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by: Maxwell M. Small

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NATURAL SEWAGE RECYCLING SYSTEMS

MAXWELL M. SMALL

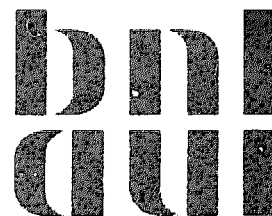
January 1977

DEPARTMENT OF APPLIED SCIENCE

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Abstract

This paper reviews the work done at Brookhaven National Laboratory in the development of natural systems which produce potable water from sewage.

Conventional treatment plant hardware beyond aeration is not used in these prototype marsh/pond and meadow/marsh/pond systems and no sludge is generated.

Experiments with two prototype systems are described and performance data are presented in detail for the marsh/pond.

Empirical interpretations of results achieved to date are suggested for use in the design of marsh/ponds as natural sewage recycling systems.

Construction and operating costs for a proposed 250,000 G.P.D., state-of-the-art plant are presented.

Natural Sewage Recycling Systems¹

In 1973, Brookhaven National Laboratory began experiments with three natural systems to determine their effectiveness in the treatment of domestic sewage. This work is still proceeding as a cooperative system development effort between the Town of Brookhaven, N.Y. and the Atomic Energy Commission, now the Energy Research and Development Administration. The Laboratory provides a part of its 5500 acre site and pays for half project staff costs; the Town provides all the hardware and pays for the other half of the operating and development staff costs. The project is now in the fifth year of carrying out this collaborative contract.

Capital expenses to date have been about \$250,000 and operation and development expenses will have been almost \$1,400,000 by the end of Fiscal Year 1977. These operating costs do not include the considerable expense for laboratory analysis incurred by the Suffolk County Water Authority and not billed to the project, nor the laboratory analytical expense also contributed from time to time by the Suffolk County Health Department, and the N.Y. State Department of Environmental Conservation at Stony Brook.

¹ Presented at the New York Water Pollution Control Association Winter Meeting, New York City, January 17, 1977.

Under this arrangement, three natural systems have been investigated as to their relative effectiveness in renovating aerated sewage to drinking water quality. For the first two and a half years of the project, all three systems were operated in various modes simultaneously. These were the Upland Spray open sites for one; and two different lowland spread closed systems. During the second two and a half years of the five-year development period, only the lowland closed systems continue to be investigated.

The open upland systems have been described and reported, on previously, in some detail, by Brookhaven National Laboratory. (1-4) In brief, this work confirmed that of other engineering investigators, namely that given sufficient land, spray irrigated, vegetated plots will renovate sewage. For the porous soils of Long Island, their land requirement of greater than 130 acres per MGD, simply priced open system spray irrigation sites out of the running. Moreover, since there is a finite limit to the sewage fractions which safely can be accumulated in upland crops and soils, it was concluded (5) that controlled, open system, upland spraying is better suited to farming. In crop production, the rate and strength of nutrient, toxins and water applied to the land as sewage need to be regulated in order to

gain the best harvest and the least contamination of land. These objectives and necessary controls are not compatible with the incidental use of land and vegetation simply as media for the renovation to drinking water of sewage, no matter its composition or rate of delivery. Consequently, experiments with open spray application systems stopped early in 1975 and since that time, all effort at BNL has been in the development of the two closed lowland systems, which accept sewage as it comes and is applied by gutter spreading rather than by spraying.

The two closed lowland systems also have been described previously, and some preliminary results for both have been reported by BNL.⁽¹⁻⁷⁾ Briefly reviewed, one system is a meadow/marsh/pond series prototype plant. The other is a prototype marsh/pond series. Both experimental systems accept raw sewage blended with septage. Before application, the blends are pretreated by degritting for removal of non-degradables, comminuted, mixed, and aerated. Figure 1 shows a schematic and flow sheet of the pretreatment and experimental test facilities. Sewage flow through pretreatment generally is pumped intermittently. Flow through the experimental area is continuous, by gravity, after delivery from the final aerated hold-up pond through the marsh and pond to recharge of the pond overflows.

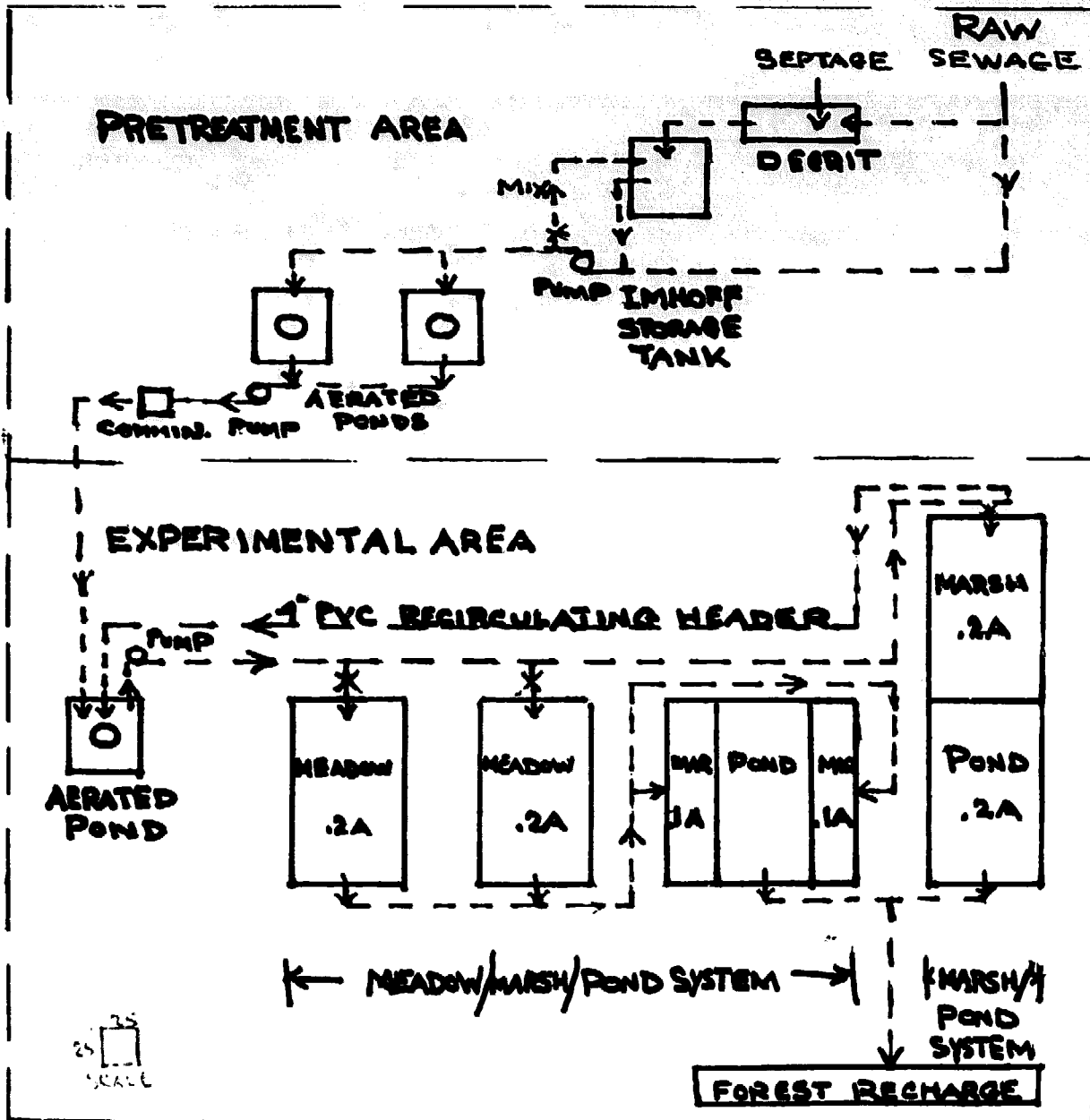


Figure 1. Brookhaven National Laboratory schematic lowland treatment systems.

