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Management of Recycled Waste-Process Water Ponds

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May 1973

MANAGEMENT OF RECYCLED WASTE-PROCESS WATER PONDS

By

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ABSTRACT

This study describes the successful operation of a storage pond used to collect treated wastewaters and runoff for recycle to manufacturing operations under conditions of drought and severe water shortages. Treated sewage and cafeteria wastes are stored in an air sparger mixed pond and are returned to the manufacturing plant to provide water for evaporative cooling and a variety of production processes. By applying long term storage, air sparger agitation, and controlled stratification during the summer, it has been possible to increase the effectiveness of limited well supplies from six to fifteen times.

The efficiency of the pond depends in large part upon biological processes that go on in the comparatively shallow areas of the system. These act to capture phosphorus and to stabilize algal organics generated in the pond itself.

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SECTION I

CONCLUSIONS

1. It is possible and practical to use stored, secondary treated domestic wastewaters for a variety of industrial purposes, particularly for air conditioning heat exchange, cooling towers, and a variety of machine tool cutting operations.

2. Successful application of this supplementary water source requires that industrial operations be modified to accept water containing varying concentrations of organics, color, suspended materials and particulate stuffs generated during storage or in transmission. It also requires that the storage pond provide residence time and conditions necessary to stabilize organics delivered in the treated wastewater streams and generated by algal production in the pond itself.

3. Storage and reuse of treated wastewaters during drought periods is a practical method of extending the available water supply for some industries and communities. It is also a device for achieving zero effluent during critical, low stream flow periods. Ultimately, however, the storage system must be recharged.

4. A recycled waste-process water pond with relatively large volumes stored in shallow areas will produce water of greater stability and lower organic content than a deep pond of the same volume. Sequences of biological activities that take place on the illuminated shallow bottom — two to three feet deep — favor the production of stable, nutrient-low water.

5. While not of the technological character usually associated with closed loop systems, the approach described does, in fact, succeed in achieving a high level of water reuse, particularly when water is in short supply.

SECTION II

RECOMMENDATIONS

This study was carried out at a time when there was widespread general concern with the availability of industrial water sources during drought. At that time there was considerable interest in the development and expansion of industries in foothill areas and other portential sites where water is normally limited after spring flood runoff. The project itself was designed to discover "why" the wastewater storage source used at Black and Decker's Hampstead plant worked, with the expectation that the findings might be used to develop similar reserve and water conservation systems when and where necessary.

Since weather, and especially long term weather, is unpredictable, it would appear desirable to review the applicability of a drought period water conservation system such as that described in this study under new existing and pending state and federal regulations.

SECTION III

INTRODUCTION

The Black and Decker Manufacturing Company's electric hand tool plant at Hampstead, Maryland, is the largest manufacturing facility of its kind in the world. The growth of the plant, and its continued operation, has depended upon the recycling of stored, treated wastewaters and a program of internal water conservation and management. By rigorous engineering control of a limited primary well supply and recycled wastewaters, the plant has managed to expand the effective usefulness of its available primary water supply about ten times, and this during a sequence of record drought years in which the plant's working population doubled.

The Hampstead plant is located about twenty miles north of Baltimore on farmland just south of Hampstead, a Carroll County community midway between Baltimore, Maryland, and Hanover, Pennsylvania, It borders the east side of Maryland Route 30. Geologically, the general area of Hampstead is an unpromising aquifer. The soil burden of this ancient mountain plain is shallow; there is little higher ground, and most streams originate in and drain down from Hampstead.

Initially, during the plant's early history, the well system was adequate for the general requirements of slowly expanding operations. But a spectacular failure of the supply early in the summer of 1955 demonstrated the need for a substantial emergency reserve of water.

The uncertainties of yields from local aquifers, water rights, storage capabilities, anticipated plant growth and changing processes, and especially, the rising requirements for air conditioning led the company's water engineering consultants to recommend the development of a large water storage pond to capture treated sewage, manufacturing wastewaters, storm runoff from roofs, parking lots, and the pond's watershed. A recycle pumping system was designed to deliver stored water back to the plant for uses admitting a lower quality of water, principally for cooling operations. At the same time, a systematic program of internal water conservation was established to secure the most efficient uses of the higher quality primary supplies.

A storage pond and recycling pump system were build and placed in service in the fall of 1956. For the following five years, stored treated plant wastewaters were used to supplement the well supplies.

In May, 1962, the Project Director was called to the Hampstead plant as a consultant to investigate a series of biological problems associated with the sudden development of anaerobic septic conditions in the pond and the appearance of hydrogen sulfide in the recycled water. An atmosphere of hydrogen sulfide about evaporative cooling towers near the fresh air intake to the plant's ventilating system is a cause of understandable concern where manufacturing processes require mass production of precision shafts, bearings, and other reactive metal parts.

Interim control of hydrogen sulfide production by heavy chlorination was secured, but a quick review of the economics and physical requirements of this treatment or any other then recognized system made it clear that hydrogen sulfide removal after formation would not be practical.

Fortunately, the causes of the condition were determined withing a few hours after the first visit. Two unanticipated factors operated to produce an anaerobic pond and sulfate reduction. First, the high rate trickling filter of the wastewater treatment plant was made ineffective by altered raw wastewaters from the plant. These bore slugs of strongly alkaline salts that raised the pH of wastewaters sprayed over the filter surfaces to pH 10.0 or higher, sometimes above pH 11.0. The stone surfaces of the filter were literally scoured free of active biological films. Reduction in organic load of the wastewater passing through treatment was limited to settling of solids in primary Imhoff tanks.

Second, the storage pond receiving the ineffectively treated wastewaters had become thermally stratified. A warm water surface layer, eight to ten inches deep, generated by solar radiation and atmospheric warming during windless late spring, effectively sealed off the deeper water from atmospheric exchange with the water mass.

Two recommendations were made and followed. Automatic acid neutralization was established in the raw wastewater sewer. A fixed air sparger was placed in the deeper section of the pond to break up thermal stratification and to prevent redevelopment in intervals of warm quiet weather.

The compressed air sparger was placed in service in June, 1962. With the exception of short intervals required for maintenance, it has remained in service under varying diurnal schedules through the warm months since that date. The device has been completely effective in preventing troublesome thermal stratification and hydrogen sulfide production. (A full description of the sparger and its operation will be given in another section.)

SECTION IV

EARLY BIOLOGICAL PROBLEMS OF TREATED WASTEWATER STORAGE

Although the institution of sparged air vertical mixing to break thermal stratification of the storage pond and the correction of pH of wastewater fed to the biological treatment system eliminated further incidences of hydrogen sulfide in recycled water from the pond, other biological problems appeared in the wake of the changes.

Several heavy infestations of dead and living snails delivered in the recycled stream clogged screens and orifices in cooling lines of presses and other manufacturing equipment. Masses of Chironomus larvae (midge-redworms) and tubificid worms appeared in some process water streams. Sloughed bacterial slimes and mats of decomposing algae accumulated in dead ends of water lines, sumps, and traps. At intervals recycled water in sumps developed offensive odors. Heavy blankets of blue-green algae accumulated in pockets of heat exchangers developed biological reduction cells that produced pockets of corrosion.

Over the three years prior to the initiation of the study described in this report, practical solutions were found to most of these problems. For example, dead ends, pockets and other quiet zones in which fine organic solids might accumulate and condense were eliminated; where this was not possible, cleaning access and routine cleaning was established. Apertures were enlarged, protective screens were made more readily cleared, sumps were automatically drained or were eliminated, and other plant changes were made to adapt operations to water that might carry solids.

With changing manufacturing processes a continuous review of the possible uses of the two separate water supplies in early planning stages was established in plant engineering and plant maintenance. Water at the Hampstead plant was treated as a chemical plant might regard basic solvents and recoverable reagents. At all times, however, basic aesthetics were preserved; recycled water was not used where health hazards might be involved or where the appearance of hazard existed. It was not used where it would be offensive to users. For example, high quality well water was used for toilet flushing. Cooling and quenching processes in manufacturing operations were modified to reduce splash and mists. Plant workers, a large proportion of them women, were fully aware that recycled water was used in various plant processes.

Following the institution of sparger vertical mixing in the pond, a number of field experiments were carried out in efforts to control algal blooms, plagues of worms and snails, weeds, leaves, and other causes of "biological incidents." These included attempts to suppress water weeds in shallow margins with chemical weed killers; control of snails and small crusteaceans with insecticides; and ultimately, control of filamentous algal growth with nigrosin dye additions. Through all of these trials, one unresolved variable always emerged. What was the effect of sparger mixing and mixing schedules upon the various blooms and swarms that developed? It was true that the current nuisances did not exist when the greater problems associated with the anaerobic stratified pond were present, so there seemed to be a causal relationship between mixing and infestations. There remained the hope that some simple change in the mixing schedule might be found that would minimize or prevent biological incidents. It was clear that we needed to know what processes were going on in the pond itself and how the sparger mixing program affected them.

SECTION V

DESCRIPTION OF THE HAMPSTEAD PLANT TREATED WASTEWATER STORAGE AND RECYCLE SYSTEM

Fresh water is pumped on controlled schedules based on drawdown plots from three to five gravel packed wells on the plant's property. The pumping rates employed during the period of this study varied from 100 gpm to 150 gpm through five and half days of the week. The water, like other well waters of the region, is soft and corrosive. It is treated with soda lime to pH 7.2 to pH 8.0 and hypochlorinated to flash residuals of 0.2 mg free chlorine per liter. The treated water is pumped to the plant and to an elevated surge and emergency supply tank.

Approximately two thirds of the water taken from the wells eventually passes as wastewater through the biological treatment plant to the storage and recycle pond. This loading arises from the demands of the washrooms and toilets, potable water supplies, and cafeterial uses. The remaining 35% to 40% is about evenly divided between special process uses in the plant and evaporative losses. Thus, between 17% and 20% of the well water passes through manufacturing and appears as untreated wastewater discharged to the pond.

