GROUND-WATER POLLUTION BY NITROGEN COMPOUNDS AT OLEAN, NEW YORK--PROGRESS REPORT, JUNE 1977

U.S. GEOLOGICAL SURVEY

Open-File Report 78-304

Prepared in cooperation with

New York State Department of Environmental Conservation

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

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ILLUSTRATIONS

CONVERSION FACTORS

The following factors may be used to convert the U.S. customary units of measurement in this report to the International System of Units (metric system).

Multiply	by	To obtain
feet	0.3048	meters
square feet	.0929	square meters
gallons	3.785	liters
million gallons per day	.0438	cubic meters per second
gallons per minute	.0631	liters per second
pounds	.4536	kilograms

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ABSTRACT

Ground water in an area in Olean, New York contains high concentrations of nitrogen compounds. Construction and regular use of an additional production well there has been proposed as a method of increasing the rate of nitrogen removal from the aquifer. Such a well would increase the rate at which nitrogen-rich water flows downward from the silty upper part of the aquifer to the permeable lower part, and would decrease the distance that this water must flow through the aquifer to the nearest point of withdrawal. Consequently, the rate of nitrogen removal should increase appreciably during the first several months of pumping while the system is adjusting to the new conditions. A further increase could be achieved by leaving a production well southwest of the polluted area idle while continuing regular operation of production wells on the opposite side. An alternative method would be to construct and pump shallow wells tapping the upper part of the aquifer, and (or) to pump some already existing test wells. Once the new production well (or shallow wells) had been pumped for several months and a slug of nitrogen-bearing water had been removed, the rate of further nitrogen removal would depend on the rate at which nitrogen compounds are leached from soil above the water table by infiltrating precipitation. This process could not be influenced by wells, but could probably be accelerated by artificial watering or irrigation of the area. A production well with screened intervals opposite the entire aquifer would capture more nitrogen than one screened only near the base of the aquifer.

INTRODUCTION

A locality in Olean, New York where ground water is contaminated with nitrogen compounds is being studied as part of a cooperative program between the U.S. Geological Survey and the New York State Department of Environmental Conservation. Periodic progress reports on the changing situation in this locality are planned to describe current findings and to address problems as they arise. The present report evaluates several alternative possibilities for speeding withdrawal of nitrogenous compounds from the aquifer, including a proposal to construct an additional production well in the area of highest nitrogen concentration and to pump it regularly. Other pollutants known to have been present in the aquifer in smaller concentrations (Randall, 1976, p. 9) are not considered in this report.

According to a previous report (Randall, 1976, fig. 8), ground water has been polluted with nitrogen compounds in a small area southwest of the center of the Felmont Oil Corp. well field at North Olean. Most of the nitrogen compounds apparently entered the ground about 2,000 feet southwest of the center of the well field, where concentrations of ammonia plus nitrate in water regularly exceeded 2,000 milligrams per liter as nitrogen from 1970 to 1974. No single predominant source has been identified, but various spills and leaks of fertilizer (chiefly urea), process compounds (including nitric acid), and wastewater have occurred in this area over the years.

The sand and gravel aquifer tapped by the Felmont Oil Corp. well field and by other industrial wells at North Olean 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. During the 1970's, ground-water withdrawal maintained a cone of depression a few thousand feet in diameter and about 30 feet deep at the center. Test borings suggest that shallow water-table mounds in two small areas within this cone (Randall, 1976, fig. 7) are caused by localized clay lenses. Therefore, it is believed that all precipitation that infiltrates in areas within the cone of depression has been captured by it and withdrawn by wells, together with ground-water underflow beneath Olean Creek and some induced infiltration from streams. The nitrogen-bearing water flows generally toward the center of the Felmont well field, and all of it is eventually withdrawn by wells.

