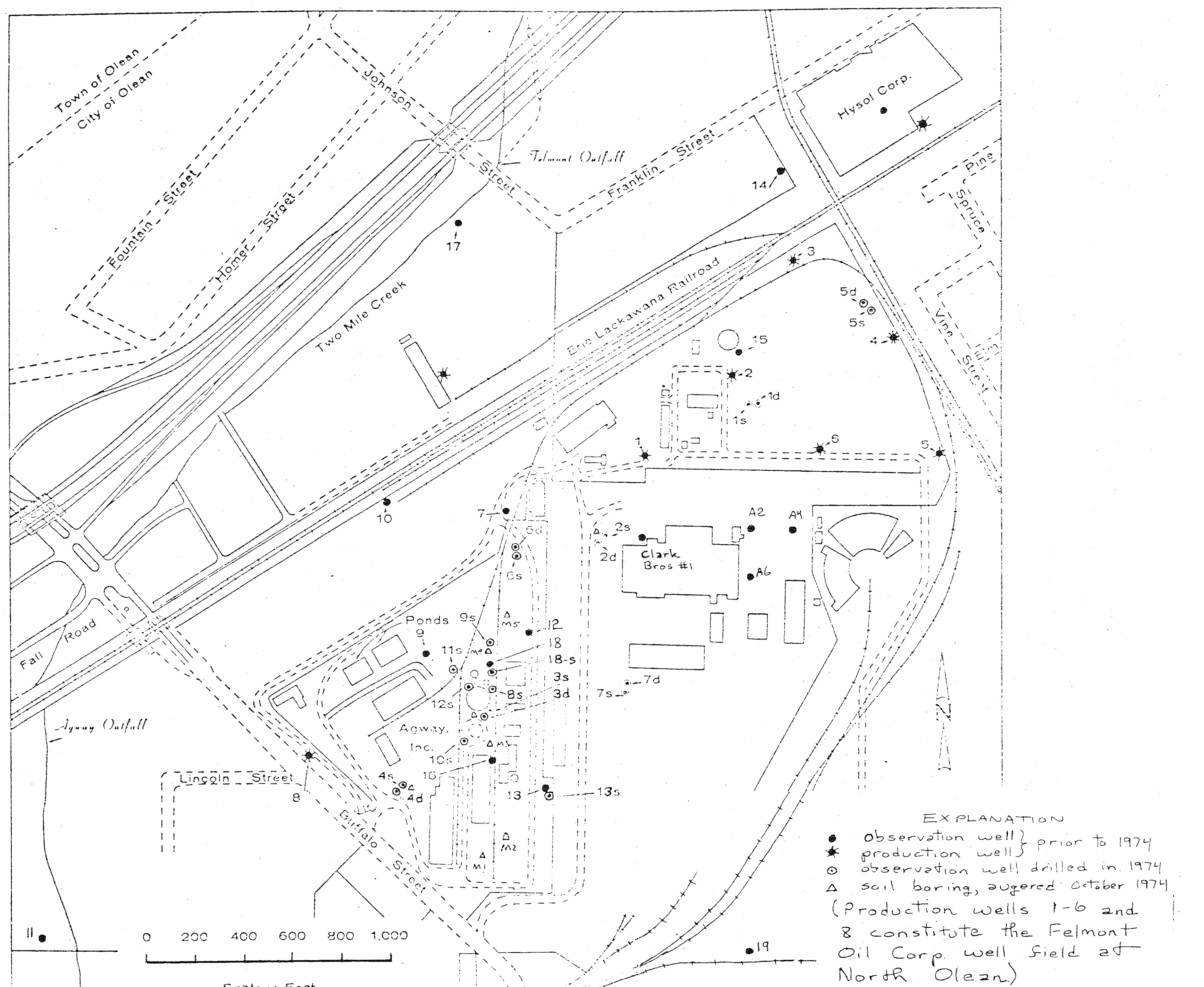
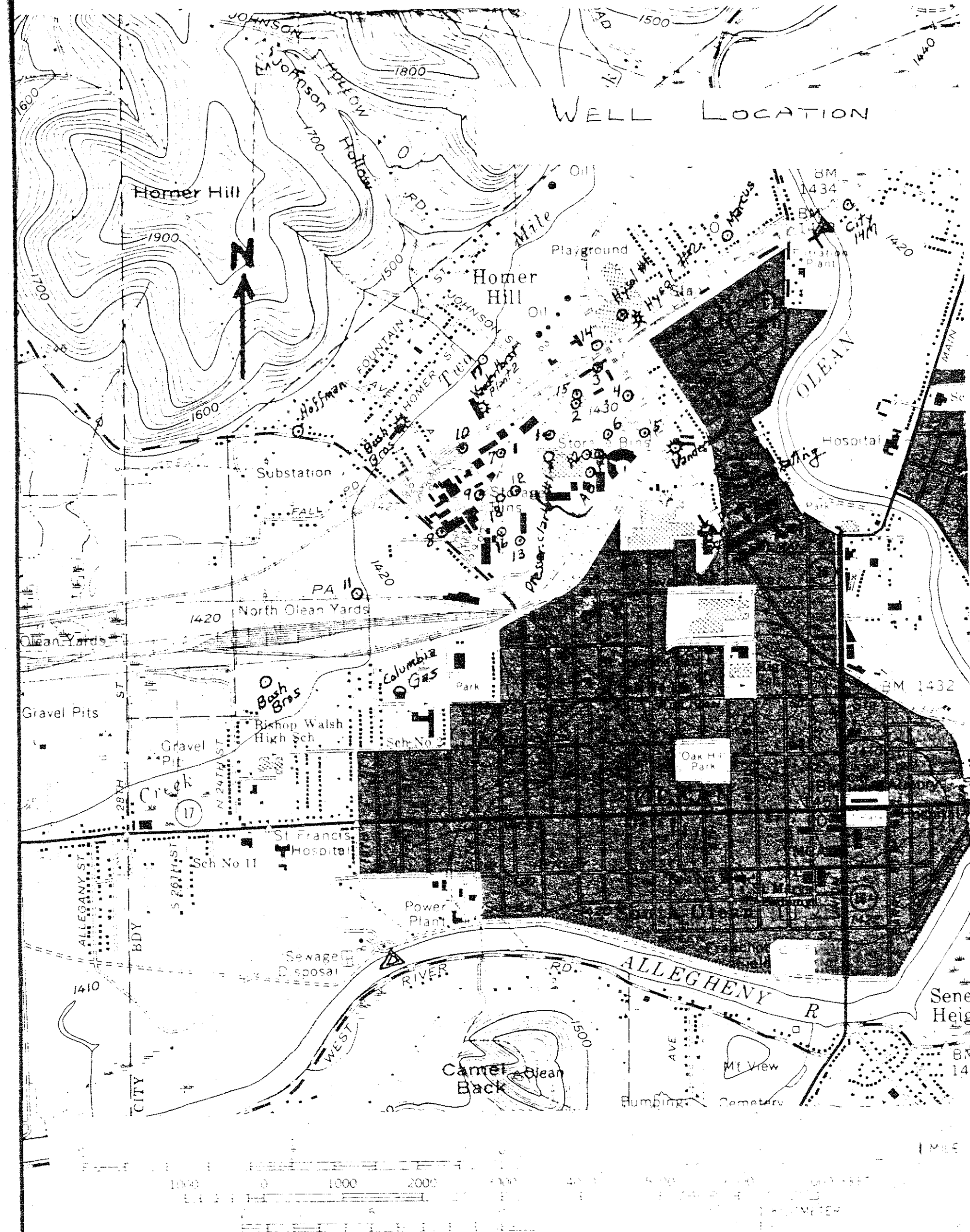
