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THE BIOCHEMICAL RESPONSE OF PROVO BAY
TO NUTRIENT INFLOW

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A Thesis
Presented to the
Department of Zoology
Brigham Young University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science

by

R. Bruce Sundrud

August 1971

This thesis by R. Bruce Sundrud is accepted in its present form by the Department of Zoology of Brigham Young University as satisfying the thesis requirement for the degree Master of Science.

Typed by Diana Rice

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This thesis is dedicated to my parents, who made it possible, and to my wife and children, who made it worthwhile.

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INTRODUCTION

Provo Bay is a marshy body of water located south of Provo, Utah, and which opens into the eastern side of Utah Lake. It is surrounded by farmlands and is bordered on the east by the Interstate-15 freeway. It is presently used for recreation by bird hunters, fishermen, and occasional boaters and water skiers.

Provo Bay is also known as Mud Lake. This more descriptive title is derived from the bottom sediment, a Macbeth type ranging from 2.5 to 9.1 m deep, and composed of particles, from 0.05 mm to 0.002 mm in diameter, mixed with organic matter (White, 1963). The Bay is approximately 5.6 km wide (Siewart, 1968), and at compromise water level, 1,368.35 m (4,489.34 ft) above sea level, has an area of 2,800 hectares (7,000 acres) and a capacity of 0.032 km^3 (26,000 acre-feet) (U.S. Department of the Interior, 1963). It presently receives the effluents from the Provo, Springville, and Spanish Fork sewage treatment plants, the Kuhni meat by-products plant, the Ironton Pipe Plant, the Provo City Sanitary Land Fill, and surrounding farms.

The water of Utah Lake is pumped into the Jordan River and is utilized for irrigation of the Salt Lake Valley. During low water levels, Provo Bay consisted of a series of spring and stream-fed ponds bearing separate names such as Spring Lake, Crystal Lake, and Mud Lake, the

latter of which has been used to denote the entire area. In 1933, a low water year, canals were dug to increase drainage from these ponds into Utah Lake (White, 1963). At the time of this study the Lake was at a high water level, and Provo Bay was a continuous body of water with Utah Lake. Bullrushes and cattails growing on the sides marked the channels that were used by boats to gain access to the Bay.

The present plans of the Central Utah Water Project of the Department of the Interior include the building of a dike 10.4 km in length to separate Provo Bay from Utah Lake, draining the Bay area, and channeling the inflows directly to the Lake (Central Utah Project News Report, 1968; U. S. Department of the Interior, 1968). This project is designed to reduce water loss due to evaporation and allow reclamation of the Provo Bay area for agricultural purposes.

A brief survey of the water quality of Provo Bay was conducted in 1969 (Sundrud, et al., 1970). The survey indicated that Provo Bay had the characteristics of a tertiary treatment pond, i.e., that Provo Bay was removing the nutrients from the effluents it received before releasing the water into Utah Lake. This present study was performed with the purpose of proving or disproving the hypothesis that Provo Bay is a tertiary treatment pond.

REVIEW OF THE LITERATURE

Eutrophication, or the increase in the nutrients available for plant growth, is a natural process which has been accelerated by the waste products of man's increasing population and technology. The disposal of wastes into lakes has caused increased algal blooms (Hasler, 1947), odor nuisances (Prescott, 1960), foul tastes (Jackson and Meier, 1966), and increased insect populations such as midges and gnats (Lindquist and Deonier, 1942). Lakes which have been used for waste disposal have deteriorated markedly in their water quality; e.g., Lake Sebasticook, Maine; Lake Winnisquam, New Hampshire; Lake Monona, Wisconsin; Lake Washington, Washington; and Lake Erie (Beeton, 1969; Edmondson, 1969).

In Lake Erie, which receives the effluents from many industrial centers, the ammonia nitrogen increased fivefold and the total nitrogen increased about threefold between 1930 and 1958 while phosphorus concentrations doubled between 1942 and 1958 (Beeton, 1969). During this time pollution-tolerant insects have become more abundant (Wright, 1955), increased biochemical oxygen demand has caused rapid oxygen depletion in the lower strata of the Lake (Carr, 1962), and blue-green algae blooms have become prevalent (Casper, 1965). Because of these changes Lake Erie has lost much of its value for fishing (International

Board of Inquiry for the Great Lakes Fisheries, 1943) and recreation (Ambassador College Research Department, 1968).

Lake Washington, which is surrounded by Seattle and its suburbs, has undergone some fluctuations in water quality associated with the amounts of effluent it has received. In the early 1930's, nuisance conditions caused by the disposal of raw sewage into the Lake were temporarily alleviated by the diversion of the sewage into Puget Sound (Scheffer and Robinson, 1939). This trend was reversed, however, as urban development continued around the Lake and by 1955 it was receiving the effluent from ten secondary treatment plants (Comita and Anderson, 1959). Public concern over the subsequent deterioration of the Lake caused the formation of the Municipality of Metropolitain Seattle for the purpose of improving the sewage disposal systems and diverting wastes from Lake Washington (Clark, 1967). In 1963, one fourth of the effluent was diverted. At that time the Lake had 0.057 mg/l phosphorus (0.174 mg/l ortho-phosphate), 0.428 mg/l nitrogen, and 0.038 mg/l chlorophyll. After the first diversion steady improvement was noted. In 1968 the last treatment plant effluent was diverted from Lake Washington, and by 1969 phosphorus was only 28% of the 1963 level, nitrogen was 80%, and chlorophyll was reduced to only 20% of what it was in 1963 (Edmondson, 1970).

Lake Monona, Wisconsin, received sewage effluents that caused the growth of an algae scum which produced a foul odor. After

control of the algae by cooper sulfate application proved inadequate, the sewage effluents were diverted from the Lake (Mackenthun, Leuschow, and McNabb, 1960). Although large populations of algae still occur in Lake Monona, the odor-producing scum no longer forms (Edmondson, 1969).

The composition of sewage effluents may vary. According to Weinberger, Stephan, and Middleton (1966), primary sewage treatment, which is the removal of pollutants from wastewater by physical means such as sedimentation, screens, etc., removes 20% of the nitrogen, 10% of the phosphorus, and 35% of the biochemical oxygen demand (BOD. BOD is a measure of the rate of utilization of oxygen caused by the oxidation of organic substances in water). Primary sewage treatment followed by secondary treatment, which is the removal of pollutants from wastewater by biological means such as activated sludge and trickling filters, removes as much as 50% of the original nitrogen, 30% of the phosphorus, and 90% of the BOD. Despite the removal of much organic material, after secondary treatment 50% of the nitrogen and 70% of the phosphorus still remains. This results in an average composition of 25 mg/l ortho-phosphate, 15 mg/l nitrate, and 20 mg/l ammonia. The formation of algae blooms requires approximately 0.3 mg/l nitrate nitrogen (or 1.3 mg/l nitrate), and 0.01 mg/l phosphate phosphorus (or 0.3 mg/l ortho-phosphate) (Lee, 1970). Most algae also require vitamins, such as B₁₂, thiamine, and biotin, for growth

(Provasoli, 1958). Secondarily treated sewage is rich in vitamin B₁₂, biotin, and other growth factors (Neujahr, 1955, 1960, 1961; Provasoli, 1969), and thus is capable of supporting dense algal blooms due to its abundance of both macro- and micro-nutrients.

The process of nutrient removal from wastewater after secondary treatment is termed tertiary treatment. There are many processes by which nutrients can be removed (Atkins, 1965), but of concern to this study is the removal of these nutrients by algae. Pooling of the wastewater is followed by blooms of algae which incorporate the nutrients into biomass which can then be harvested (Neel, McDermott, and Monday, 1961). Beck demonstrated (1965) that the growth and harvest of algae in secondarily treated sewage could effect a 90% removal of nitrogen in less than three days retention time, while Mackenthun (1965) indicates the possibility of as much as 98% reduction in ponds with greater retention times. The reduction of phosphorus levels of 65-95% in such ponds may be due to precipitation caused by the increased pH in addition to the reduction caused by algae growth.

METHODS AND PROCEDURES

Eleven stations were established in Provo Bay (Figure 1).

These stations were selected by the Utah Lake Diking Research Project to provide a wide sampling of the Bay and also to concentrate on the points of greatest flow into and out of the Bay. For this study only stations 1, 2, 4, 8, 10, and 11 are considered, as they are along the major line of flow through the Bay.

Station 2 is easily located at the northeast side of the Bay at the union of the Mill Race with the channel receiving Hobble Creek and Dry Creek, and has a depth of 1.5 m.

Station 1 is located 373 m (1,223 ft) east of station 2 up the channel of the Mill Race, and has a depth of 1.3 m.

Station 4 is located down the channel 465 m (1,526 ft) west of station 2, and has a depth of 1.5 m. From this point on the Bay has no defined channels until station 8.

Station 8 is located at the head of the major channel 263 m (8,642 ft) southwest of station 4, and has a depth of 1.9 m.

Station 10 is located in the middle of the opening into Provo Bay, approximately 1,800 m (6,000 ft) from station 8, and has a depth of 2.1 m.

