Chemical Response of Utah Lake to Nutrient Inflow

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Utah Lake is a large fresh water lake in the central portion of Utah (Figure 1). The lake is 25 miles (40.25 km) long, 11 miles (17.7 km) wide and has an average depth of 9 ft (2.7 m). Most of the inlets to Utah Lake are on the east shore and the only outlet is the Jordan River to the north.

Utah Lake is presently used for recreation, sport fishing, hunting, and commercial fishing and also as a reservoir for the water users of the Utah Lake and Jordan River irrigation system. In addition, the lake has become a biological oxidation system for the treated wastewater from nine municipal treatment (primary and secondary) plants and a settling pond for one medium-size steel plant and other small industries.

When Utah Valley (the area around Utah Lake) was settled in the early 1850's commercial fishing was the main industry.[1] There is still some commercial fishing on the lake; however, the type of fish has changed from native trout to introduced fish varieties such as carp and perch.[1, 2] The probable reasons for the change in the fish population were the chemical changes in the water resulting from a rapid increase in irrigation of the region, as well as the regulation of Utah Lake for storage of water for Salt Lake County.[1]

A great change in the water chemistry was noted for the years before 1900. In 1884, the total dissolved salt content was 306 mg/l with only small quantities of sodium (17.8 mg/l) and chloride (12.4 mg/l).[3] In 1899, the total dissolved salts increased to 892 mg/l with the major increases in sodium (234 mg/l) and chloride (316.8 mg/l).[4] One reason for this increase in salts was a 5-ft (1.5-m) decrease in the level of the water in Utah Lake. Even with this decrease, however, the amount of salt changed to a great extent. Sodium and chloride contents increased by a factor of about 20, while sulfate increased by less than a factor of 2 (130.6 to 236.4 mg/l). Since 1900, the salt content has remained fairly constant. During years of high lake levels, the water contains less salt per volume, while in low water years it contains a higher level of salt.[5] Even though there were numerous water analyses before 1968, no data on nutrient levels in Utah Lake have ever been published.[5]

During the summer of 1969, it was noted that the nutrient levels were very high in the water of Provo Bay where the Provo, Springville, and Spanish Fork, Utah, wastewater effluents entered (Figure 1).[6] An extensive bloom of algae covered the entire bay and extended into Utah Lake.[7] An odor nuisance and increase in insect population over other areas of Utah Lake were also observed. These are characteristics of lakes that have received wastewater effluents.[8] A study of the effects of wastewater discharges to Utah Lake was made so that recommendations concerning the control of the undesirable effects could be presented to the various governing bodies in the valley.

Procedure

Sampling stations were set up in Provo Bay along canals that were originally dug in 1932 when the water level was low (Figure 2). These stations were sampled weekly during the summer months and periodically during the winter using either a boat or snowmobile.

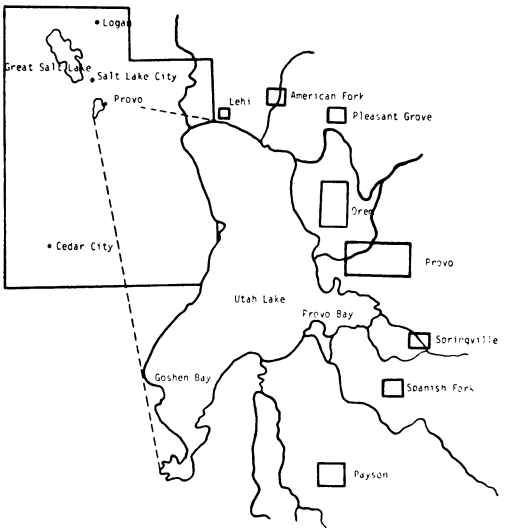

FIGURE 1.—Utah Lake, Provo, Utah.

