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CONSIDERATIONS ON INLAND SEWAGE DISPOSAL IN FALMOUTH, MASSACHUSETTS

by

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Ralph F. Vaccaro

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TECHNICAL REPORT

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CONSIDERATIONS ON INLAND SEWAGE DISPOSAL

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INTRODUCTION AND SUMMARY

The Town of Falmouth, Massachusetts, has employed the engineering firm of Whitman & Howard, Inc., to design a sewerage system to be considered by the Town for disposal of domestic wastes. In their report (Jones, 1968), Whitman & Howard recommended that a sewage treatment plant, with primary and secondary treatment, be located near Nobska Point, and that the treated effluent be disposed of in Vineyard Sound through a strategically located marine outfall. As possible alternates to the plant near Nobska Point, Whitman & Howard suggested two inland disposal sites - one near the corner of Brick Kiln and Sandwich Roads and the other on Blacksmith Shop Road near the Town dump. These inland plants would discharge secondary treated effluent into the ground through appropriate sand filter beds.

A group of investigators at Woods Hole Oceanographic Institution has suggested an optimal location for the marine outfall in terms of its possible effects on the waters of Vineyard Sound. (Bumpus and others, 1969). This report is a companion to their report, and considers the consequences of disposing treated effluent at the alternative inland sites.

For the terminal disposal of treated sewage effluents, transfer into the ground can be an acceptable and effective method. Very many, if not most, of the terrestrial sewage treatment plants in this country operate in this manner.

In many instances, such practice enhances water conservation by helping maintain ground water reserves. However, in towns such as Falmouth, which depend upon ground water for potable water, great care must be taken to assure that recharging does not cause any undue contamination of the local ground water system.

Nitrate is one of the more unpredictable by-products of sewage treatment and its ultimate appearance in natural waters can have an adverse effect on water quality. In ground water, nitrate is mobile and persistent and can be of public health significance since excessive concentrations in drinking water can lead to circulatory disturbances in infants and certain susceptible animals. The U. S. Public Health Service recommends that drinking water contain no more than 45 ppm (parts per million) of nitrate. Furthermore, excessive amounts of nitrate, in conjunction with other plant nutrients, can lead to unsightly blooms of nuisance aquatic plants once exposure to sunlight is provided.

Unfortunately there is no certain way to predict accurately how a Falmouth installation might change the nitrate content of the Town's ground water supply. The magnitude of the change would depend on the degree of dilution by uncontaminated ground water and upon the efficiency of poorly understood natural processes that operate in the subsoil of the disposal area and in the ground water itself. Adequate allowance for this uncertainty should be provided at the planning stages of any inland sewage disposal plant which depends upon terminal disposal into the ground.

Our studies indicate that effluent from a sewage disposal plant located at Alternate Site 1 on Brick Kiln Road will ultimately flow underground into Coonamessett River and Great Pond. If the nitrate content of the effluent waters is excessive and not adequately controlled (either naturally, by biological and physical processes operating in the subsoil, or artificially, at the treatment plant), the addition of nutrient material can be expected to enhance the growth of algae in Great Pond.

Effluent from a sewage disposal plant located at Alternate Site 2 on Blacksmith Shop Road, will drain toward and eventually enter the Town water-supply reservoir at Long Pond. Here the consequences could be more serious since nitrate enrichment of the drinking water supply at Long Pond may eventually require treatment to reduce the nitrate content and to remove the disagreeable tastes and odors which might be produced by the excessive growth of algae in Long Pond.

Ground water moves slowly, and effluent waters from a disposal plant at Alternate Site 2 would not reach Long Pond for several decades. If a contamination problem appeared after that time, a further period of at least equal length would be required to flush the contaminant from the ground water between Blacksmith Shop Road and Long Pond. Consequently an early-warning monitoring system of observation wells near the disposal site is recommended to detect any incipient contamination problem before it becomes serious.

If the Town constructs a sewage treatment and disposal plant at an inland site, we recommend that it take the following steps to protect the quality of its ground water and its future water supply.

1. Allow space and design access for possible future installation of nitrogen-removal equipment (tertiary treatment).

2. Monitor the quality of the ground water in inexpensive observation wells located appropriately near the disposal site.

3. Install nitrogen-removal equipment in the treatment plant if the monitoring shows it to be necessary.

CONTAMINATION BY NITRATE

Experience in other areas of the country shows that the main contamination problem near inland sewage disposal sites is the accumulation of nitrate in ground water. Nitrogen compounds in the effluents of secondary treatment plants are rapidly oxidized to nitrate when they are exposed to oxygenated soils and subsoils. Unlike some other contaminants and constituents of treated sewage effluents (especially phosphate, and probably also DDT and heavy metals) which are rapidly adsorbed by soil particles and removed from solution, nitrate often persists in solution without being removed by the soil.