Each aeration pond has a 60,000 gallon capacity. During the experimental period, flows through the system have increased from an initial 12,000 GPD to the present 40,000 GPD. Thus theoretical detention time for preaeration and mixing have decreased from an initial 15 days to the present 4 1/2 days. Because of the physical arrangement, it has not been possible further to reduce aeration time to the one day which is believed to be sufficient for odor control and completely mixed solids suspension. Each aerated pond has a single 5 hp floating aerator which is more than adequate to supply air but is necessary to assure ice-free mixing in the winter.

Each experimental system has received half the daily sewage input on a 24 hour, 7 day basis since continuous operation began in April 1975. Several blends of septage to raw sewage have been tried from 1:2 at the outset, through 1:10 for a 6 month period, to 1:5 from January 1976 to the present. Since one objective in the development of these systems is to avoid sludge generation for separate disposal, the relative capacities of the two systems to accept high solids blends at high application rates has been a principal evaluation factor. When operated at 1:2 blend, even at only 6,000 GPD (half the 12,000 GPD initial total input) the meadows clogged with a 2 week on/

2 week off alternating application mode. The meadows produced a satisfactory effluent at 1:10 blends in a 3 week alternation mode at 10,000 GPD, but do not appear capable of operating at 1:5 at 10,000 GPD each in a 3 week alternating mode. They became seriously clogged by that application rate and strength when operated continuously (without alternation) from April through August 1976.

Despite meadow clogging and its consequent lower performance under high solids applications, the meadow/marsh/pond system as a whole continued to discharge satisfactory pond water. In fact, the pond water discharged by both the meadow/marsh/pond and the marsh/pond systems, under the same rate and strength applications, is of about equal quality. From these observations, it is apparent that a marsh/pond series alone will renovate the entire spectrum of applied sewage blends from very weak meadow-filtered effluent through the highest strengths and rates that we have applied to date. Since a marsh/pond series requires roughly half the land needed for a meadow/marsh/pond series, the former is the more efficient sewage treatment/water producing system of the two. Because of its domination in renovation, the balance of this paper is devoted to a more detailed examination of the marsh/pond only.

A look at Figures 2 through 11 gives a feel for a marsh/pond system in operation.

- Figure 2 --Septage being delivered by Town tanker to the pretreatment area.
- Figure 3 --Aeration and mixing in one of the 60,000 gal. pretreatment hold-up ponds: in summer.
- Figure 4 --Ditto--in winter; note open area in center around considerable ice formation.
- Figure 5 --Ditto--the final pretreatment pond in summer with visitors anxious to detect some odor--no odor, no flies, minimum aerosols.
- Figure 6 --The gutter feed to marsh--note no spray, hence no aerosols.
- Figure 7 --Biologist planting cattails in the marsh--note membrane which underlies this and all components of these closed systems.
- Figure 8 --Field technician in marsh three months after replanting--June 1976. Note volunteer Lemna (Duckweed) which is

prolific in nutrient uptake and is a water aerifier: great to have in the marsh--a nuisance in the pond.

Figure 9 --Marsh/pond system in summer in pond with carp stocked--no Lemna--they eat it.

Figure 10 --Pond--without carp--prolific Lemna which must be harvested weekly in summer--mass will double in 6 days. If not harvested, pond will go anaerobic and kill fish for lack of O₂.

Figure 11 --Marsh/pond system in winter--despite sere vegetation and ice cover, if deep enough the renovation will continue and Lemna still in the marsh will continue to vegetate.

The preceding illustrations show the marsh/pond system as it has looked since first put in operation in 1973 as an experimental facility. Until April 1975, it was operated in a weekly batch recycling mode for basic research in the uptake of nutrients from sewage. At that time, it was decided that since no longer were there sufficient funds to support the basic



Figure 2.



Figure 3.

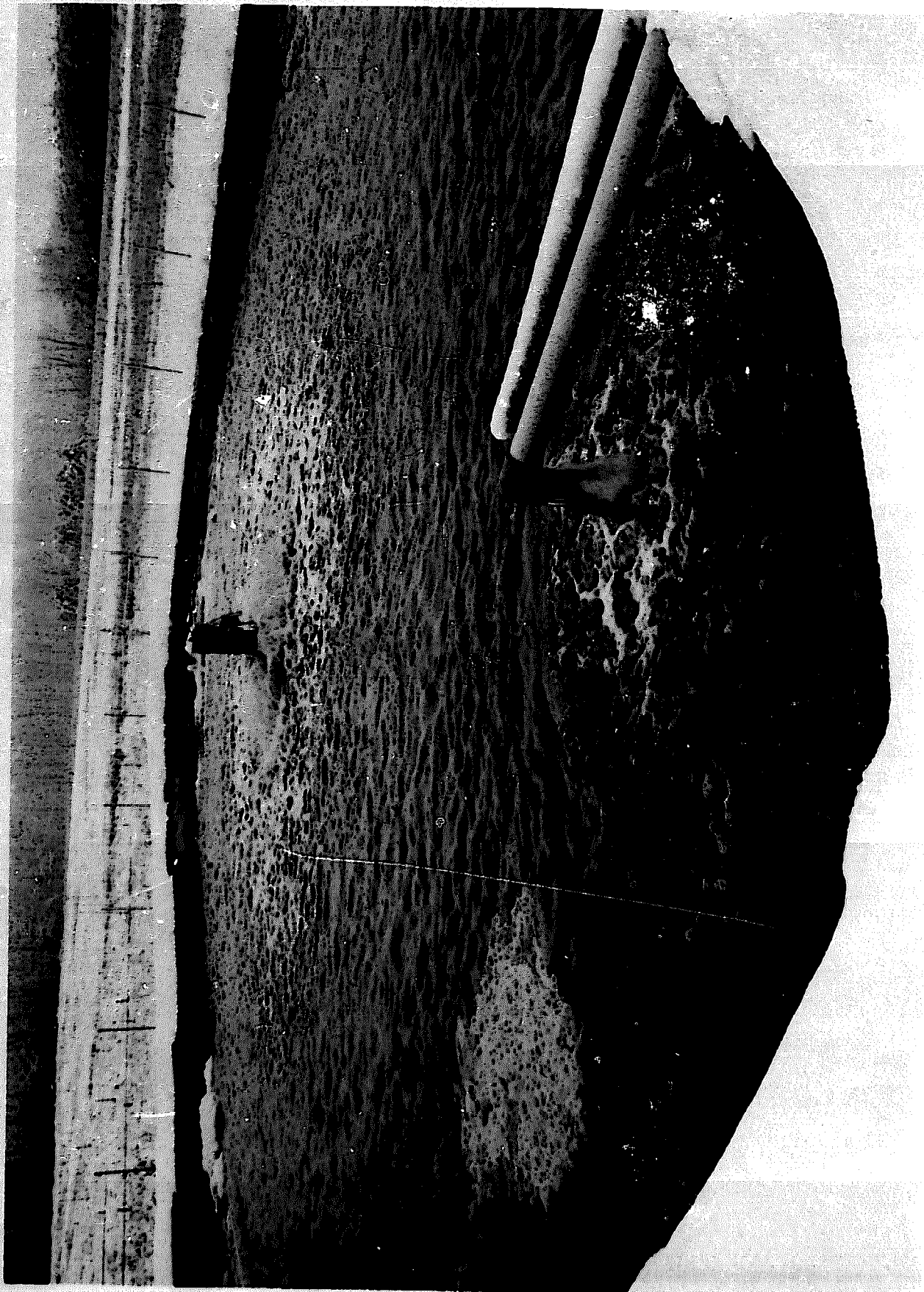


Figure 4.