At the time of sampling, measurements were taken of dissolved oxygen (DO) using a Hach modified Winkler method,[9] carbon dioxide using a colorimeter method,[9] and pH using a pH meter* equipped with a combination glass electrode and calibrated each morning with a standard buffer of pH 7.00. Samples of water from the bottom were obtained using a Kemmer water sampler. Turbidity was also measured immediately using both a Hach photocell colorimeter [9] and a Secchi disk. Water samples were taken to the laboratory for analysis of biochemical oxygen demand (BOD), coliform bacteria density, phosphates, nitrates, and ammonia. The BOD, bacteria, and chemical samples were stored in ice chests and refrigerators until analyzed.

In the laboratory, BOD was determined by averaging the one station's readings from two samples that were analysed on the Hach BOD apparatus [9] for 2.5 days at 37°C. Coliform counts were determined by standard plate count on commercially prepared agar.[10] Phosphates and nitrates were measured using a portable laboratory [9] in the field. Duplicate samples were also analyzed according to "Standard Methods" [10] using the stannous chloride method to measure phosphates and the Jenkins modification of the Brucine method to measure nitrates. The results in both cases were reported in milligrams per liter of total phosphorous and total nitrogen. Ammonia-nitrogen concentrations were determined using the distillation procedure in "Standard Methods." [10]

The phytoplankton were collected using a vertical Birge cone net, counted in a Sedgwick-Rafter cell, and reported as phytoplankton per liter. An Eckman dredge was used to collect the midge larvae. The benthic samples were washed in a large screen pail (0.5-mm mesh), and chironomids were counted in a ruled-light sorting tray.

The other chemical parameters (calcium, magnesium, sodium, potassium, chloride, bicarbonate, and sulfate) were determined using standard techniques.[10]

* Model PBL S-30009, Sargent-Welch.

RESULTS AND DISCUSSION

Figures 3 through 5 show the mean data values from the summer of 1970 for the six stations in Provo Bay. The mean concentrations of the nutrients are given in

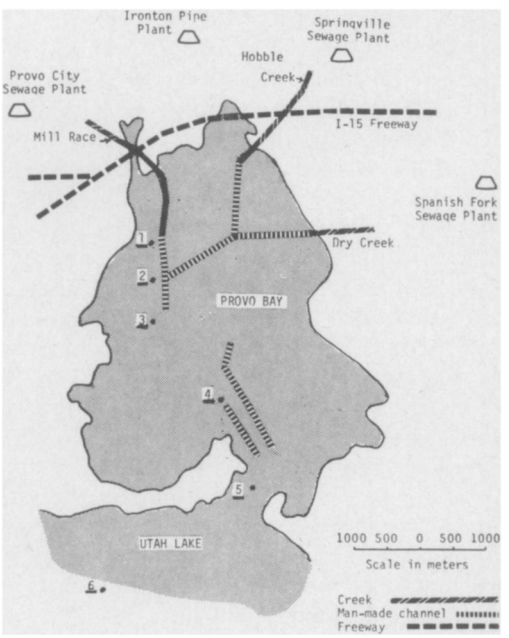

FIGURE 2.—Map of Provo Bay, Utah, showing Stations 1 through 6.