Changes in subsurface nitrogen concentration with time since 1974 have been monitored intensively and analyzed by Hydro Systems, Inc. (1975, 1976, 1977). In general, concentrations in most test wells have declined from peak values formerly recorded, but still ranged from 100 to 1,200 milligrams per liter as N in many wells in 1975-76 and seemed to have stabilized in several wells (Hydro Systems, Inc. 1977, p. 6). Annual calculations of change in mass of ammonia and nitrate stored in the aquifer and overlying unsaturated sediment (Hydro Systems, Inc., 1975, 1976, 1977) have thus far failed to account for all of the nitrogen in water pumped from production wells, even though the area and (or) data base for the calculations have been expanded each year. Water and soil samples from the upper part of the zone of saturation have consistently contained more nitrogen than samples from greater depth (Randall, 1976, p. 10; Hydro Systems, Inc., 1977, table 5). As of September 1976, the nitrogen concentration in water in the upper 20 feet of the zone of saturation near wells 12, 16, and 18 probably averaged between 350 and 700 milligrams per liter as N (inferred from samples from several wells analyzed by N.Y. State Dept. of Environmental Conservation; J. Beecher, written commun., 1976). The persistence of the nitrogen pollution has stimulated discussion of whether flushing of the aquifer could be accelerated by some means such as pumping a new well or wells in the polluted area.

PROBABLE EFFECT OF A NEW PRODUCTION WELL

The area and the wells discussed in this report are shown in figure 1. If a new production well were installed somewhere between test wells 12, 16, and 18 and pumped regularly, a temporary increase in the rate of flushing of the aquifer could be expected as a result of (1) increased downward gradient near the well and (2) less distance from the source of nitrogen to a point of withdrawal. Let us consider these factors in turn.

1. To calculate the drawdown that would be caused by a new well, the following conditions were assumed:

   (a) Uniform aquifer composition with transmissivity of 0.35 feet squared per second, as determined for the immediate vicinity of the well field at North Olean by Hydro Systems Inc. (1975, fig. II-1) from their digital model, and supported by computations made for this study.

   (b) Impermeable hydraulic boundaries at distances of 2,500 feet to the northwest and southeast of the proposed new well. The former boundary is the bedrock wall of the valley, the latter is a simple means of roughly simulating the smaller transmissivity suggested by steep hydraulic gradients to the northeast and southeast (fig. 2). The Hydro Systems model also indicates lower transmissivity values in outer parts of the cone of depression, and, in a previous report (Randall, 1976), an average transmissivity of 0.18 feet squared per second was used for calculation of regional flow.

   (c) A storage coefficient of 0.15, which is typical of sand and gravel deposits under water-table conditions, when drained or refilled over periods of many months. A storage coefficient

0.015 was reported by Hydro Systems Inc. (1975) without explanation; presumably it was based on short-term tests of the lower part of the aquifer, which may be temporarily confined by the silty upper part during such tests.

(d) A pumping rate of 1 million gallons per day (= 700 gallons per minute) from the new well, continued for a year.

Under these assumed conditions, an increase in drawdown of about 5 feet could be expected in the lower part of the aquifer at a distance of 50 feet from the new well. This would approximately double the average downward gradient that prevailed in September 1976 as determined from U.S. Geological Survey measurements at three pairs of wells that tap the upper and lower units of the aquifer.[1/] This sudden increase in downward gradient--more than double the previous gradient within 50 feet of the new well, and a smaller increase at greater distances--would temporarily cause the contaminated water in the upper unit of the aquifer to flow downward faster than before until enough water had drained out of the upper unit to lower the head significantly in that unit and thereby return the average rate of flushing to approximately what prevailed before use of the new well.

1/ These units have been described by Randall (1976, p. 6) and by Hydro Systems, Inc. (1975, p. 10-16 and appendix I). Both reports interpret geologic and chemical data as indicating that the upper 40 to 50 feet of the aquifer is siltier than the part below, and that near test wells 12, 16, and 18 the upper part contains a mound, or reservoir, of contaminated water that slowly percolates downward through or around clay lenses into the more permeable lower part, through which water flows more rapidly toward production wells. However, the "shallow aquifer" as defined in the material-balance calculations of Hydro Systems, Inc. (1975, 1976, 1977) is not equivalent to the semiperched reservoir of ground water above the clay centered on Agway property, but rather is defined as all material between 41 and 58 feet in depth. Many wells finished in this depth interval have heads identical to those in deeper wells, which indicates that hydraulically these wells represent the top of the lower unit of the aquifer.