Sanitary, washroom, and cafeteria wastewaters are collected into a common gravity sewer that carries them through a comminutor chamber (and acid neutralization in the latter course of the study) to a divider box that distributes the flow to two parallel Imhoff tanks that provide primary settling and digestion of settled solids from primary and secondary steps. Effluent from the tanks flows to a dual sump and pumping controls from which it is delivered to a high rate trickling filter. The trickling filter is 22 ft in diameter and 8 ft deep, and is equipped with a single arm rotary distributor. Effluent from the filter underdrains passes through a box type secondary clarifier; the settled sludges are pumped to the Imhoff tank-digesters, and the supernatant moves by gravity to a baffled chlorine contact chamber. The contact chamber is designed to provide a minimum of 20 minutes contact with available chlorine residuals of 0.5 mg/l at discharge to the sewer leading to the pond.

The pond itself was constructed in the lowest available area of the plant property. It was developed by excavating and lining a swampy creek bed that drained the north-western section of the site. Excavation was carried to firm soil and the basin sealed with a one foot thick membrane of compacted clay. A wide riprapped earthen dam, approximately 23,000 cubic yards in volume, closes the basin and secures the impoundment.

A general schematic of the flow plan of fresh water, treated waste-waters, and recycled process water is given below in Figure 1, "Plant Water Supply and Process Water Recycle System."

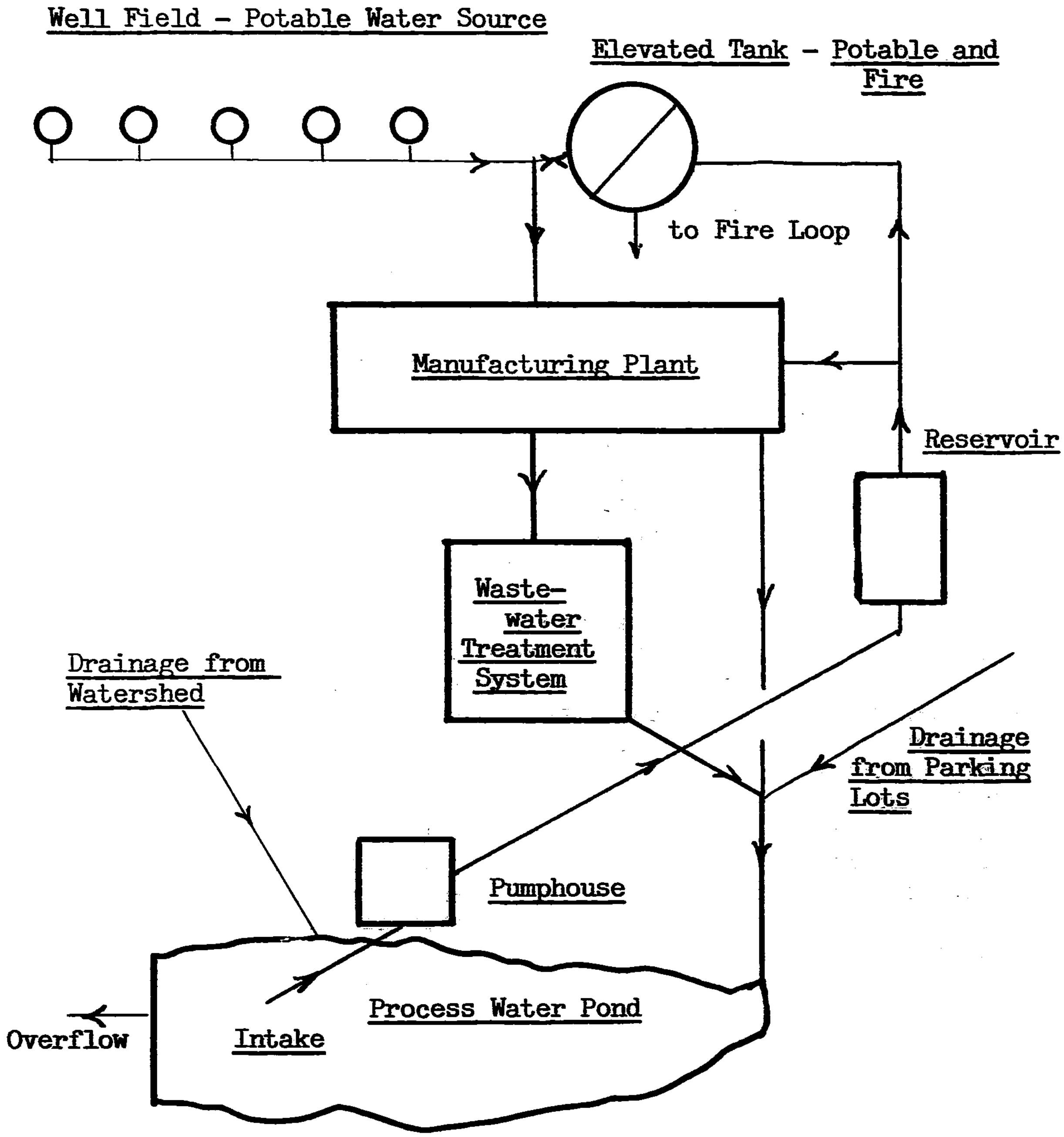

Figure 1 — PLANT WATER SUPPLY AND PROCESS WATER RECYCLE SYSTEM

In recycle service water is taken through a submerged intake located 2.5 ft from the bottom in the deep end of the pond and drawn through 10 mil conical automatic backwashing screens to dual pressure pumps located in a service building on the border of the pond. The pumps deliver water at rates required by operations and weather — from low rates of 288,000 gal/day to 2,600,000 gal/day, with average recycle returns of 1,150,000 gal/day. No treatment other than screening is applied at the pump-house.

Depending on the rainfall pattern, the pond receives variable flows of storm water from roofs, the watershed, and parking lots. These flows during storm conditions can be very heavy and may carry loads of eroded soil and solids. At the time of this study the roof of the main plant was 17 acres. In addition, the impervious surfaces of roads and parking lots represented 13 acres. A flash rain of 0.5 in yields 416,000 gallons, roughly 2.3 times the daily well yield. The contribution from the pond's pervious watershed of approximately 120 acres will vary with the history of rainfall, but, in very long wet periods, it may represent three or four million gallons per day.

The process water storage pond differs substantially from conventional oxidation pond design in that its major volumes are held in broad shallows. A graphic plot of the pond's volume vs depth is given in Figure 2, "Volume vs Depth of Process Water Pond."

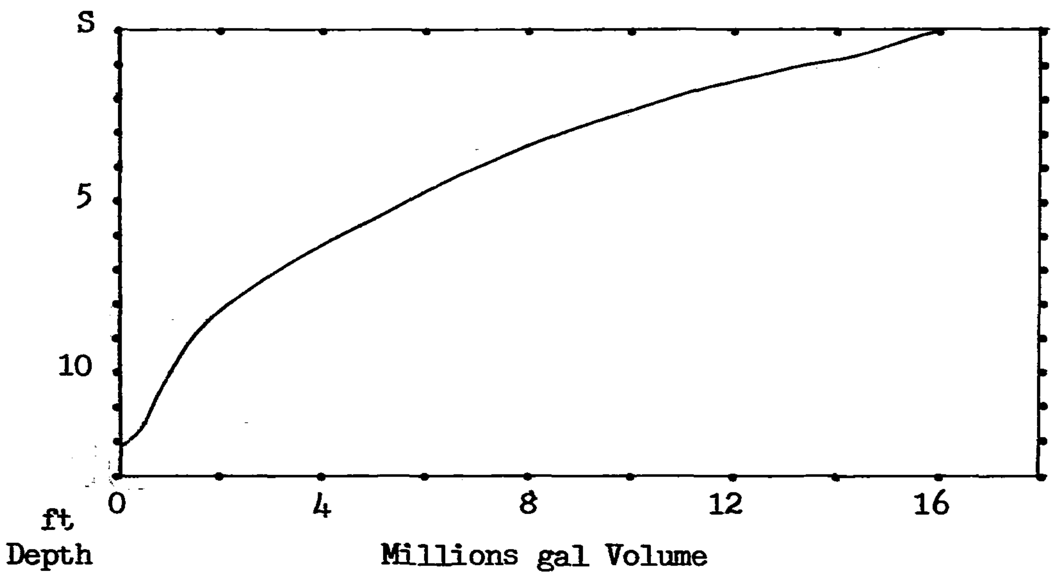

Figure 2 — VOLUME VS DEPTH OF PROCESS WATER POND

The volume of the pond, filled to overflowing at the spillway, is about 16.0 million gallons. At this level, the pond has an area of approximately 8.3 acres.

The pond's greatest depth is 12.5 ft. When filled, about 40% of the pond's volume is held in depths of three feet or less, and about two thirds of the total volume exists at five feet and above. The deep waters are contained in a sump area; less than 10% of the pond's volume exists below 10 ft.

The air sparger installed in 1961 consisted of a float-manifold of 8 in diameter pipe, 30 ft long, anchored in the deep end of the pond. From the float-manifold two 8 ft air lines extend downward to a lateral distributor carrying sixteen evenly spaced 2 ft wrapped aerator candles, eight on each side of the distributor. A 5 ft Rootes blower, operating at 2.5 hp capacity, supplied air at 20 lb/in^2 through a floating rubberized hose.

In service, the sparger acts as a massive low level air lift pump. The action is shown in Figure 3, "Sparger Air Mixing of Pond," below. Fine and coarse air bubbles discharged at the candles form a relatively light air-water dispersion. This low density dispersion is pushed upward by the surrounding denser water. At the surface, the light dispersion spreads outward in all directions. When the bubbles break, the cold water "rains" downward through the warmer water below and mixes with it to form water of intermediate temperatures. At the same time cold deep water is being pushed into the rising air water dispersion column. Eventually, the pond's water are mixed to uniform temperature.