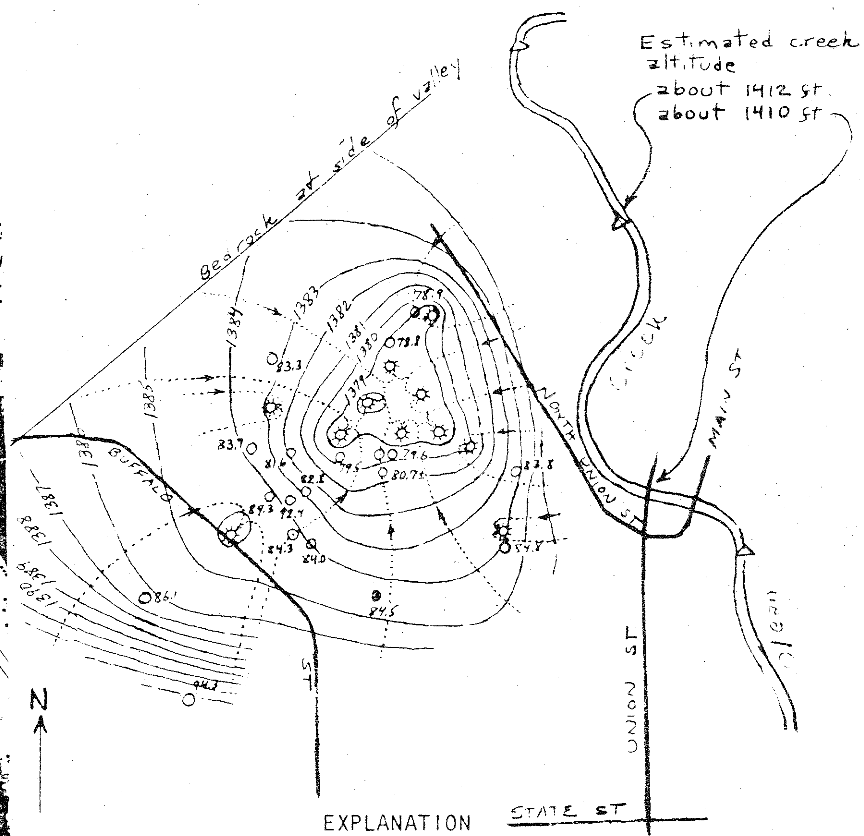