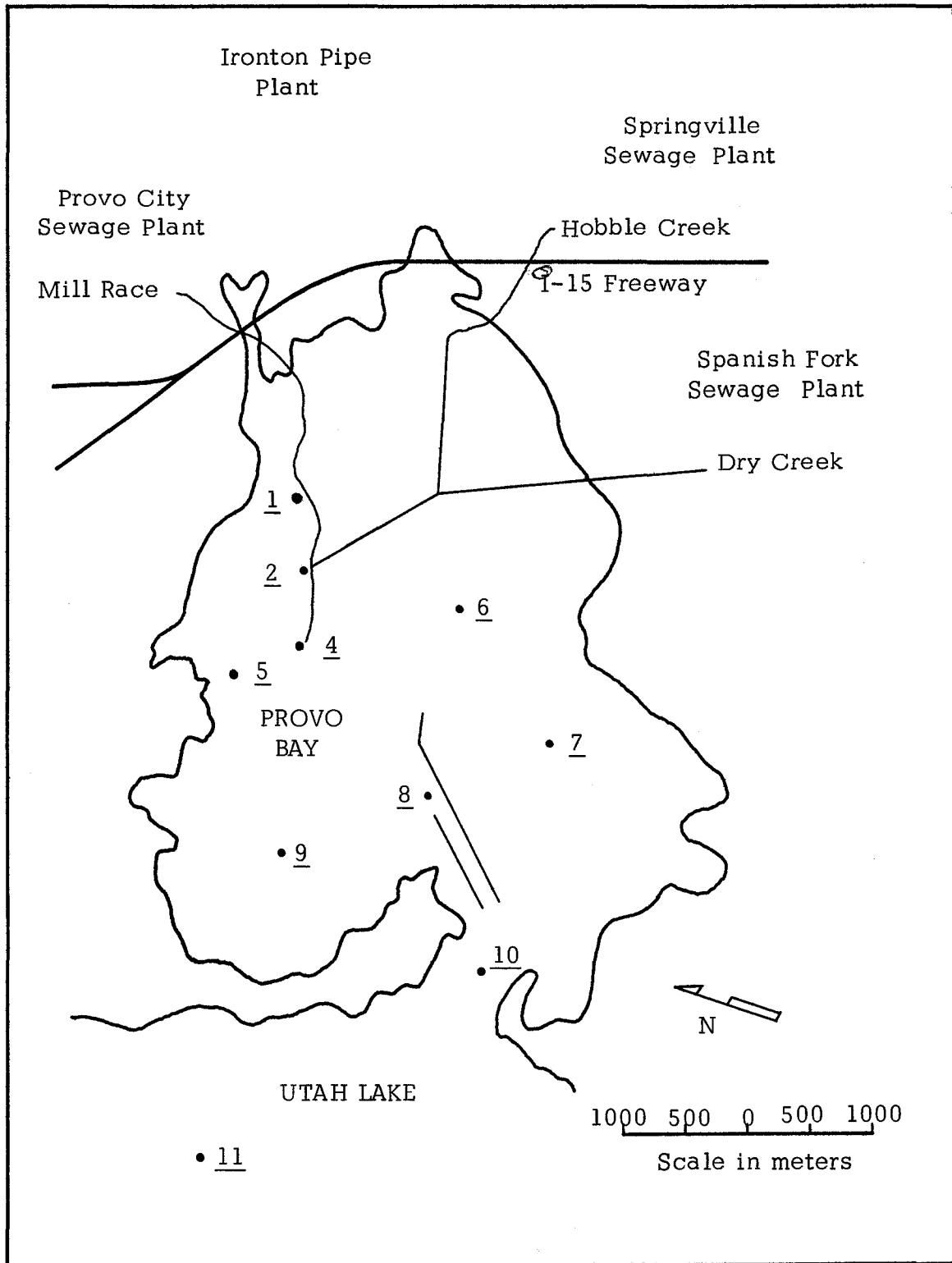


Fig. 1. Map of Provo Bay indicating stations one through eleven
(modified from Stewart, 1968).

Station 11 is located in Utah Lake proper, approximately 2,700 m (9,000 ft) northwest from station 10, and has a depth of 2.2 m.

From June 19, 1970 through February, 1971, these stations were sampled for water quality. An attempt was made to sample weekly during the summer and monthly after September but adverse conditions such as inclement weather, ice cover, etc., occasionally prevented regular sampling.

The stations were reached with an outboard catamaran except during the winter when stations 1, 2, and 4 were reached by rowboat and the other stations by snowmobile.

At the time of sampling, measurements were taken of dissolved oxygen and carbon dioxide using the Hach method (Hach Chemical Co., Ames, Iowa), and pH using a Sargent-Welch pH Meter (Model PBL S-30009) which was equipped with a combination glass electrode and which was calibrated with a standard buffer of pH 7.00 each morning. Samples of water from the bottom were obtained using a Kemmer water sampler. Turbidity was also measured immediately using both the Hach photocell colorimeter (Hach Chemical Co., Ames, Iowa), and the Secchi disk. Water samples were taken to the laboratory for analysis of biochemical oxygen demand (BOD), coliform bacteria density, and phosphates and nitrates. The BOD and bacteria samples were stored in ice chests and refrigerators until analyzed.

In the laboratory, BOD was determined by averaging the

readings of two simultaneous samples from the same station which were run on the Hach BOD apparatus for $2\frac{1}{2}$ days at 37 degrees Centigrade. Coliform counts were determined by standard plate count on commercially prepared agar (American Public Health Association, 1965). Phosphates and nitrates were measured using the Hach portable laboratory (Hach Chemical Co., Ames, Iowa). Samples were also analyzed monthly according to standard methods (American Public Health Association, 1965), using the stannous chloride method to measure phosphates and the Jenkins modification of the Brucine method for nitrates. The results in both cases are reported as milligrams per liter ortho-phosphate and total nitrogen.

Ammonia nitrogen concentrations were not measured during this period. However, on April 29, May 15, and May 21, 1971, samples were collected at the Mill Race just beyond the Provo sewage treatment outfall, and at stations 1, 2, 8, 10, and 11. These samples were analyzed for ammonia nitrogen according to Standard Methods (American Public Health Association, 1965), using the distillation procedure.

RESULTS

Physical Description

The water which flows past station one has a murky, brownish-gray color. When viewed in a beaker it is relatively clear with many small particles in suspension. Along the sides of the channels, particularly towards the end of summer when the water level drops and exposes the banks, thick growths of attached blue-green algae occur. The bottom is composed of a combination of sludge and decaying vegetation, particularly bullrushes. Many carp are seen, often producing an audible sucking sound as they lift their mouths above the surface, an action which is common in waters with low oxygen concentrations (Brinley, 1943). Here, and at station two, agitation of the bottom produces a rush of bubbles composed of methane, ammonia, carbon dioxide, and also hydrogen sulfide, which is quite noticeable due to its odor (Atkins, 1965).

At station two the water appears the same as at station one, although some of the particulate matter has settled out. A species of blue-green algae, Oscillatoria tenuis C. A. Agardh (Harding, 1971), is able to grow on the bottom of the channel due to the penetration of sunlight allowed by the transparency of the water. During the day the

action of photosynthesis produces oxygen which is trapped by the aggregated trichomes of the algae, causing it to rise to the surface of the water in clumps approximately five centimeters in diameter. Occasionally the floating clumps formed a solid mat on the surface of the water. These clumps were observed to break up and sink towards evening when the oxygen was no longer produced.

Occasionally planktonic algae was found suspended in the water at station two, but this was usually due to wind action blowing the surface water eastward against the direction of flow. Stations four through ten had continuous algae blooms consisting largely of Ceratium hirudinella (O. F. Muell.) Dujardin (Harding, 1971). At no time from the onset of summer were dense blooms of algae not observed at these stations. The density of algae was such that a finger run through the water would produce a visible trail in the algae.

Between stations ten and eleven the water from Provo Bay merged with the Lake water. Often a sharp line of demarcation existed between the deep green of the Bay water and the milky color of Utah Lake (White, Cox, and Sundrud, 1970). Because of the higher temperature of the Provo Bay water, it at times flowed over the water of Utah Lake, and a boat moving through the green Bay water would stir up cloudy Lake water from underneath.

With the onset of winter conditions near the end of September the dense algae blooms disappeared, leaving the Bay water a brown

color throughout.

Results of Analyses

Because the main concern of this thesis is the biological processes as they occur in the summer and vary from station to station rather than as they change with time, the means and the standard deviations of the data from June 19 to August 27, 1970, have been calculated. These means show that there was an inverse relationship between the levels of dissolved oxygen (DO) and carbon dioxide (Table 1) as the water moved through Provo Bay. The levels of oxygen of the surface water rose from 5.4 mg/l to 10.2 mg/l and then decreased to 6.9 mg/l at stations 1, 8, and 11 respectively, whereas carbon dioxide dropped from 38 mg/l at station 1 to 0 mg/l at station 8 and then rose to 6 mg/l at station 11. A similar relationship existed with the water at the bottom of the stations, as DO rose from 2.0 to 7.9 mg/l and then decreased to 6.9 mg/l whereas CO₂ decreased from 49 to 6 mg/l and then to 5 mg/l for stations 1, 8, and 11 respectively.

The hydrogen ion concentration (Table 2) correlated closely with the CO₂ concentration, the pH of the surface water being 7.5 at station 1, 9.0 at station 8, and 8.2 at station 11. The pH was not observed to vary greatly with depth.

The Secchi disk readings (Table 3) dropped from 63 cm at station 2 to 22 cm at station 4, and did not vary greatly from then on.

Table 1. Dissolved oxygen (DO) and carbon dioxide (CO_2) concentrations at the various stations in Provo Bay, June 19 to August 27, 1970.

Station	Surface DO mg/l	Bottom DO mg/l	Surface CO_2 mg/l	Bottom CO_2 mg/l
1	$5.4 \pm 4.2^{\text{a}}$	2.0 ± 1.4	$38 \pm 25^{\text{a}}$	49 ± 26
2	8.3 ± 5.3	3.9 ± 3.2	21 ± 24	38 ± 27
4	10.2 ± 3.3	7.2 ± 4.8	3 ± 5	7 ± 11
8	8.3 ± 3.1	7.9 ± 2.7	0 ± 0	6 ± 11
10	7.7 ± 1.6	6.9 ± 1.0	3 ± 8	3 ± 5
11	6.9 ± 1.0	6.9 ± 1.0	6 ± 8	5 ± 6

^aSeasonal mean \pm standard deviation.

Table 2. pH of the water at the various stations in Provo Bay, June 19 to August 27, 1970.

Station	Surface pH	Bottom pH
1	7.5 ± 0.4 ^a	7.4 ± 0.2
2	7.9 ± 0.4	7.8 ± 0.3
4	8.7 ± 0.4	8.5 ± 0.4
8	9.0 ± 0.3	8.8 ± 0.3
10	8.7 ± 0.3	8.5 ± 0.4
11	8.2 ± 0.2	8.3 ± 0.2

^aSeasonal mean ± standard deviation.

Table 3. Secchi disk readings, turbidity, and biochemical oxygen demand (BOD) of the various stations at Provo Bay, June 19 to August 27, 1970.

Station	Secchi disk cm	Turbidity JTU	BOD mg/l
1	62 ± 16 ^a	19 ± 12	17 ± 16
2	63 ± 28	41 ± 32	13 ± 9
4	22 ± 16	80 ± 65	27 ± 11
8	21 ± 11	114 ± 49	51 ± 4
10	18 ± 7	96 ± 43	18 ± 10
11	20 ± 2	57 ± 18	9 ± 0

^aSeasonal mean ± standard deviation.

However, turbidity as measured in Jackson Turbidity Units (Table 3) increased steadily from 19 at station 1 to 114 at station 8, and then declined to 57 at station 11. The turbidity of the water at station 11 is due not to algae but to the high concentration of dissolved and suspended solids of the Lake water (Bradshaw, et al., 1969).

The biochemical oxygen demand (BOD) (Table 3) declined slightly from 17 mg/l at station 1 to 13 mg/l at station 2, increased almost fourfold to 51 mg/l at station 8, and then dropped rapidly to 9 mg/l at station 11.

Because the Hach tests for nitrates and phosphates (Table 4) were repeated more often than the more laborious analyses by standard methods (Table 5), and because there are inherent differences in the accuracy of these methods, identical values were not obtained. However, these values do exhibit similar trends, i.e., the reduction in nitrates and phosphates from stations 1 through 11.

The Hach method (Table 4) shows the nitrate nitrogen declining from a surface mean of 0.28 mg/l and a bottom mean of 0.35 mg/l at station 1 to a surface mean of 0.18 mg/l and a bottom mean of 0.07 mg/l at station 11. As measured by Standard Methods (Table 5), the nitrates decline from a surface mean of 0.71 mg/l at station 1 to a mean of 0.00 at station 11.