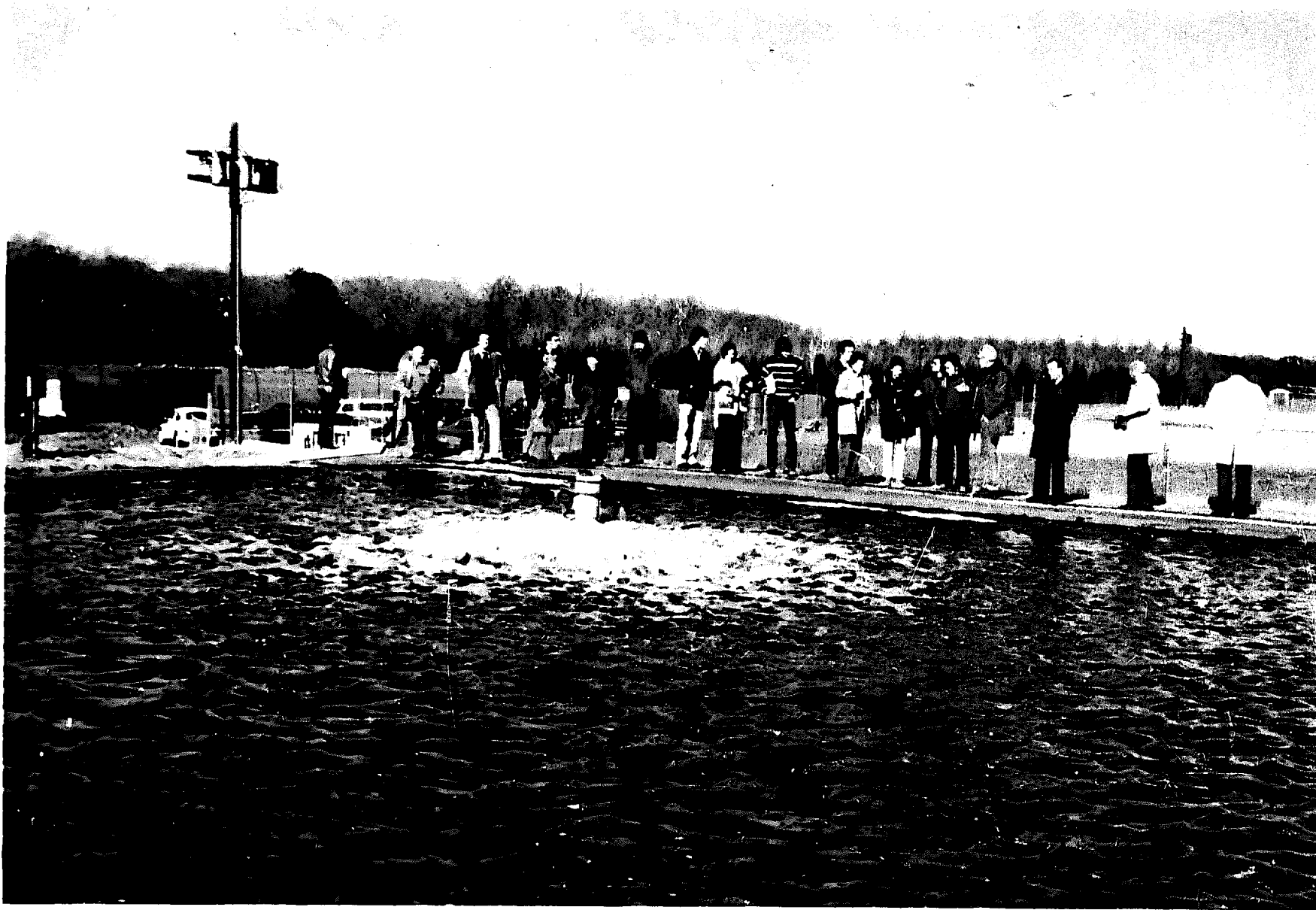


Figure 5.

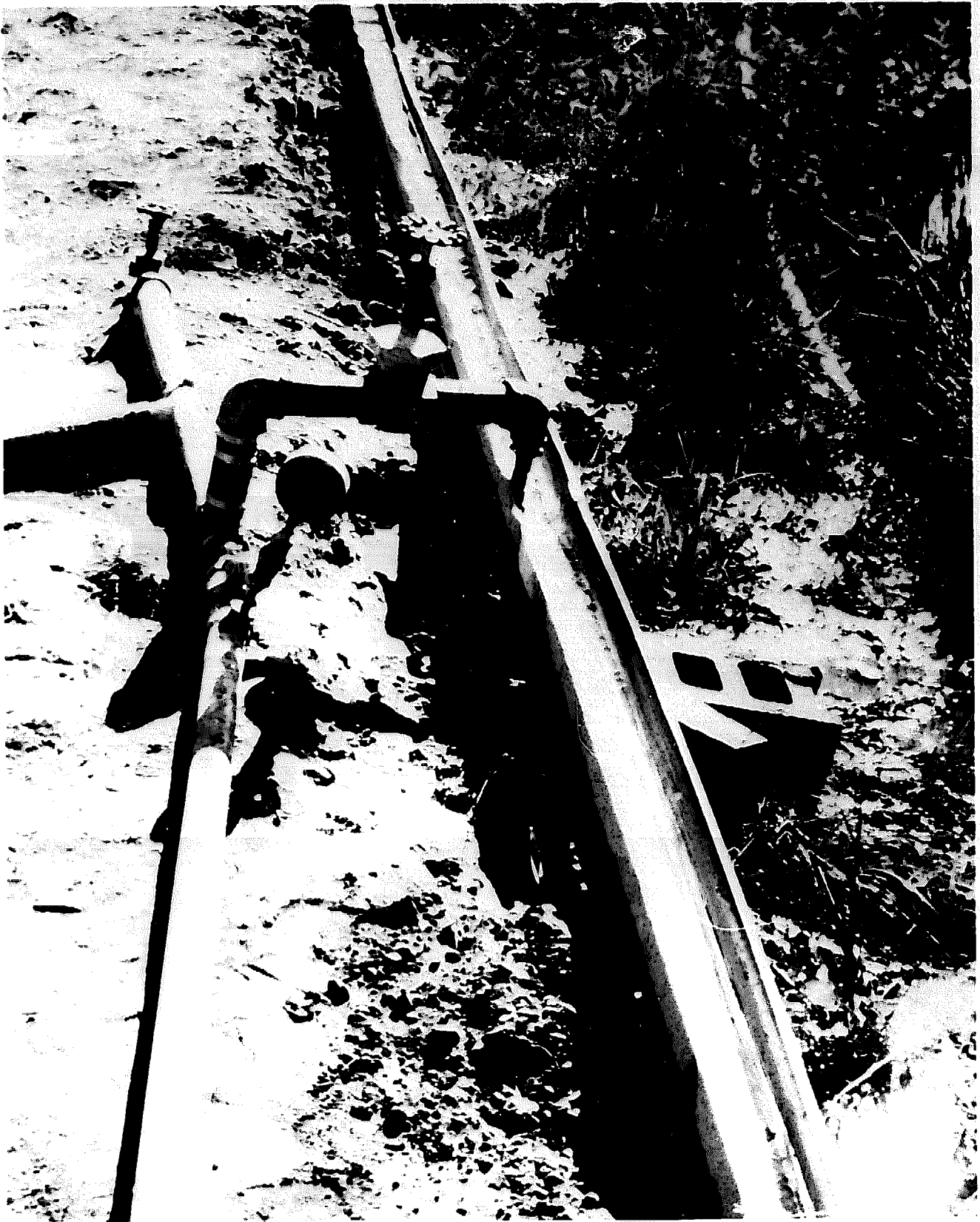


Figure 6.