Studies on the mobility of nitrate in ground water have been made in Texas and on Long Island. Because these observations were conducted in sandy and gravelly materials similar to the subsoils of Falmouth, their results should be helpful in predicting what may happen locally near the proposed inland disposal sites. In the Texas experiment (Scalf and others, 1968), water that contained 24 ppm nitrate was pumped through a recharge well into a sandstone aquifer at a rate of 0.5 mgd (million gallons per day). Water in an observation well 66 feet away from the recharge well eventually contained 23 ppm nitrate, indicating that the nitrate passed essentially undiminished through the sandstone. In the Long Island experiments (Nassau-Suffolk Research Task Group, 1969), ground water quality was monitored downstream of household cesspools. Where cesspools were well above the water table and effluents percolated down to the water table through an unsaturated and oxygenated subsoil zone, nitrates formed in substantial concentrations. These nitrate concentrations persisted in the ground water with essentially no decrease for horizontal distances as great as 45 feet (the greatest distance tested at the site) downstream of one cesspool, and they diminished somewhat after travelling 31 feet (greatest test distance at the site) downstream of another cesspool. That is, at one site the nitrate remained essentially constant and at another site it diminished somewhat as the ground water moved away from the source of contamination.

Concentrations of nitrates in ground waters have been reported in other areas where sewage effluents are disposed into sandy and gravelly subsoils. The town of Clovis (near Fresno), California, has a sewage treatment plant that has operated intermittently since the early 1940s (continuously since 1955) and has processed an average of about 1 mgd of sewage in recent years. Effluent is disposed of in ponds and allowed to percolate down to the water table. Nitrate concentrations as great as 50 ppm are found in ground water below the treatment plant, and they decrease to 25 ppm half a mile downstream of the plant (Behnke and Haskell, 1968). Whether the decrease in concentration is due mainly to dilution by uncontaminated ground water or to some chemical or bacterial process in the sandy subsoil is unknown. In Nassau County on Long Island, the composition of waters from public wells has been monitored annually for about 15 years, and the nitrate concentration of many of these waters has been increasing steadily. Of 333 wells whose waters were analyzed, 80 showed a progressive increase in nitrate concentration, 20 already (1969) exceed the safety limit recommended by the U. S. Public Health Service (45 ppm).

and 55 more will exceed this limit within the next 50 years if the present trends continue (Smith, 1969). That is, more than one fifth of the well waters that were analyzed either already contain excessive nitrate or will contain excessive nitrate by the year 2020. The organic nitrogen and ammonia of domestic sewage is the main source of this nitrate - about 800,000 people in Nassau County dispose of their sewage through cesspools.

To help interpret conditions closer to Falmouth, we collected water samples for nitrate analysis from wells near the sewage disposal plants in Hyannis and Otis Air Force Base. In neither case, however, were we able to show conclusively that nitrates from the treatment plants either were or were not accumulating in the ground water. In Hyannis, we detected no high nitrate concentrations that could be related unequivocally to the disposal plant. However, two factors make this result inconclusive. First, the Hyannis plant is small and only processes about 0.5 mgd of sewage, which is only about 15 percent of that proposed for the Falmouth plant. And second, no wells were available directly downstream (southeast) from the Hyannis plant, and so we could not sample the ground water that was most likely to be contaminated by the effluent. Near the Otis treatment plant, we found nitrate concentrations that were anomalously high (but still acceptable for drinking water) in well waters in the upper part of the valley that contains Ashumet Pond and eventually leads to the head of Green Pond. However, too few wells were accessible for us to be certain that these high concentrations were in fact due to effluents from the Otis sewage treatment plant. Details of these analyses are listed in Appendix A.

To sum up this discussion of nitrates, we believe that the concentrations of nitrate probably will increase in ground waters adjacent to and downstream of the proposed inland sewage disposal sites in Falmouth. To what degree this increase would affect Falmouth's ground water is presently unknown. Nevertheless, any sewage disposal design for an inalnd site should anticipate an eventual need for further treatment to regulate the intrusion of nitrate into the ground water.

GROUND WATER IN FALMOUTH

All fresh water in Falmouth - in the ground, in streams, and in ponds - comes from precipitation that falls directly on Cape Cod. Falmouth's average rainfall of about 45 inches per year represents an average of about 2 mgd per square mile. Of this amount, about half is returned to the atmosphere by surface evaporation or through transpiration by plants, or it runs off directly in streams. The other half, or about 1 mgd per square mile, percolates into the ground and recharges the ground water. As the area of Falmouth, exclusive of ponds, is about 40 square miles, the ground-water recharge within the Town averages about 40 mgd.

The ground water moves seaward through the subsoil at velocities of a few inches per day. Some of the ground water returns to the surface in streams, such as the Coonamessett River, or in ponds that are drained by streams. Most of the ground water probably seeps eventually into coastal ponds and marshes or directly into Buzzards Bay and Vineyard Sound. The methods used to estimate the effects of effluent on ground water flow are summarized in Appendix B.