2. At present, after the nitrogen-bearing water seeps downward into the lower part of the aquifer, it flows laterally toward Felmont wells 1 and 2. The lower part of the aquifer may be compared to a pipeline filled with sand, in that its function is to convey the nitrogen-bearing water to the nearest point of withdrawal. A significant amount of nitrogen is in transient storage within this "pipeline." According to the most recent material balance by Hydro Systems Inc. (1977), there are 78,000 pounds of nitrogen between depths of 58 and 80 feet (their "deep aquifer") and 254,000 pounds between depths of 41 and 58 feet; all of the 78,000 pounds and a substantial part of the 254,000 pounds are within the lower part of the aquifer, where flow is predominantly lateral toward the center of the well field. A new production well near or slightly southwest of test well 12 would provide a point of withdrawal nearer the source of the nitrogen-bearing water and should capture most of that water, thus reducing the length of the "pipeline." Therefore, regular operation of the proposed new well should ultimately result in a smaller quantity of nitrogen compounds in transient storage in the lower part of the aquifer, and the rate of nitrogen withdrawal should increase temporarily during the period of readjustment. However, because of the need to limit the nitrogen concentration in combined industrial wastewater discharged to nearby streams, withdrawal of nitrogen-rich water from the proposed new well might be limited to rates much smaller than maximum well yield, which would prolong the period of readjustment. Incidentally, it is unlikely that any single well tapping the lower unit, wherever it were placed, could capture all the nitrogen-bearing water. Some would probably flow laterally through the cleanest layers in the upper unit to the margin of the clay layer(s) that separate the two units, where it could more easily seep downward; this process might result in some contaminated water seeping downward so far from the new well that it could continue to follow a flow path leading to Felmont well 1 or 2.

The two changes in ground-water flow pattern considered above would reduce the volume of contaminated water stored below the water table, reduce the time required to move contaminated water from the water table to a point of withdrawal, and speed the rate of nitrogen withdrawal temporarily while the reduction in storage is taking place. An auxiliary effect would be to reduce the amount of nitrogen reaching production wells 1 and 2. However, new well(s) would not do anything to remove nitrogen compounds stored in the soil above the water table. According to the material balances calculated by Hydro Systems, Inc. (1976, 1977) for October 1975 and October 1976, about 75 percent of the nitrogen in the system is stored in the soil above the aquifer (although part of what they call "lower soil" may actually be saturated). If their material balance calculations are approximately correct, once any new wells(s) had been in operation for some months and had removed part of the nitrogen stored in the upper and lower units of the aquifer, a new stability would have been achieved and the rate of further removal would depend on the rate at which nitrogen is leached from the soil and carried to the aquifer by infiltrating precipitation (adjusted for current addition of nitrogen, if any, from leaks or spills). The rate of leaching seems to be a major factor controlling the present rate of nitrogen removal through Felmont wells 1 and 2. If this is true, after a new stability is achieved the total rate of removal through all pumped wells would be much the same as if only the present wells were in use.

Each of the production wells constructed for Felmont Oil Corp. is designed with a screen open to the lowest 20 feet of permeable sand and gravel at the particular site in order to obtain the maximum available drawdown and hence maximum yield. If a new production well were designed with a screen open to shallower levels in the aquifer also, it would capture and remove nitrogen compounds somewhat more effectively. This could be done by using more than 20 feet of screen, by interspersing sections of screen with sections of blank pipe, by setting the entire screen at the shallowest depth consistent with the design yield, or possibly by installing a thick gravel envelope extending above the shallowest permeable layer. There would be no need to place a screen above a depth of 30 feet, which was approximately the average depth to the water table under 1970-77 conditions.

ALTERNATIVE METHODS OF NITROGEN REMOVAL

At least three alternative techniques could be used in addition to, or instead of, a new production well to speed the rate of nitrogen removal from the soil and ground water in the contaminated area. These techniques are to increase the rate of infiltration, shift the location of withdrawals, and (or) pump from shallow wells.