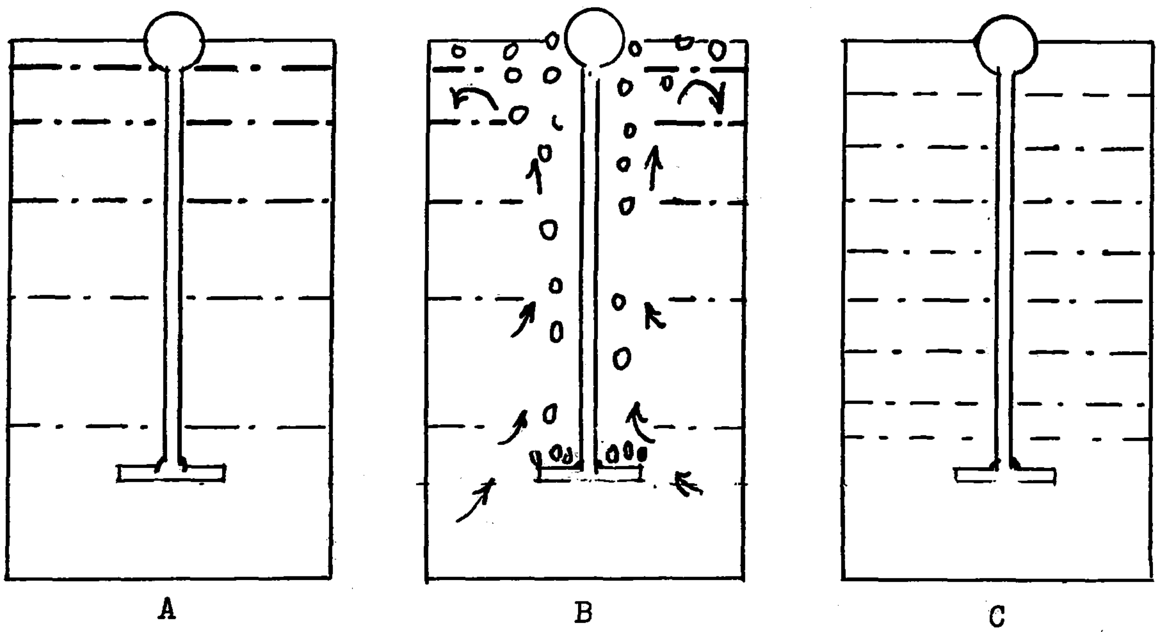

Figure 3 — SPARGER AIR MIXING OF POND
(A) Stratification established; (B) Air lift mixing;
(C) Stratification eliminated, water uniformly mixed

It should be pointed out that the air sparged, recycled wastewater pond is neither an "oxidation pond" nor an "aerated lagoon," though it has superficial features of both. A wide range of planktonic and sessile algae and changing populations of zooplankton predators are present in the plant's storage pond, as in conventional oxidation ponds, but vertical zonation is absent. The process water storage pond has no anaerobic hydrolytic phase of accumulated digesting solids as oxidation ponds commonly do.

On the other hand, the aeration capabilities of the air sparger mixing system are small compared to the demand of the pond. Spargers of this type powered at the level of 2.5 hp may be expected to supply not more than 60 lb of oxygen per day to an oxygen deficient system. The oxygen demand of the treated wastewater is in the order of 200 to 250 lb oxygen per day. The greater fraction of this requirement is met by photosynthetic production of oxygen and the conversion of wastewater organics to more stable organic stuffs by the complex of predators.

The retention time of the pond at full volume and influent rates of about 144,000 gal/day is approximately 114 days, but the exchange time with recycle at ten times this rate is around 11 days. At low levels, as in the summer of 1966, with the pond containing 11.5 million gallons and high recycle rates of 2,600,000 gal/day, the exchange time was reduced to 4.4 days.

Average retention time affects biological processes by controlling the degree of completion of serial processes. At full volume and low recycle rates, the pond has the characteristics of a storage system with very long residence time. The BOD loadings under these conditions are about 20 to 25 lb BOD per surface acre per day, which places the loading in the low range of conventional oxidation ponds.

SECTION VI

PERFORMANCE OF HAMPSTEAD PLANT'S STORAGE-REUSE POND; BOD-COD

The most striking characteristics of the water furnished for recycled use from the process water pond were (a) low BOD values, (b) relatively high COD/BOD ratios, and (c) low 20 day/5 day BOD ratios. All three characteristics indicate high biological stability of persisting organics in the water.

Two extended series of tests established these properties. The first series was run during an extended low water, drought period in the month of June, 1966, when treatment plant efficiency was poor. The second was carried out in the middle weeks of September, 1967, during a period when the wastewater treatment plant was operating within design efficiencies of 70% to 80% BOD removal. The data of these two series are presented in Table 1, "BOD-COD of Recycled Water, June, 1966," and Table 2, "BOD-COD of Recycled Water, September, 1967.

Samples analyzed in both series represent 24 hour continuous collections from the waste treatment plant outfall and from the barge sampler (described in a later section) — the first representing the feed to the pond; the second, stored water fed back to the plant.

It is to be noted that both series show substantial reductions in BOD concentrations during residence in the pond. Pond BOD values are commonly less than 10% of the treated wastewater BOD values, and usually less than 5% of the 20 day BOD values. Day to day changes in influent BOD and COD going to the pond may be expected to have little effect on pond values since dilution by mixing with the pond water is more than a hundred fold.

The greater biological stability of organics in the recycled water is evident in both series. This shows itself in two ways; in the spread of 5 day BOD/COD ratios of treated wastewater fed to the pond and that of the water in the pond itself; and in the relatively smaller differences in 5 day BOD and 20 day BOD values of the pond water. In the series of Table 1, representing inefficient wastewater treatment conditions, COD values of effluents are commonly more than twice the 5 day BOD values; in general the 20 day BOD values are slightly more than one and a half times the 5 day BOD values, which is within anticipated ranges. The pond waters, on the other hand, show COD values ranging from six to ten times the pond 5 day BOD values, and 20 day BOD values that vary from 1.2 to 1.3 times the 5 day BOD's.

Table 1 — BOD-COD OF RECYCLED WATER, JUNE, 1966 SERIES

Date (1966)	Day	Feed BOD 5 day (mg/l)	Feed BOD 20 day (mg/l)	Pond BOD 5 day (mg/l)	Pond BOD 20 day (mg/l)	Feed COD (mg/l)	Pond COD (mg/l)	Feed BOD/COD	Pond BOD/COD
6/3	Fri	85	122	4.2	5.0	170	30	0.50	0.14
6/6	Mon	70		3.8		170	28	0.41	0.14
6/8	Wed	90	141	3.4	4.4	185	30	0.48	0.11
6/10	Fri	78		3.0		165	28	0.47	0.11
6/13	Mon	65	101	3.8	4.8	152	32	0.42	0.12
6/15	Wed	88	108	4.1	4.8	158	36	0.56	0.11
6/17	Fri	110	161	3.4	4.1	218	28	0.50	0.12
6/20	Mon	72		3.2		151	30	0.47	0.11
6/22	Wed	84	125	4.1	5.0	171	32	0.49	0.13
6/25	Fri	96	138	3.3	4.4	178	30	0.51	0.11
6/27	Mon	60		3.6		141	32	0.42	0.11
6/29	Wed	75	108	4.0	4.4	149	36	0.50	0.11
7/1	Fri	92		3.8		175	34	0.52	0.11
Averages		82	125	3.4	4.6	167	31	0.49	0.12

Table 2 — BOD-COD OF RECYCLED WATER, SEPTEMBER, 1967 SERIES

Date (1967)	Day	Feed BOD 5 day (mg/l)	Feed BOD 20 day (mg/l)	Pond BOD 5 day (mg/l)	Pond BOD 20 day (mg/l)	Feed COD (mg/l)	Pond COD (mg/l)	Feed BOD/COD	Pond BOD/COD
9/6	Wed	40		3.6		75	47	0.53	0.08
9/7	Thur	60	98	6.2	4.3	92	42	0.65	0.10
9/8	Fri	52		4.6		90	40	0.57	0.12
9/9	Sat	35	58	2.8	3.6	75	25	0.47	0.11
9/10	Sun	20		4.2		45	30	0.44	0.14
9/11	Mon	35	55	2.8	3.6	68	24	0.51	0.12
9/12	Tue	35		4.0		65	30	0.54	0.13
9/14	Thur	60		3.8		101	28	0.60	0.14
9/15	Fri	58	90	3.6	4.7	100	28	0.58	0.14
9/16	Sat	52		2.8		98	22	0.53	0.13
9/17	Sun	28		4.0		65	33	0.43	0.12
9/18	Mon	—	—	3.6	4.7	—	30	—	0.12
9/19	Tue	41	70	3.0	4.1	75	27	0.55	0.11
Averages		43	74	3.8	4.2	79	31	0.53	0.12

In the June, 1966 series, when wastewater treatment operated inefficiently, the COD of the stabilized water in the pond was approximately 18.5% of the treated feed. During the September, 1967 series, when markedly better treatment operated, the COD of the stabilized pond water was about 39.2% of the treated wastewater flowing to the pond. It is interesting to note that average COD of the pond water ranged about the same values — an average of 31 mg COD/l — in both series. This suggests that the prevailing pond COD represents residuals from near terminal biological processes.

A striking and consistent feature of the BOD measurements made at irregular intervals through the three summers of the project was their low values. The highest single measurement, 9.0 mg BOD/l, was found after an autumn storm in October, 1968. Values were consistently so low that Hach respirometers proved unsatisfactory for routine measurements and were abandoned in analytical work. Undiluted pond samples rarely fell outside the 60% oxygen depletion levels in BOD bottles. There were no evidences of inhibitory substances in the pond water, and routine measurements of BOD were taken with undiluted preparations.

SECTION VII

PERFORMANCE OF STORAGE-REUSE POND — NITROGEN AND PHOSPHORUS

The summer of 1966 was uniquely suited for studies of the nitrogen and phosphorus balance in the Hampstead plant's treated wastewater storage-recycle pond. From June to early September, a period of eighty days, no rain fell, and earlier showers had been light. The weather was bright and clear with little cloud cover. No water flowed over the spillway of the dam during this period, and in July and August the volume of the pond was down to minimum levels of 11.5 million gallons. Conditions were excellent for establishing "steady state" values for the distribution of nitrogen and phosphorus in the system. The wastewater treatment plant was operating poorly at that time, and relatively small fractions of these nutrients were being removed in sludges and lost to the accounting. In normal operation, from 35% to 45% of the nitrogen and phosphorus would have been disposed of off-site in the biological sludge generated in treatment.