PREDICTED EFFECTS OF INLAND SEWAGE DISPOSAL ON GROUND WATER IN FALMOUTH

Two inland sites, one near the corner of Brick Kiln and Sandwich Roads and the other on Blacksmith Shop Road near the Town dump, have been proposed for secondary treatment and disposal of sewage. Treated effluent waters are expected to amount eventually to 3.7 mgd and to contain 10 ppm of phosphorus and 40 ppm of nitrogen. Effluents will be applied on sand filter beds at the rate of 2 gallons per square foot per day, and they will percolate through at least 20 feet of unsaturated subsoil before reaching the water table. Under these conditions essentially all the phosphorus will be removed by the soil particles. Many of the nitrogen compounds, on the other hand, will be oxidized to nitrate. In the unlikely event that the entire 40 ppm of nitrogen in the effluent is converted to nitrate, the concentration of nitrate in the effluent waters would be 180 ppm. Because it is probable that the organic nitrogen and ammonia in the effluent will be only partly converted to nitrate, a more likely concentration of nitrate in the effluent that reaches the water table would be about half this amount.

The present ground-water levels and approximate directions of ground-water flow in the central Falmouth area are shown in figure 1. Contour lines on figures 1, 2, and 3 show the elevation of the water table (top of the saturated subsoil) above mean sea level. Flow lines, which cross the contours at right angles, show the directions in which the water is flowing. These water levels and flow directions will be changed somewhat if 3.7 mgd of recharge water is added at either one of the 60-acre

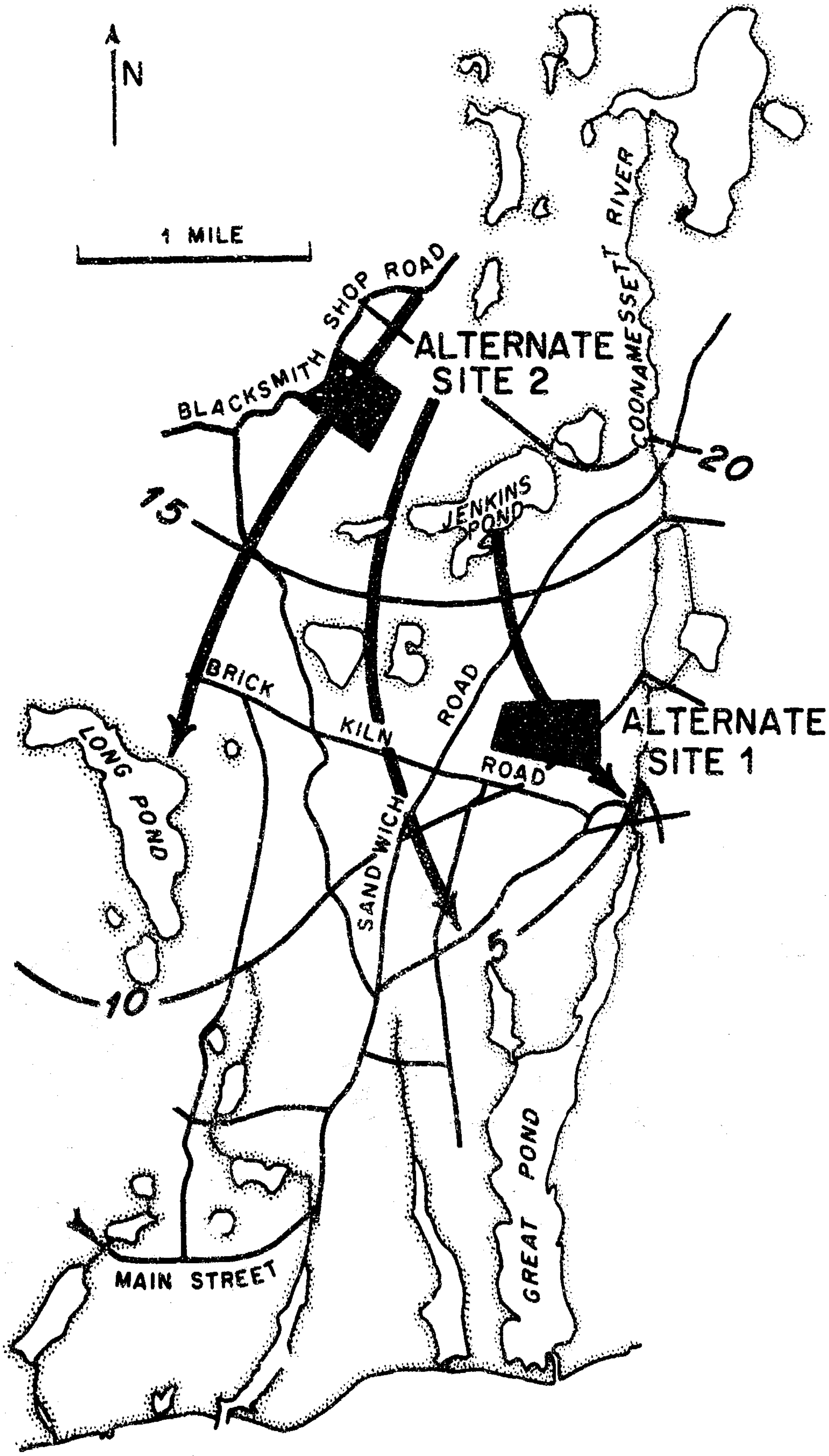

Figure 1. Present average directions of ground-water flow (arrows) in central Falmouth. Contours show elevation of water table in feet above mean sea level, taken mainly from pond levels indicated on topographic maps (scale 1:24,000) of U.S. Geological Survey plus supplementary levels from wells between Sandwich Road and Long Pond.

inland disposal sites. Some specific effects of effluent disposal at each of the two proposed locations are considered below.