Similarly, the Hach method shows the ortho-phosphate declining from a surface mean of 2.62 mg/l and a bottom mean of 4.88 mg/l at

Table 4. Surface and bottom nitrate nitrogen and ortho-phosphate concentrations at the various stations in Provo Bay, June 19 to August 27, 1970.^a

Station	Surface Nitrate mg/l	Bottom Nitrate mg/l	Surface Ortho-phosphate mg/l	Bottom Ortho-phosphate mg/l
1	0.28 ± 0.10 ^b	0.35 ± 0.17	2.62 ± 1.45	4.88 ± 4.58
2	0.28 ± 0.25	0.28 ± 0.16	2.91 ± 0.62	3.34 ± 0.55
4	0.09 ± 0.10	0.16 ± 0.12	1.30 ± 0.97	0.73 ± 0.26
8	0.20 ± 0.15	0.03 ± 0.00	1.20 ± 0.73	1.35 ± 0.96
10	0.18 ± 0.11	0.15 ± 0.15	0.51 ± 0.21	0.37 ± 0.43
11	0.18 ± 0.10	0.07 ± 0.10	0.09 ± 0.08	0.10 ± 0.06

^aAs determined by the Hach method (Hach Chemical Co., Ames, Iowa).

^bSeasonal mean ± standard deviation.

Table 5. Nitrate nitrogen and ortho-phosphate concentrations at the stations in Provo Bay, June 19 to August 27, 1970.^a

Station	Nitrate Nitrogen mg/l	Ortho- Phosphate mg/l
1	0.71 ± 1.01 ^b	3.62 ± 1.26
2	0.02 ± 0.03	2.00 ± 0.70
4	0.09 ± 0.09	1.50 ± 1.08
8	0.08 ± 0.09	0.94 ± 0.15
10	0.12 ± 0.20	0.88 ± 0.60
11	0.00 ± 0.00	0.15 ± 0.10

^aAs determined by Standard Methods (American Public Health Association, 1965).

^bSeasonal mean ± standard deviation.

station 1 down to a surface mean of 0.09 mg/l and a bottom mean of 0.10 mg/l at station 11 (Table 4). Standard Methods (Table 5) indicate the surface ortho-phosphate as declining from 3.62 mg/l at station 1 to 0.15 mg/l at station 11.

Analysis for ammonia nitrogen showed a mean concentration of 2.93 mg/l at the Mill Race just beyond the Provo sewage treatment plant outfall, 1.41 mg/l at station 1, 0.41 mg/l at station 1, and only 0.09 mg/l at station 11 (Table 6).

The coliform density (Table 7) declined drastically from 31,000/100 mls at station 1 to 31/100 mls at station 8 and 0/100 mls at station 11.

The observations from which these means were calculated have been placed in the Appendix.

Table 6. Ammonia nitrogen concentrations for the Mill Race and the various stations in Provo Bay, April 29 to May 21, 1971.

Station	Ammonia Nitrogen mg/l
Mill Race	2.93 \pm 1.36 ^a
1	1.41 \pm 0.41
2	0.41 \pm 0.24
8	0.29 \pm 0.24
10	0.28 \pm 0.24
11	0.09 \pm 0.07

^aSeasonal mean \pm standard deviation.

Table 7. Coliform bacteria concentrations at the various stations in Provo Bay, June 19 to August 27, 1970.

Station	Coliform bacteria /100 ml
1	31000 ± 31500 ^a
2	14000 ± 34000
4	2300 ± 2240
8	31 ± 8.3
10	9 ± 10.2
11	0 ± 0.0

^aSeasonal mean ± standard deviation.

DISCUSSION

Provo, Springville, and Spanish Fork all have secondarily treated sewage. The clearness of the water at station one indicates that the gross material has mostly been removed, and what remains settles to the bottom of the channels where it decomposes. The decomposition of this material utilizes oxygen (Jackson, 1965). Consequently the dissolved oxygen at station one is reduced far below saturation (Figure 2). Often the water at the mud-water interface at the bottom of the channels has been depleted of oxygen; consequently, anaerobic decomposition occurs, producing methane, ammonia, hydrogen sulfide, and carbon dioxide (Atkins, 1965). Figure 3 indicates the high CO₂ content at stations one and two, particularly at the bottom of the channel.

Carbon dioxide goes into solution as carbonic acid (H₂CO₃), which dissociates into hydrogen and bicarbonate ions (H⁺ and HCO₃⁻). In addition, organic acids are produced from decaying vegetation (Chow, 1964) and waste decomposition (Jackson, 1965; Adamse, 1968). Consequently anaerobic decomposition has an acidifying effect on the water. This is reflected in the lower pH values from the bottom of the channels at stations one through ten as compared to the surface

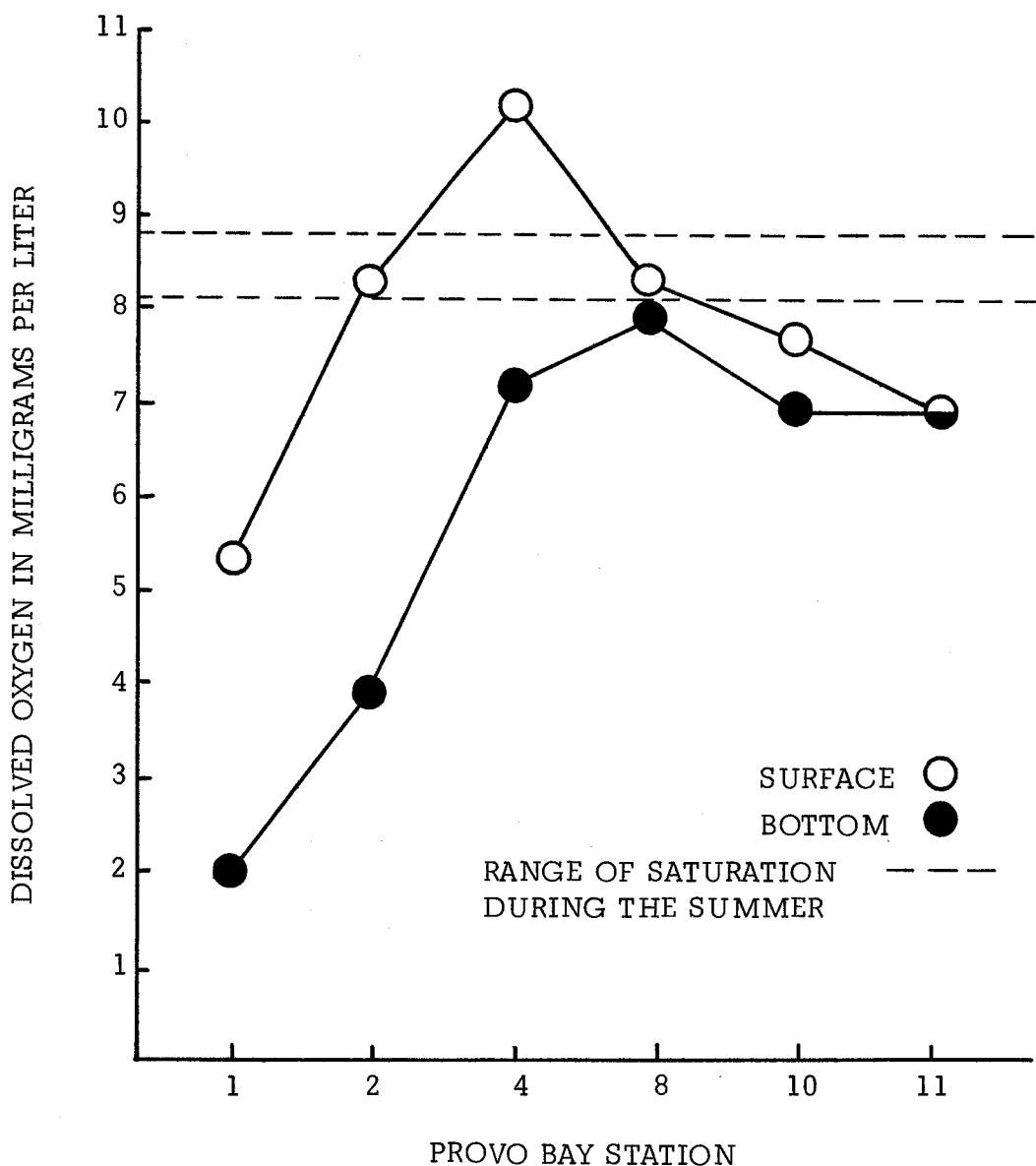


Fig. 2. Mean concentrations of dissolved oxygen for stations 1, 2, 4, 8, 10, and 11 in Provo Bay from June 19 to August 27, 1970.

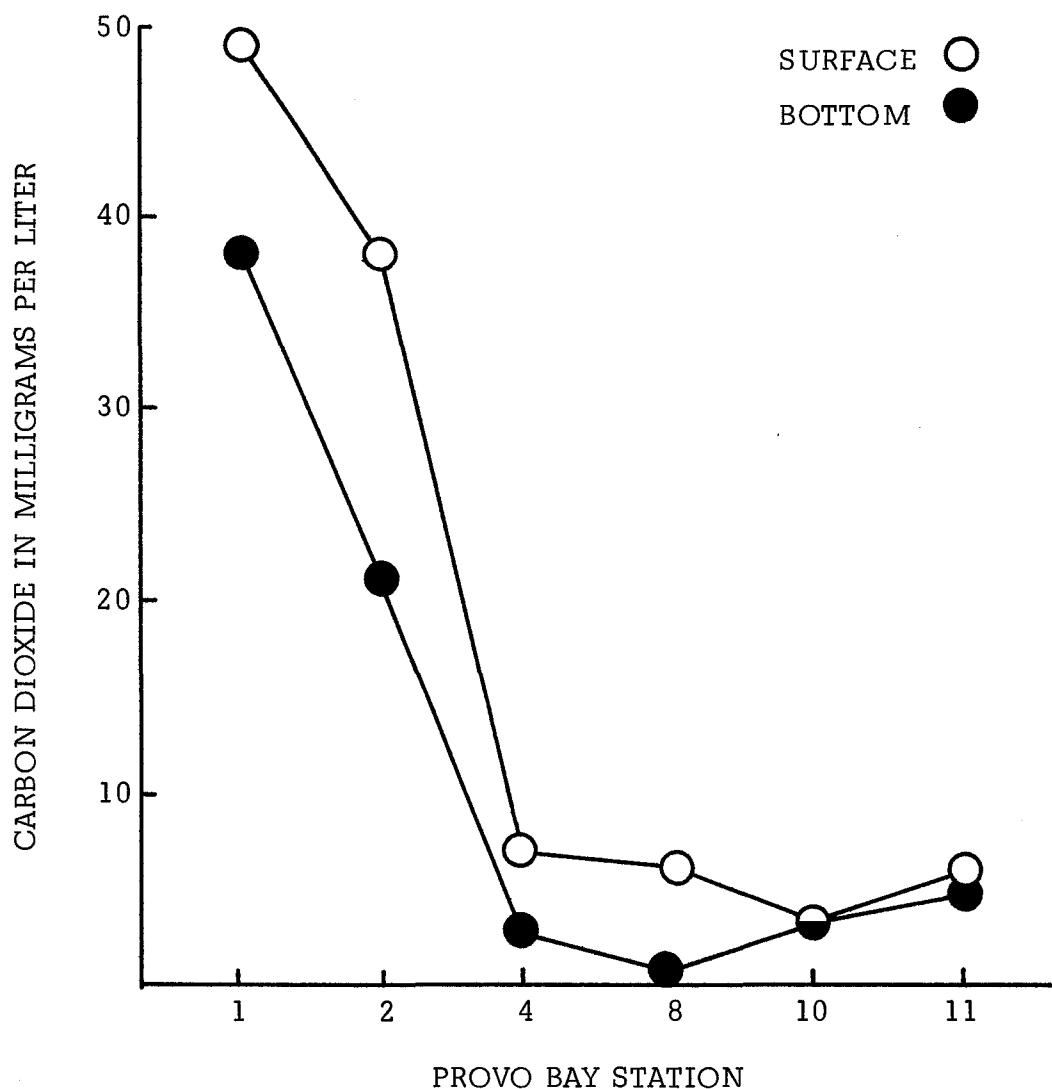


Fig. 3. Mean concentrations of carbon dioxide for stations 1, 2, 4, 8, 10, and 11 in Provo Bay from June 19 to August 27, 1970.