The most obvious approach to increasing the rate at which nitrogen is leached from soils above the water table would be to increase the rate of infiltration through those soils. The average annual rate of infiltration to the water table from precipitation is probably about 24 inches; it should be neither difficult nor prohibitively expensive to substantially increase this rate by some form of sprinkler irrigation during the summer over the small area (about 600,000 square feet minus area of buildings) on Agway property where soil borings indicate the highest concentrations of nitrogen compounds. About 9 million gallons of water would be required to double the annual infiltration over this area. The extensive literature on ammonia adsorption and release from soils (Mortland, 1958; McVicker and others, 1966) suggests that leaching occurs fairly readily. However, a review of the literature should be made before any irrigation is attempted, particularly to consider whether some simple modification of the chemical character of the water used would make it more suitable for leaching nitrogen compounds.

One way to increase the rate at which nitrogen is flushed from different parts of the aquifer would be to adjust the rates of withdrawal from existing and (or) proposed production wells. Figure 2 is a provisional contour map of water levels in the aquifer (or the lower unit thereof) based on measurements in mid-September 1976, when Felmont wells 1-5 and 8 were in use. Figure 3 shows the calculated long-term effect of adding a new production well at test well 12. Note the ground-water divide between the new well and well 8. The gentle gradients here, in the western part of the zone of historically highest nitrogen concentration in ground water, would result in relatively slow flushing of contaminated water from this part of the aquifer, as was also the case in September 1976. Figure 4 shows calculated water levels if the new well were added and well 8 shut down. Although this map has some inconsistency as a result of overlapping calculations that do not perfectly represent the real aquifer, it is clear the gradients are steeper and flow is in one direction from the west edge of the contaminated zone to the new well; consequently, more rapid and effective flushing of the western part of the contaminated zone should result. However, note that whether or not well 8 is pumped, a ground-water divide would develop between the new well and Felmont well 1 (figs. 3, 4). This divide would lie within the plume of contaminated water now moving toward Felmont well 1, and could greatly delay flushing of the immediate area. It might be helpful to operate the new well at different rates, for a few months at a time, to shift the position of the divide; but there may be no sure method of eliminating this problem. Some improvement in flushing rate would result even without a new well if it were possible to pump Felmont wells 1-6 continuously and leave well 8 idle; this would eliminate the present ground-water divide and near-stagnant ground water within the contaminated zone.

An alternative method for withdrawing contaminated water from the upper unit of the aquifer without constructing a new production well would be to install shallow wells or pump existing test wells that tap that unit in the area where heads are several feet higher than in the lower unit. For example:

(a) State well 18 is no longer essential for observation purposes because there are so many new observation wells. It would therefore be possible to fill in the lower part (below 50 feet), perhaps make 1 or 2 additional perforations at 42 feet, then pump the well at a few tens of gallons per minute. The water might be used to supplement plant process water or be discharged directly into wastewater pipelines.

(b) Perhaps one of the Agway test wells could be pumped at a similar rate.

(c) New, relatively shallow wells could be constructed to tap the upper unit--ideally near well 12, between wells 8s and 7s, and perhaps east of well 3s. Because it is likely that only small yields could be obtained from silty gravel, the most practical design might be a dug well excavated with clamshell or bucket auger, lined with porous concrete tile, and terminated at a depth of about 45 feet.

Although pumping rates from wells tapping the upper unit of the aquifer would be small, significant quantities of nitrogen could be withdrawn. For example, according to Hydro Systems, Inc. (1975), the average nitrogen concentrations in the "shallow aquifer" in October 1974 within "area 1" of the material-balance calculation in use then (which included wells 12, 8s, 7s, and 3s) were 590 milligrams per liter ammonia and 535 milligrams per liter nitrate, or a total of 607 milligrams per liter nitrogen as N. Probably a total pumping rate of 120 gallons per minute could be achieved from four wells tapping the upper unit and constructed as described above. If such wells had been in operation in October 1974, about 870 pounds of nitrogen per day[1/] could have been withdrawn, which is comparable to the amount actually withdrawn by Felmont wells 1 and 2. This alternative might prove less costly and, combined with a shutdown of well 8, would eliminate any problems associated with a ground-water divide within the lower unit, as discussed previously. However, this alternative would lack the capability of high-rate withdrawal to maintain the cone of depression during a prolonged shutdown of the Agway-Felmont complex.

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McVicker, M. H., Martin, W. P., Miles, I. E., and Tuckers, H. H. (ed.), 1966, Agricultural anhydrous ammonia, technology and use: Amer. Soc. Agron., Madison, Wis.