Although automatic sampling equipment had not yet been installed, it was possible to collect vertical profile samples during the stratified daylight period and during the mixed night and early morning period, and to make rough estimates of "primary productivity." It was found, however, that losses of total nitrogen and phosphorus well in excess of sampling variation and error were occurring in the pond. Only 20% to 25% of the anticipated total nitrogen could be found in the water phase, including suspended materials, and nitrite and nitrate nitrogen commonly exceeded the organic fraction. Maximum total nitrogen found in mixed pond water receiving treated sewage containing 15 to 25 mg total N/l ranged from about 4.0 to 5.0 mg N/l, more than 80% of these concentrations as nitrite and nitrate combined. Ammonia was found only in trace concentrations.

The phosphorus budget also showed unanticipated shortages in the mixed water phase; treated wastewater effluent samples ranged from 5 mg P/l to 12 mg P/l, with most values falling around 7 mg P/l. A few fine filter separations indicated that most of the phosphorus was present as fine particles.

Unfortunately, September storms brought the work to a close before we stumbled upon the clues to the mechanism of nitrogen and phosphorus losses. These came later in the review of dissolved oxygen/thermal stratification data and the analyses of bottom sediment samples picked up early in the summer.

During a series of temperature-dissolved oxygen profile measurements in July, 1966, using improvised thermistor and dissolved oxygen probe equipment, we noted intervals of 4 to 6 hours in which no dissolved oxygen could be measured in depths below 5 feet — commonly from early afternoon until an hour or more after air sparger mixing was started at 6:00 pm. Although no oxygen was indicated by the probe, hydrogen sulfide was not formed in the oxygen deficient layers. This was confirmed by lowering panels painted with white lead paint into the anaerobic layers. (Many oxygen deficiencies were noted in the lower strata during the summer of 1967 when automatic vertical sampling and analyses were used.)

The peculiarities in the nitrogen balance may be explained by assuming the following reasonable sequences. The relationships must remain as conjectures, however, since critical experimental checks were not made. First, it may be anticipated that ammonia nitrogen from wastewater treatment and from degradation of organic nitrogen added to the pond will be biologically oxidized to nitrite and nitrate. The long holding periods, the pH range, the ammonia concentrations and temperatures are all favorable for this conversion. Oxygen is available at intervals from photosynthetic processes. Second, it is possible that nitrate and nitrite are reduced biologically during intervals of zero oxygen. The reduction of nitrate and nitrite precedes the reduction of sulfate in polluted waters. Reduction of nitrate and nitrite yields nitrogen gas which may be lost to the atmosphere during mixing-equilibration. Unfortunately, we did not set up gasometric analyses to check swings in dissolved nitrogen in the pond water.

Phosphorus losses are supported by somewhat better evidence. During the summer of 1966, as water levels in the pond receded and the algae-coated freshly exposed shoreline dried and caked, a number of samples of the cake were taken for calcium carbonate analyses. The white cake that appeared in some places suggested marl formation.

Samples of the chips and cake were dried and taken to the laboratory for analysis during the winter. In the initial acid treatment of this material, there was a vigorous effervescence with carbon dioxide evolution. Analyses for PO_4^{-3} yielded concentrations ranging from 16,600 mg P/kg to 26,600 mg P/kg dry weight of material. The CO_2 evolved was measured on some specimens and was found to represent carbonate concentrations ranging from 12,000 mg CO_3^{-2}/kg to 13,500 mg CO_3^{-2}/kg. Calculated as calcium carbonate, the values range from 2% to 3.8% $CaCO_3$.

We did not at first recognize the significance of these analyses. Initially, we attributed the high phosphate concentrations to the activities of flocks of tame mallard ducks that lived on the pond, along with visiting migratory wild fowl, gulls, and other transient water birds. The ducks were particularly active in the shallows and along shore where they fed on the bottom stock and performed the useful function of keeping down emergent weeds. We credited the ducks with a phosphorus contribution that belonged elsewhere.

The role of the shallow bottom processes of the pond will be treated in another section, but a summary of our observations of marl formation should be entered at this point to clarify the mechanisms by which phosphorus is removed from the water and concentrated in the shallow bottom solids. The history of our late concern with the pond's shallow areas arises from a "prejudice" favoring thermal stratification and mixing schedules as factors in the troublesome algal blooms and floating algal mats reported at various times before the study was begun. Until May of 1968, however, no blooms were observed by the study group, and the older notions of their production continued to dominate our thinking. However, on the early afternoon of May 30 of that year we were surprised to find a classic bloom in progress.

We discovered this first as a heavy carpet of brown, greasy, puffy, algal stuffs that had accumulated as a band fifteen to twenty feet wide along the northern shore of the pond. At the shallow embayed end of the pond, near the entering return flow from the plant, small pads of algae were still rising from the bottom, floating together into mats, and drifting with the very light south wind to join the pack along the north shore. The accumulation was slow but steady.

It was possible to observe the process itself in shallows 8 inches or less in depth. The loose carpet of mixed algae that grew on the shallow bottom — principally Oscillatoria and naviculoid diatoms, together with entangled small predators ranging from armored amoebae to rotifers and fly larvae — was covered with fine gas bubbles. Here and there flakes of material would tear loose and be buoyed to the surface to join the drift. When the bottom was disturbed gently, the carpet broke up and detached readily from the muddy clay bottom, floated to the surface in fragments, and merged with neighboring floating stuffs. The floating, consolidated drift packed along shore into a blanket an inch or more thick and developed pressure folds where there was gentle wave action. When stirred, the blanket broke into a watery mass, bubbles were released with an audible rustling, and much of the stirred material settled into the water.

The flotated bloom material was watery and loose; a mass scooped by hand slipped through the fingers like light oil. Fourteen mesh kitchen strainers used for collecting larger benthic organisms retained only a few large fly larvae and worm tubes from the mass. The material broke into a coarse suspension and settled into density fractions — an oily residual film formed at the surfaces of buckets holding the screens. The bloom material and liquors showed surfactancy, in the form of a slight spreading film, when placed on top of clean water.

The oxygen gas in the flotated blanket was identified by the classical method of Lavoisier. Bubbles stirred loose from the coated bottom and collected through a plastic funnel in a test tube by water displacement were tested with a red hot iron wire; the wire sparkled in a lively fashion and the tube became coated with a thin film of iron oxide.

The water over the shallow bottoms showed high pH values ranging from pH 9.2 to pH 10.0. These high values were anticipated from observations taken with the continuous pH recorder from the upper strata of the deep sampling area during bright weather thermal profile studies. When the pH probe was lowered into the bottom algal mats themselves, the pH values rose even higher; rises of from 0.3 to 0.5 pH units prevailed through the bottom inch of mat material. Higher pH values were also found in the floating mat stuffs.

A number of samples of floating bloom and bottom mat stuffs collected from the bottom in shallows five to eight inches deep at the inflow end of the pond were taken. These were dried and analyzed for phosphate, carbonate, and total nitrogen. The data from these analyses are given in Table 3, "Analysis of Bottom Algal Mat and Bloom Materials" on the following page.

The relatively high ratios of phosphorus to nitrogen in the mat materials, roughly 1.3 P/1.0 N, suggest that the phosphate exists in a precipitated inorganic form rather than as cellular stuffs. Since the primary well water itself is soft, with calcium hardness falling below 40 mg $CaCO_3$/1, the marl carbonate and phosphate must represent calcium and phosphorus contributed by domestic sewage, cafeteria wastes, and a limited amount of phosphate detergent used in parts washing. The binding of phosphorus at the bottom of the pond's shallows is an exaggerated version of the phosphorus trapping that goes on in large lakes. The high hydroxyl ion concentrations generated by photosynthetic stripping of carbon dioxide and bicarbonate force calcium carbonate and phosphate out of solution to precipitate on or in the biological mat structure.

Table 3 — ANALYSES OF BOTTOM ALGAL MAT AND BLOOM MATERIALS

Sample #	Phosphorus (a) (mg/kg)	Carbonate (b) (mg/kg)	Nitrogen (c) (mg/kg)
1 - 5/30/68	15,700	22,100	12,500
2 - "	20,500	18,600	12,800
3 - "	17,200	10,900	16,400
4 - "	14,400	18,300	—
5 - "	15,500	12,700	11,200
6 - "	17,800	18,100	13,000
7 - "	14,900	16,200	12,100
8 - "	16,600	14,100	11,900
9 - "	19,300	12,800	12,700
A - 7/18/66	16,600	14,400	
B - "	26,600	23,500	
C - "	20,400	18,200	
D - "	19,800	18,700	

(a) measured as PO_4^{-3}; (b) as CO_3^{-2}; (c) Kjeldahl N
Samples 1 - 6 bottom mat; 7 - 9 floating mat; A - D, shore cake

Mud taken directly below the bottom mat, 6/6/68, one week after the bloom, showed 25,600 mg P/kg. This material dried to a hard, gray marl-like material. Other shallow mud samples from the bloom area yielded from 640 mg P/kg to 16,000 mg P/kg. Variations in the mud samples followed wide differences in the sand and organic content of the materials. It was not possible to take satisfactory cores in these delta-like shallows.

If we take conservative values of 1% phosphorus in the bottom mud of the shallows and assume the mud to be 10% dry solids, a one inch layer over one acre will contain approximately 435 pounds of phosphorus. Again, assuming an initial concentration of 7 mg/l phosphorus in the treated sewage, and an average wastewater flow of 120 gal/min, each acre inch of mud would have captured 360 days' contribution of sewage phosphorus — roughly a year's total contribution.