(Figure 4).

Secondarily treated sewage still retains much of its phosphates and nitrates (Weinberger, Stephan, and Middleton, 1966). It is also rich in vitamin B₁₂, an algal micronutrient (Neujahr, 1955; Provasoli, 1969). The anaerobic digestion occurring at the bottom of the upper channels also produces vitamins (Provasoli, 1969). Consequently, the water moving down these channels is rich in the nutrients requisite for algal growth. The growth of algae first occurs between stations two and four, where the current is greatly slowed and the algae has time to multiply. From station four to station ten is a continuous growth of algae flourishing upon the nutrient-laden effluent.

Under the action of sunlight photosynthesis occurs. Carbon dioxide is taken up by the algae, and is reduced to oxygen (Beyers, 1965; Jackson, 1965). The removal of CO₂ from the water alters the equilibrium between carbonic acid and the bicarbonate ion, reducing the hydrogen ion concentration, and increasing the pH. With the depletion of carbon dioxide many aquatic plants, including algae, can actively assimilate HCO₃⁻, utilize the CO₂ from the ion, and release hydroxyl ions to maintain electrostatic balance (Ruttner, 1969). The uptake of CO₂ and the release of the hydroxyl ions accounts for the continual increase in pH from station one to station eight (Figures 3 and 4).

The production of oxygen by photosynthesis in the algae increases the oxygen concentration in the surrounding water. Figure 2

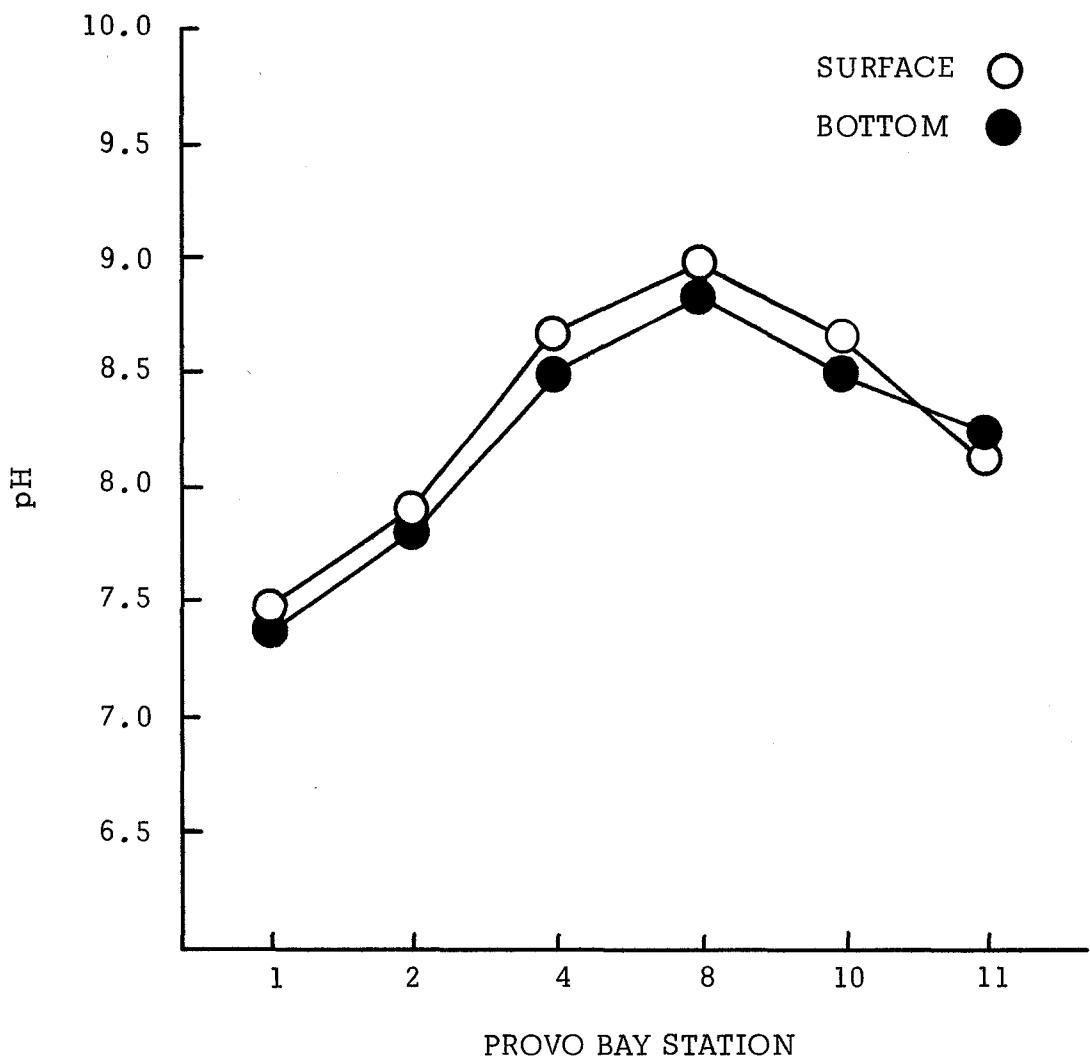


Fig. 4. Mean values of pH for stations 1, 2, 4, 8, 10, and 11 in Provo Bay from June 19 to August 27, 1970.

shows this increase in dissolved oxygen from station one to station four. Stations four through eight were often supersaturated with oxygen. As the water leaves Provo Bay, the dissolved oxygen drops to the average level of the Lake, which is not far below saturation during the summer.

Figure 5 shows a comparison of the Secchi disk and the Hach photocell measurements of turbidity. As algae growth occurs, the previously clear water becomes extremely turbid due to presence of algal cell bodies. Note that the turbidity remains rather high as the water moves into Utah Lake, due to the amount of suspended solids in the Lake water rather than algae cells (Bradshaw, et al., 1969).

The tremendous growth of algae which occurs in Provo Bay is due to the nutrients in the water which the Bay receives. The production of algae, however, utilizes these nutrients to form biomass. The algae formed then either dies and settles to the bottom, or is harvested by the many zooplankton in the water (White, Cox, and Sundrud, 1970), which in turn either die and become sediment or are harvested by higher organisms in the food chain. The consequence of this is the removal of nutrients from the water. Figures 6 and 7 show the top and bottom phosphate and nitrate levels respectively as determined by the Hach method, and Figure 8 shows the phosphate and nitrate levels as determined by standard methods. The levels of phosphate and nitrate at station one are much higher than is necessary to support an algae bloom, being 0.71 mg/l nitrate nitrogen and 3.62 mg/l ortho-phosphate whereas

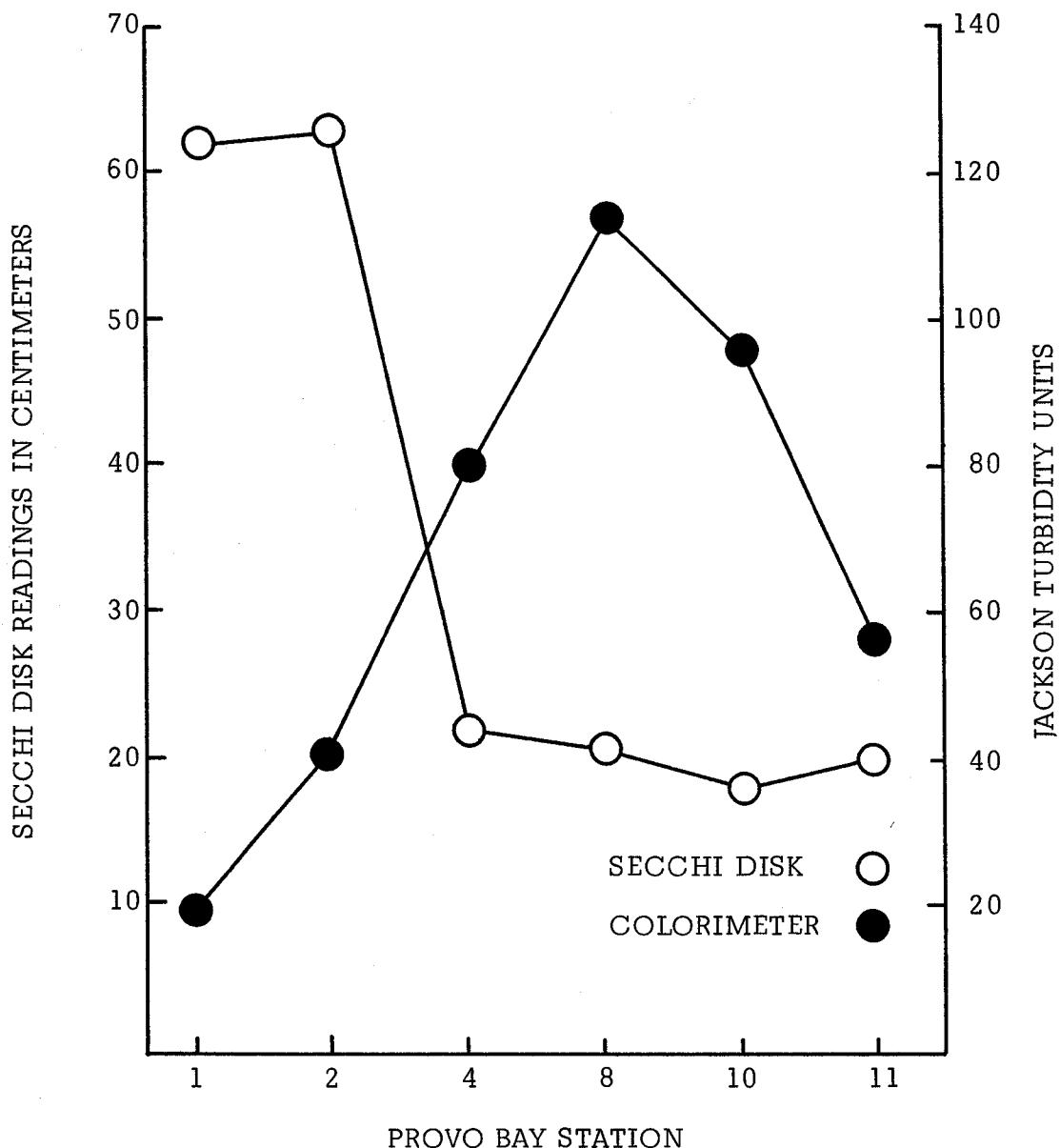


Fig. 5. Mean values for turbidity as measured by Secchi disk and Hach colorimeter at stations 1, 2, 4, 8, 10, and 11 in Provo Bay from June 19 to August 27, 1970.