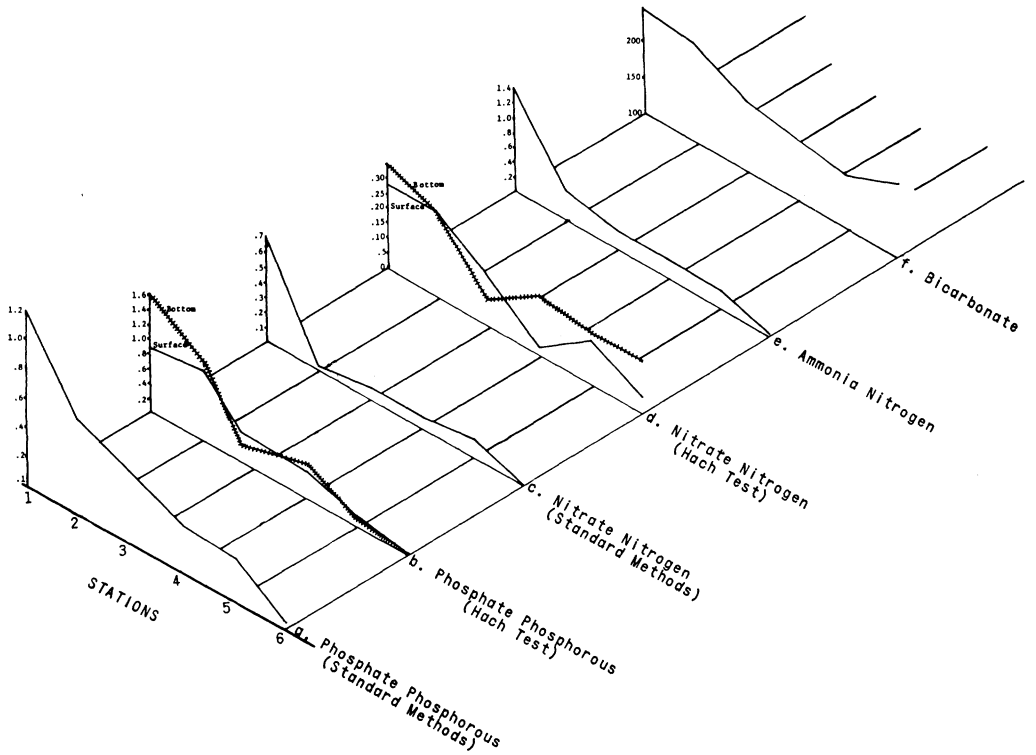

FIGURE 3.—Nutrient concentrations in mg/l found in Provo Bay during the summer of 1970.

Figure 3. The mean values for DO, and carbon dioxide, pH, and turbidity are shown in Figure 4, and the mean biological factors are shown in Figure 5. A chemical analysis of the water in Provo Bay for May 1971 is given in Table I. Table II shows a partial analysis taken in January 1971.

It is evident from the data in Figures 3 through 5 that great changes occurred in Provo Bay. The nitrogen and phosphorous levels decreased significantly (Figure 3) while the BOD, algal, and chironomid larvae levels increased significantly. The other chemical, physical, and biological factors also changed as the water passed through Provo Bay. These changes resulted from the biological changes caused by the heavy nutrient load introduced to Provo Bay by wastewater effluents.

Provo, Springville, and Spanish Fork, Utah, all have secondary treatment. The clearness of the water at Station 1 (Figure 4) indicates that most of the large material had been removed and what remained settled to the bottom of the channels and decomposed. The decomposition of this material consumes oxygen.[11] Consequently, the DO at Station 1 was reduced far below saturation (Figure 4). Often, the water at the mud-water interface at the bottom of the channels had been depleted of oxygen; consequently, anaerobic decomposition occurred and produced methane, ammonia, hydrogen sulfide, and carbon dioxide.[12] Figure 4 also indicates a high carbon dioxide content at Stations 1 and 2, particularly at the bottom of the channel.

Carbon dioxide goes into solution as carbonic acid (H_2CO_3), which dissociates into hydrogen and bicarbonate ions (H^+ and HCO_3^-). In addition, organic acids are produced from decaying vegetation[13] and waste decomposition.[11, 14] Consequently, anaerobic decomposition has an acidifying effect on the water. This is re-

flected in the lower pH values found at Station 1 where the wastewater enters Provo Bay (Figure 4).

Treated wastewater from secondary plants still retains most of its phosphate and nitrate content.[15] It is also rich in vitamin B_{12}, an algal micronutrient.[16, 17] Thus, the water moving down the channels was rich in the nutrients requisite for algal growth. The growth of algae first occurred between Stations 2 and 3, where the current was slow and the algae had time to multiply. From Station 3 to 5, a continuous growth of algae that flourished on the nutrient-laden effluent was evident (Figure 5).