1/ 607 milligrams per liter x 120 gallons per minute x 1440 minutes per day x 8.35×10^{-6} (conversion of units) = 870 pounds per day.

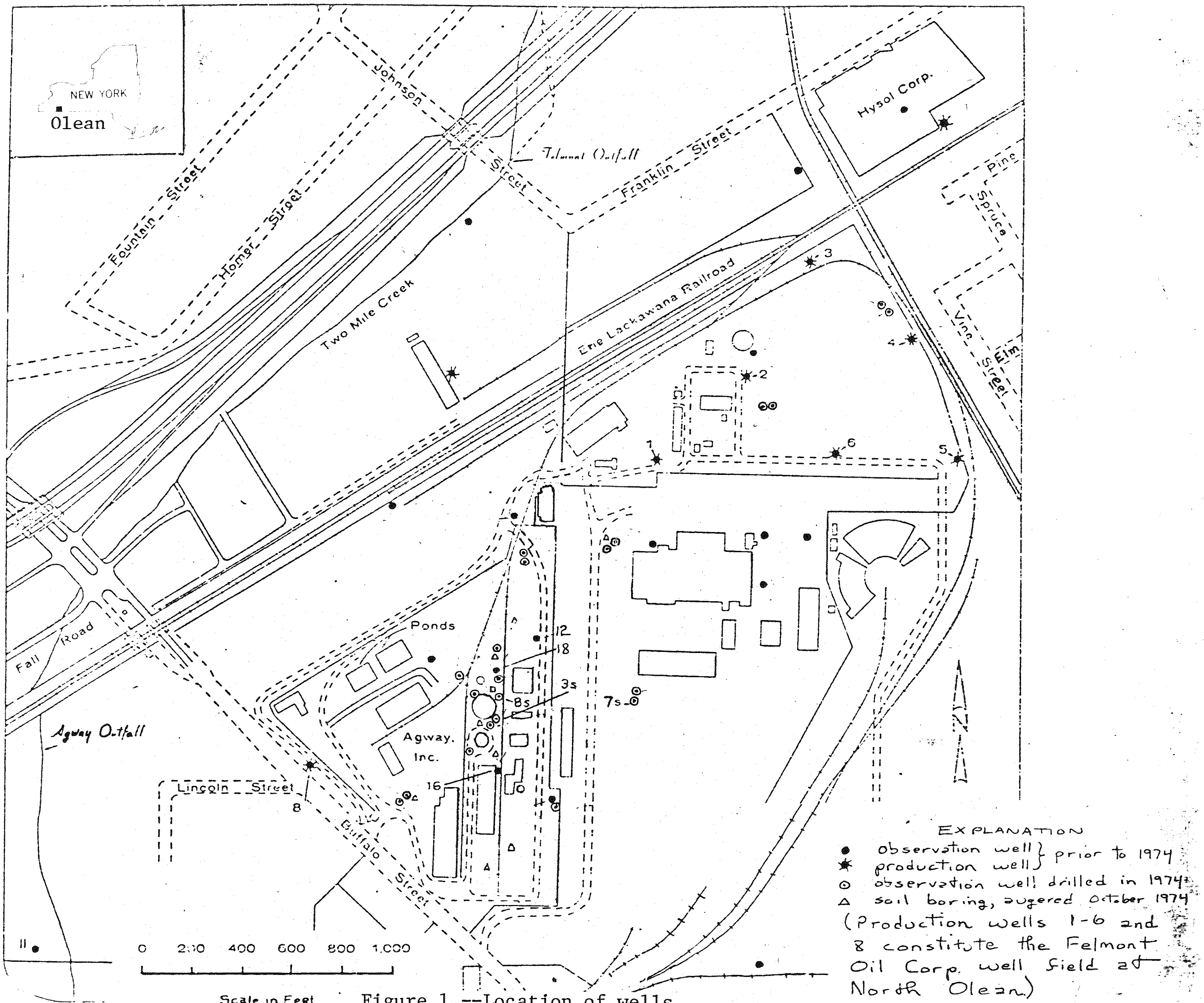

Figure 1.--Location of wells.