Figure 7.



Figure 8.

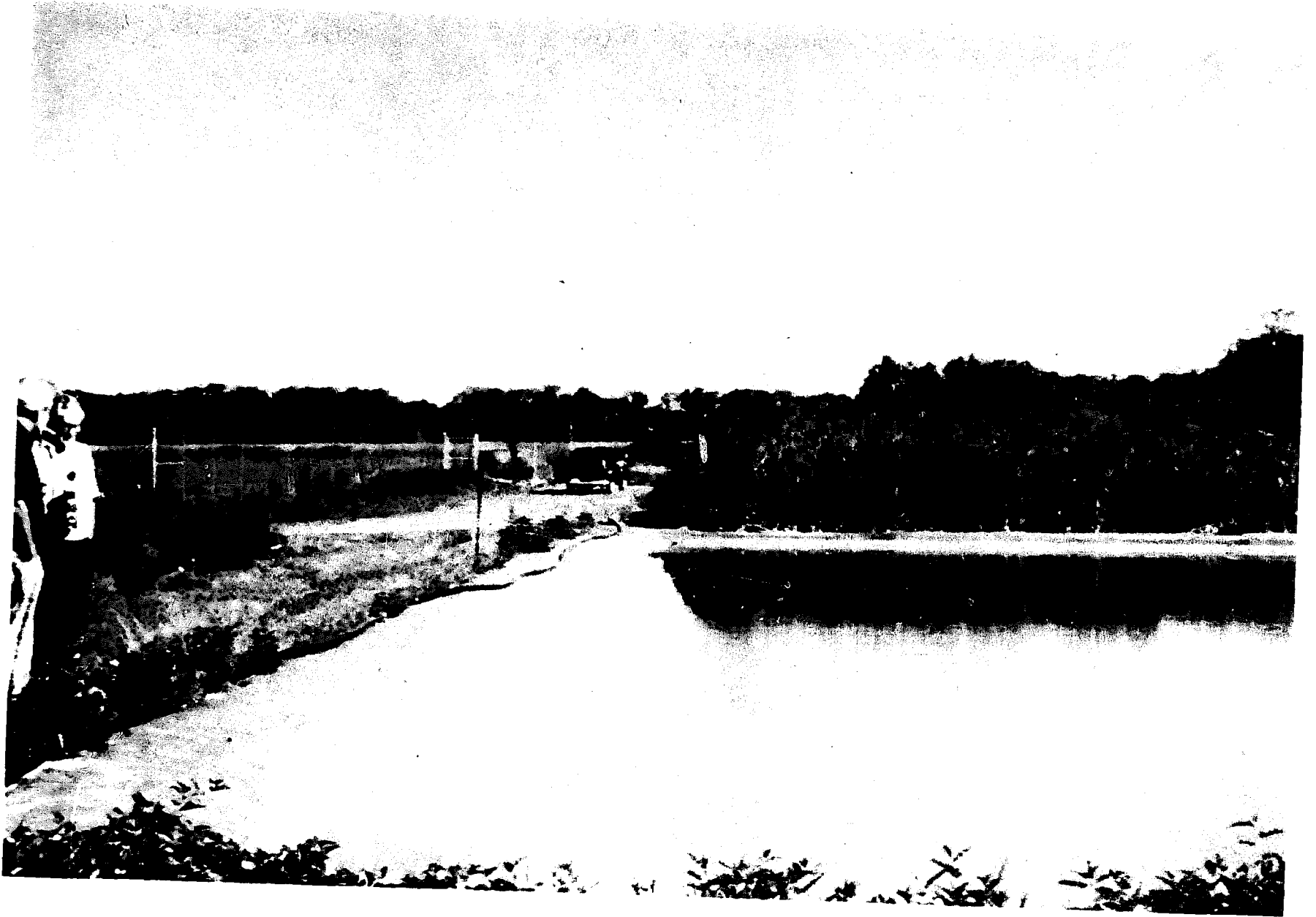


Figure 9.



Figure 10.



Figure 11.

research necessary to understand the marsh/pond system, a pragmatic approach would be used to determine its effectiveness as a sewage-to-water treatment plant.

The system development design plan then was set under which the marsh/pond would be operated in a continuous, straight through mode. First, the continuous hydraulic application rate gradually would be increased to that rate at which the renovative capacity of the marsh/pond began to fail, thus establishing an hydraulic upper limit. Next, at that hydraulic upper rate, the sewage blend strength gradually would be increased to that strength at which the renovative capacity of the marsh/pond began to fail, thus establishing an apparent upper total loading limit. Renovative failure was defined as the production of pond effluent which, after filtration through vegetated plots, was not potable. The marsh/pond would be satisfactory if, roughly as built, it would accept domestic sewage and septage as it came and produce water for reuse without hazardous or otherwise objectionable environmental effects.

This experimental plan has progressed to the point of establishing an hydraulic design upper limit of 100,000 GPD/acre of marsh or about 50,000 GPD/acre of marsh/pond. It has been demonstrated that performance can be maintained at that

design loading rate increased by 100% overload such as would occur with 4 inches of rain in 24 hours. A greater hydraulic capacity is suspected but has not been demonstrated. Thus the design hydraulic rate of 2.3 GPD per square foot each of marsh and pond, has been set.

Since April 1976, the marsh has been loaded at this hydraulic rate which will be continued without increase at least through April 1977. The marsh has been loaded with the same blend strengths over the same time periods mentioned earlier for the meadow system but, contrary to that experience, without any noticeable change in marsh performance with increase in strength. It is concluded from these results that the marsh safely can be loaded with a blend of 5 parts sewage to 1 part septage. The marsh is suspected capable of assimilating still higher strength loading but this has not been demonstrated. At that blend, the influent is at about the strength of medium domestic sewage. This strength is now being increased.

To avoid odors, it is believed that influent must be delivered to the marsh in an aerobic state. An excess of pre-treatment air, in addition to controlling odor, will produce a reduction in BOD and the hydrolysis of organic nitrogen⁽¹³⁾ which is all to the good but is probably a luxury. However, the

probably much lower limit for necessary air has not yet been determined for fresh sewage entering a marsh since all pretreatment to date has been of old, often septic blends of cesspool pumpings and sewage. A conservative minimum of .3 hp of floating aerator per 1,000 gallon/day design rate of marsh influent is set by BNL experience as the design minimum for these recirculated sewage blends. BNL work has demonstrated that this amount of air assures BOD₅ and Total N reductions on the order of 50% and 40% respectively in a completely odor-free influent which is acceptable to the marsh.

Following the pragmatic development plan, as mentioned previously, sewage delivered to the present 15 hp pretreatment aerators is now being strengthened. Septage deliveries were stopped and only domestic sewage settled raw solids were accepted in steadily-increasing quantities after August 1976. Since then, pretreatment BOD₅ has increased from the previously yearly average of about 220 to 2,000 ppm. Despite this strength increase ahead of aeration, the subsequent BOD₅ in applied marsh influent has continued to average below 100 ppm with no odor-- a 95% reduction by preaeration. Come this Spring, the amount of pretreatment air will be reduced in stages until odor is noticeable, and/or contaminant loading proves to be excessive.