In the presence of sunlight, photosynthesis occurs. Carbon dioxide is taken up by the algae and oxygen is released.[11, 18] The removal of carbon dioxide 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 HCO_3^-, use the CO_2 from the ion, and release hydroxyl ions in order to maintain electrostatic balance.[19] The uptake of carbon dioxide and the release of the hydroxyl ions accounts for the continual increase in pH from Stations 1 to 8 (Figure 4). In this case, an actual decrease in bicarbonate ion concentration was observed (Figure 3 and Table I). This decrease was not observed during the winter months when little photosynthesis was taking place (Table II).

The production of oxygen from photosynthesis in the algae increases the oxygen concentration in the surrounding water. Figure 4 shows this increase in DO from Stations 1 to 3. Stations 3 and 4 were often supersaturated with oxygen. As the water leaves Provo Bay, the DO concentration drops to the lake's average level, which is not much below saturation during the summer.

Figure 4 shows a comparison of the Secchi disk and the Hach photocell measurements of turbidity. As algal growth

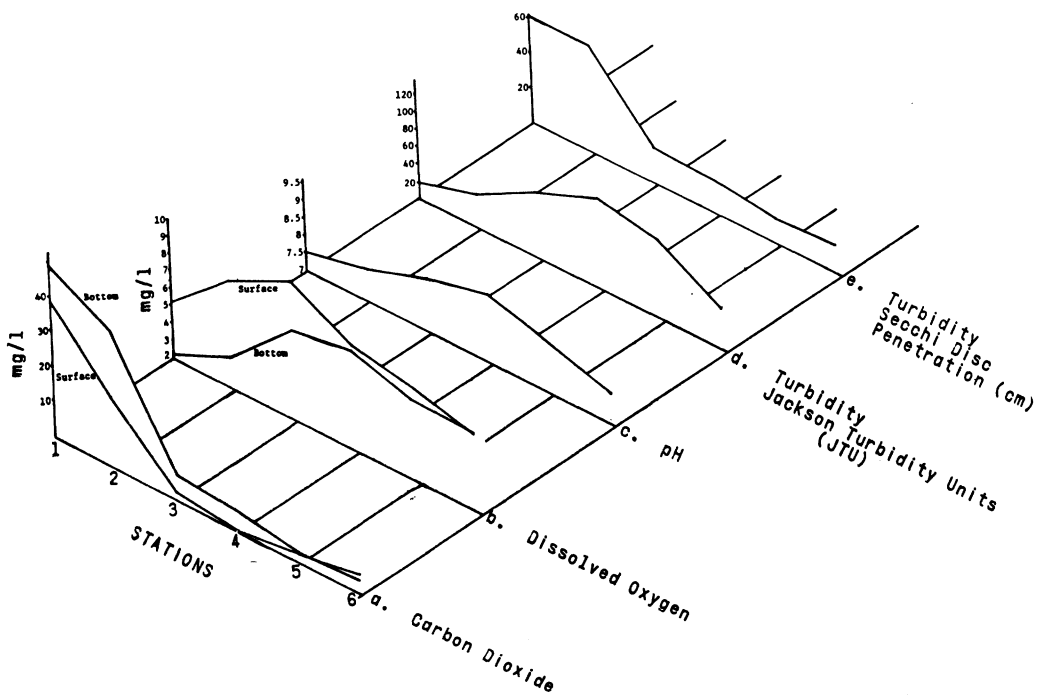

FIGURE 4.—Chemical and physical parameters of Provo Bay found during the summer of 1970.