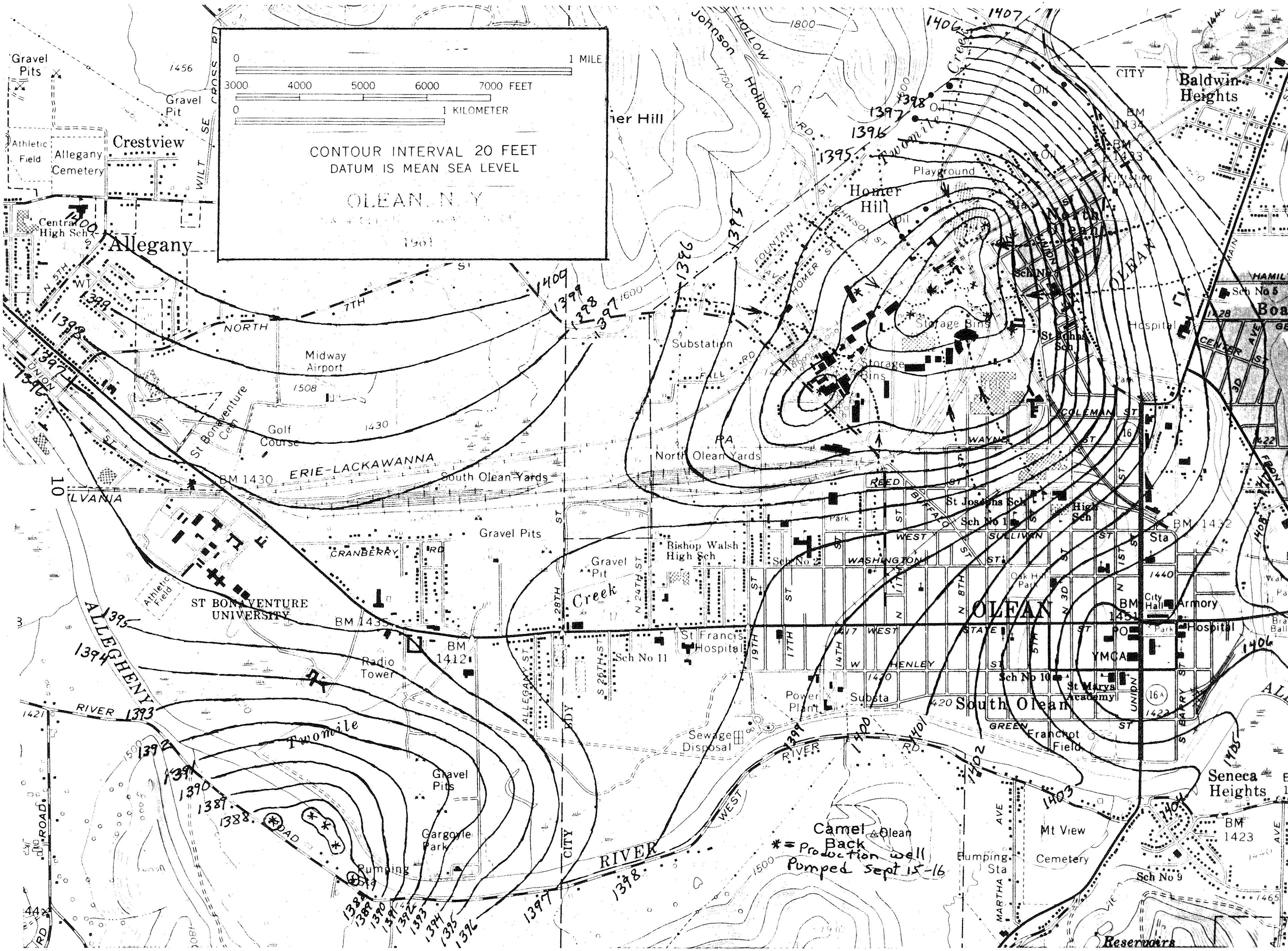

Figure 2.--Water levels on September 15-16, 1976.