SECTION VIII

PERFORMANCE OF STORAGE-REUSE POND

THERMAL STRATIFICATION AND SPARGER MIXING

THE OXYGEN CROP

During the late spring of 1967 automatic sampling-analytical equipment designed to follow changes associated with the development and breaking of thermal stratification in the pond was completed and tested. A small covered steel raft was built to support the sampling apparatus. This device, developed by Black and Decker's maintenance shop, consisted essentially of a continuous worm-type pump coupled with a variable depth intake and programmed to deliver water for five minutes from vertical profile stations 6 in. apart. The water was pumped from the raft to the shore laboratory trailer through a 350 ft, 1 in. ID, rubber hose and delivered to a common sensor-sampling trough established at one end of the trailer. The raft sampler was placed in the deepest section of the pond, in the 12.5 ft bowl, and adjusted to take samples from 6 in. below the surface to 12 ft below. A small Genevamatic movement winch stepped the sampling — 24 samples over 2 hrs in the lowering cycle, 5 minutes rewind to the 6 in. level, and repeat. The sampler-analyzer examined a vertical profile once each 125 minutes.

Electrodes, probes, and continuous pressure tape recorders were established in the system to sense and record temperature, dissolved oxygen concentration, pH, and conductivity. It was also possible to take grab samples of up to 3 gallons from any selected depth. In practice, 3 minutes of flow were allowed to waste in order to clear sample mix-through or drastic temperature changes.

A continuous sampling pump was placed at the treatment plant outfall. This pumped treated wastewaters through a buried line 600 ft long to the sampling system at the trailer laboratory when desired; a remote switching relay system controlled this pump.

This relatively elaborate sampling system was designed to give detailed information for the design of an optimum sparger mixing program. The expectation was that such a program would minimize troublesome blooms and infestations experienced in the past.

Continuous turbidity and light transmittance measuring equipment were originally included in the monitoring system. These units were taken out of the study early in the program because of maintenance difficulties.

Prior to the 1968 observations that established the role of the bottom biological processes in the development of algal blooms, the sparger mixing schedule was considered to be the most probable cause for the development of algal blooms and for their failure to appear. Mixing determined the efficiency of light utilization by suspended algal masses and the mixing schedule adopted was based on reducing primary production to a minimum.

Several mixing schedules were possible.

A. The pond could be mixed continuously — 24 hrs a day.

B. The pond could be mixed intermittently through the day and night to prevent any stratification whatever.

C. The pond could be mixed during the day to prevent thermal stratification and allowed to rest during the night.

D. The pond could be mixed at night and allowed to stratify during the bright daylight hours.

Schedule D, mixing during the late evening, night and early morning, and permitting stratification during the bright warm daylight interval was chosen as the system most likely to limit algal growth. This choice was based on the expectation that "self shielding" of the stable upper strata would limit photosynthetic processes in the deeper water. Field studies of light transmittance during the summer of 1966 indicated varying degrees of absorption in upper layers of the pond — commonly more than 90% of visible bands within the upper 3 ft, and 95% to 99% within the upper 5 ft. The 3 ft to 5 ft band commonly showed dissolved oxygen gains from photosynthesis, and the "zone of compensation" as determined by the hanging bottle technique appeared to be somewhere between 5 ft and 7 ft from the surface on bright August days.

From these data, and the "logic" of the self shielding concept, the mixing schedule was fixed to fit the practical shift schedules of those in charge of waste disposal operations. The sparger was turned on in the evening at 6:00 pm (DST) and turned off automatically at 6:00 am (DST).

The summers of 1967 and 1968 differed from the classical drought summers of the previous five years. The clear, dry, warm periods were broken with numerous showers, winds, and heavy storms. The longest "undisturbed" record of summer thermal stratification that we were able to secure in 1967 and 1968 was fifteen days.

The patterns of vertical stratification and breakdown vary with weather. Wind patterns are especially important. The pond lies in a shallow protected bowl. East-west winds move along its long axis and push warm water against the dam. North-south winds cross the pond's narrow section. In the late afternoon there is usually a gentle flow of air down the northern slope of the basin that forces warm water toward the south shore. Saturated air fills the basin on quiet evenings. On clear nights with gentle air movement, the bowl begins to cool after 10:00 pm to 11:00 pm and heavy dew forms on the slopes. Thermal stratification appears in late April or early May, following a succession of quiet nights. Stratification commonly disappears in the first or second week of October. Thus, the need for cooling water for air conditioning coincides with the normal period of thermal stratification in the pond.

Day to day differences in the thermal input and loss patterns, wind, weather, and storm surges cause wide variations in the building and breakdown of vertical temperature profiles. Figure 4,"Development and Breakdown of Thermal Stratification in Storage Pond," on the following page, presents a representative sequence of changing profiles during a relatively quiet warm period — June 11 and 12, 1968.

The profiles were sampled over 125 min period; each 2 hrs and 5 min the automatic profile sampling barge pumped samples to the shore laboratory from which the temperature at 6 in. increments in depth were taken. To simplify the presentation in Figure 4, the profiles given by alternate lowerings are presented.

The day begins in the figure at 6:00 am DST, at the time that the air sparger mixing was automatically turned off. It will be seen that the temperatures are uniform from surface down to the 10 ft level. This is the level at which the intake to the pumphouse is located. Below the 10 ft level a puddle of cooler water extending to the bottom prevails. This cool pool is not available to the plant; it is a static water mass that is mixed into the overlying water only during the natural autumn thermal overturn of the pond.

At the finish of the 10:10 am lowering, a layer of warm water more than 3°C above the mixed column temperature has been formed through the first foot of depth; this has mixed down through the lower water to a depth of 2.5 ft. Below this depth, the column is identical to that which existed four hours earlier.

At 2:20 pm warm water has been developed down to 5 ft below the surface. A thin layer of 30°C water exists at the surface, and there is a sequence of less warm bands below this layer extending to the mixed column below 5 ft.

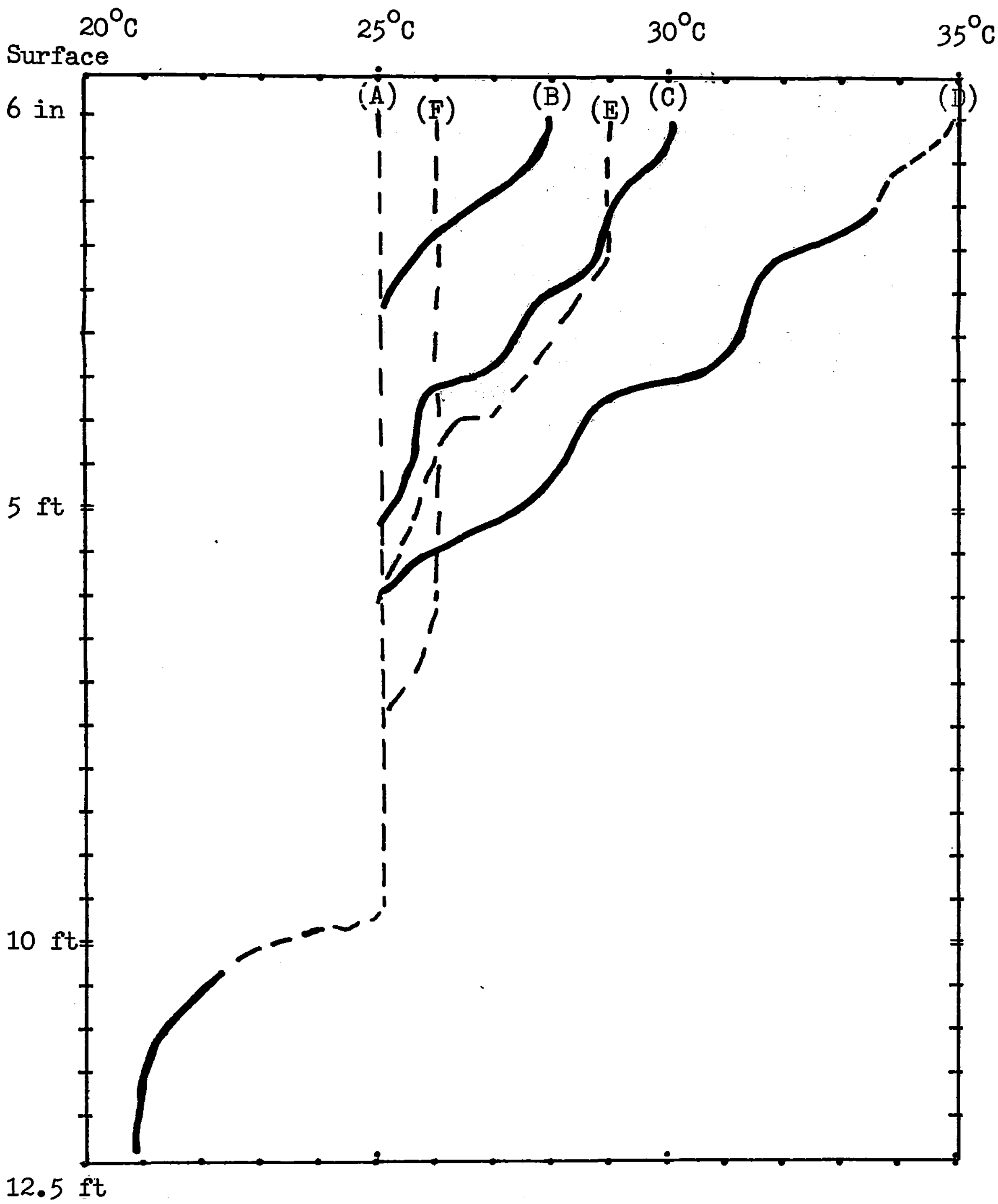

Figure 4 — DEVELOPMENT AND BREAKDOWN OF THERMAL STRATIFICATION IN STORAGE POND

(A) 6:00 am 6/11; (B) 10:10 am 6/11; (C) 2:20 pm 6/11;
(D) 6:30 pm 6/11; (E) 10:40 pm 6/11; (F) 2:50 am 6/12

At 6:30 pm a further increment of heat has been absorbed in the upper bands of water; the sparger mixer has been in service for half an hour. It will be seen in profile (D) that the upper 6 in. of the pond has warmed to 35°C and that the water down to 6 ft had accumulated heat. The waves in the long broken line indicate the effects of variable light winds in mixing down warm water into the column. Practically, the pond continues to gain total heat well after sundown, but surface temperatures drop rapidly after mixing begins.