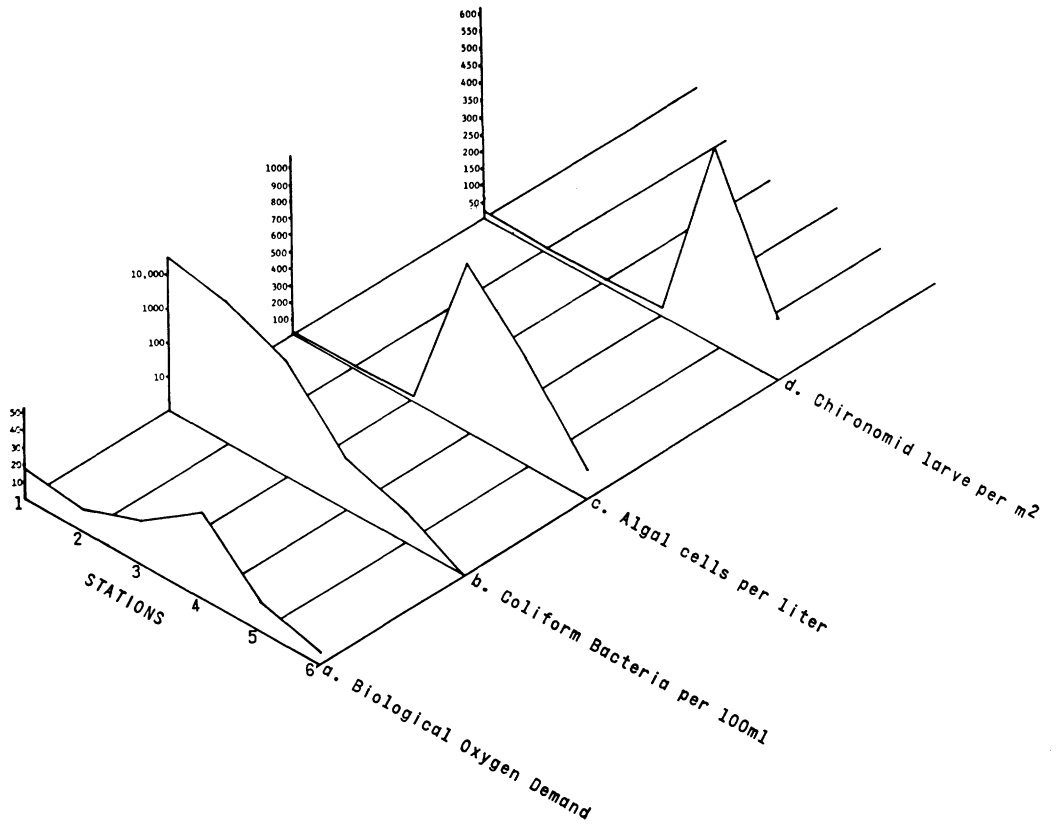

FIGURE 5.—Biological parameters of Provo Bay found during the summer of 1970.

occurs, the previously clear water becomes extremely turbid because of the presence of algal bodies. Note that the turbidity remained high as the water moved into Utah Lake. This is because of the large amount of suspended solids in the lake water rather than algae cells.[5] The Secchi disk measurements proved to be better at low turbidity [10 to 40 Jackson turbidity units (JTU)], while the photo cell produced better results at high turbidity (40 to 200 JTU).

The tremendous algal growth that occurred in Provo Bay resulted from the nutrients that the bay received. The production of algae, however, uses these nutrients to form biomass. The algae formed then either died and settled to the bottom or were harvested by the zooplankton, which in turn either died and become sediment or were harvested by higher organisms in the food chain. It is interesting to note that chironomid larvae, one of the many consumers, had a peak bloom at Station 5 (Figure 5), which is downstream from the main algal bloom at Station 4 (Figure 5). It was found that 80 percent of the larval diet was composed of algal cells. The net result of these activities was removal of bay nutrients.

Figure 3 shows the top and bottom phosphate and nitrate levels determined by the Hach method and the levels determined by "Standard Methods."[10] The results showed that the Hach method for phosphate was comparable to "Standard Methods"[10] but that the nitrate test was not. The levels of phosphate and nitrate at Station 1 were much higher than necessary to support an algal bloom. Levels were 0.71 mg/l nitrate-nitrogen (Figure 3) and 1.18 mg/l orthophosphate (Figure 3) while