Assuming renovation continues to be acceptable up to that point, as is anticipated, it will then be possible to set the low pretreatment air design limit as a function of sewage strength as well as flow.

Irrespective of such optimism, however, it is possible to design a marsh/pond system now only on the basis of predictions which safely can be extrapolated from measurements made to date. The Laboratory has just published ⁽⁸⁾ the first marsh/pond data report as a presentation of 32 parameter data tabulated and/or plotted after analysis of 53 weeks of sampling the marsh influent and the pond effluent. These reported data were used as the basis of a proposed 250,000 GPD marsh/pond system ⁽⁹⁾ to serve a new housing development under construction in the Town of Brookhaven. The predicted performance of this proposed system in removing BOD and Nitrogen are shown in Figure 12.

Based on the experience of others, ⁽¹⁰⁾ the BOD curve in this figure is predicted to begin at 210 ppm (2,500 pop. x .17 #BOD₅/person = 425 #BOD₅/day. And 2,500 x 100 = .25 MGD so, $425 / (.25 \times 8.34)^{\sim}$ 210 ppm): from general experience, 24 hours of aeration, will reduce BOD₅ at least by 50% resulting in about 105 ppm entering the marsh: an average detention time in the marsh will give a 52 ppm BOD₅ marsh effluent entering the pond: ⁽⁸⁾

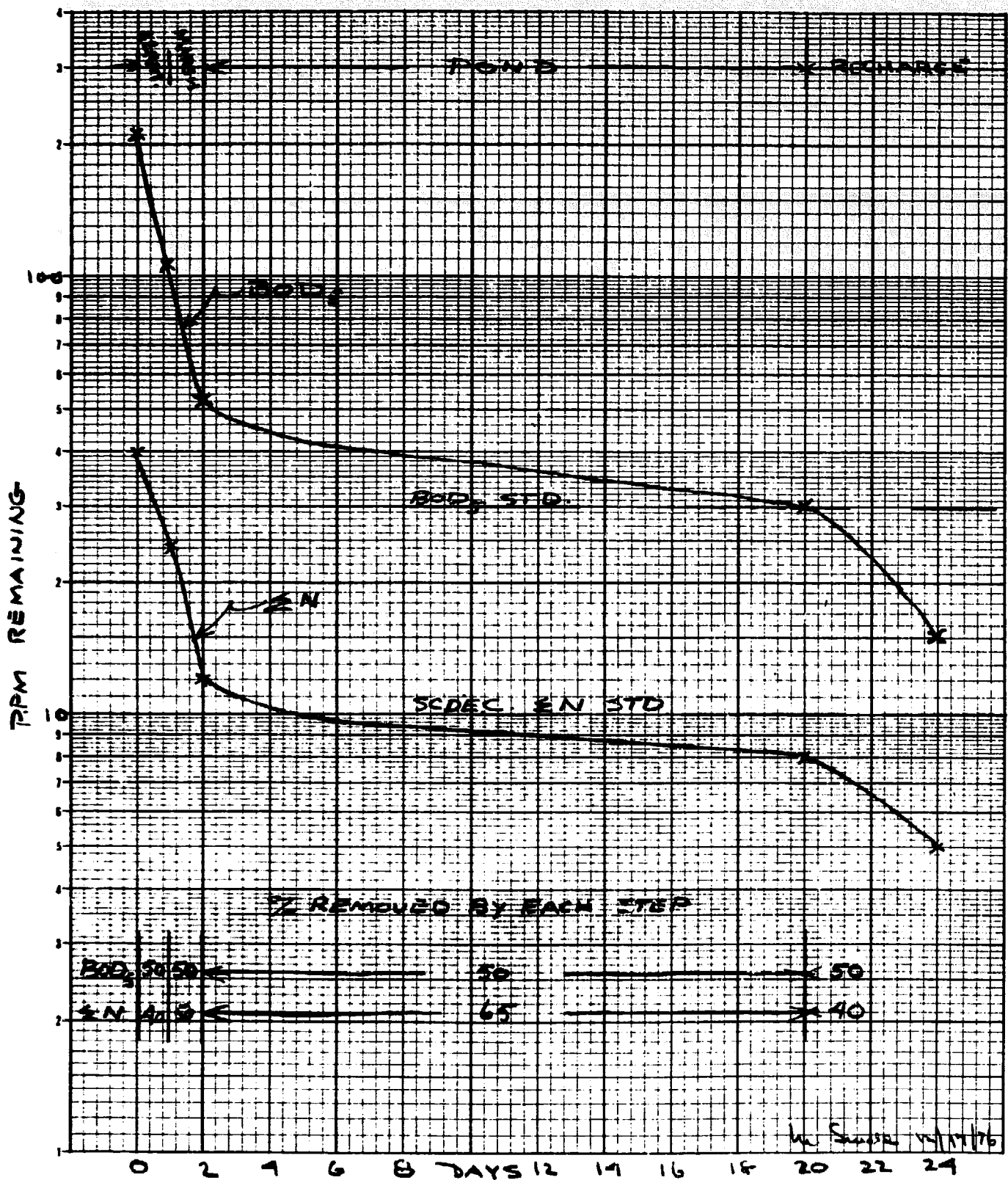


Figure 12. Predicted remaining BOD₅ and eN marsh/pond proposal, Rustic Ridge.

an average 18 day period in the pond will produce a pond effluent not over 30 ppm.⁽⁸⁾ Final recharge through a littered, mixed pine and deciduous forest floor will result in final effluent reaching the water table containing not over 15 ppm of BOD₅ and probably less than 5 ppm^{(11) (13)} -a 98% total removal.

The Nitrogen curve begins with an estimated⁽¹²⁾ content of 40 ppm total N in domestic sewage of medium strength. From the experience of others⁽¹³⁾ and at BNL,⁽⁸⁾ preaeration is expected to reduce total N to about 25 ppm in the influent to the marsh. Passage of this blend through the BNL existing marsh/pond prototype, reduced total N to an average of 10 ppm in effluent from the pond. By deepening the marsh and retaining a sewage temperature of 50^oF through preaeration and application, a total N removal of 80% is expected in the proposed system divided among the components about as shown in Figure 12. Recharge experiments at BNL⁽⁵⁾ showed a yearly average total N reduction of about 40% when percolated through a forest floor. Thus it is predicted that recharging through the forested area of the proposed system will result in a remainder not averaging over 5 ppm in the percolate reaching the water table-an 87.5% total removal.

It is noted that the BOD and total N removals cited above are predicted at the water table. It is emphasized that a marsh/pond system can not be recommended for recharge without passage of the pond effluent through or over a vegetated soil if the highest removals are to be gained. Infiltration through a mixed pine and deciduous forest has proved to give the most polishing among the scrub pine, old field, and Timothy fields tested and reported on by the project for the sandy loam on Long Island.⁽⁵⁾ The passage of pond effluent through or over some vegetated surface before reuse is desirable to filter out the coliforms and turbidity due to algae and detritus that flow out of a natural pond. In tight soils, overland flow would polish pond effluent but upwards of 5 acres of recharge area alone would be required⁽¹¹⁾ for a .25 MGD plant: the porous soil, as at the Brookhaven recharge site requires only .5 acre for .25 MGD.