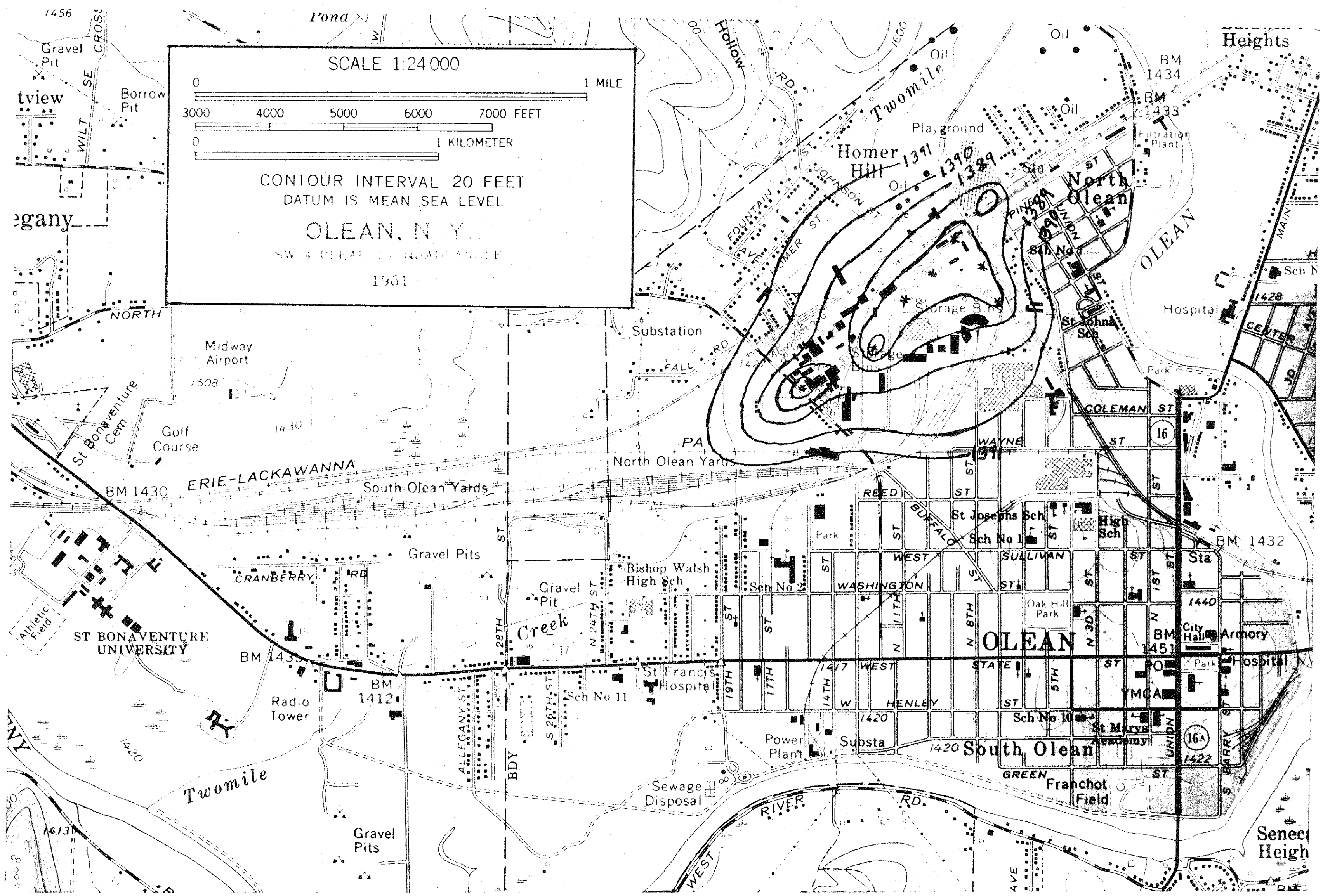

Figure 3.--Calculated water levels for September 1976 with new production well added.