Figure 4.--Locations of wells





EXPLANATION

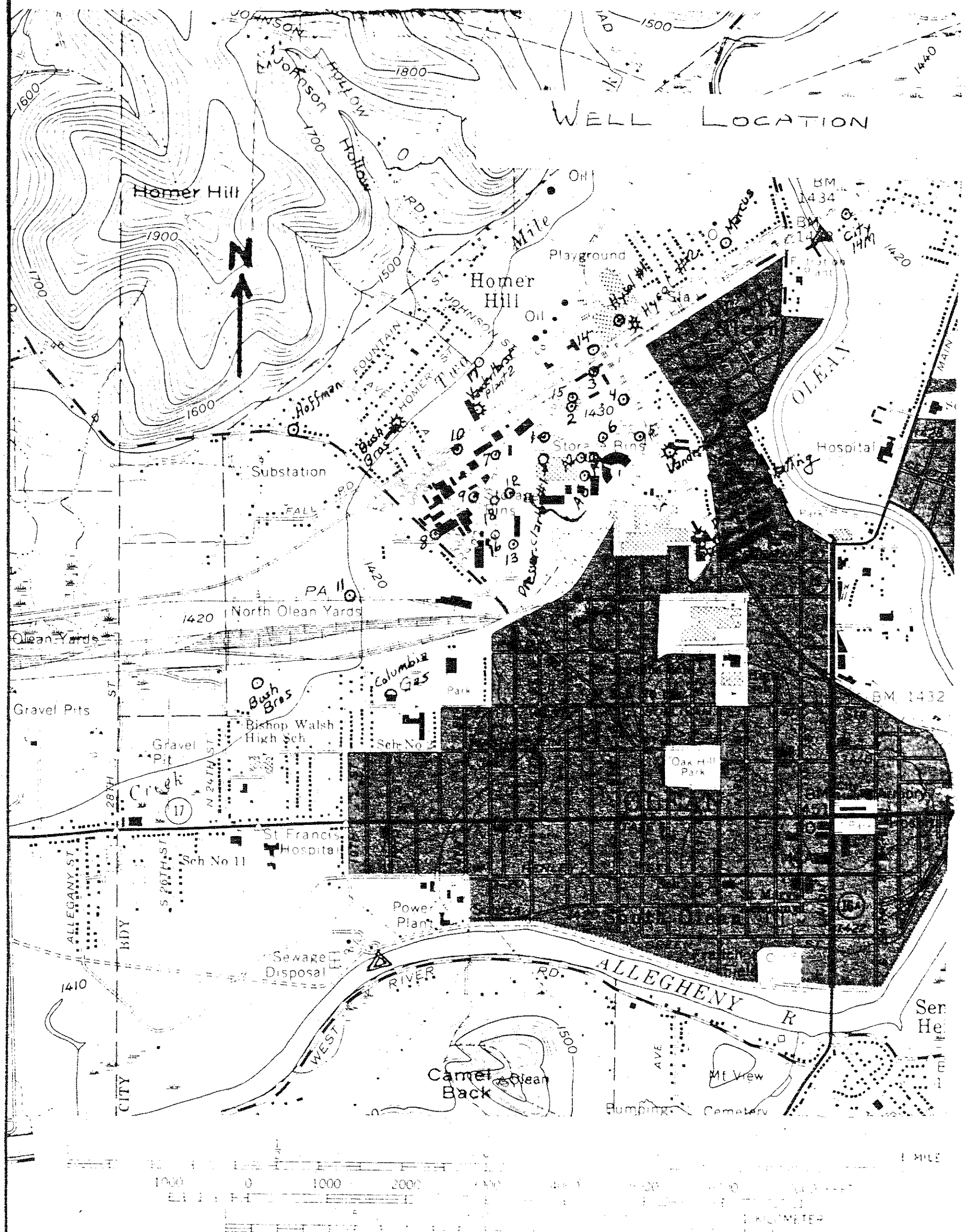
1384 — Potentiometric contour; reflects water levels in wells finished in principal aquifer. Contour interval 1 foot; datum is mean sea level.