By 10:40 pm, 6/11, the vertical temperature profile (E) shows that surface water has been thoroughly mixed through the top two feet and the slope of temperature below that level indicates the upward mixing of cool water into the reservoir of warm water developed during the bright day. The air sparger hangs 8 ft below the surface and the mixing produced is most marked above this level. Mixing does occur, however, down to the level of the pumphouse intake at 10 ft from the surface.

The temperature profile (F) ending at 2:50 am on 6/12 shows mixing downward of warmed water to the 7 ft level. The difference between this column and that existing on the morning of 6/11 is approximately 1°C. Below the 7 ft level mixing in has not yet occurred. The full record extending through 7:00 am on 6/12 shows a gain of approximately 2.0°C through the mixed column down to 10 ft. There has been a slight total gain in heat uptake.

Under normal undisturbed bright weather in June, a band of water about five feet deep, 5°C to 7°C warmer than the underlying bands, persists through the night. This stable warm layer of water effectively isolates the lower water and blocks exchange of dissolved gases with the atmosphere. The degree of thermal stratification developed on 7/11/68 would have required strong storm winds over several hours duration to mix and break up this stable seal.

The pond's capacity as a heat sink was studied during weather stable periods in July, 1968. Net gain and loss of heat energy can be estimated from temperature data given by vertical sampling of the sort developed by the automatic depth sampling system. The findings were not wholly satisfactory as a heat budget study, though it was clearly shown that the heat added by the return of warm process water from the plant was negligible compared to that added from the sun and air mass.

The schedule of daytime stratification and nighttime mixing captures and makes available a larger part of the oxygen that is produced by photosynthesis in the illuminated upper layers of the pond. This represents a much larger "oxygen crop" than that delivered by mechanical aeration or by direct transfer from the overlying atmosphere. The sequences of production and transfer are outlined in the figure below, Figure 5, "Vertical Distribution of Dissolved Oxygen and pH during Thermal Stratification and Breakdown."

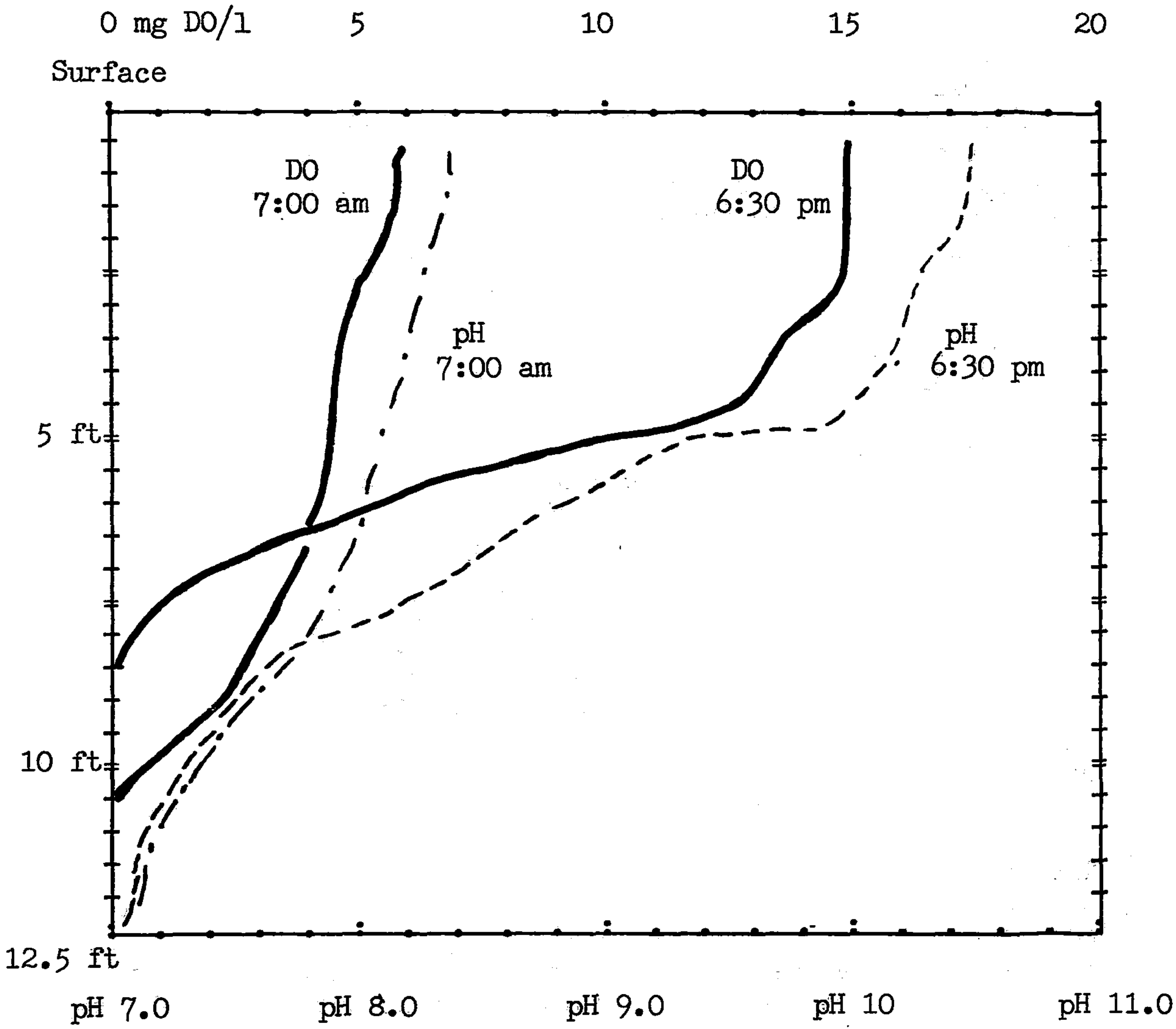

Figure 5 — VERTICAL DISTRIBUTION OF DISSOLVED OXYGEN AND PH DURING THERMAL STRATIFICATION AND BREAKDOWN

(6:30 pm, 7/11/68 stratification — 7:00 am, 7/12 breakdown)

It may be seen that at the close of the unmixed illuminated day (1) oxygen concentrations in excess of 15 mg DO/l exist through the top two feet of depth, (2) DO concentrations in excess of 11 mg DO/l extend to the 5 ft level, and (3) the dissolved oxygen concentrations drop off sharply to essentially zero at 7.5 ft and below. At temperatures prevailing during these runs, the upper two feet show slightly more than 100% supersaturation with DO, and the water between two and five feet shows between 30% and 40% supersaturation. These levels of DO supersaturation indicate active photosynthetic production beyond respiratory and BOD demands.

The oxygen load carried in the upper two feet of the pond is in excess of 590 lb; that in the next three feet is in excess of 560 lb; the total oxygen down to five foot levels represents a daily product of more than 1150 lb. (These estimates are low since the recorder did not register values exceeding 15 mg DO/l.)

To evaluate the oxygen contribution from photosynthesis on 7/11/68, some rough approximations of equivalent mechanical aeration requirements may be made. At 2 lb DO•hp•hr for a mechanical surface aerator, the roughly 1200 lb DO load found represents the work of two, twenty five horsepower floating aerators operating in the pond for 12 hours, or 25 hp•days aeration.

Not all of the oxygen generated by photosynthesis is available to the system, however. During nighttime mixing, some is lost by "desaturation" or reequilibration of the supersaturated surface layers with the atmosphere. The load of oxygen held in the water down to the 9 ft level at 7:00 am on the morning of 7/12 is slightly more than 500 lb. Approximately 650 lb DO has been lost during the night — some by desaturation and some by respiratory uptake and the satisfaction of chemical oxygen demand of the deep water. It is to be noted that the surface 18 in. of water is about 25% below saturation in the morning. This indicates mixing in of deficient deep water.

Photosynthetic processes during the daytime are marked by the development of high pH in surface waters as well as by oxygen supersaturation. As pointed out earlier, the relatively high hydroxyl ion concentrations associated with the photosynthetic reduction of dissolved carbon dioxide and bicarbonate ion are associated with the formation of phosphate bearing marl over the shallows. Figure 5 shows the wide swings in pH that occur through the vertical water column during daytime stratification and nighttime mixing. The extreme ranges are represented by the 6:30 pm 7/11/68 and the 7:00 am 7/12/68 samplings. On the evening of 7/11, the uppermost 18 in. of the pond showed pH values about pH 10.5; the next morning this depth showed readings of pH 8.4, suggesting that the changes in carbon dioxide concentrations associated with photosynthesis and respiration may be in the order of 100 times.

Changes in pH due to photosynthesis found in the stratified pond are much like those observed in very hard pond water or in sea water where photosynthetic processes are active. The pH values rise with rising oxygen and fall with declining oxygen concentrations. Below levels of sparger mixing in the pond, at 8 to 10 ft below the surface, the day and night range of pH values is narrow, commonly between pH 7.4 and pH 7.6, like that of water recycled to the plant. These lower pH values represent low rates of loss of biologically generated carbon dioxide from the less completely equilibrated deep water reservoir.

About 0.6 lb of primary organics will be produced per pound of oxygen yielded by photosynthesis in a rich pond like the Hampstead plant's process water storage system. The daily production of 1150 lb DO means that about 690 lb of organic stuffs is being formed. This represents an incremental concentration of about 96 mg/l/day, an extremely high rate of primary plankton production. It is known that oxidation ponds frequently yield effluents bearing much higher concentrations of total organics than are fed them. If photosynthesis were the only biological process controlling organics in the process pond, it is obvious that organics would ultimately crowd out the water.

The organics produced by photoreduction in the process water pond include a wide range of biodegradable stuffs. A fraction undergoes biological oxidation and shows respiratory demand at a continuous, relatively high rate. This is represented in the daily oxygen demand indicated by nighttime losses. The residue, which contains the more stable fractions, breaks down at a lower rate and either moves out of the pond in overflow, "flies or crawls out of the pond" as predatory animals, birds, or insects, or accumulates in the bottom as detritus. About half of the organics , around 350 lbs, appears to be oxidized during the dark periods; another half is metabolized at lower rates. In the steady state condition, of course, the oxygen demand and oxygen production rates approach one another. The process water pond is essentially a system that trades relatively unstable organics in the treated wastewater feed streams for a lesser quantity of comparatively stable stuffs. The net yield of algae, predators, and detritus is ultimately set by the available accessory nutrients, principally phosphorus and nitrogen. Both of these are kept in short supply in the Hampstead Pond — phosphorus is removed by marl formation, nitrogen is removed by denitrification of nitrates.