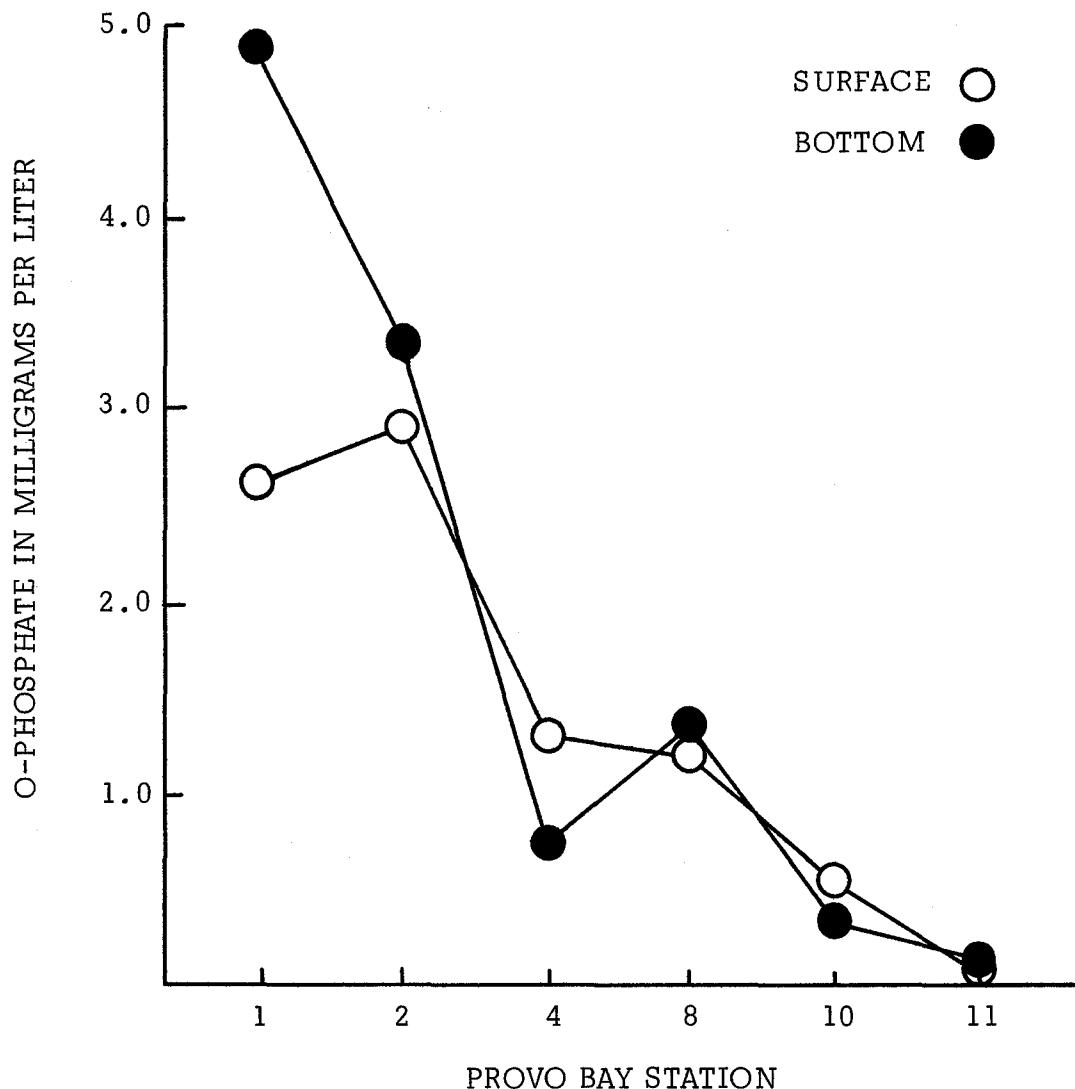


Fig. 6. Mean concentrations of ortho-phosphate as determined by the Hach StannaVer method for stations 1, 2, 4, 8, 10, and 11 in Provo Bay from June 19 to August 27, 1970.

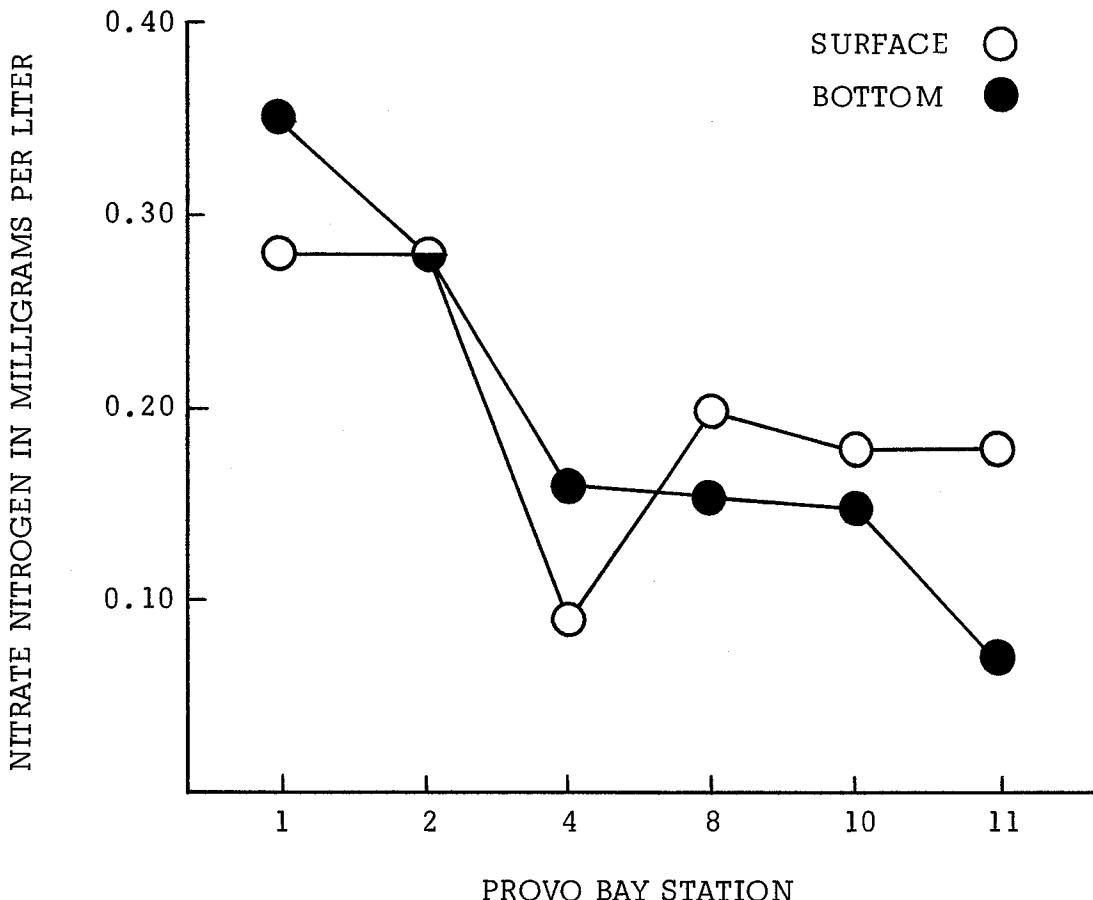


Fig. 7. Mean concentrations of nitrate nitrogen as determined by the Hach cadmium reduction method for stations 1, 2, 4, 8, 10, and 11 in Provo Bay from June 19 to August 27, 1970.

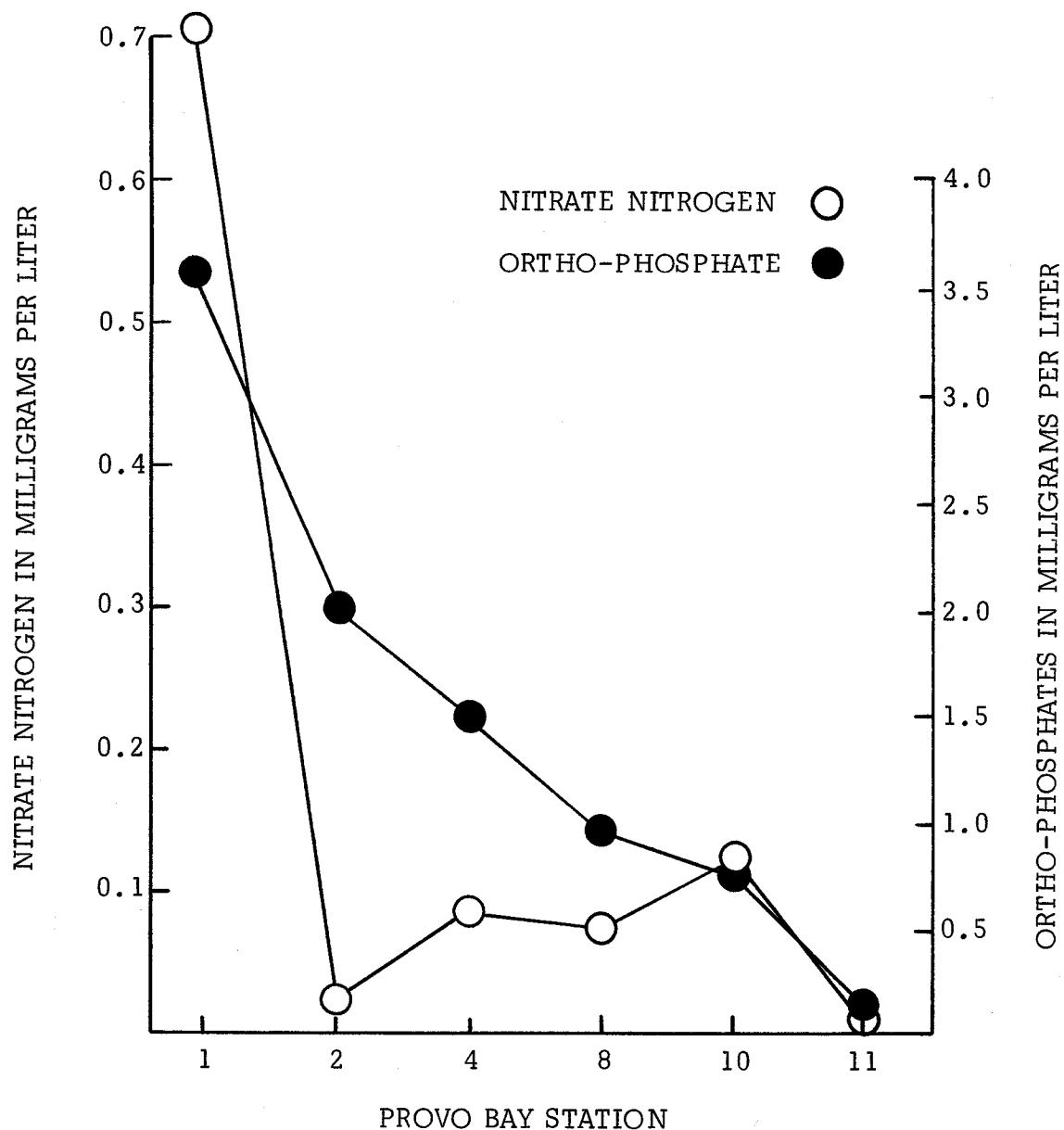


Fig. 8. Mean concentrations of nitrates and phosphates as determined by standard methods for stations 1, 2, 4, 8, 10, and 11 in Provo Bay from June 19 to August 27, 1970.

algae requires only 0.3 mg/l nitrate nitrogen and 0.03 mg/l ortho-phosphate (Lee, 1970). In addition to the nitrate nitrogen, however, is ammonia nitrogen which has a concentration of 2.93 mg/l at station one (Figure 9). This form of nitrogen is easily utilized by the algae and at this concentration greatly exceeds their nutritional requirements. Algae is not observed in the water at station one, however, due to the rapid flow. As the algae blooms develop from station 2 on, note the reduction which occurs in the concentrations of these nutrients.