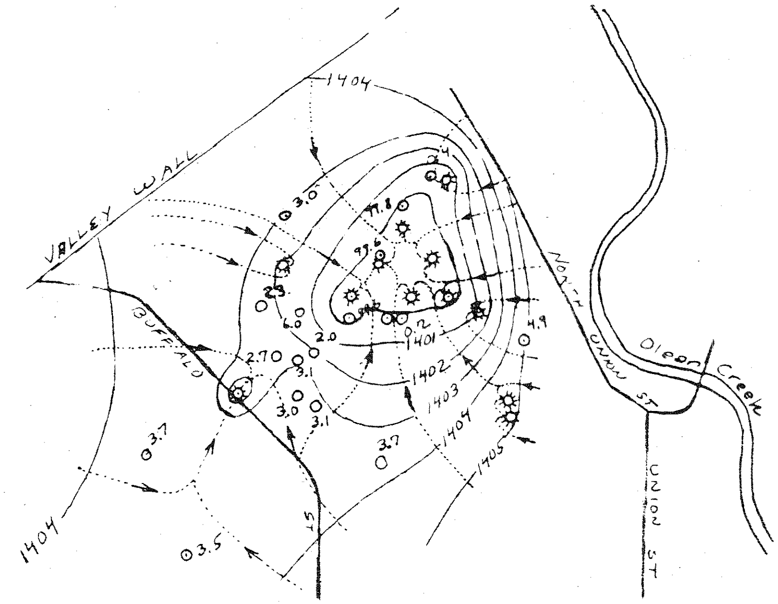
Direction of ground-water flow.

o 83.1 Observation well with altitude of water level (first 2 digits omitted).

Production well.

Figure 5.--Water levels August 12, 1971





EXPLANATION

1404 —— Potentiometric contour; reflects water levels in wells finished in principal aquifer. Contour interval 1 ft; datum is mean sea level.

······> Direction of ground-water flow.

○ 99.6 ○ 2.0 Observation well with altitude of the water level, in ft (first 2 or 3 digits omitted).

☼ Production well.

Figure 6.--Water levels July 18, 1972

EXPLANATION

⊙ Thin layers of clay or silty clay present within depth interval 30 to 50 feet, according to driller's or geologist's log.