Alternate Site 1: Brick Kiln Road

The pattern of ground-water flow that will accompany sewage disposal at the Brick Kiln Road site is shown in figure 2. It is anticipated that the coincident heavy pumping of the Long Pond reservoir will cause a localized depression in the water table. Most of the treated sewage effluent will seep into the Coonamessett River or directly into Great Pond. Effluent from this disposal site will not flow toward Long Pond under average conditions, nor is it likely to flow significantly near Long Pond even during droughts.

The present ground-water flow beneath the Brick Kiln Road site is probably about 1 mgd, or considerably less than the 3.7 mgd that is the proposed effluent flow from the treatment plant. The greatest diluti of the effluent that can be expected near the plant, therefore, is about one part uncontaminated ground water to four parts effluent. Assuming one-to-four dilution and a nitrate concentration of 100 ppm in the effluent, ground water downstream from the plant will contain 80 ppm of nitrate. The portion of the effluent that reaches the Coonamessett River will be diluted further, probably in proportions of two or three parts river water to one part contaminated ground water (the flow of the river in June, 1950, was about 7 mgd according to Ketchum, 1951). Even when diluted by the Coonamessett River, however, the nitrate concentration of the inflowing

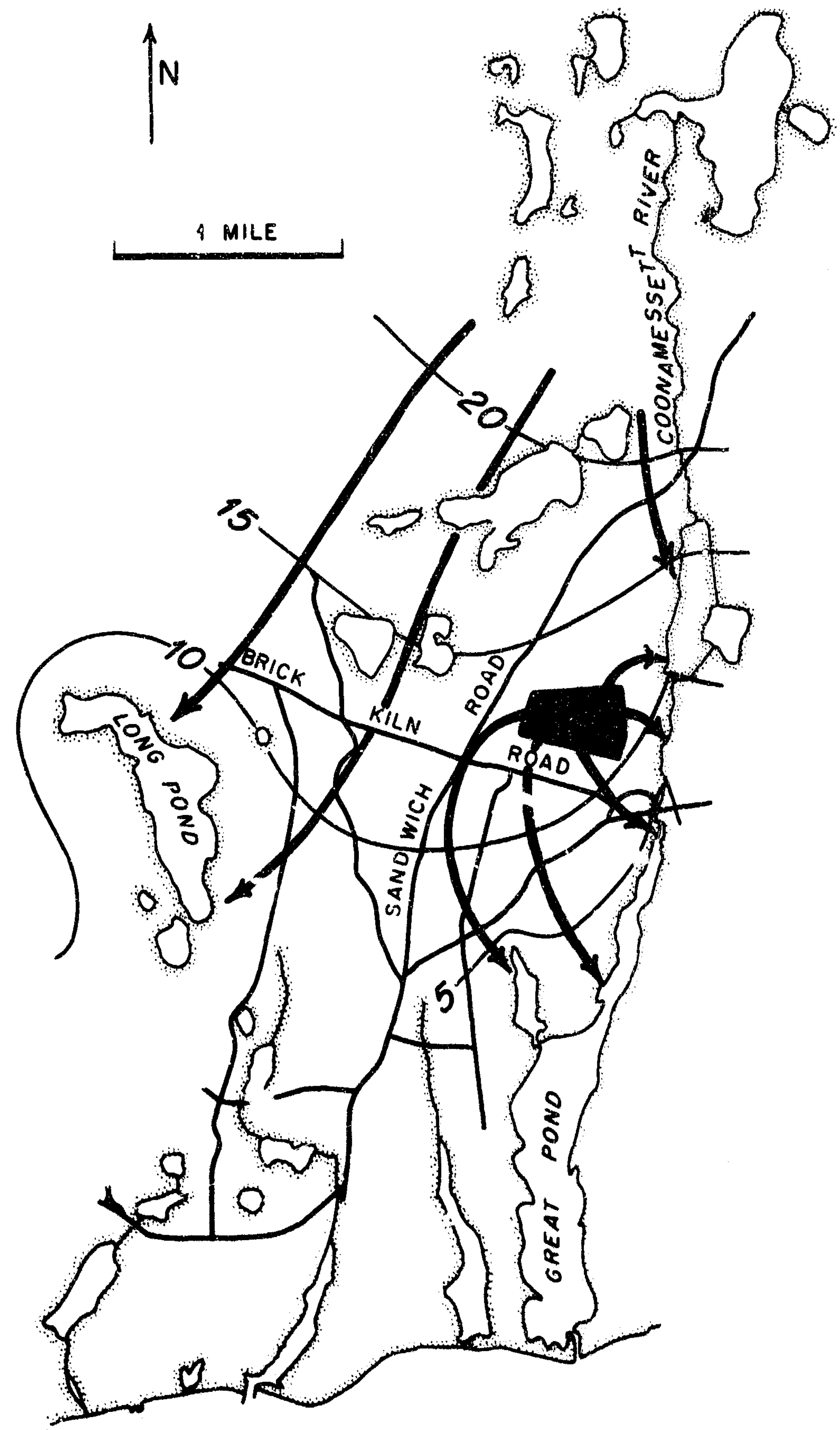

Figure 2. Predicted directions of ground-water flow (arrows) in central Falmouth, if sewage disposal plant on Brick Kiln Road is adding 3.7 mgd to the ground water and a similar amount is being pumped from Long Pond.

water will be substantially greater than the concentration in Great Pond, which is usually less than 1 ppm (Conover, 1958). The result of the added nitrate may well be an unpleasant excess of algae in Great Pond if other essential plant nutrients are available in the water.

The velocity of the ground-water flow will probably be such that the excess nitrogen will not reach the Coonamessett River for several years after the treatment plant begins operation. It probably will not seep directly into Great Pond itself for several more years. Should remedial action be initiated, an additional period of time of equal or perhaps even greater length will be required to flush the excess nitrates from the ground water between the disposal site and Great Pond.

Alternate Site 2: Blacksmith Shop Road

At present, ground water beneath the Blacksmith Shop Road site flows toward the Town reservoir at Long Pond. This flow pattern will continue at an accelerated rate if sewage effluent is disposed at the site, as shown in figure 3. Jenkins Pond and other nearby ponds will also receive effluents from the plant.

The dilution of the effluent by ground water may be slightly greater than at Brick Kiln Road, but it will not be significantly greater than one to four when the plant is discharging its proposed average effluent of 3.7 mgd at the Blacksmith Road site. Ground water immediately downstream of the disposal site may be expected to contain about 80 ppm of nitrate. How much this concentration will be diminished by progressive