Station one shows a higher mean BOD than does station two due to the suspended organic particles which settle out between stations one and two (Figure 10). From station two to station four, however, the BOD doubles, and doubles again between stations four and eight. The rapid photosynthetic production of biomass forms short-lived algal bodies composed of complex organic molecules. When the algae die, the organic molecules require oxygen to decompose, thus causing a great oxygen demand. Note the correlation between BOD and turbidity (Figure 5). The reduction in BOD from stations 8 to 11 indicates the removal of algae through harvest and sedimentation.

The coliform bacteria concentration (Figure 11) declines markedly through the Bay due to attenuation and biological assimilation during the lengthy retention period of several days (Loveless, personal communication).

Dilution of the effluents is not a significant factor in the

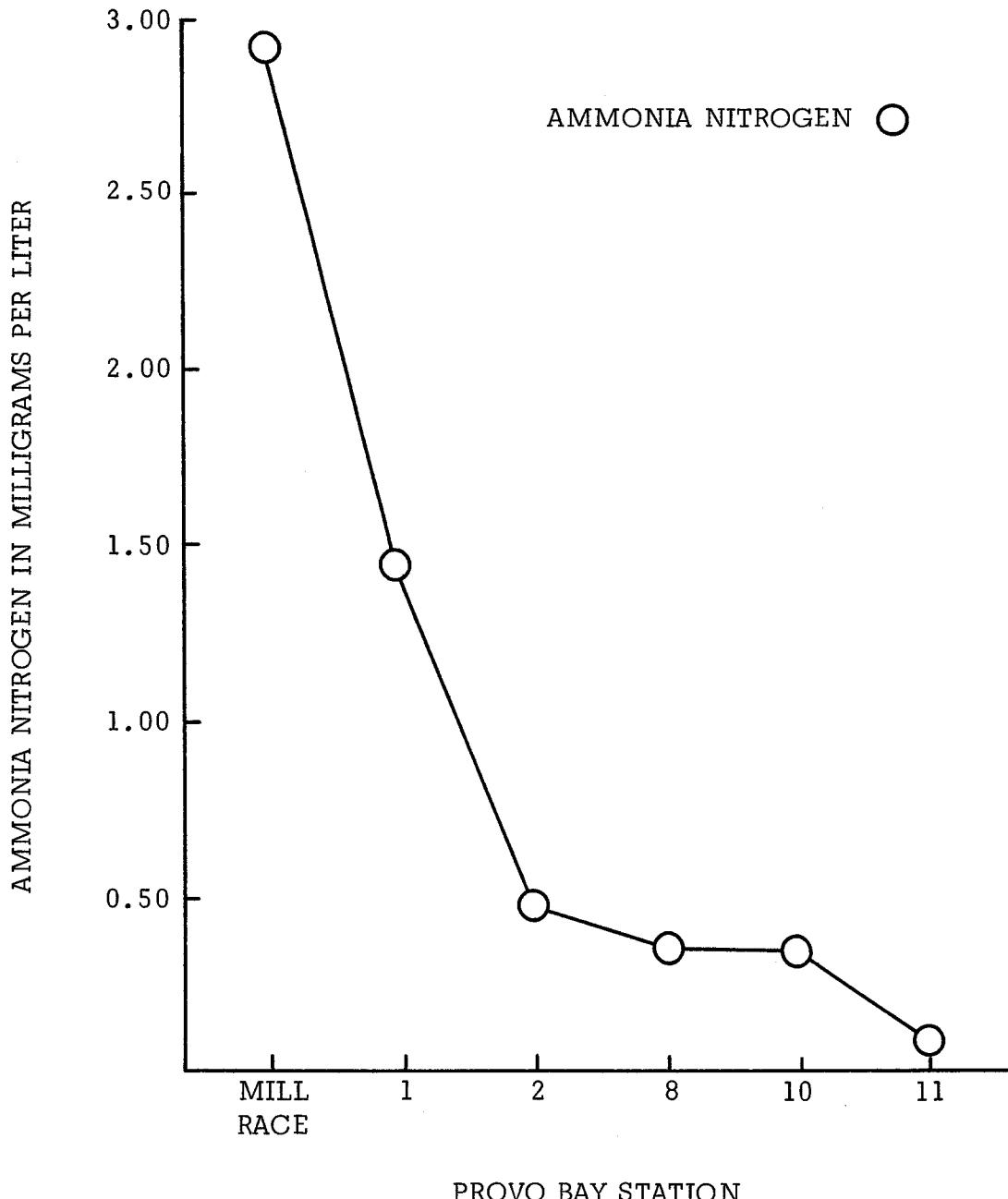


Fig. 9. Mean concentrations of ammonia nitrogen as determined by standard methods for the Mill Race and stations 1, 2, 8, 10, and 11 in Provo Bay from April 29 to May 21, 1971.

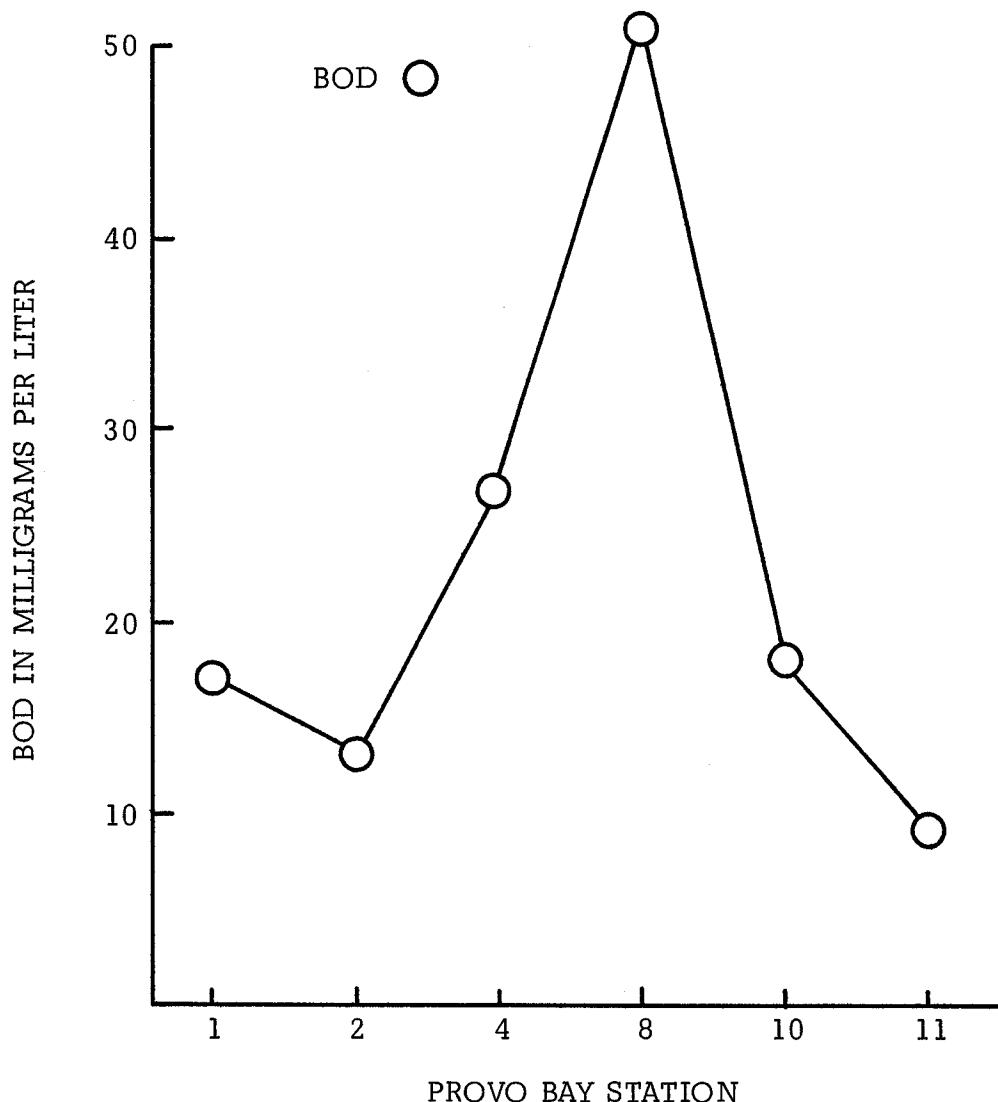


Fig. 10. Mean biochemical oxygen demand (BOD) for stations 1, 2, 4, 8, 10, and 11 in Provo Bay from June 19 to August 27, 1970.