× Well finished above clay layer, water level several feet higher than potentiometric surface in principal aquifer.

+ Water-yielding zone reported in log, at depth above potentiometric surface in principal aquifer.

↙ Temperature sometimes warm and unchanging rather than decreasing with depth, interpreted as suggesting downward flow inside or oustide casing from shallow aquifer.

▲ Soil samples from augered hole, in which concentration of NH_3 and in some cases NO_3 per unit weight of soil increases sharply below 30-32 feet; might be due to increased saturation (although soil moisture reported by laboratory does not correlate with depth).

( ) Minimum area apparently underlain by clay layers.

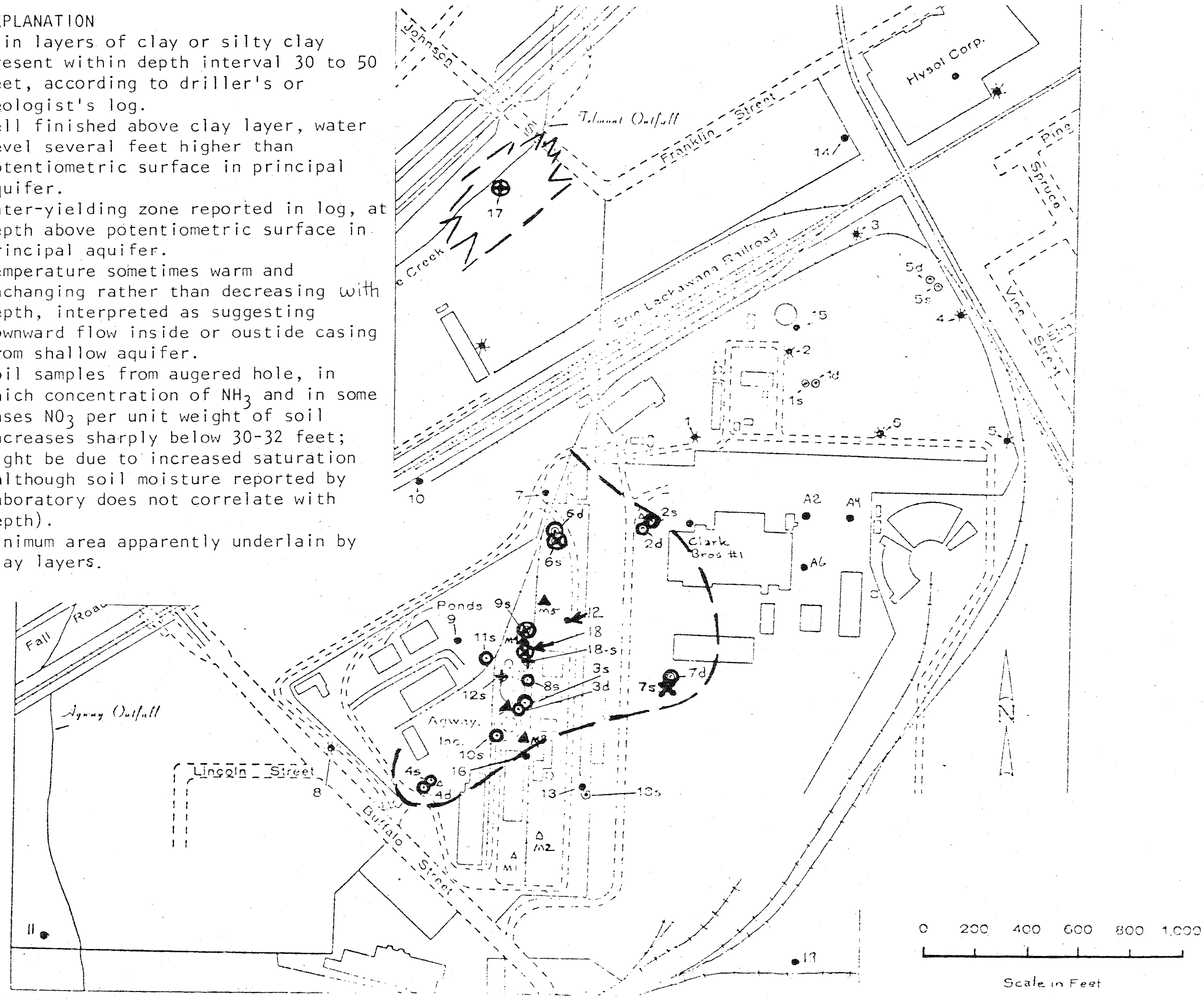


Figure 7.--Extent and effect of clay layers.