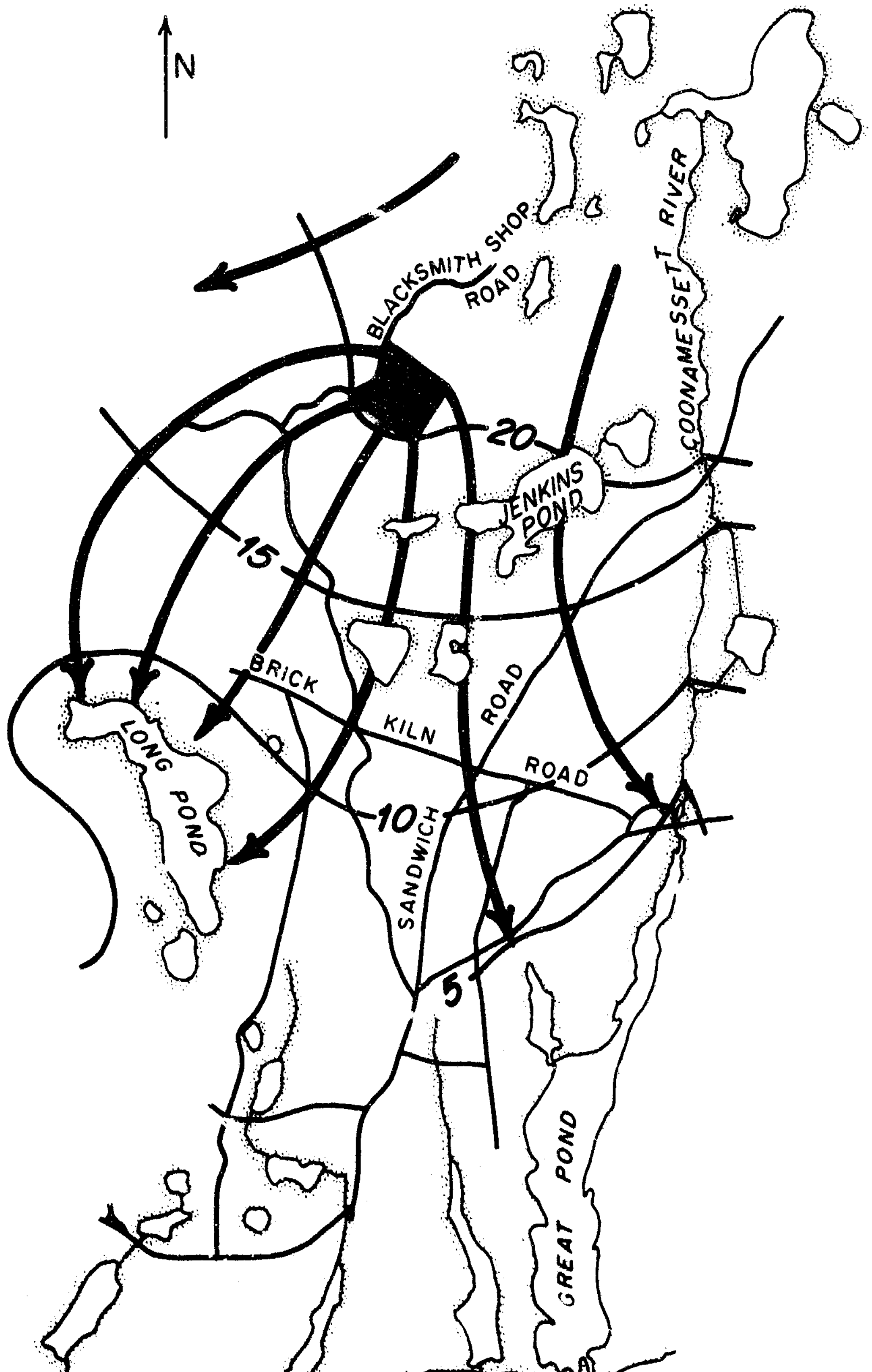

Figure 3. Predicted directions of ground-water flow (arrows) in central Falmouth, if sewage disposal plant on Blacksmith Shop Road is adding 3.7 mgd to the ground water and a similar amount is being pumped from Long Pond.

dilution or by other processes in the subsoil before the effluent reaches Long Pond is uncertain.

The velocity of ground-water flow will be such that a decade or two will be required for the effluent from the plant at the Blacksmith Road site to reach Long Pond. Even if no further contaminants were percolated into the ground at the end of that period, another period of several decades would pass before contaminants ceased to enter Long Pond.

PREDICTED EFFECTS OF AN OCEAN OUTFALL ON GROUND WATER IN FALMOUTH

How would a sewage treatment plant with an ocean outfall affect the ground-water balance in Falmouth? All of Falmouth's water supply comes from ground water (the Town reservoir at Long Pond is supplied essentially by seepage from ground water), and most of the water now used is returned to the ground via cesspools and other disposal facilities. This water eventually reaches the ocean by slow seepage through the ground. The ocean outfall under consideration would discharge 3.7 mgd, an amount equivalent to about 10 percent of the Town's total ground-water recharge, directly into Vineyard Sound. The result of this diversion will be a slowing of the rate of natural ground-water seepage into the coastal waters and a slight decrease in the vertical angle of slope of the boundary between fresh and salty ground water. At the proposed rate of effluent discharge of 3.7 mgd, however, this poses no particular threat to the ground-water balance in general or to the present water-supply sources in particular.

Looking to the distant future, however, a significant increase above the proposed 3.7 mgd of effluent discharged to the ocean could seriously deplete Falmouth's ground-water supply. Depletion would be especially serious during periods of protracted drought. During the middle years of the 1960s, for example, ground-water recharge averaged less than 30 mgd. If at some future time effluents reached an average of 8 to 10 mgd throughout the year, and were discharged through an ocean outfall during such a drought period, ground-water levels in the Town would decline seriously.

CONCLUSIONS AND RECOMMENDATIONS

If secondary treated sewage effluent is disposed into the ground at Alternate Site 1 on Brick Kiln Road, it will eventually enter the Coonamessett River and Great Pond. If it is disposed at Alternate Site 2 on Blacksmith Shop Road, it will eventually enter the Town reservoir at Long Pond. Of the two disposal sites, Alternate Site 2 on Blacksmith Shop Road offers the greater potential hazard to the quality of the Town's ground water.