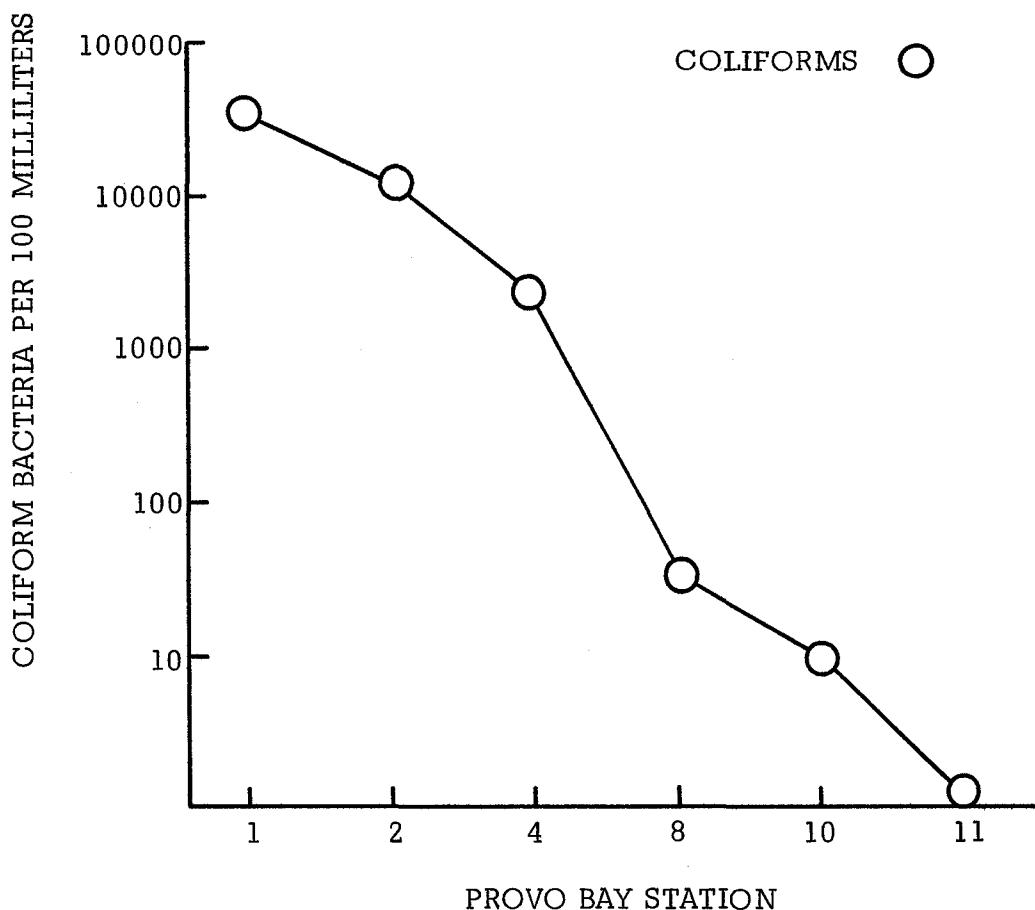


Fig. 11. Mean coliform count for stations 1, 2, 4, 8, 10, and 11 in Provo Bay from June 19 to August 27, 1970.

reduction of these nutrients. Of the water that enters the Bay 52% flows past station one (Loveless, personal communication). Assuming the other 48% is devoid of nutrients, the dilution factor would be no greater than 2:1, whereas the actual nutrient reduction is greater than 10:1 (Tables 4, 5, and 6).

CONCLUSIONS

It is evident that Provo Bay, through biological means, is removing nutrients from the effluents which flow into it before discharging the water into Utah Lake. Because tertiary treatment is defined as the removal of organic nutrients from wastewater (Atkins, 1965), it can be concluded that Provo Bay is a tertiary treatment pond for the effluents which it receives.

During the summer months, Provo Bay receives approximately 43% of the surface waters which enter Utah Lake (Loveless, personal communication). This is a significant percentage of the Lake inflow, particularly since this water contains the waste of approximately 45% of the population of Utah County. Utah Lake is undergoing cultural eutrophication at the present time (Kenison, 1971). That is, an increase in the nutrients responsible for plant growth such as algae is occurring. In May of 1970 a series of calm sunny days produced an algae bloom which stretched across the Lake from shore to shore, and so thick it appeared as a scum on the surface. This was an isolated occurrence, but it indicates that Utah Lake may be in a marginal condition, capable of producing nuisance algae blooms with only slight additional nutrient inflow (Kenison, et al.). Because Provo Bay receives the wastes of

a significant portion of the population in Utah Valley, elimination of Provo Bay, without providing some means of nutrient removal in its place, could cause frequent algal blooms in the Lake throughout the summer, creating a nuisance, reducing the value of the Lake as a recreation area due to esthetic and health reasons, and increasing the rate of filling in of the Lake, all of which are consequences of eutrophication.

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APPENDIX

Table 8. Biological oxygen demand (mg/l) in the water at the surface of the various stations in Provo Bay, 1970-1971^a.

Date	Station					
	1	2	4	8	10	11
July 2	1	17	--	--	4	--
July 9	20	25	38	--	19	--
July 16	49	28	--	38	18	--
July 23	8	8	--	38	18	--
Aug 6	11	9	--	46	25	--
Aug 27	10	2	16	47	37	9
Sept 3	30	25	34	60	--	65
Sept 10	7	10	12	40	33	20
Oct 17	-- ^b	1	--	8	10	10
Nov 21	--	22	--	26	20	--

^aThe samples were analyzed using the Hach manometric apparatus at 37° C. for 2½ days (Hach Chemical Co., Ames, Iowa).

^bThis station could not be sampled by catamaran due to low water.

Table 9. Coliform bacteria per 100 mls of the water at the surface of the various stations in Provo Bay, 1970-1971^a.

Date	Station					
	1	2	4	8	10	11
July 2	1700	75	--	--	0	--
July 9	75000	500	25	--	25	--
July 16	7500	1700	--	0	0	--
July 23	3500	6000	--	0	10	--
Aug 6	65000	30000	--	10	0	--
Aug 27	60000	94000	4500	20	20	0
Sept 3	35000	35000	3250	55	--	0
Sept 10	3000	15000	1000	0	0	0
Oct 17	-- ^b	1000	--	0	10	0
Nov 21	--	10500	--	10	0	--
Jan 9	--	750	30	0	0	--

^aThe counts were determined using a standard plate count on commercially prepared agar (American Public Health Association, 1965).

^bThis station could not be sampled by catamaran due to low water.

Table 10. Ammonia nitrogen concentrations (mg/l) in the water at the Mill Race and various stations in Provo Bay, April 29 to May 21, 1971.^a

Date	Mill Race	Station				
		1	2	8	10	11
April 29	3.86	2.96	0.69	0.45	0.60	0.15
May 15	3.92	1.08	0.46	0.40	0.22	0.11
May 21	1.00	0.20	0.10	0.01	0.02	0.01

^aThe analysis was done using the distillation method (American Public Health Association, 1965).

Table 11. Temperature (degrees Centigrade) of the water at the surface of the various stations in Provo Bay, 1970-1971.

Date	Station					
	1	2	4	8	10	11
June 19	22.3	24.5	24.9	26.8	24.7	26.3
June 25	29.5	28.5	28.5	24.9	24.6	24.5
July 2	21.5	21.9	22.4	19.2	20.1	19.4
July 10	20.0	24.0	-----	-----	-----	22.7
July 16	26.6	27.5	26.9	25.0	24.0	24.0
July 23	18.7	23.0	26.5	21.6	21.7	21.7
Aug 6	23.4	25.6	26.5	26.4	24.0	23.5
Aug 13	23.3	24.6	23.6	28.5	23.1	23.3
Aug 27	21.5	22.0	22.5	22.0	21.5	23.0
Sept 3	-----	19.0	23.5	19.0	23.0	23.0
Sept 10	16.5	16.5	17.0	15.0	15.5	15.0
Sept 26	----- ^a	16.0	15.0	12.5	12.0	12.5
Oct 17	-----	14.5	14.0	11.0	10.0	10.0
Nov 21	-----	9.0	-----	3.0	3.0	3.0
Jan 9	-----	-----	-----	2.2	0.0	1.0

^aThis station could not be reached by catamaran due to low water.

Table 12. Dissolved oxygen concentrations (mg/l) in the water at the surface of the various stations in Provo Bay, 1970-1971^a.

Date	Station					
	1	2	4	8	10	11
June 25	14	8	13	11	8	7
July 2	2	19	11	10	8	6
July 16	5	10	11	9	8	7
July 23	4	3	14	6	6	7
Aug 6	5	3	11	15	10	6
Aug 13	5	7	9	--	8	9
Aug 27	3	4	3	6	5	6
Sept 3	5	4	7	7	10	9
Sept 10	-- ^b	5	4	7	8	7
Sept 26	--	7	6	--	15	11
Oct 17	--	5	6	16	10	11
Nov 21	--	6	--	14	10	10
Jan 9	--	--	6	5	6	--
Jan 30	4 ^c	4	--	--	--	--
Feb 6	7	11	--	--	--	--
Feb 13	4	14	12	--	--	--

^aThe analysis was done using the Modified Azide-Winkler method (Hach Chemical Co., Ames, Iowa).

^bThis station could not be sampled by catamaran due to low water.

^cThese stations were sampled by rowboat. The remainder of the stations had ice cover.

Table 13. Dissolved oxygen concentrations (mg/l) in the water at the bottom of the various stations in Provo Bay, 1970-1971^a.

Date	Station					
	1	2	4	8	10	11
June 25	2	4	14	10	8	7
July 2	0	0	10	9	7	7
July 16	4	11	8	9	8	7
July 23	3	3	--	4	6	6
Aug 6	3	3	--	4	7	6
Aug 13	0	4	4	10	7	9
Aug 27	2	2	0	4	5	6
Sept 3	-- ^b	12	--	5	8	7
Sept 10	--	4	--	4	7	7
Sept 26	--	7	--	8	9	9
Oct 17	--	--	--	12	10	11
Nov 21	--	--	--	13	9	13
Jan 9	--	--	--	4	6	--

^aThe analysis was done using the Modified Azide-Winkler method (Hach Chemical Co., Ames, Iowa).

^bThis station could not be sampled by catamaran due to low water.

Table 14. Carbon dioxide concentrations (mg/l) in the water at the surface of the various stations in Provo Bay, 1970-1971^a.

Date	Station					
	1	2	4	8	10	11
June 25	15	0	0	--	15	--
July 2	65	10	5	0	5	5
July 16	30	0	0	0	0	5
July 23	85	75	0	0	0	25
Aug 6	15	15	0	0	0	0
Aug 13	25	10	0	0	0	0
Aug 27	30	15	15	0	0	0
Sept 10	25	15	10	0	0	5
Sept 26	-- ^b	15	15	0	0	0
Oct 17	--	15	10	0	0	0
Nov 21	--	10	--	0	0	0
Jan 30	5 ^c	5	5	--	--	--

^aThe sample was analysed using phenolphthalein indicator and sodium hydroxide titrant (Hach Chemical Co., Ames, Iowa).

^bThis station could not be sampled by catamaran due to low water.

^cThese stations were sampled by rowboat. The remainder of the stations had ice cover.

Table 15. Carbon dioxide concentrations (mg/l) in the water at the bottom of the various stations in Provo Bay, 1970-1971^a.

Date	Station					
	1	2	4	8	10	11
June 25	75	25	0	30	15	--
July 2	75	85	5	15	5	10
July 16	50	15	0	0	0	15
July 23	80	60	0	0	0	5
Aug 6	20	20	--	0	0	0
Aug 13	30	15	5	0	0	0
Aug 27	15	25	30	0	0	0
Sept 10	--	15	--	0	0	0
Sept 26	--	20	--	0	0	0
Oct 17	--	--	--	0	0	0

^aThe samples were analysed using phenolphthalein indicator and sodium hydroxide titrant (Hach Chemical Co., Ames, Iowa).

^bThis station could not be sampled by catamaran due to low water.

Table 16. pH of the water at the surface of the various stations in Provo Bay, 1970-1971.