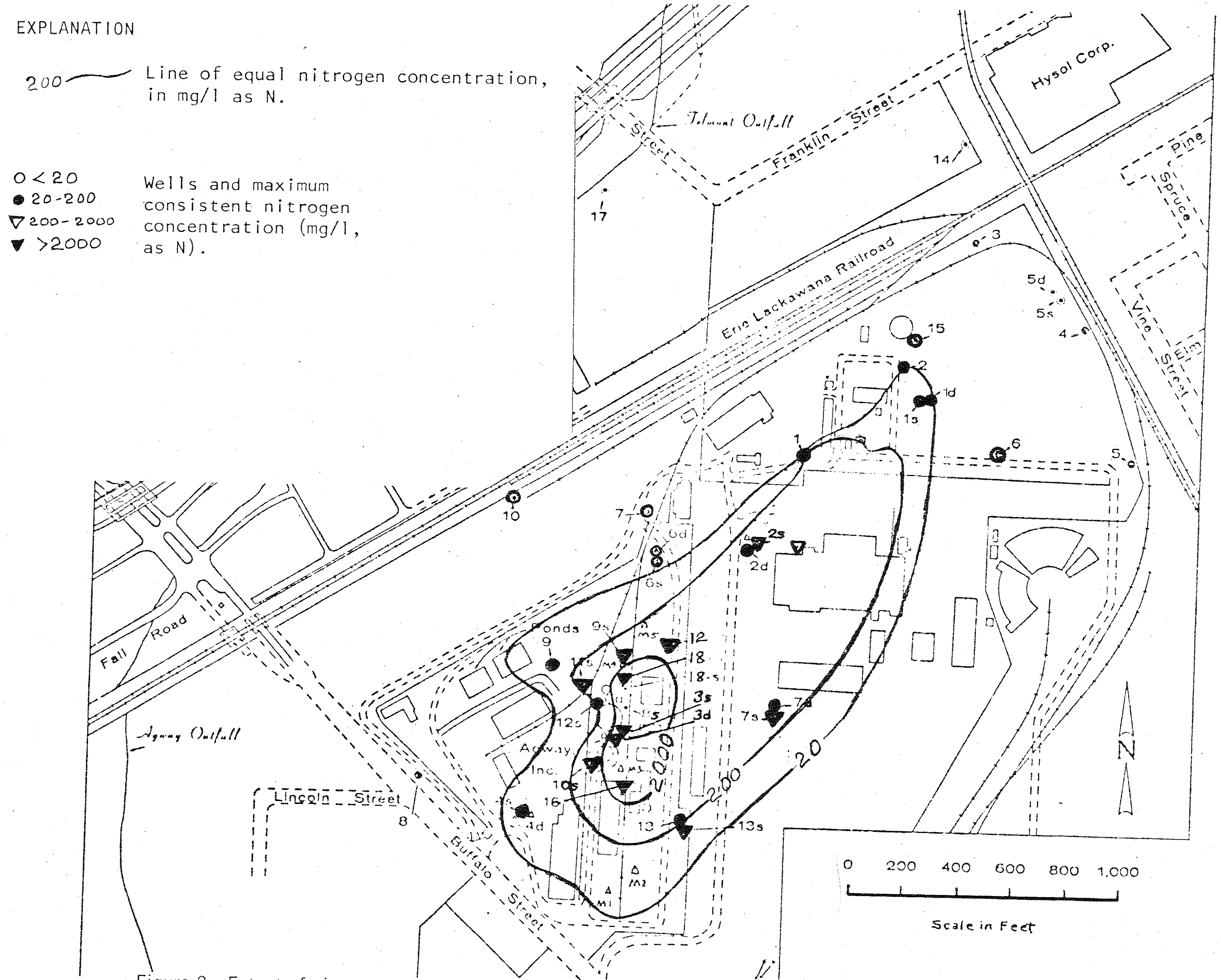


Figure 8.--Extent of nitrogen pollution. Contours represent maximum concentration observed consistently at some time during 1971-74. For wells identified with suffix "s" or "d" ("shallow" or "deep"), data collection began in October 1974; maximum nitrogen was assumed to have been higher in previous years. In general, maximum concentrations occurred near top of saturated zone.