Evidences of the production of soluble stable organic fractions in the pond are given by the relatively high COD/BOD ratios of the pond water — approximately 8/1 — compared to the ratios in the treated wastewaters going to the pond — around 2/1. See Tables Nos. 1 and 2.

As will be noted later, the organics leaving the pond on wing, as insects, well fed ducks, and migratory water birds is an appreciable fraction of that generated. The resident residue of slowly degrading organics in detritus, cell fragments, casts of invertebrates, and dead bits accumulate on the bottom. Such a pond system ultimately becomes a bog. However, heavy storm flows with strong wind mixing prolong the process water storage pond's life by flushing out part of the settleable solids and carrying away the organic-rich suspension as storm runoff. Without floods, rivers themselves become sequences of channels, pools, and bogs.

SECTION IX

STABILIZATION OF CONVERTED ORGANICS IN THE POND

ROLE OF THE GRAZING ORGANISMS

At times prior to the start of these studies, engineers at the Hampstead plant observed that the color and turbidity of water in the process water storage pond changed markedly from day to day. An interval of greenish turbidity would be followed by a day or more in which the water was decidedly less turbid but rusty. Secci disc readings confirmed the wide day to day swings in turbidity.

In attempts to produce a running record of the color and turbidity changes, daily samples of recycle water were drawn through Millipore filters and the adhering solids preserved with acetic acid and copper sulfate fixing solution. This produced a chart record running through several summer months. The membranes mounted in calender fashion showed sequences of striking color shifts — from green and copper green to straws, brown, to straw and green. No color persisted for more than two or three days, and no fixed sequence of colors appeared.

Microscopic examination of the filter-captured materials showed a dominance of planktonic diatoms and green or blue-green planktonic algae — usually motile flagellates — in the greenish preparations. The rusty preparations showed relatively few diatoms or algal masses, but yielded numbers of small crustaceans: Limnocalanus, Cypris, Bosmina, and sometimes Daphnia.

In the late summer of 1967, some observations made by accident on the behavior of large batch samples brought into the trailer laboratory gave this earlier set of observations new meanings and altered the direction of our studies of the pond. A series of one gallon samples taken for laboratory studies were stored in aquaria on the counter in the trailer and left over the week-end. On Monday morning it was discovered that the water in the aquaria, initially green and turbid, had cleared to a light straw color and now contained some hundreds of small Bosmina flipping freely about.

The bottoms of the aquaria were covered with a light film of detritus and fecal pellets, together with moults of Bosmina. By the end of the working day, most of the Bosmina were dead and on the bottom. Those that swam were pale and empty.

We left these aquaria in the light for five days to see if plankton algae would redevelop. This did not occur.

Instead, very light films of attached blue-green algae grew on the walls of the aquaria, and oily bacterial films bearing packs of armoured amoeba appeared on the water surfaces.

This grazing experiment was repeated four times with variations. Whenever heavy growths of green or blue green algae appeared in the pond, gallon aquarium samples would be taken and stored in the trailer laboratory for close observation. Usually, noticeable changes in color and turbidity would take place within four or five hours, and always overnight. The direction was the same in all cases; the shift would be from turbid greenish color to clear straw or yellowish. Phacus and Euglena mixed with diatoms and occasional blooms of Pandorina would change to suspensions of swimming Cladocerans which starved and died. The sequence time at 22°C was four days.

These closed aquaria systems differ from the process pond in that they have no steady input of nutrients. Full recycle in the aquaria requires regeneration of all nutrients from the decomposing debris. In the pond slow regeneration from the debris undoubtedly occurs, but there is, in addition, a daily input of fresh nutrients that serves to maintain a more nearly steady state condition.

Following observations on the building of the algal bloom in May, 1968, a series of walled cells were set up in the shallows. These consisted of "bottomless boxes" — 24" long, 12" wide, and 12" deep — made of acrylic plastic. These compartments were set on the bloom producing bottom in water about 8" deep, maintaining 4" freeboard. The cells effectively limited flow and mixing exchange of water over the enclosed bottoms but did not appreciably shade the enclosed water. Materials that floated up from the bottom could not float away.

In two days it became apparent that the grazing organisms and other predators had taken over on the sheltered bottom. The water itself had cleared up and the carpet on the bottom of the cells was riddled with holes produced by snails, worms, and fly larvae. Many snails were visible and stringy slime tracks covered the loose settled detritus; hundreds of fly pupae and casts had accumulated around the upper margins of the cells, gnat larvae, mosquito larvae, and worms were swimming freely in the overlying water. The algal carpet which still existed over large patches of the open shallows was reduced to frayed networks within the cells.

The grazing invertebrates continued to dominate the biota of the cells for five more days. The cells were then lifted and moved to another area in the shallows. Within three days the old grazed over areas occupied by the cells were covered with fresh carpets of algae.

This simple experiment demonstrated (a) that the presence of heavy growths of bottom blue greens and other algae in the bottom carpet of the shallows — from which the floating algal blooms were derived — required a continuous supply of nutrients from the overlying water, (b) that the regeneration of nutrients from the bottom itself is slow, and (c) that air sparger mixing schedules applied to the deeper waters of the pond had nothing to do with the incidence of blooms.

When the same grazing breakup of the shallow carpets in the newly located cells began to appear in 2 to 4 days, the cells were covered with transparent plastic panels. On the following morning all covered cells were examined. Massive emergences of Chironomid gnats and small Tabanid flies were found on the upper side-walls and undersides of the covers, most trapped in droplets of water condensate. Numbers of Chironomids exceeded 500 in two of the cells, and 700 in two others. The Tabanids trapped ranged from 15 to 78. Culex mosquitoes were found in only one cell — 10 adults trapped in condensate.

After inspection, the cover plates and free sidewalls of the cells were wiped free of adhering insects and the covers replaced. The cells were left in their original positions. After three days, the systems were again examined for continued emergences of insects. This time the cover plates were literally felted with Chironomus gnats, standing room only. The insects were trapped in the condensate and matted into a thick film by entomophagus fungus hyphae; a count and identification of the mass was too laborious to consider. The density of gnats on the surface plate exceeded $10/in^2$, indicating emergences of over 1500 per square foot of bottom. A continuous film of pupal casts and other floating debris covered the enclosed water surfaces of the cells. Microscopic examination of this oily film showed a zoogleal bacterial structure and a wide range of large grazing ciliates, clusters of amoebae, and nematode worms. Water mites were also abundant.

It would appear that the quiet surfaces provided by the sheltering cells and cover favored the successful emergence of the large gnat population. At intervals, spiraling swarms of gnats were noted about the edges of the pond, but these did not suggest the high densities and activities of larvae in the coated shallow bottom. It would also appear that night emergences are common. Casts of gnat pupae commonly appeared in surface films swept along shore by gentle winds, but these gave no indication of the large populations active in the shallows of the pond.

SECTION X

LEAF WASH, DRIFT, STORMS AND FILLING OF SHALLOWS

The useful life of a storage pond is determined by the rate at which it fills with silt or other solids and by the accumulation of materials that limit useful water quality. The processes involved are like those that take place in all natural lakes and ponds. Feeder streams, storm flows, and winds carry soil and organics into the pool and they can be moved out only by flood carryover. Flushing is always incomplete, and there is a net accumulation of water displaced stuffs in the basin.

In small natural lakes, the sequence of filling — from lake, to pond, to marsh, to swamp — is accelerated by the growth of emergent weeds, shrubs, and trees in the shallows and around the borders. These contribute seasonal loadings of dead plant stuffs, seeds and pollen, leaves, twigs, fallen limbs and trunks to build a border that encroaches upon the deeper waters. This border buildup also captures storm-borne solids. The net effect is the projecting of a swamplike shoreline into the deeper areas. The deep areas fill last. As waterlogged materials, leaves, and fines collect in deep areas, a false bottom of anaerobic, slowly decomposing organics builds up. The lower oxygen-free strata of collected organics in the false bottom are essentially "pickled." Organics are lost relatively slowly by anaerobic fermentation from these boglike bottoms; methane and a variety of organic acids are lost to the overlying water by slow diffusion or gasification.

The Hampstead plant process water storage pond would normally evolve into a swamp with no storage value if left alone. A number of routine maintenance operations operate to forstall progress to this end. First, the margins have been kept clear of weeds and woody plants by mowing and other landscaping operations. Second, air-sparging of the deeper pond has prevented the accumulation of fine debris as a false bottom. Third, ducks and visiting waterfowl reduce the emergent and floating weed populations in the shallows. In addition, the high densities of small invertebrates — insect larvae, snails, beetles, and worms — break down leaf materials and other plant tissue that drifts into the shallows where they are active. At various times after the sparger system was installed, Black and Decker's maintenance engineers made studies of the pond's bottom in the vicinity of the pumphouse intake. A specially built illuminated water periscope permitted direct viewing of the bottom 12 ft deep. In this area, the bottom was found to be a clean clay surface free of any organic sludges or recognizable fragments.

The drought of the summer of 1965 was so extreme that a deep trench was dug around the western border of the plant's property to capture all surface runoff that might be generated by providential rains and to carry this to the pond. There were no rains, but during the fall the trench served an unanticipated function; it collected a large fraction of the hardwood leaf fall from some acres of forested slope, stored them, and then discharged the whole load into the pond with the first storms of early winter.

This incident was cause for concern. A wet leaf is an appreciable object in a process water stream. Up to this washout, however, no clogging of lines, orifices, or screens by recognizable leaves or stems had occurred, though leaves undoubtedly reached the pond on earlier storms. The leaf load delivered from the emergency runoff trench represented an unprecedented slug loading, and nothing whatever was known about the fate of leaves in the pond.