TABLE 1.—Chemical Parameters of Provo Bay on May 14, 1971

Characteristic (mg/l)	Station						Utah Lake Center*
	1	2	3	4	5	6	
Ca	98	90	86	67	74	68	62
Mg	29	32	35	35	39	54	51
Na	47	69	80	83	103	145	140
K	6	7	7	7	9	16	18
Cl	34	49	62	61	85	173	188
Bicarbonate, HCO_3	259	245	245	217	214	214	266
Sulfur, SO_4	111	121	127	124	147	205	213
Nitrate-nitrogen, NO_3	0.34	0.12	0.11	0.06	0.08	0.28	0.32
Ammonia-nitrogen, NH_3	1.08	0.46	0.34	0.40	0.22	0.11	—
Phosphorous, PO_4	2.62	1.12	0.64	0.47	0.09	0.13	0.26
pH	7.95	8.20	8.30	8.40	8.45	8.50	8.05
Conductivity, μMHOS/cm	620	670	720	700	770	1,075	1,370

* Performed by Utah Division of Health, May 14, 1970.

algae require only 0.3 mg/l inorganic nitrogen and mg/l orthophosphate.[20] In addition to the nitrate-nitrogen, there was ammonia-nitrogen that had a concentration of 1.41 mg/l at Station 1 (Figure 3). This form of nitrogen is easily utilized by the algae, and at this concentration greatly exceeded their nutritional requirements. Algae were not observed in the water at Station 1 because of a fast current. As the algal blooms developed beyond Station 3 (Figure 5), the reduction that occurred in the concentrations of these nutrients and bicarbonate can be seen.

Station 1 showed a higher mean BOD than did Station 2 because of the suspended organic particles that settled out between Stations 1 and 2. Between Stations 2 and 3, however, the BOD doubled, doubling again between Stations 3 and 4. The rapid photosynthetic production of biomass formed short-lived algae composed of complex organic molecules. When the algae died, the organic molecules required oxygen to decompose and thus caused a large BOD. The correlation between BOD and turbidity can be seen in Figure 4. The reduction in BOD from Stations 4 to 6 indicates the removal of algae through harvest and sedimentation.

The coliform bacteria concentration declined markedly through the bay. This decrease was attributed to attenuation and biological assimilation during the lengthy retention period.

Dilution of the effluents was not a significant factor in the reduction of nutrients. Of the water that entered the bay, an estimated 50 perecent flowed past Station 1. Assuming the other 50 percent was devoid of nutrients, the dilution factor would be no greater than 2:1, whereas the actual

TABLE II.—Chemical Parameters of Provo Bay during January 1971

Characteristic (mg/l)	Station					
	1	2	3	4	5	6
Bicarbonate, HCO_3	259	265	280	282	258	226
Nitrate-nitrogen, NO_3	0.55	0.36	0.33	0.28	0.10	0.11
Ammonia-nitrogen, NH_3	2.08	2.67	2.05	1.87	0.83	—
Phosphorous, PO_4	3.10	4.00	3.00	2.60	2.00	0.40
pH	7.45	7.60	—	8.10	8.30	8.45
Conductivity, μMHOS/cm	1,065	665	600	805	825	1,145

nutrient reduction was greater than 10:1 (Figure 3).

SUMMARY

It is evident that Provo Bay was removing nutrients from the effluents that flowed into it before being discharged into Utah Lake. This is important to the overall quality of Utah Lake water because over 40 percent of the surface waters entering the lake do so through Provo Bay. This surface water contains waste from approximately half of the population around the lake. The water of Utah Lake has excess phosphorous but not enough nitrogen to support extended algal blooms, except during the winter and early spring months. At those times, the water is too cold and there is not enough sunlight to support extensive photosynthesis. Occasionally a large algal bloom does occur in the late spring. One such occurrence happened in May 1970 after a series of calm sunny days. The algal bloom appeared as a scum on the surface of Utah Lake from the east to the west shore. This event shows that Utah Lake is in a marginal condition for agal growth support. An increase in nutrients (particularly nitrogen) would create a much greater algal nuisance than normally would be expected.

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