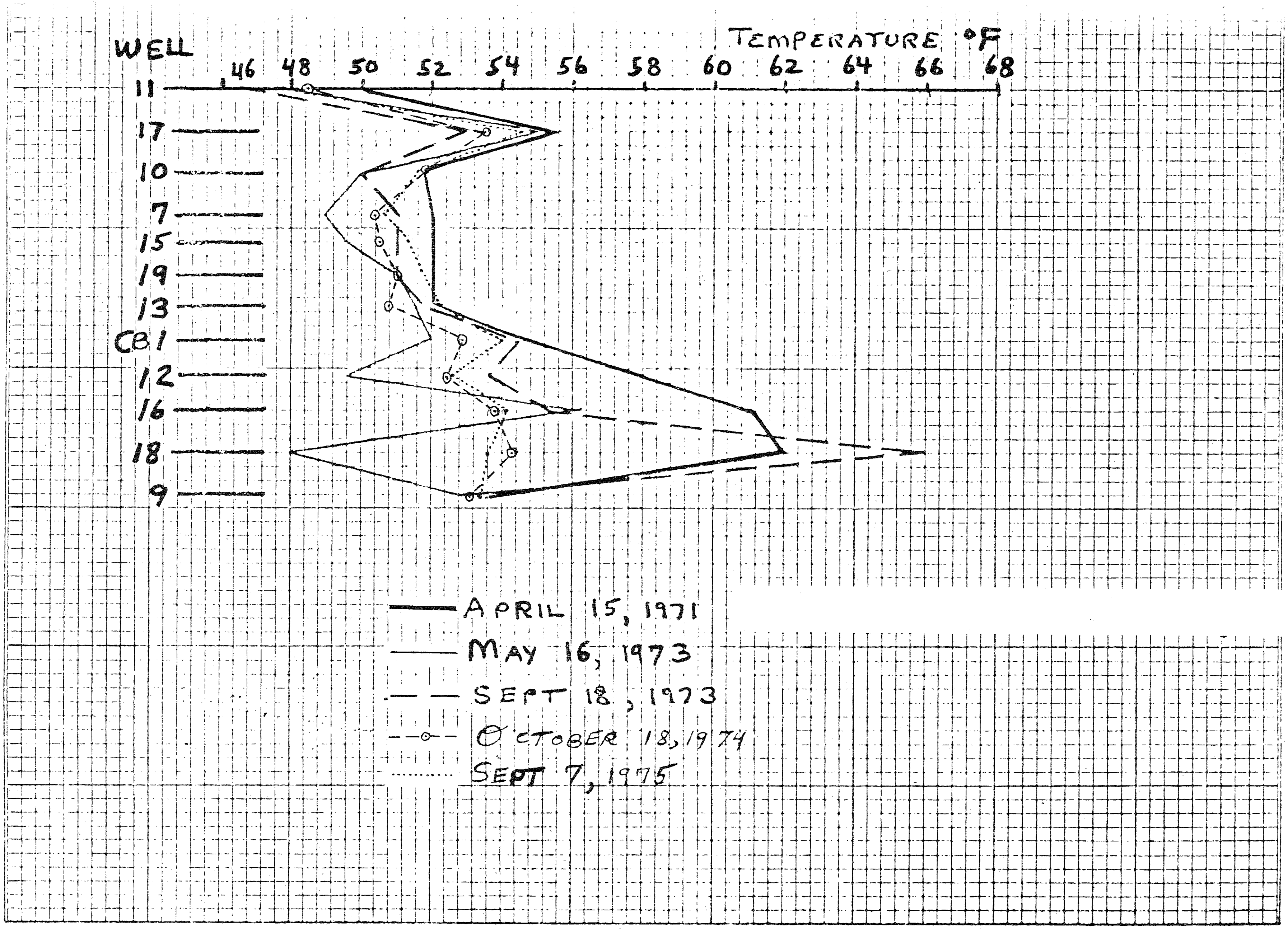


Figure 9.--Maximum temperature at depths of 40 to 55 feet (generally taken about 10 feet below water level, below any effect of thermal conduction along casing)