While soluble phosphate will probably be removed from the effluent waters by adsorption onto soil particles, nitrate can be expected to persist in the effluent for an extended period. However, there is no certain way of estimating the concentrations of nitrate that would eventually reach Great Pond or Long Pond, and therefore no certain way of predicting whether or not their effects would be deleterious.

Taking this uncertainty into account, we recommend that consideration be given to the eventual need for an expanded installation to remove nitrates from the effluent even though the immediate installation of nitrogen-removal equipment be delayed. Specifically, we recommend the following course of action.

1. Acquire the necessary acreage and design the disposal plant so that equipment for removal of nitrogen can be installed in the future with minimum effort and expense if it becomes necessary.

2. Install several inexpensive observation wells to intercept the effluent ground water at appropriate locations near the

disposal site and monitor the nitrate content of the water frequently enough to give early warning of enrichment so as to permit prompt remedial action.

3. If nitrate concentrations in the ground water approach unacceptable levels, effective nitrogen removal facilities should be installed at the plant. If nitrate does not increase significantly after many years of monitoring, such facilities should not be necessary.

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APPENDIX A: PHOSPHORUS AND NITROGEN CONCENTRATIONS IN GROUND WATERS OF CAPE COD

To help characterize the ground waters of upper Cape Cod, a preliminary study of some pertinent chemical characteristics was initiated. Results, which include analyses for phosphate, nitrite and nitrate from the three areas, Falmouth, Otis Air Force Base, and Hyannis, are recorded in table A1. Samples from Otis Air Force Base were collected with the cooperation of Louis H. Kruger of the Otis Water and Sewer Department. Samples from Hyannis were collected with the cooperation of Francis Lambert, Health Officer for the Town of Barnstable. Samples from wells 11 and 12 were collected earlier and reported by Whitman & Howard (1967). The samples collected in 1969 were analyzed at the Oceanographic Institution by Nathaniel Corwin. Nitrate concentrations are listed in the table in two forms: as nitrogen to compare with nitrite, and as nitrate to compare with figures cited in the main text of this report.