The table in Figure 13 shows the average, maximum and minimum concentrations of contaminants in the pond effluent before it percolates through the forest litter and soil. The average level of each contaminant is at or below established effluent and drinking water standards except for total coliform, total suspended solids and turbidity which will be filtered out during percolation and, for iron, manganese and sodium which are not significantly high nor important to public health.

Characteristics of Effluent Water From Pond
Averages for 13 Month Study Period 8/75 - 8/76
(in ppm = mg/l except for pH and as noted)

Parameter	Ref.	Concentration			
		Effluent Criteria	Average	Max.	Min.
Total Solids			206	300	142
Total Volatile Solids			102	142	40
Total Suspended Solids	(11)	30	43	100	14
Total Volatile Suspended Solids			35	76	11
Total Dissolved Solids	(12)	500	163	242	112
Biochemical Oxygen Demand (BOD ₅)	(11)	30	19	46	1
Chemical Oxygen Demand			58	120	20
Total Nitrogen (liquid + solid)	(10)	10	9.5	18	2.5
Total Kjeldahl Nitrogen (liquid + solid)			6.8	14	1.7
Ammonia Nitrogen (liquid)			3.5	11.5	.05
Total (NO ₂ + NO ₃)-N(liquid)	(12)	10	2.6	6.7	.4
Total Phosphorous (liquid + solid)			2.1	4	.4
Orthophosphate-P (liquid)			1.3	3	.2
Total Coliform (#/100ml)	(12)	4	*2200	234,000	40.0
Fecal Coliform (#/100ml)	(11)	200	*50.0	10,600	0.00
pH			7.4	9.1	6.2
Turbidity (J.U)	(12)	5	8.5	74	.7
Temperature (°C)			11	24	-6.
Specific Conduct. (mho)			262	340	151
MBAS (ABS)	(12)	.5	.24	1.4	<.02
Calcium	(10)	Sat.	14	26	8.8
Chloride	(12)	250	30	46	15
Chromium	(12)	.05	.01	.03	<.01
Copper	(12)	1.0	.03	.14	<.01
Fluoride	(12)	.6	.4	.6	.2
Iron	(12)	.3	1.2	5.5	.3
Magnesium			3.6	6.3	2.1
Manganese	(12)	.05	.1	.3	.04
Potassium			4	9	.5
Sodium	(10)	20	25	52	15
Zinc	(12)	5	.2	.6	.03

Figure 13

*Geom. mean #/100ml

References to published standards are cited to demonstrate compliance of the system for those contaminants which were measured.

Areal requirements for a marsh/pond system design to renovate medium strength domestic sewage to at least the water quality standards cited in Figure 13, can be determined by expanding the Brookhaven test site dimensions. It appears from data obtained to date that total N is the limiting parameter for these natural systems. In other words, most other contaminants appear to be removed satisfactorily to the extent that Nitrogen is removed. Based on the Brookhaven experiments, a conservatively designed recharge system which will reduce total N from 40 ppm in raw sewage to 5 ppm at the water table, for a raw sewage flow of .25 MGD, one should allow:

Pretreatment area		.5	Acres
Marsh	"	2.5	"
Pond	"	2.0	"
Recharge	"	.5	"
Access	"	<u>1.5</u>	"
Total system	"	7.0	"

Since the pivotal component in the marsh/pond system is the marsh, with the other components scaled to it as above, a useful design unit may be the square feet of marsh required per pound of total N in the raw sewage to be renovated. For

the Σ N removal cited in Figure 12, this works out to be

$$\frac{43,560 \times 2.5}{40 \times 8.34 \times .25} \sim 1300 \text{ ft}^2 \text{ marsh/\# } \Sigma \text{ N/Day.}$$

It is of interest to compare the performance of marsh/pond systems with that of a contemporary A.W.T. plant. Perhaps a good comparison is the Brookhaven 20,000 GPD experimental and 250,000 GPD proposed on-line systems, with the Blue Plains 100,000 GPD three-sludge, suspended growth pilot plant. (13) Figures 14 through 17 are plots of four significant parameters for these three plants, showing the percentages of contaminants remaining after the several process steps.

From Figure 14, it is seen that Total Nitrogen remaining after preaeration in the Brookhaven process is about the same as that following high rate organic synthesis in the Blue Plains pilot. Nitrogen removal prior to final sand filtration is better for Blue Plains, but because of the vegetated sand filter, the Brookhaven 20,000 GPD test managed 85% removal and the 250,000 GPD proposed plant is predicted to remove 88% against 90% for the Blue Plains pilot.

BOD₅ and COD removals for both Brookhaven plants are 96% against 88% for Blue Plains as shown in Figure 15. Figures 16 + 17 indicate that the marsh/pond components are about as effective as Blue Plains in removing both phosphorous and total suspended solids.