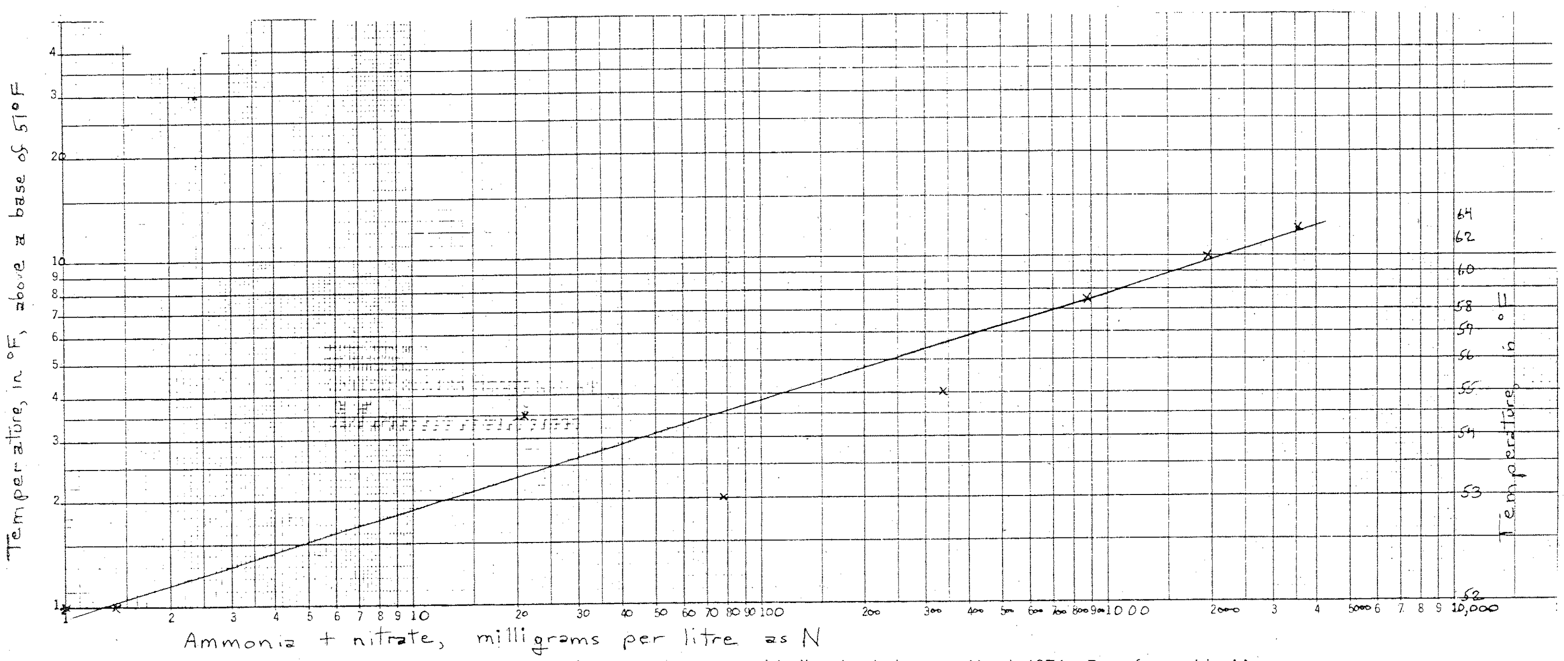


Figure 10.--Comparison of ground-water temperature with dissolved nitrogen, March 1971. Data from table 4A