The six wells sampled in Falmouth were all located between Homestead Lane and Long Pond, the source of the town water supply. The maximum distance from Long Pond for the locations selected was slightly in excess of one mile. Wells #1, 5, and 6 had the highest nitrate concentrations of this group of wells, though all were within acceptable limits. Well #3 had unusually high nitrite content, a compound which can be oxidized to nitrate by biological activity. This may reflect some local source of contamination. The higher nitrate concentrations from wells #5 and 6 probably reflect the use of inorganic fertilizers in the agricultural area bordering Sandwich Road.

TABLE A1. PHOSPHATE, NITRITE, AND NITRATE IN GROUND WATERS SAMPLED ON CAPE COD

Well	Date Sampled	Phosphate as phosphorus (ppm)	Nitrite as nitrogen (ppm)	Nitrate as nitrogen (ppm)	Nitrate as nitrate (ppm)	Remarks
* 1	11/17/69	0.006	0.001	0.85	3.8	
2	11/5/69	.004	.002	.30	1.3	
3	11/3/69	.001	.75	.12	0.53	
4	11/3/69	.003	.005	.03	.13	
5	10/31/69	.029	.0006	2.5	11.1	
6	11/3/69	.003	.003	2.2	9.7	
** 7	11/5/69	0.056	0.0007	0.53	2.3	
8	11/5/69	.022	.0007	3.2	14.2	
9	11/4/69	.005	.001	3.8	16.8	
10	11/4/69	.004	.019	0.40	1.8	
11	9/27/67			1.8	8.0	
12	9/21/67			5.2	23.0	Well 65' deep
12	11/10/67			1.6	7.1	Well 60' deep
*** 13	11/17/69	0.004	0.001	5.7	25.2	
14	11/17/69	.001	.0006	0.65	2.9	
15	11/10/69	.003	.0008	13.4	59.4	
15	11/17/69	.003	.001	13.7	60.7	Well resampled
16	11/10/69	.002	.001	0.056	2.5	
17	11/10/69	.004	.0003	.010	0.044	
18	11/10/69	.003	.0007	.019	.084	
19	11/10/69	.003	.0007	.043	1.9	

* Wells 1 - 6 - Falmouth, between Long Pond and Great Pond.
** Wells 7 - 12 - Otis Air Force Base and Ashumet Pond area.
*** Wells 13 - 19 - Barnstable, vicinity of Hyannis sewage disposal plant.

Locations of the seven wells sampled within the Otis and Ashumet Pond area were all within one and a half miles of the Otis sewage treatment plant. Although these wells generally contained more nitrate than the Falmouth wells, all were within acceptable limits. Nitrate concentrations were highest in samples collected from the upper part of the valley that contains Ashumet Pond.

Seven wells within 0.8 miles of the Hyannis sewage disposal plants were also sampled. Of these, well number 15 actually exceeded the safety limit for nitrate in potable waters according to recommendations of the U. S. Public Health Service. Upon investigation it was learned that this well is located very close to a former disposal site for cesspool sludge. Well number 13, which also showed a high, but acceptable, level of nitrate, is located about one-third of a mile from well number 15. Despite termination of the sludge disposal practice for some 40 years, high nitrate concentrations apparently still persist in the ground water in this local area. Neither the phosphate nor nitrite concentrations of these wells, however, show a similar abnormality.

APPENDIX B: METHODS USED TO ESTIMATE EFFECTS OF EFFLUENT ON GROUND-WATER FLOW

To estimate the effects of the disposal of 3.7 mgd on the pattern of ground-water flow, we used the results of a pumping test that was made by Whitman & Howard (1967) near the corner of route 151 and Sandwich Road (well 12 shown in table A1). Although the ground-water aquifer is probably thinner at the pumping test site than at the proposed inland disposal sites, the aquifer materials (sand and gravel) are rather similar, and the pumping test results probably can be applied to the proposed disposal sites without introducing too much error.

The measured drawdown near the pumping well, which reached a stable configuration after about 5 days of pumping at 0.47 mgd, is shown in figure B1. An estimated drawdown curve for a pumping rate of 3.7 mgd, about eight times the rate used in the pumping test, is also shown in figure B1. With the assumption that the buildup due to 3.7 mgd of recharge would equal the drawdown due to 3.7 mgd of discharge, the curve for 3.7 mgd was used to estimate the buildup of the water table below and adjacent to the proposed inland disposal sites. For example, at a radial distance of 1,000 feet from the center of the disposal site, the addition of 3.7 mgd of effluent would raise the water table 2 feet above its normal level. At a radial distance of 4,000 feet, the buildup would be about 1 foot. Likewise, the drawdown of the water table from the pumping of Long Pond at 3.7 mgd would be about 1 foot at a radial distance of 4,000 feet from the center of the Pond. These buildups and drawdowns were