A series of battery jar and BOD bottle tests were set up in the University laboratory to see if the leaf wash might be significant in the recycle from the pond during the next summer. The results were not reassuring. Layers of leaves mixed with pond soil and stored under 10 in. of water at 8°C showed occasional bubbles of gas, the water became stained, and nothing else seemed to happen over a six month period. Loss of organic carbon was approximately 3% per month. At 4°C it could not be measured. BOD tests of diluted leaf suspensions indicated that 8% to 10% loss per month in aerobic water might be expected at 8°C. It appeared from this that leaves might be a problem in water recycle. They had been washed into the pond, and some interval of neutral suspension of the waterlogged stuffs was inevitable.

In May, 1966, small snapper samples from the bottom muds of the general bottom were examined for identifiable stems, leaf fragments, and other evidences of the heavy charge pushed in from the trench during the previous winter. These mud samples taken from the 3 ft, 5 ft, and 10 ft levels showed only occasional fragments of bark and rotted twigs, but nothing recognizable as leaf material. The bottom at 10 ft to 12 ft depth was free of organic mud.

During the late August, 1968, studies of the grazing activities of insect larvae and other invertebrates in the shallows, dry leaves from the woods were placed in two of the cells in the 8 in. shallows and lightly stirred into the surface mud. The wetted leaves were examined over the following two months. Within ten days the leaves were reticulated by small beetles and fly larvae; within a month the heavy vein structures of oak and hickory leaves that remained fell apart on handling. Microscopic examination showed limited fungus attack of the heavier tissue; the general pattern indicated mechanical attrition by cutting and chewing.

Numerous fecal pellets containing globules of plant resins were mixed through the mud film.

The relatively large shallow areas of the Hampstead plant's process water pond appear to be effective sites for invertebrate grazing of leaf materials that would normally accumulate in the unstirred deeper waters of wooded ponds where these organisms may not be so effective. For reasons not clear, whole leaves were not picked up by the pump intake system. Observations of the shallow pool at the discharge of the cone seive backwash line failed to show any leaves or stems at any time during the summers of 1967 and 1968.

Shallow borders are more efficient settling systems than deep pools are. This is demonstrated in Hampstead plant's storage pond where delta formation at the mouths of channels and sloughs feeding the pond has taken place following heavy floods. First, the distance that heavy solids travel to meet the bottom is shorter in the shallows. Second, winds push floating stuffs to the shore where they waterlog and settle.

Following torrential storms in September, 1967, which gullied sections of the feed trench and undermined parts of the plant's parking lot, much heavy material, fragments of masonry, rocks, pebbles, sand and debris was swept into the shallow influent neck of the pond to build a substantial bar and to extend the delta that encroaches on the shallows. At lowering water levels, new, firm land stood above water, and the barely wet submerged areas grew the start of a water weed crop that developed in the following May as a dense weedy patch of Persecaria, fox tail, water willow, and emergent grasses. Approximately half an acre of shallow water surface was lost in this changeover. A gravel spit developed beyond the sluice carrying water from the western plant boundary.

Rooted vegetation stabilizes deltas and islands formed in this way and limits the loss of solids with storm exchanges through the pond. Inevitably, over a long period and many floods, the pond will lose its useful volume and this occurs most rapidly in the shallows. Dredging is the only practical method of recovering these biologically useful areas.

SECTION XI

QUALITY OF WATER IN PROCESS WATER POND

The most distinctive feature of the water in the process water pond during low rainfall summer months, such as those of 1965 and 1966, when there was almost no dilution with runoff water, was its straw to yellowish-green color. This color was only slightly reduced when the water was filtered through 0.47 mu Millipore membranes; the tint itself persisted. Color densities ranging to 20 units on the standard chloroplatinate were usual for the filtered samples. This color was not changed by changes in pH over the practical pH adjustment range — pH 7.0 to pH 8.2. It decreased slowly in samples stored in Saran bags exposed to bright sunlight. Hypochlorination to 20 mg flash residual chlorine/l reduced the color from 20 units to less than 5 units. This persistent color limited the usefulness for such otherwise possible applications as toilet flushing.

The high pH values in water encountered in shallows and surface strata during bright days has been mentioned earlier. The water appears to be saturated in respect to calcium ion at these high alkalinities. This limited the use of recycled water for plant applications where flash heating over surfaces might deposit calcium carbonate crusts as in the cooling of rectifier tubes and hollow cored welding operations. Lime deposit was not significant for massive cooling and quenching steps. The apparent high calcium hardness obtained from surface water of the pond — exceeding the solubility of calcium carbonate at pH 9.6 to pH 10.0 — seems to be related to local concentrations of colloidal marl. Calcium carbonate hardness determined by EDTA titration gave high values of 800 mg $CaCO_3$/l and median values of 400 mg $CaCO_3$/l during the very dry summer period of 1966. Hardness of the treated wastewater inflow during this period ranged from 350 mg $CaCO_3$/l to 425 mg $CaCO_3$/l.

The odor of water from the pond during summer storage varied. A variety of opinions may be expected from any large group aware of the sources of water used in manufacturing processes in which they are involved. Over the period of the study there were very few complaints. The best point for judging odor quality objectively is the outdoor area in the vicinity of the evaporative cooling tower. Here the odors have been described as "woody," "fishy," and "grassy." In the vicinity of the pond itself and around the sampling sink of the trailer laboratory, the odors were predominantly woody and grassy. There were occasional intervals of light kerosene-like odors in this area. It was not possible to determine the sources and no "slicks" were noted.

Only at the inlet feeder end of the pond was there any suggestion of a phenolic-sewage odor. Judging the odor of the pond itself was complicated by the considerable areas of mowed lawn around the basin.

Total bacterial counts were highly variable and subject to the technique used. Agar plate counts of recycled water ranged from high values exceeding 50,000/100 ml to less than 1000/100 ml. Common soil spreaders were abundant and confused total counts badly. Coliform values ranged from more than 1000/100 ml to zero with most values falling between 100 - 500/100 ml. The coliforms, determined by MF Endo techniques, did not demonstrate the high rates of acetaldehyde production characteristic of fecal strains. Essentially, the bacterial characteristic of the process water pond were much like those of the farm water conservation pond.

Metals were surprisingly low in the recycled water — iron was present in traces, below 0.05 mg total iron per liter; total zinc and copper ranged below 0.1 mg/l; and total chromium below 0.02 mg/l. Cyanide could not be found and detergent concentrations (as anionics) fell below 0.5 mg MBAS/l in the recycled water.

Ether soluble oils gave maximum values of 40 mg/l, and ranged about 20 mg/l. (The plant removes and recovers cutting oils and coolants in an internal separation-extraction-recycle system.)

Chlorides during the summer of 1966 ranged about 80 mg Cl^-/l, with maximum values of 110 mg Cl^-/l. These concentrations occurred during a period in which the pond lost volume through evaporation.

The recycled water showed no unusual foaming tendencies, though surf-active substances, indicated both by spreading force tests and DuNuoy balance tests, were present. At various process points in the plant, some foam accumulation was observed, but this condition could not be separated from additions at these points.

Since the principal and important function of the recycled water was to remove heat from the plant and plant processes — by direct and by evaporative cooling exchange — and secondarily, to wash and cool metal surfaces in production processes, potable water standards are inapplicable in judging the usefulness of the water. The heat adsorbing and heat exchanging capabilities of recycled waters are only affected by quality changes that produce scaling, corrosion, sliming, foaming, clogging or which limit heat exchange and washing.

As a rough estimate, approximately 60" of water was evaporated from the pond during the long dry summer of 1966 when no rain fell.

In that interval, about 20 million gallons of water was pumped from the wells — slightly more than the total volume of the pond. During peak cooling, the evaporative losses were estimated to be about equal to the well production. This water loss by evaporation increased the concentration of stable components from the treated sewage approximately 200%. That increase in mineral content and stable substances was less than that developed by evaporation in creeks and rivers in a number of high water use areas of the East coast.

SECTION XII

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SECTION XIII

BIBLIOGRAPHY

A number of presentations of various phases of this study were made before professional groups during the investigations. The following papers derived from the project were published.

1. Renn, Charles E.; Squeezing More Out of Water
   Proceedings of the 11th Annual Conference; Water for Texas, Texas A. and M. University, Nov. 21-22, 1966 — pp 9 - 12

2. Renn, Charles E.; Serendipity at Hampstead, a Study in Water Management
   Industrial Water Engineering; 4 (9); September, 1967, pp 25 - 28

3. Jensen, Loren D. and Charles E. Renn; Use of Tertiary Treated Sewage as Industrial Process Waters
   Water and Sewage Works; April, 1968, pp 38 - 41

4. Renn, Charles E.; Experience in the Treatment and Re-Use of Industrial Waste Waters
   Proceedings of the 24th Industrial Waste Conference; Purdue University, May 6 - 8, 1969, pp 961 - 968

5. Sculley, J. R.; An Energy Budget Study of a Small Industrial Process Water Pond
   Master's Essay, The Johns Hopkins University, Department of Engineering Science, May, 1970 — (Jointly with Edison Electric Institute)

SELECTED WATER RESOURCES ABSTRACTS INPUT TRANSACTION FORM	1. Report No.	2.	3. Accession No. **W**

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16. Abstract

This study describes the successful operation of a storage pond used to collect treated wastewaters and runoff for recycle to manufacturing operations under conditions of drought and severe water shortages. Treated sewage and cafeteria wastes are stored in an air sparger mixed pond and are returned to the manufacturing plant to provide water for evaporative cooling and a variety of production processes. By applying long term storage, air sparger agitation, and controlled stratification during the summer, it has been possible to increase the effectiveness of limited well supplies from six to fifteen times. The efficiency of the pond depends in larger part upon biological processes that go on in the comparatively shallow areas of the system. These act to capture phosphorus and to stabilize algal organics generated in the pond itself.

17a. Descriptors

*Water Reuse, *Biological Treatment, *Self Purification

17b. Identifiers

*Lagoon, Aeration, Waste Assimilative Capacity, Industrial Wastes

17c. COWRR Field & Group

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