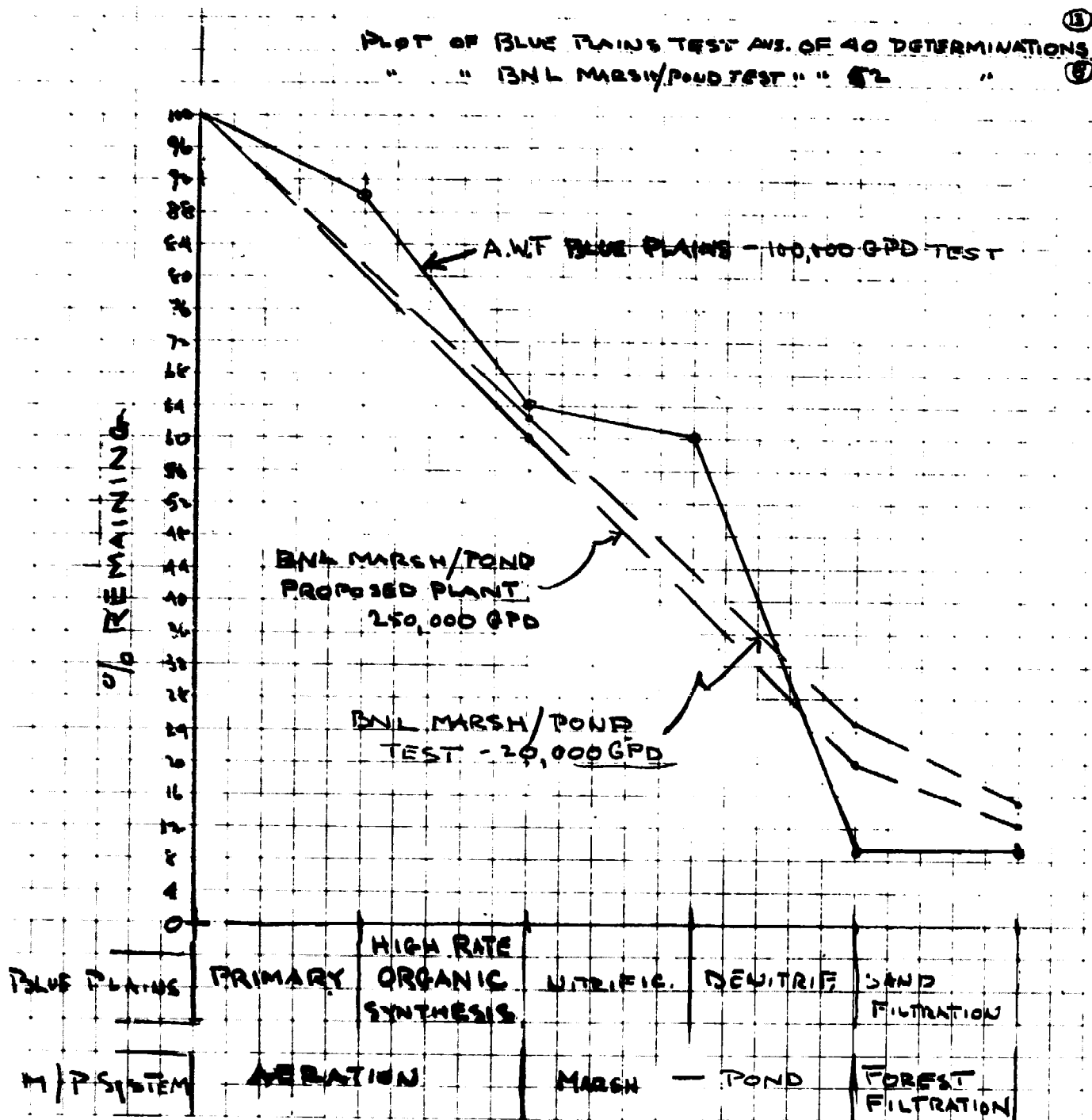
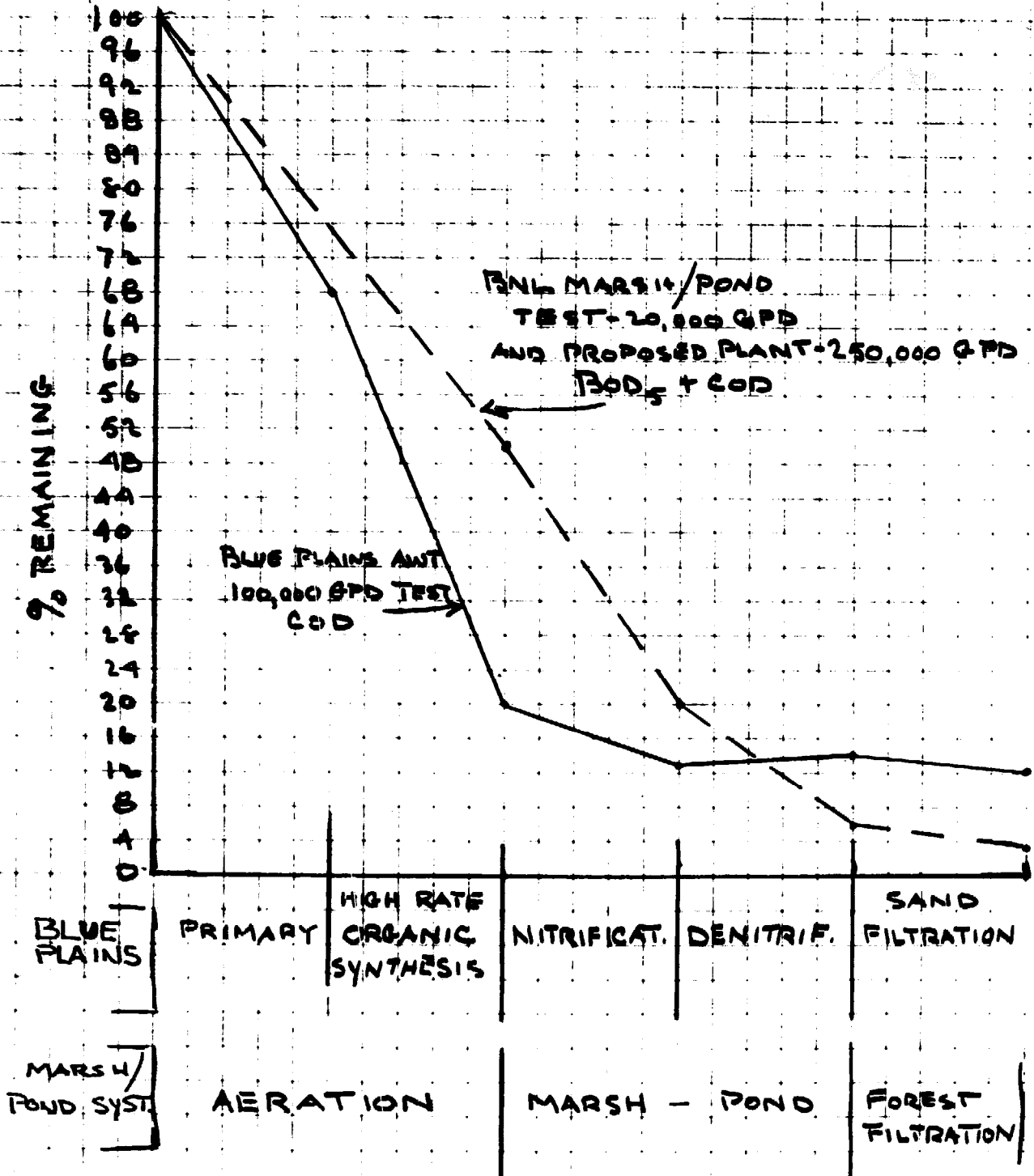


Figure 14. Total nitrogen.

⑬
 PLOT OF BLUE PLAINS TEST AVERAGE OF 40 DETERMINATIONS

" " MARSH/POND " " " 52 " " ⑭



BLUE PLAINS AWT
 100,000 GPD TEST
 COD

MARSH/POND
 TEST - 20,000 GPD
 AND PROPOSED PLANT - 250,000 GPD
 BOD₅ + COD

BLUE PLAINS

PRIMARY HIGH RATE ORGANIC SYNTHESIS NITRIFICAT. DENITRIF. SAND FILTRATION

MARSH/POND SYST

AERATION MARSH - POND FOREST FILTRATION

12/20/76
 M.H.S.

Figure 15. BOD₅ + COD.

PLOT OF BLUE PLAINS TEST AVS. OF 40 DETERMINATIONS
 " " BAIL MARSH/POND " " " 52 " "