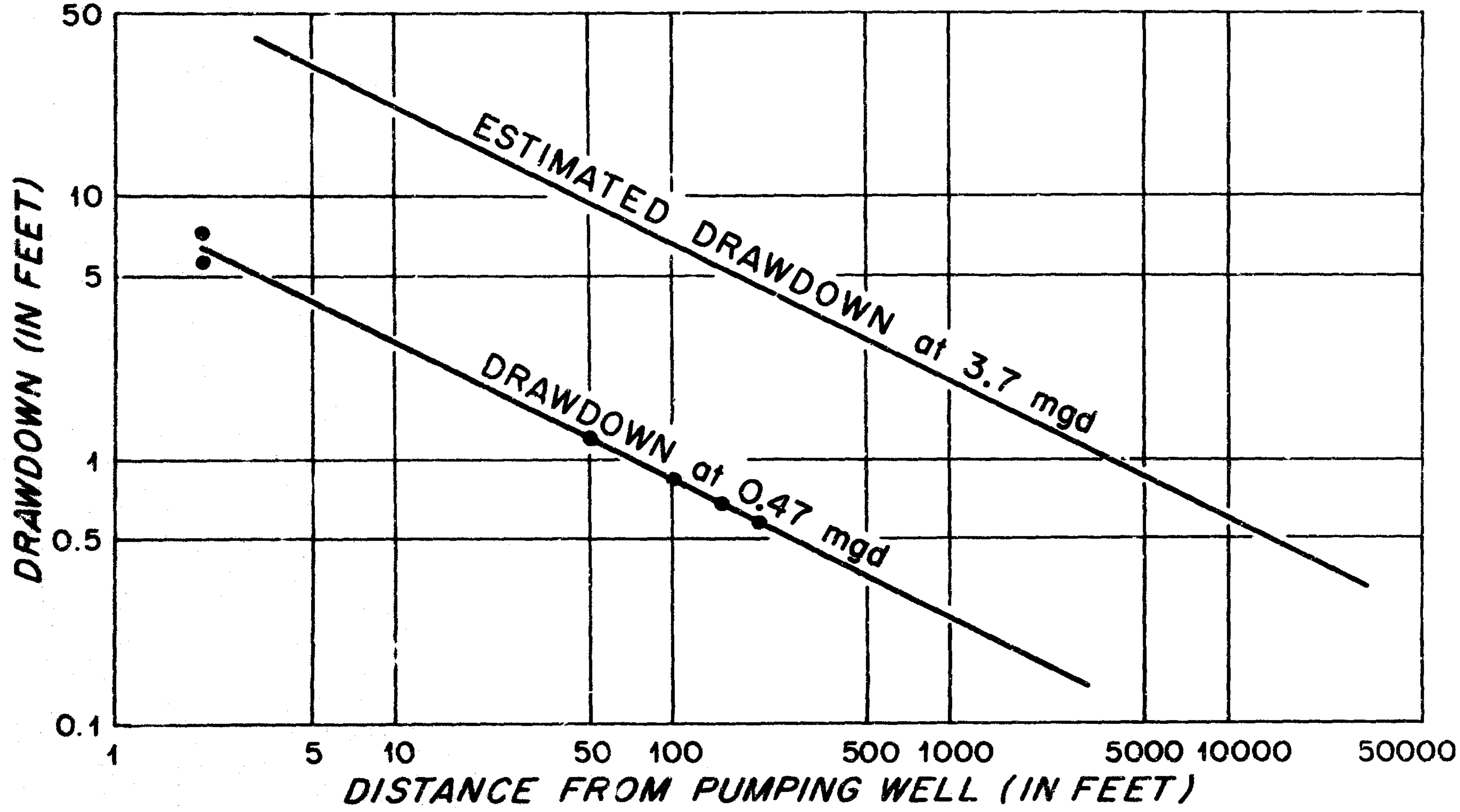

Figure B1. Drawdown curves for pumping wells in sand and gravel aquifers in Falmouth. Data for drawdown at 0.47 mgd collected by Whitman & Howard (1967).

added to or subtracted from the average water levels shown in figure 1 to derive the predicted water levels shown in figures 2 and 3.

In estimating the volume and velocity of ground-water flow, we assumed a transmissibility of 1,000 gallons per square foot per day at a standard reference gradient of one foot per foot. This is a reasonable assumption for medium-to-coarse sands that contain some gravel. The gradients shown in figure 1 range from 5 feet in two miles to 5 feet in one half mile. The corresponding ground-water flows per square foot of aquifer cross section would range from 0.5 to 2 gallons per day.

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13. ABSTRACT

This report is a companion report to WHOI Ref 69-87, and considers the consequences of disposing treated effluent at the alternative inland sites. Nitrate is an unpredictable by-product of sewage treatment and its ultimate appearance in natural waters can have an adverse quality effect. In ground water, nitrate is mobile and persistent and an excessive concentration in drinking water is a matter of public health concern.

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Water pollution

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