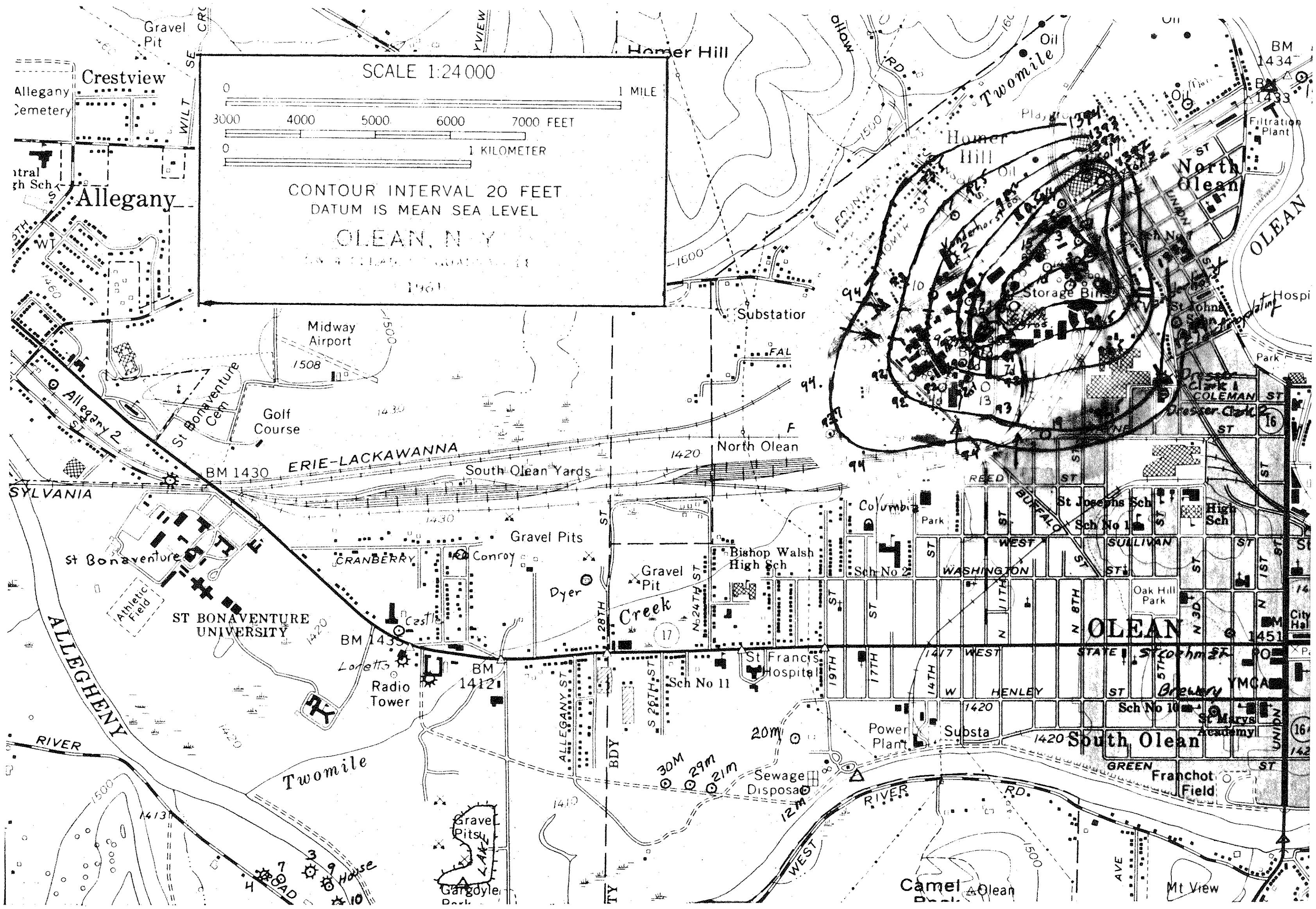

Figure 4.--Calculated water levels for September 1976 with new well added and Felmont well 8 idle.

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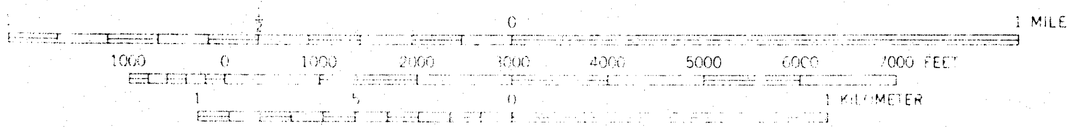
Add to Figures 2, 3, 4

Scale



CONTOUR INTERVAL 20 FEET
DOTTED LINES REPRESENT 10 FOOT CONTOURS
DATUM IS MEAN SEA LEVEL

Base Credit

OLEAN, N. Y.
SW 4 OLEAN 15' QUADRANGLE

1961