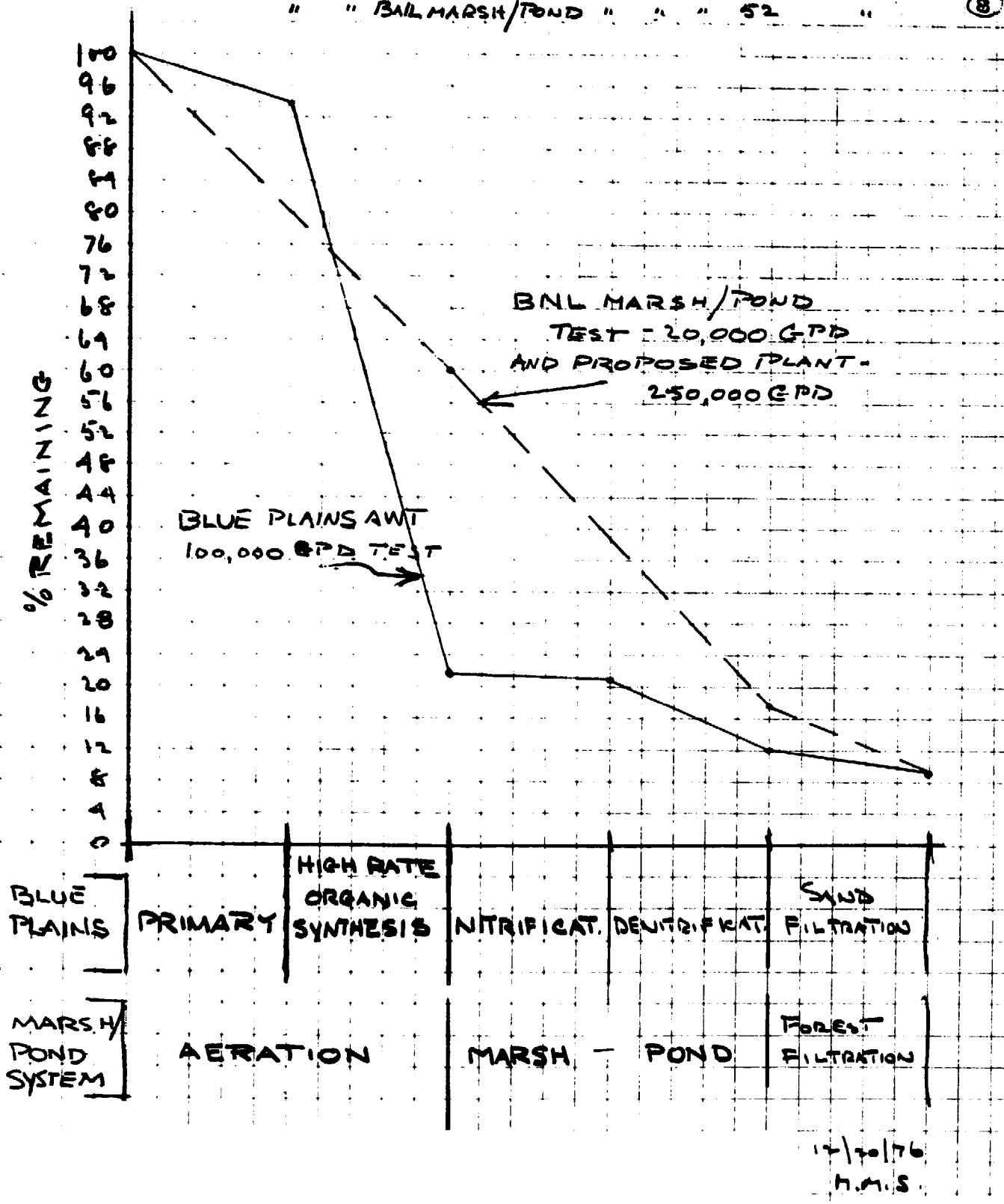


Figure 16. Total phosphorus.

PLOT OF BLUE PLAINS TEST AVS. OF 40 DETERMINATIONS (13)
 " " BNL MARSH/POND " " " 52 " (8)

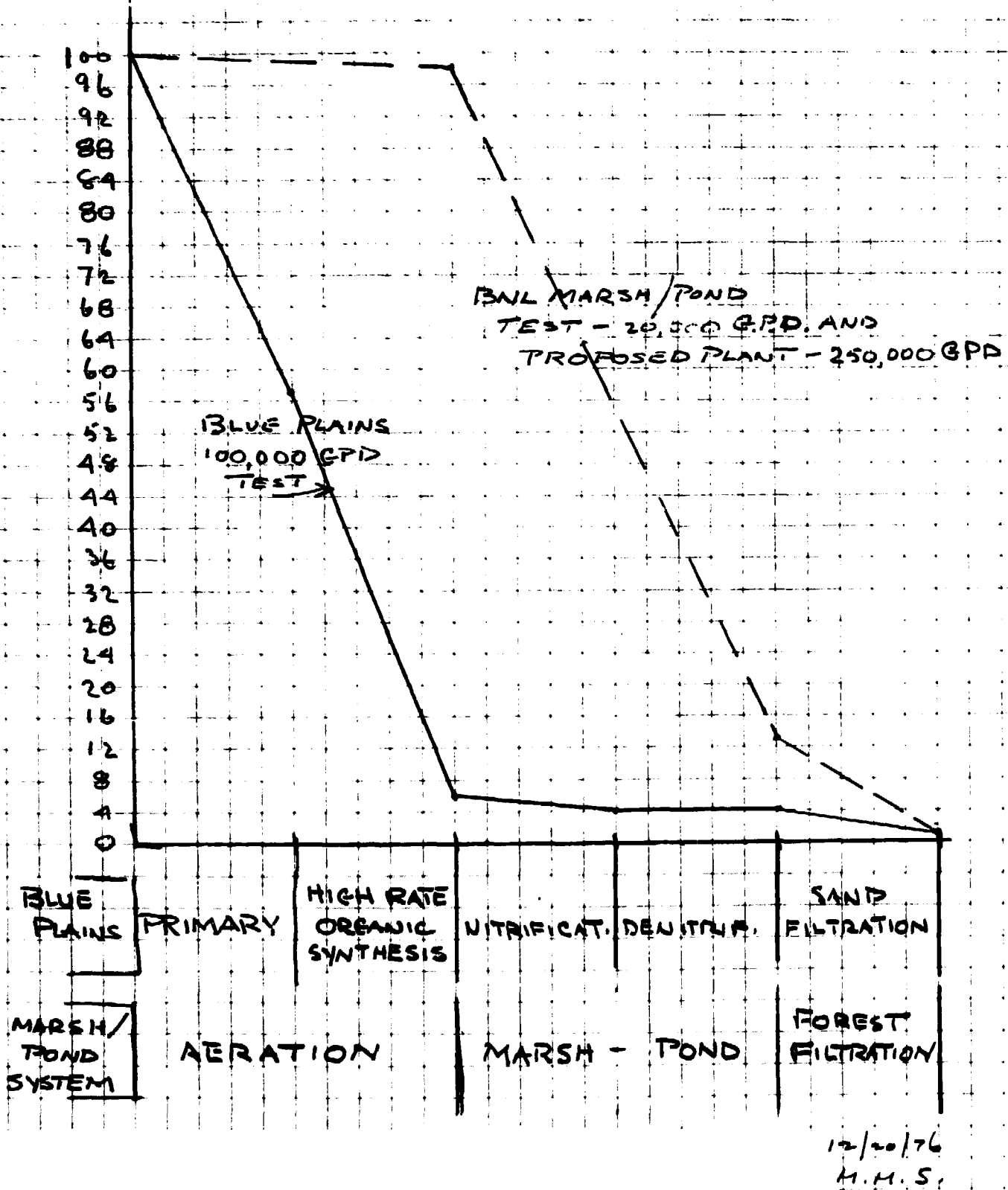


Figure 17. Total suspended solids.

Despite this favorable performance comparison with a central plant pilot, it is not suggested that marsh/ponds be considered as single systems alternative to large central treatment plants such as the Washington, D.C. Blue Plains 300⁺ MGD plant or the now-building Bergen Point 30 MGD plant for the Suffolk County, N.Y., Southwest Sewer District. Rather, it is suggested that marsh/ponds be considered as alternatives to so-called package treatment plants to handle in the range of .1 to 1 MGD flows. In those circumstances where the use of small plants in that flow range provides an economical alternative to a central plant, multiple marsh/ponds should provide an alternative still more cost-attractive than other small systems. Furthermore, in regions such as eastern Long Island, where scavenger wastes are a problem, a marsh/pond provides an economical method of sludge-free treatment, not possible with package systems.

A cost comparison of marsh/pond systems with other small treatment plants that will produce an effluent suitable for groundwater recharge is difficult, since one has not yet been put on line in that service. The 250,000 GPD system proposed for Brookhaven Town as an alternative to an extended aeration plant complete with deep bed denitrification filter and recharge to groundwater through sumps, has been estimated by others⁽¹⁷⁾ to offer a first cost saving of approximately \$150,000 and lower

annual costs since chemicals and sludge removal are not required. This preliminary estimate comparison is appropriately conservative as befits the first commercial application of a new system. For its own purposes, the project estimates a first cost for a M/P system, without land, for a .25 MGD flow, to be around \$1 per gallon-day; operating and maintenance expense, without the cost of money, is estimated at about 50¢/1000 gallons.

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