Date	Station					
	1	2	4	8	10	11
June 19	6.95	8.10	8.40	8.51	8.40	8.20
June 25	8.30	8.35	8.70	8.80	8.60	8.31
July 2	7.30	8.65	8.46	8.50	8.30	8.20
July 9	7.10	7.38	-----	-----	-----	8.05
July 16	7.70	8.50	8.90	8.97	8.90	8.20
July 23	7.60	7.60	9.15	8.80	8.40	7.95
Aug 6	7.55	7.60	8.65	9.10	8.80	8.20
Aug 13	7.90	7.95	9.05	9.65	8.70	8.50
Aug 27	7.50	7.70	8.00	9.15	9.15	8.60
Sept 3	7.40	7.70	7.85	8.60	9.25	8.65
Sept 10	7.60	7.60	7.80	8.95	9.00	8.55
Sept 26	----- ^a	7.90	8.00	9.15	9.20	8.50
Oct 17	-----	7.70	7.80	9.15	9.20	8.40
Nov 21	-----	7.80	-----	9.05	8.90	8.45
Jan 9	-----	7.75	8.05	7.90	8.05	-----

^aThis station could not be sampled by catamaran due to low water.

Table 17. pH of the water at the bottom of the various stations in Provo Bay, 1970-1971.

Date	Station					
	1	2	4	8	10	11
June 19	7.15	8.00	8.50	8.52	8.00	8.15
June 25	7.35	8.20	8.75	8.70	8.35	8.25
July 2	7.30	7.98	8.40	8.40	7.85	8.00
July 9	7.10	7.40	----	----	----	----
July 16	7.70	8.20	8.70	8.77	8.50	8.30
July 23	7.50	7.55	8.70	8.50	8.50	----
Aug 6	7.35	7.70	----	8.80	8.60	8.30
Aug 13	7.90	7.70	8.80	9.35	8.70	8.50
Aug 27	7.45	7.60	7.60	9.10	9.10	8.55
Sept 3	---- ^a	7.50	----	8.75	8.85	8.50
Sept 10	----	7.55	----	8.90	8.95	8.55
Sept 26	----	7.90	----	9.10	8.95	8.75
Oct 17	----	----	----	9.10	9.05	8.70
Jan 9	----	----	----	7.80	7.90	----

^aThis station could not be sampled by catamaran due to low water.

Table 18. Secchi disk readings (cm) of the water at the various stations in Provo Bay, 1970-1971.

Date	Station					
	1	2	4	8	10	11
June 19	76	18	38	38	30	23
June 25	24	23	34	35	28	27
July 2	76	17	26	30	19	21
July 16	64	16	18	18	17	22
July 23	67	77	0 ^a	11	12	--
Aug 6	76	60	0	12	13	25
Aug 13	58	186	13	12	12	20
Aug 27	58	90	45	12	12	21
Sept 3	-- ^b	--	49	15	14	20
Sept 10	--	58	32	16	17	24
Sept 26	--	94	54	25	21	23
Oct 17	--	49	--	26	20	21
Nov 21	--	55	--	27	27	21
Dec 12	--	--	--	--	28	27
Jan 9	--	--	-- ^c	110	83	--
Feb 6	-- ^{c,d}	61	--	--	--	--
Feb 13	122	62	36	--	--	--

^aAlgae scum covered the surface.

^bThis station could not be sampled by catamaran due to low water.

^cSecchi disk was visible to the channel bottom.

^dThese stations were sampled by rowboat. The remainder of the stations had ice cover.

Table 19. Turbidity (Jackson Turbidity Units) of the water at the various stations in Provo Bay, 1970-1971^a.

Date	Station					
	1	2	4	8	10	11
June 19	--	58	25	45	44	65
June 25	43	50	22	25	30	65
July 2	10	85	35	40	75	60
July 9	20	45	--	--	--	50
July 16	25	95	100	90	82	65
July 23	25	20	220	130	135	90
Aug 6	15	25	120	130	155	40
Aug 13	15	0	100	130	115	50
Aug 27	0	15	20	165	135	70
Sept 3	2	15	0	105	150	70
Sept 10	0	15	28	75	110	70
Sept 26	-- ^b	15	15	60	80	65
Oct 17	--	11	12	55	95	75
Nov 21	--	24	--	78	53	48
Dec 12	--	--	--	--	75	62

^aThe samples were analyzed using the Hach Colorimeter (Hach Chemical Co., Ames, Iowa).

^bThis station could not be sampled by catamaran due to low water.

Table 20. Nitrate nitrogen concentrations (mg/l) in the water at the surface of the various stations in Provo Bay, 1970-1971^a.

Date	Station					
	1	2	4	8	10	11
July 16	0.32	0.05	0.03	0.05	0.03	0.06
July 23	0.36	0.27	0.27	----	0.31	0.31
Aug 6	0.30	0.28	----	0.30	0.24	0.26
Aug 13	0.13	0.73	0.03	----	0.12	----
Aug 27	----	0.06	0.03	0.41	----	0.10
Sept 10	0.24	----	----	0.13	----	----
Sept 26	---- ^b	0.65	1.00	0.58	0.17	0.22
Oct 17	----	1.25	0.90	0.06	0.06	0.06
Nov 21	----	0.52	0.95	0.05	0.05	0.16
Jan 9	----	0.20	----	0.01	0.05	----

^aThe analysis was done using the cadmium reduction method (Hach Chemical Co., Ames, Iowa).

^bThis station could not be sampled by catamaran due to low water.

Table 21. Nitrate nitrogen concentrations (mg/l) in the water at the bottom of the various stations in Provo Bay, 1970-1971^a.

Date	Station					
	1	2	4	8	10	11
July 16	0.47	0.19	0.04	0.03	0.01	0.09
July 23	0.14	0.37	0.27	----	0.30	0.04
Oct 17	---- ^b	----	----	0.06	0.05	0.05
Nov 21	----	----	1.00	0.04	0.08	0.15
Jan 9	----	0.75	----	0.06	0.09	----

^aThe analysis was done using the cadmium reduction method (Hach Chemical Co., Ames, Iowa).

^bThis station could not be sampled by catamaran due to low water.

Table 22. Ortho-phosphate concentrations (mg/l) in the water at the surface of the various stations in Provo Bay, 1970-1971^a.

Date	Station					
	1	2	4	8	10	11
July 2	4.90	2.5	0.45	0.53	0.36	0.14
July 16	3.80	1.40	0.94	1.65	0.93	0.09
July 23	1.40	2.60	0.88	0.77	0.26	0.04
Aug 6	1.62	3.70	-----	2.80	0.45	0.07
Aug 13	-----	3.50	1.00	1.45	0.53	-----
Aug 27	1.40	2.65	3.20	1.35	0.52	0.23
Sept 26	----- ^b	0.80	2.50	0.43	0.70	0.05
Oct 17	-----	1.55	1.35	0.07	0.06	0.05
Nov 21	-----	2.50	-----	0.52	0.12	0.08
Jan 9	-----	4.10	3.80	2.20	1.05	-----
Feb 13	-----	1.8	0.04	-----	-----	-----

^aThe analysis was done using the StannaVer method (Hach Chemical Co., Ames, Iowa).

^bThis station could not be sampled by catamaran due to low water.

Table 23. Ortho-phosphate concentrations (mg/l) in the water at the bottom of the various stations in Provo Bay, 1970-1971^a.

Date	Station					
	1	2	4	8	10	11
July 2	13.0	2.7	0.07	2.70	0.35	0.17
July 16	3.00	2.70	1.07	0.71	0.38	0.13
July 23	1.90	3.50	0.44	0.64	0.32	0.06
Aug 6	2.5	4.00	----	----	0.42	0.04
Oct 17	---- ^b	----	----	0.28	0.24	0.13
Nov 21	----	----	----	0.64	0.24	0.12
Jan 9	----	3.80	3.90	1.55	1.45	----
Feb 13	----	----	----	----	----	----

^aThe analysis was done using the StannaVer method (Hach Chemical Co., Ames, Iowa).

^bThis station could not be sampled by catamaran due to low water.

Table 24. Ortho-phosphate concentrations (mg/l) in the water at the surface of the various stations in Provo Bay, 1970-1971^a.

Date	Station					
	1	2	4	8	10	11
July 9	5.00	----	0.06	----	0.40	----
July 16	3.90	1.30	1.10	1.00	0.90	0.10
Aug 27	1.95	2.70	2.70	1.30	1.85	0.20
Oct 17	---- ^b	2.70	----	0.65	0.36	0.50
Nov 21	----	3.25	----	----	0.43	0.77
Jan 9	----	3.28	3.50	2.60	2.00	----
Jan 30	3.10 ^c	4.00	3.00	----	----	----
Feb 6	3.05	3.70	2.42	----	----	----
Feb 13	2.11	2.17	0.95	----	----	----
Feb 23	2.11	1.25	0.87	0.13	0.23	0.60

^aThe analysis was done using the stannous chloride method.

^bThis station could not be sampled by catamaran due to low water.

^cThese stations were sampled by rowboat. The remainder of the stations had ice cover.

Table 25. Nitrate nitrogen concentrations (mg/l) in the water at the surface of the various stations in Provo Bay, 1970-1971^a.

Date	Station					
	1	2	4	8	10	11
July 9	0.00	----	0.09	----	0.41	----
July 16	2.14	0.04	0.00	0.04	0.00	0.00
Aug 27	0.00	0.00	0.18	0.16	0.00	0.00
Oct 17	---- ^b	0.91	----	0.06	0.05	0.05
Nov 21	----	0.41	----	----	0.07	0.22
Jan 9	----	0.76	1.12	0.28	0.10	----
Jan 30	0.44 ^c	0.36	0.33	----	----	----
Feb 6	0.45	0.40	0.33	----	----	----
Feb 13	0.43	0.21	0.06	----	----	----
Feb 23	0.22	0.05	0.05	0.09	0.11	0.15

^aThe analysis was done using the Jenkins modification of the Brucine method (American Public Health Association, 1965).

^bThis station could not be sampled by catamaran due to low water.

^cThese stations were sampled by rowboat. The remainder of the stations had ice cover.

THE BIOCHEMICAL RESPONSE OF PROVO BAY
TO NUTRIENT INFLOW

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Department of Zoology

M.S. Degree, August 1971

ABSTRACT

Provo Bay of Utah Lake, Utah, receives the effluents from farms, industry, and three cities. In order to determine the effects of these effluents, eleven stations were established throughout the Bay. At weekly intervals from June 19 to October 26, 1970, and monthly thereafter until March, 1971, the water at these stations was sampled for dissolved oxygen (DO), carbon dioxide (CO₂), turbidity, pH, phosphates, nitrates, biochemical oxygen demand (BOD) and coliform bacteria.

Due to intense algal blooms, the quality of the water changes as it passes through Provo Bay. Average values for the inflow, mid-Bay, and point of discharge respectively during the summer are as follows: DO, 5.4--10.2--6.9 mg/l; CO₂, 38--0--6 mg/l; turbidity, 19--80--57 Jackson Turbidity Units; pH, 7.5--9.0--7.2; phosphates, 3.62--0.94--0.15 mg/l; nitrates, 0.71--0.08--0.00 mg/l; BOD, 17--27--9 mg/l; and coliforms, 31,000--31--0/100 ml. These results indicate that during the summer Provo Bay is acting as a tertiary treatment pond for the effluents which it receives.

COMMITTEE APPROVAL: