Hydrobiologia vol. 40, 3, pag. 297—319, 1972.

The Physicochemical Limnology of a Stretch of the Guadalupe River, Texas, With Five Main-stream Impoundments

by

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INTRODUCTION

Few physicochemical studies of a comprehensive nature have been undertaken on fresh water ecosystems in Texas. With the exception of studies conducted in the Edward's Plateau region by KUEHNE (1955), HIGGINS & FRUH (1968), and FRUH & DAVIS (1969), most of the studies are for impoundments located in north Texas (CLARK, 1966). None of these studies consider the physicochemical conditions of a reach of river including a sequence of main-stream reservoirs that do not exhibit thermal stratification. MACKENTHUM & INGRAM (1967) define a main-stream reservoir as an impoundment formed by a relatively low dam, where much of the impounded water is restricted to the original channel and water retention ranges from a few days to weeks, and water surface fluctuations usually are controlled within a few feet.

The Guadalupe River between New Braunfels and Gonzales, Texas, provides an excellent opportunity to study the effect of main stream reservoirs that do not stratify, since included in this stretch are Lake Dunlap, Lake McQueeney, Lake Placid, Meadow Lake, Lake Gonzales and Lake Wood. The objectives of this study were to determine a limnological profile for a stretch of river with these main-stream reservoirs and to determine the associated cause-effect relationships.

Received Aug. 2, 1971.

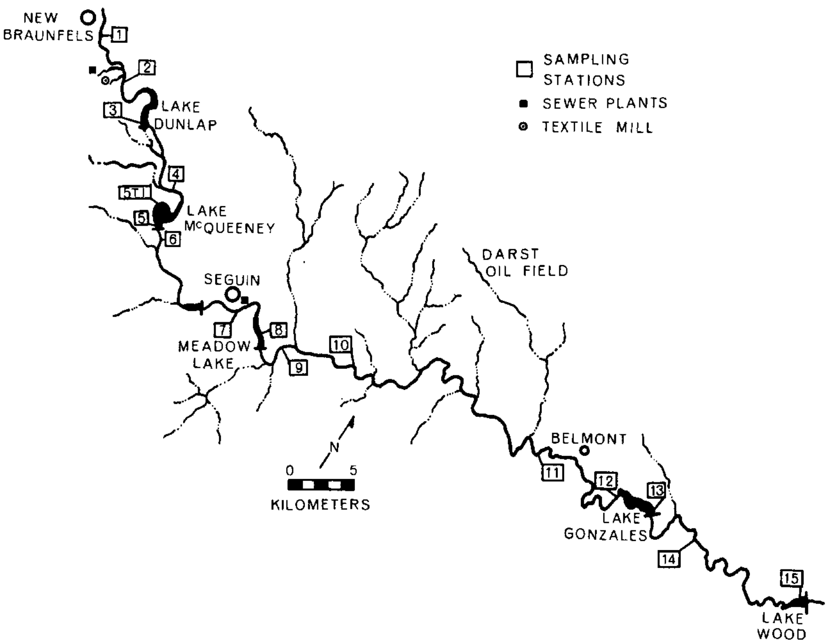

Fig. 1. Map of the New Braunfels to Gonzales stretch of the Guadalupe River.

Study area

The study area is located along a 168–km stretch of the Guadalupe River from New Braunfels to Lake Wood, upstream from Gonzales, Texas. Within this stretch of the river there are six small hydroelectric dams. The Comal River and Canyon Reservoir, a deep storage reservoir located 30 km upstream, provide the principal water sources for the study area.

Location of stations and effluents are shown in Fig. 1.

Station 1 was located directly below the Interstate 35 highway bridge approximately 1.6 km downstream from the confluence of the Comal and Guadalupe Rivers. Water depth ranged from 2.3 to 2.9 m. A relatively constant flow with surface level fluctuations up to 0.5 m due to changes in discharge from Canyon Reservoir was observed. A rock and gravel bottom with scattered pockets of mud supported sparse growths of *Ludwigia* sp. This location was chosen to determine water quality downstream from the confluence of the Comal and Guadalupe Rivers and upstream from the New Braunfels sewage outfall.

Station 2 was located about 4.2 km downstream from Station 1. The New Braunfels sewage treatment plant and the Mission Valley textile mill effluent outtalls are approximately 1.6 and 0.6 km, respectively, upstream. Water depth ranged from 3.0 to 4.3 m. A brown mud bottom with some *Ludwigia* sp. was present.

Station 3 (Lake Dunlap) was located 0.1 km upstream from Lake Dunlap Dam and 7.4 km downstream from Station 2. Water depth ranged from 7.3 to 8.0 m. No aquatic vegetation was present on the brown mud bottom. *Eichornia crassipes* increased to nuisance proportions during the summer.

Station 4 was located 6.8 km below Lake Dunlap Dam. Water depth ranged from 3.9 to 4.3 m. A bottom composed of rock with mud supported growths of *Oscillatoria* sp. and *Nuphar* sp. along both banks. Water level fluctuations of about 0.3 m and surface water velocities were dependent upon discharge from Lake Dunlap.

Station 5 (Lake McQueeney) was located about 25 m upstream from the Lake McQueeney Dam. Water depth ranged from 6.7 to 8.0 m over a mud bottom with no measurable surface water velocity.

Station 5TI was established June 14, 1969, behind Treasure Island on the north side of Lake McQueeney as a result of observations of phytoplankton blooms in that area. The island and entire lake front area of Lake McQueeney are crowded with private residences and boat concessions, with septic tanks furnishing the only known means of domestic sewage disposal. Extensive growths of *Nuphar* sp. and filamentous algae were observed. There was no measurable flow. Water depth ranged from 3.6 to 4.4 m.

Station 6 was located 0.4 km below Lake McQueeney Dam. Water dept fluctuated from 1.0 to 2.7 m due to intermittent discharge from the Lake McQueeney power station. The bottom was composed of gravel, mud, and rock.

Station 7 was located 0.6 km upstream from the Seguin sewage treatment plant outfall. Water depth ranged from 1.8 to 2.5 m with moderate flow. The bottom was composed of dark mud and organic detritus covering a rock substrate.

Station 8 (Meadow Lake) was located approximately 1.6 km upstream from Nolte Dam. Water depth ranged from 5.9 to 6.7 m with no measurable water velocity. A substrate of mud was present with scattered patches of *Eichornia crassipes* and *Nuphar* sp.

Station 9 was located in a free-flowing stretch of the river 4.1 km downstream from Station 8 and 0.4 km downstream from the Nolte hydroelectric power station. Water depth ranged from 0.8 to 1.8 m dependent upon discharge from the Nolte power station. The substrate was rock with no aquatic vegetation present.

Station 10 was located approximately 8.0 km downstream from Station 9. Water samples were taken in a shallow, rapidly flowing riffle area. Water depth ranged from 0.6 to 1.3 m over a gravel bottom with no macrophytic vegetation.

Station 11 was located approximately 35.5 km downstream from Station 10 in a shallow, gravel bottomed riffle area. Water depth ranged from 0.4 to 1.1 m. Plankton and benthic algae were the only aquatic vegetation present. Nash Creek enters the river 2.2 km above Station 11 and serves as drainage for a portion of the Darst Oil Field. No flow was observed in Nash Creek.

Station 12 was located at the entrance of the river into Lake Gonzales approximately 22.7 km downstream from Station 11. Water depth ranged from 5.3 to 5.6 m and there was a measurable velocity. The bottom was composed of mud and organic detritus with heavy growths of *Nuphar* sp. and *Philodendron* sp. bordering the river channel.

Station 13 (Lake Gonzales) was located in Lake Gonzales approximately 50 m above the dam. Water depth ranged from 3.0 to 7.3 m with a mud bottom and no measurable velocity. Growths of *Nuphar* sp. and *Eichornia crassipes* were present in nuisance proportions through the summer months.

Station 14 was located in a moderate – to fast – flowing stretch of the Guadalupe River approximately 11.1 km below Lake Gonzales Dam. Water depth ranged from 2.4 to 3.1 m over a bottom composed of a mixture of gravel and mud.

Station 15 (Lake Wood) was located 20 m above the Lake Wood Dam. The lake is small in size with the only open area of water located at the sampling station just above the dam. Water depth ranged from 3.0 to 8.1 m over a mud substrate with prolific growths of *Nuphar* sp. occurring in the littoral.

Methods

Each of the 16 stations was sampled monthly for one year beginning in February, 1969, with the exception of Station 5TI which was established in June, 1969. In February, May, August, and November, 1969, samples were taken at 4 hour intervals over a diel period. Because of the time involved in collection and analysis, determinations for Stations 1 through 9 were made over one diel period and determinations from Stations 10 through 15 were made over a diel period 7 days later. In March, April, June, July, September, October, December, 1969, and January, 1970, samples were taken and observations were made at each of the 16 stations at approximately 12 hour intervals over a diel period.

Water samples were taken with a 2–liter Kemmerer water sampler. Two depths were sampled at Stations 3, 4, 5, 5TI, 8, 9, 12, 13, and 15: a surface sample taken approximately 0.5 m below the surface and a bottom sample taken approximately 1 m above the bottom. At Stations 1, 2, 6, 7, 9, 10, 11, and 14, only surface samples were taken.

A Dwyer wind meter was used to determine wind velocity. Water and air temperature was measured with a mercury thermometer. A FT3 Marine Hydrographic thermometer was used to check for thermal stratification. The pH measurements from February through July were made with either a Beckman Model M meter or with an IL Model 175 meter, and measurements from August through January were made with the IL Model 175 meter. Specific conductance was determined with a temperature compensated (25C) Beckman RB3 Solu Bridge. Water velocity was estimated by measuring the time required for a cork to float 2 meters. Water depth was measured with weighted brass chains marked at 0.5 m intervals. Transparency was determined with a standard 20 cm Secchi disk.

The Alsterberg-azide modification of the WINKLER method was used for analyzing dissolved oxygen (APHA, 1965). Oxygen saturation values were calculated from a nomograph (REID, 1961). Alkalinity was determined by titration with 0.02 N sulfuric acid (APHA, 1965). Turbidity was measured at 450 mμ in per cent transmittance which was converted to Jackson turbidity units (Hach Chemical Company).

Chlorophyll *a* and turbidity were determined with a Bausch and Lomb Spectronic 20 spectrophotometer. For chlorophyll *a*, two 100-ml aliquants from each sample were filtered through 0.45 mμ Millipore filters and extracted in 10 ml of 90 per cent acetone for 24 hrs. at 5° C. The samples were then centrifuged and the optical density of the extract determined at 665 mμ. Optical density readings were converted to mg/l by use of the equation of Odum, MCCONNELL & ABBOTT (1958).

RESULTS AND DISCUSSION

Weather conditions

Mean air temperatures followed the normal seasonal pattern and varied from 3.5° C in November to 39.0° C in June. Wind velocity did not exhibit a significant seasonal difference.

Water temperature

Surface water temperature varied from 10.5° C at Station 6 in February to 37.5° C at Station 8 in August. Mean surface water

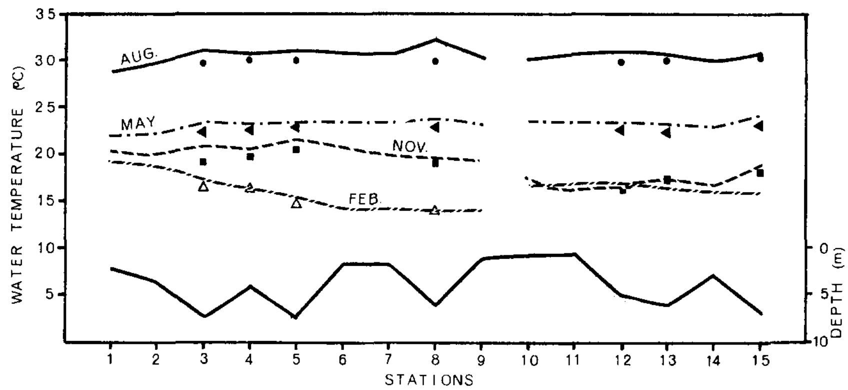

Fig. 2. Mean surface and bottom water temperatures for all samples taken at each of 15 stations during the February, May, August, and November diel sampling periods. Lines – surface samples, symbols – bottom samples.

temperatures for diel periods showed a seasonal pattern with the maximum in August and the minimum in February (Fig. 2). Mean bottom water temperatures (Fig. 2) and periodic stratification checks showed no significant thermal stratification. The maximum difference between surface- and bottom-water temperatures was 6.9° C during the August diel at Station 8, which dropped to no difference within the same diel period. Diel variations in water temperature ranged from 0.2° C on the bottom in May at Station 8 to 8.5° C at the surface in August at Station 8. Only five stations had variations of greater than 3.0° C.

Dissolved oxygen (DO)

Surface DO ranged from 3.7 mg/l and 47 per cent saturation at Station 13 in September to 19.1 mg/l and 150+ per cent saturation at Station 3 in August..

The mean of the diel surface DO concentrations followed a seasonal pattern with values greater than 8.0 mg/l at all stations in January and at the majority of stations in February, March, November and December (Fig. 3). Mean values below 6.0 mg/l were found mainly during August. An exception to low values in August occurred at Stations 3, 4 and 5 when values were greater than 8.0 mg/l as a result of photosynthesis (Figs. 3 and 7). Due to seasonal changes in temperature, DO generally decreased from February to August and increased from August to January (Fig. 3).

Minimum surface DO (Fig. 4) varied only slightly from mean surface DO (Fig. 3). The absence of major differences between minimum and mean surface DO showed a lack of significant diel

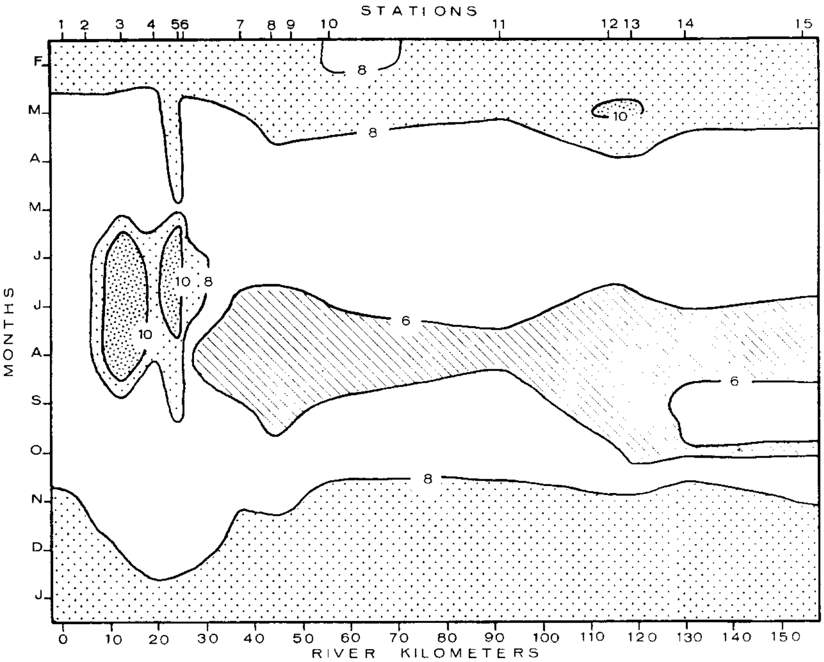

Fig. 3. Mean surface dissolved oxygen in mg/l for all samples taken during each sampling period at each of 15 stations in the Guadalupe River from February, 1969 through January, 1970.

changes for most stations. Maximum values exhibited no significant differences from mean values.

Station 2, downstream from the New Braunfels sewage outfall, had lower minimum surface DO concentrations by about 1.0 mg/l than did Station 1 upstream from the outfall. This situation was evident from July through September (Fig. 4). Increased discharge (Fig. 9) from Canyon Reservoir during October dissipated this effect at Stations 1 and 2 and created uniform DO concentrations of about 5.0 to 7.0 mg/l throughout the study area. Minimum DO values, due to cooler temperatures related to seasonal change, increased in November to around 8.0 mg/l for most stations. However, the minimum DO value at Station 2 was 2.0 mg/l lower than minimum DO at Station 1 (Fig. 4). In December, Stations 1 and 2 showed no difference in minimum DO concentrations but Stations 4, 5, and 6 had minimum oxygen concentrations of 2.3 mg/l to 4.3 mg/l lower than the upstream and downstream stations (Fig. 3 and 4). The lower DO level at Stations 4, 5, and 6 may be attributed to a decrease in water temperature during December moving an

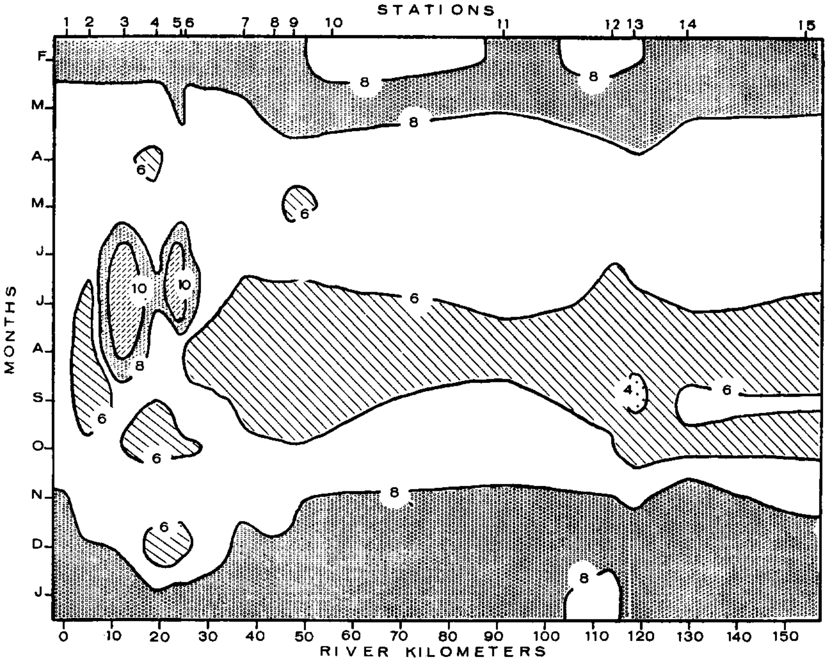

Fig. 4. Minimum surface dissolved oxygen in mg/l for all samples taken during each sampling period at each of 15 stations in the Guadalupe River from February, 1969 through January, 1970.

area of organic assimilation farther downstream. The rest of the study area showed a recovery to their wintertime highs.

Bottom DO for all samples ranged from 0.1 mg/l and 2 per cent saturation at Stations 3 and 5TI in August to 11.4 mg/l and 124 per cent saturation at Station 13 in March. Bottom DO for diel sampling periods ranged from 1.9 mg/l higher than surface samples at Station 15 in March to 19.0 mg/l lower at Station 3 in August.

Diel DO changes for Stations 3, 5TI, and 5 in August are shown in Fig. 5. These stations had the minimum values for bottom samples, and they had the maximum differences that occurred between surface and bottom for all stations. The wide variation in DO can be attributed to the impoundment of water. Ingols (1957) reports a similar deterioration of water quality as indicated by reduced DO caused by hydroelectric dams.

The shallow reservoirs in the study area have essentially zero surface velocity (Fig. 10). The reduced velocity in Lake Dunlap allows cropped vegetation from Comal Springs, organic matter from the New Braunfels sewage treatment plant, and dead plankton

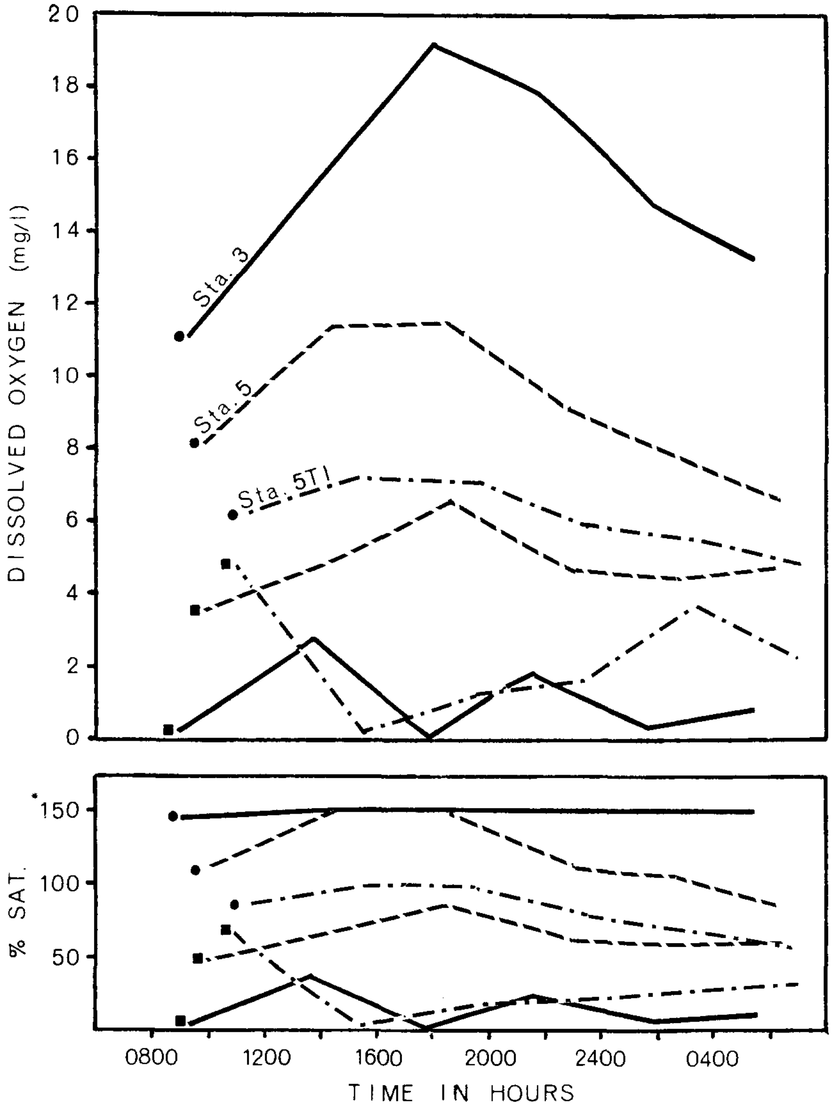

Fig. 5. Surface and bottom dissolved oxygen and per cent saturation values for Stations 3, 5TI, and 5 in August, 1970. ● Surface, ■ bottom, *150% sat. – upper limit of nomogram used in the calculation of per cent saturation.

to settle to the lake bottom. This caused an increased oxygen demand near the bottom. Deep lakes have been found to be more adversely affected by sewage effluent than flowing streams (HASLER, 1969). It appears that shallow main stream reservoirs have an intermediate adverse effect on water quality.

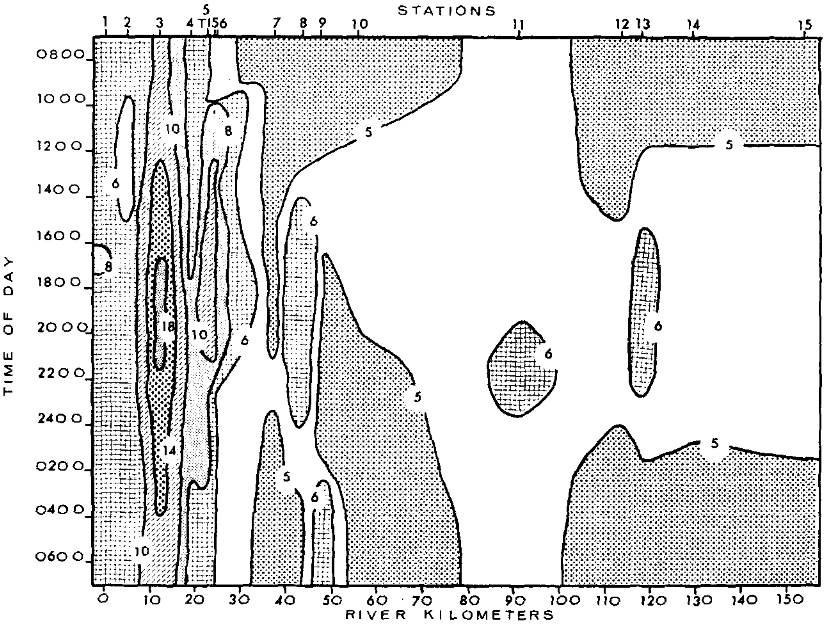

Fig. 6. Surface dissolved oxygen in mg/l at each of 16 stations in the Guadalupe River for the August 2 and August 9 diels.

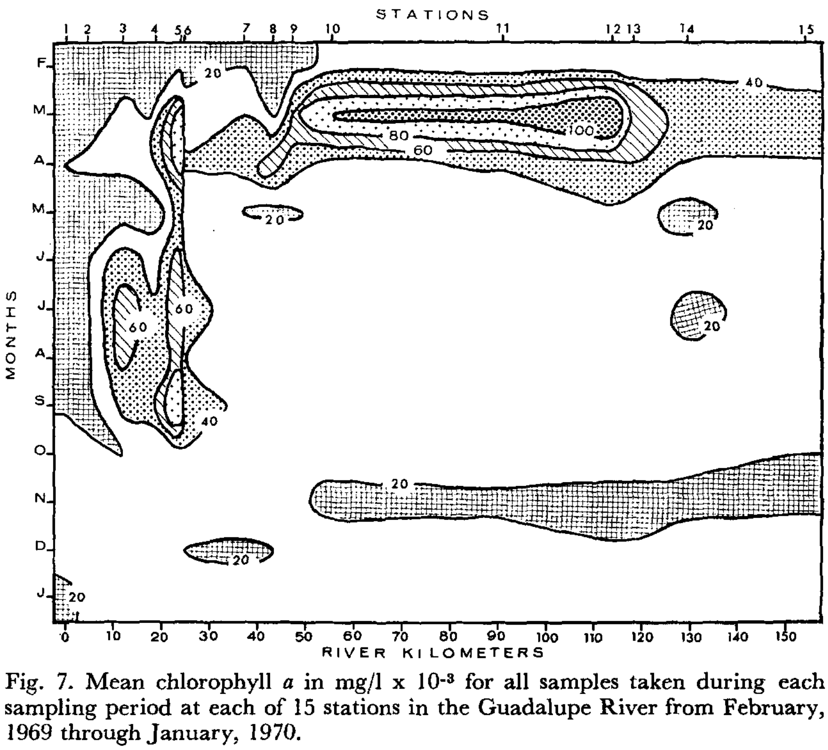

Fig. 7. Mean chlorophyll *a* in mg/l x 10^{-3} for all samples taken during each sampling period at each of 15 stations in the Guadalupe River from February, 1969 through January, 1970.

Diel fluctuations of surface DO were generally less than 2.0 mg/l. The only significant deviations in this pattern occurred in August when eight stations had greater changes. Flowing stretches of river, for example at Stations 1, 7, 10, and 11, had little diel effect troughout the 12-month study period (Fig. 6). The daily fluctuations of DO in flowing water are produced through the interactions of community respiration, photosynthetic production, temperature, and reaeration. Reaeration from turbulent flow and oxygen concentrations consistently below saturation combined with upstream influences were probably the principal contributors to diel effect in flowing stretches. Diel fluctuations of DO were much greater in the impounded waters where reduced flow permitted larger phytoplankton blooms (Fig. 6 and 7) than in flowing waters.

Occasional nocturnal increases in DO could be attributed to decreased discharge rates which resulted in water level fluctuations as great as 0.5 m. Such a departure of diel oxygen variations from the pattern has also been noted and related to physical conditions by GUNNERSON (1963) and MINTER and COPELAND (1962).

Chlorophyll *a*

Chlorophyll *a* is the principal chlorophyll in all plants that produce oxygen by photosynthesis (VERNON & SEELY, 1966). Thus, determination of the chlorophyll *a* concentration of a river or lake reveals information on the photosynthetic capacity of oxygen production (O'CONNOR, 1968).

Surface chlorophyll *a* concentrations ranged from a minimum of 0.009 mg/l at Station 3 on May 10 to a maximum of 0.260 mg/l at Station 12 on March 29. Mean planktonic chlorophyll *a* for combined daytime and nighttime samples ranged from 0.012 mg/l at several stations to 0.153 mg/l at Station 12 in March (Fig. 7).

Flow has considerable influence on photosynthesis as shown by a comparison of chlorophyll *a* concentrations at Station 5TI with those of Station 5 (Fig. 8).

Station 5TI is in a protected area behind Treasure Island outside the major flow pattern of Lake McQueeney while nearby Station 5 is within the mainstream flow of the lake. River flow during May, October, and January exceeded 1500 cu. m/min. and flow in excess of 1400 cu. m/min. occurred during November and December. Significant reductions in chlorophyll *a* concentrations occurred at Station 5 during May and from October through January. However, no appreciable reductions in chlorophyll *a* occurred at Station 5TI except during October and January when flow was very high, in excess of 1600 cu. m/min. It appears that

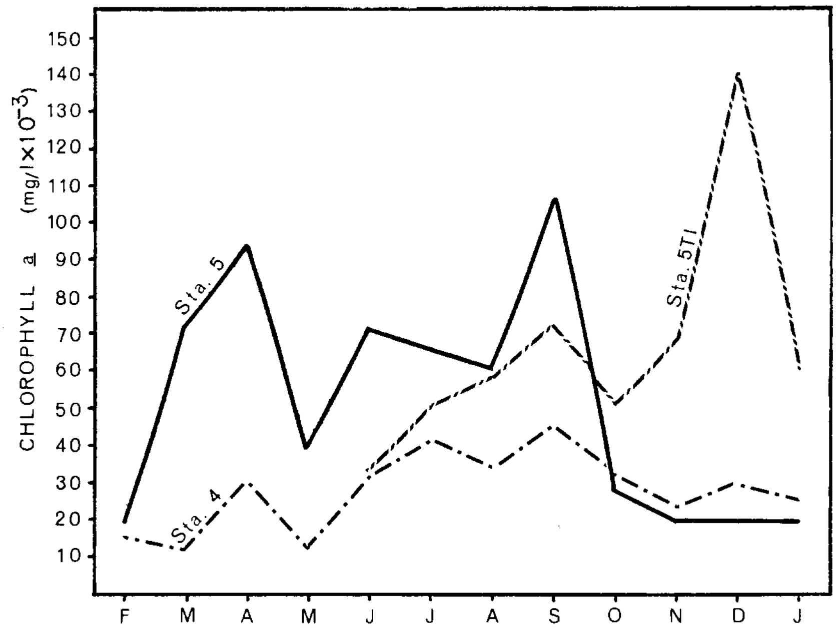

Fig. 8. Comparison of chlorophyll *a* at Stations 4, 5TI, and 5 in the Lake McQueeney stretch of the study area for the 12-month study period.

flow and velocity are both critical to controlling plankton blooms in the river. WILLIAMS (1964) has also show high stream discharge influences plankton populations.

Chlorophyll *a* concentration has also been closely correlated with sunlight and water temperature (COPELAND, MINTER & DORRIS, 1964). The Guadalupe River chlorophyll data exhibited such a relationship to change in temperature and solar illumination in the spring. Increased air temperature along with longer periods of daily illumination and increased water temperatures coincided with increases in chlorophyll concentration. Water temperature was greater (with few exceptions) than 12° C throughout the study. KNOPP (1960) has determined that significant growth and production of phytoplankton occurs only at temperatures greater than 12° C. It is assumed, therefore, that temperature would be a less significant factor to production than solar illumination in the river.

The maximum chlorophyll concentrations for the spring and summer pulses occurred in Lakes Dunlap, McQueeney, Meadow, and Gonzales (Fig. 7). Stream impoundment commonly results in phytoplankton density increases, due to increased retention times (CUSHING, 1964; OWENS & WOOD, 1968). The periods of low flow and velocity coupled with greater solar input associated with longer

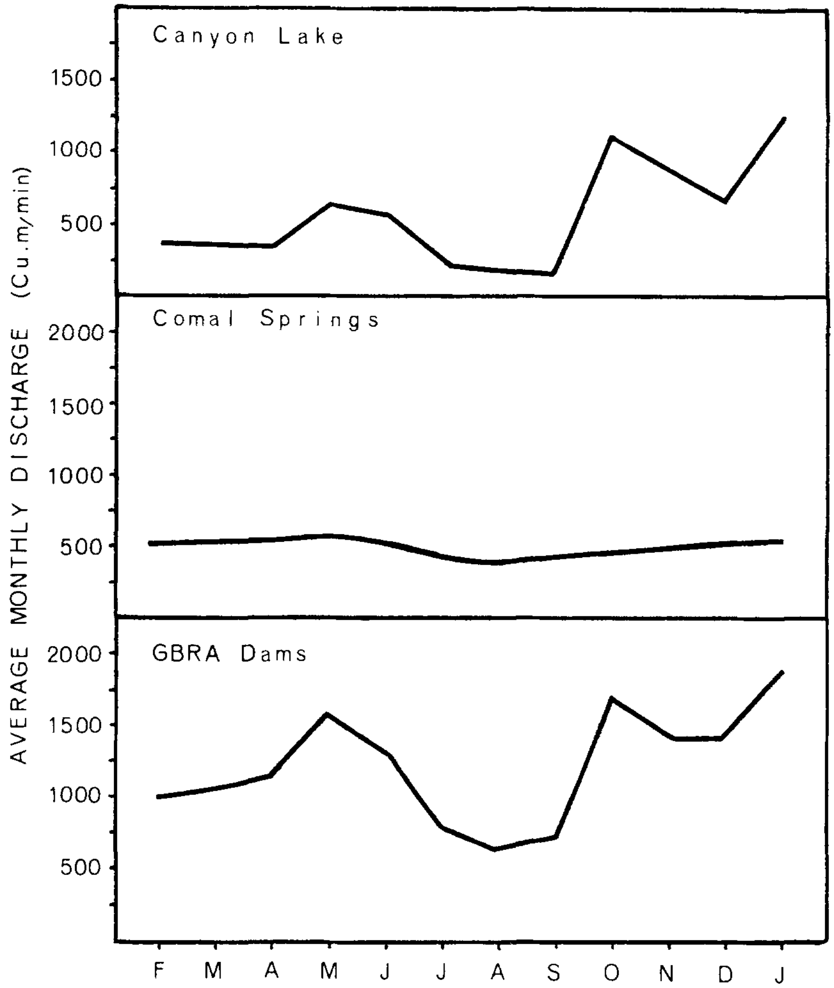

Fig. 9. Mean monthly discharge in cubic meters per minute for Canyon Lake, Comal Springs, and the Guadalupe-Blanco River Authority Dams.

days contributed to development of phytoplankton blooms in the impoundments (Fig. 7, 8, 9 and 10). An increased discharge along with the relatively small capacity of the dams were the principal factors in destroying plankton pulses.

Diel variation of chlorophyll has been shown in several aquatic ecosystems. However, a comparison of daytime and nighttime surface chlorophyll samples in this study showed no consistent diel pattern, though almost half of the samples showed a nighttime increase. Odum, McConnell & Abbott (1958) attribute such an increase to the need for more chlorophyll at low light intensities.

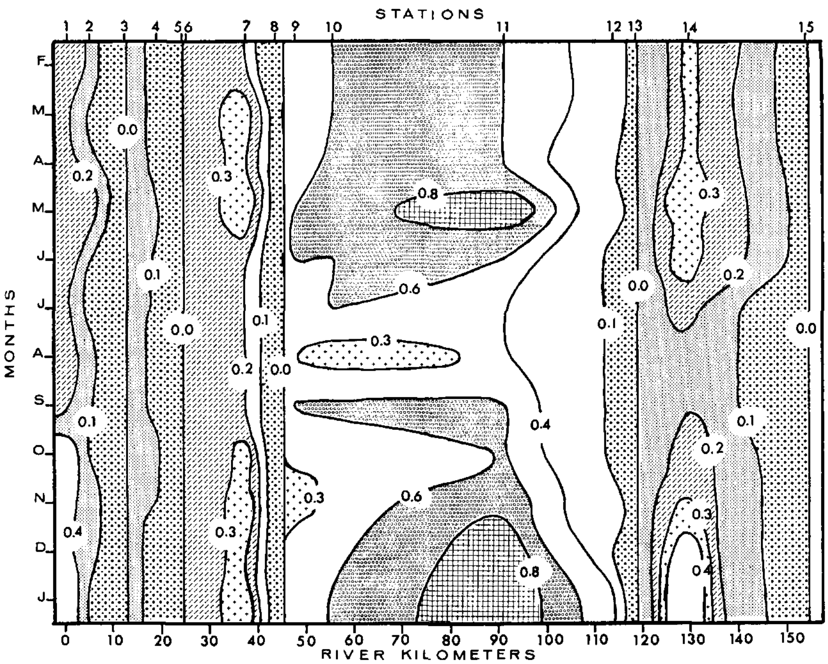

Fig. 10. Mean surface water velocity in m/sec for all samples taken during each sampling period at each of 15 stations in the Guadalupe River from February, 1969 through January, 1970.

The lack of a consistent diel pattern was apparently also related to disturbances caused by the periodic release of water through the hydroelectric peaking plants.

Flow and velocity

Mean monthly discharge (Fig. 9) and mean surface water velocity (Fig. 10) showed a seasonal trend. Mean surface water velocities ranged from no measurable flow in the impoundments to 1.0 m/sec. at Station 11 in January. Fluctuations in flow were directly related to discharge from Canyon Reservoir upstream from Station 1 and from the hydroelectric dams in the study area (Fig. 9).

Turbidity and transparency

Surface turbidity ranged from 8 Jackson units at Station 1 in August to 310 Jackson units at Station 11 in May. Bottom turbidity ranged from 21 Jackson units at Station 3 in November to 395+ Jackson units at Station 4 in February, Station 12 in April and

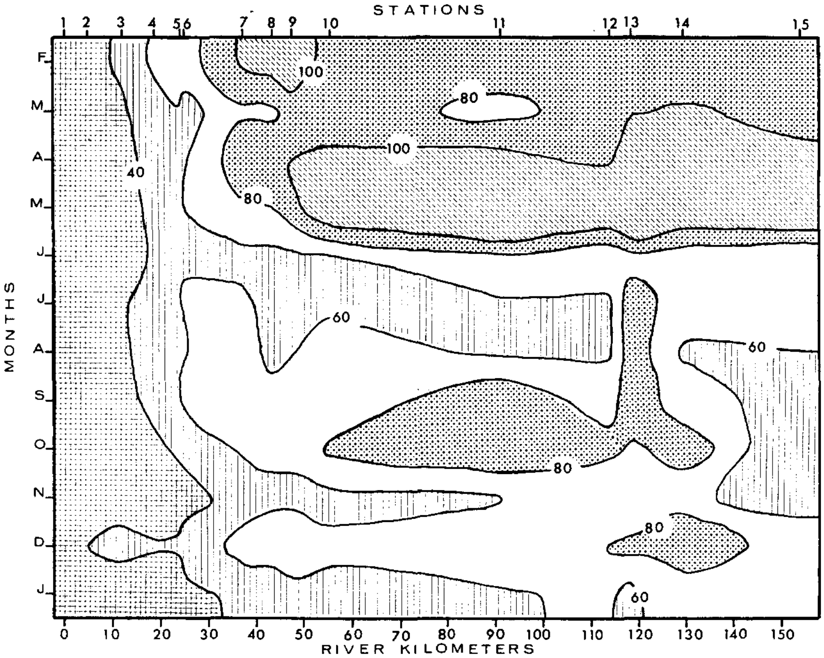

Fig. 11. Mean surface turbidity in Jackson Units for all samples taken during each sampling period at each of 15 stations in the Guadalupe River from February, 1969 through January, 1970.

Stations 13 and 15 in May. Mean surface turbidity for diel periods ranged from 13 Jackson units at Station 1 in January to 148 Jackson units at Station 13 in May (Fig. 11).

Turbidity generally increased downstream (Fig. 11). Maximum turbidity for all stations occurred during periods of maximum flow, while minimum turbidity for all stations occurred during periods of minimum flow (Fig. 9, 10 and 11). It is well documented that turbidity is generally inversely related to flow (Mathis & Dorris, 1968; Hoskin, 1959; Symons, Wiebel & Robeck, 1964). Impoundments in the study area, however, exerted no consistent influence on turbidity. The periodic high discharge from Canyon Reservoir, the relatively small size of the hydroelectric dams in the study area, the short retention times, and the periodic releases contribute to moving water through the impoundments at a velocity which generally does not cause turbidity reduction.

Secchi disk transparency ranged from 0.1 m at Station 13 in April and Station 11 in May to 1.9 m at Station 1 in March and June and Station 1 and 2 in August. In general, transparency decreased downstream throughout the study area (Fig. 12). A

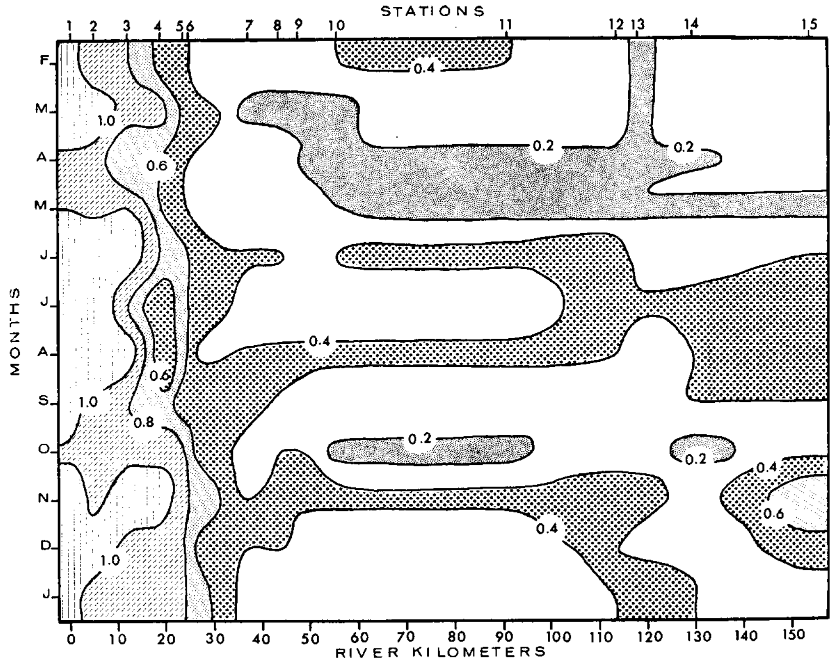

Fig. 12. Secchi disk transparency in meters for midday samples taken during each sampling period at each of 15 stations in the Guadalupe River from February, 1969 through January, 1970.

noticeable decrease in transparency occurred at Station 3 (Lake Dunlap) and Station 5 (Lake McQueeney). Minimum transparency corresponded with high turbidity during periods of high discharge (Fig. 11 and 12) and increased transparency occurred during periods of low discharge (Fig. 9 and 12).

Alkalinity

Alkalinity was principally due to bicarbonates. Surface bicarbonate alkalinity ranged from 139 mg/l at Station 9 in February to 232 mg/l at Station 9 in November (Fig. 13). Bottom bicarbonate alkalinity ranged from 138 mg/l at Station 13 in September to 232 mg/l at Station 3 in April.

Carbonate alkalinity occurred in trace amounts at Stations 8, 10, 11, 12, and 13 in March and at Stations 3 and 5 in August. Algal blooms (Fig. 7) and pH levels of 7.9 to 8.7 were present when carbonate alkalinity was detected. The phytoplankton dissociated the bicarbonate ions into carbon dioxide, carbonate ions, and hydroxide ions. The increase in hydroxide ions increased the pH, and the

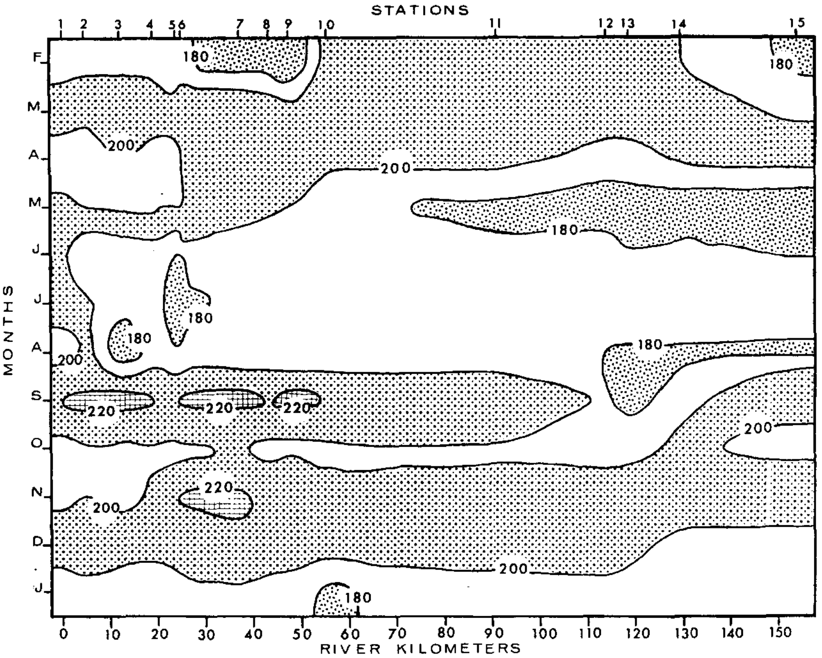

Fig. 13. Mean surface total alkalinity in mg/l for all samples taken during each sampling period at each of the 15 stations in the Guadalupe River from February, 1969 through January, 1970.

carbon doxide was utilized photosynthetically. The use of bicarbonate as a source of carbon dioxide by plants has been well established (SAWYER, 1954; NIELSEN, 1946, 1952; BRIGGS, 1959 HOUGHTON, 1955). The presence of carbonate alkalinity and increased pH values are common where algae are actively carrying on photosynthesis (NEEL, NICHOLSON & HIRCH, 1963; KLEIN, 1959).

Carbonate alkalinity is found only in the absence of free carbon dioxide. Apparently, free carbon dioxide was depleted from the water by the plants and the photosynthetic mechanism "switched" to using bicarbonate as a carbon source. Further evidence for the absence of free carbon dioxide was the high pH when carbonate alkalinity was present. Free carbon dioxide does not occur in water with a pH greater than 8.0 (REID, 1961). This is evidence that carbon would not be considered a limiting nutrient to phytoplankton development in the waters of limestone-rich regions of central Texas.

Alkalinity did not exhibit a seasonal trend (Fig. 13). High discharge rates in May, October and January apparently decreased

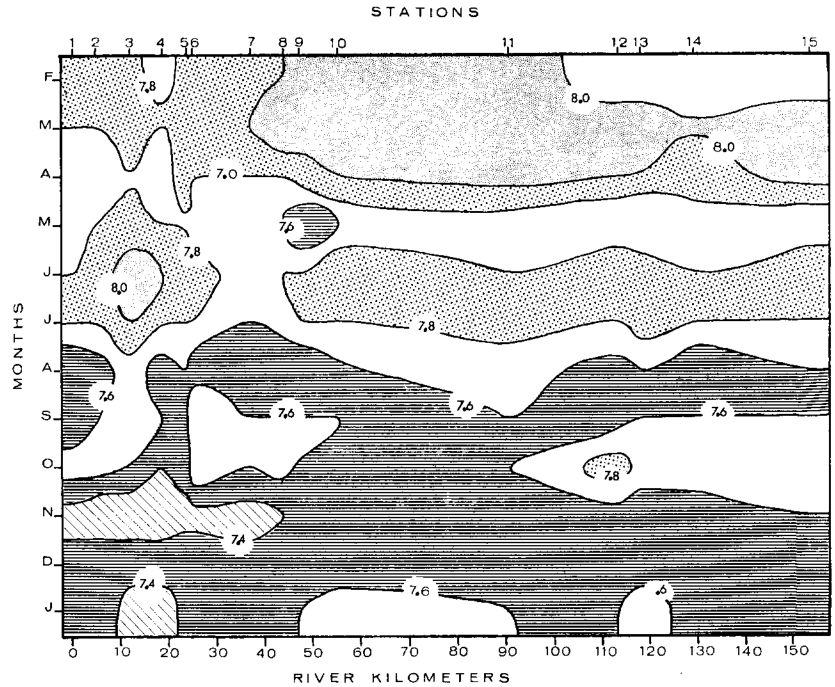

Fig. 14. Mean surface pH values for all samples taken during each sampling period at each of 15 stations in the Guadalupe River from February, 1969 through January, 1970.

the total alkalinity content of the water. An inverse relationship between discharge and alkalinity has also been noted by WOODS (1965). This is probably due to the fact that decreased discharge contains a greater percentage of ground water which increases the alkalinity content (NEEL, NICHOLSON & HIRCH, 1963). This decreased alkalinity during the summer at Stations 3 through 6 could be attributed to the use of bicarbonate ions as a carbon source during photosynthesis (Fig. 7 and 13). Decreased alkalinity also occurred from Stations 7 through 15. However, these stations did not have high planktonic chlorophyll *a* concentrations during the summer as did Stations 3 through 6 to indicate increased photosynthesis. In addition, Stations 7 through 15 had higher pH levels and lower DO concentrations. The lower alkalinity in the summer at these stations was probably due in part to reduction of organic matter (ECKENFELDER & HOOD, 1950).

Bottom total alkalinity varied very little from surface values. The major exceptions to this occurred when photosynthesis reduced surface levels or when discharge rates and flow caused fluctuations

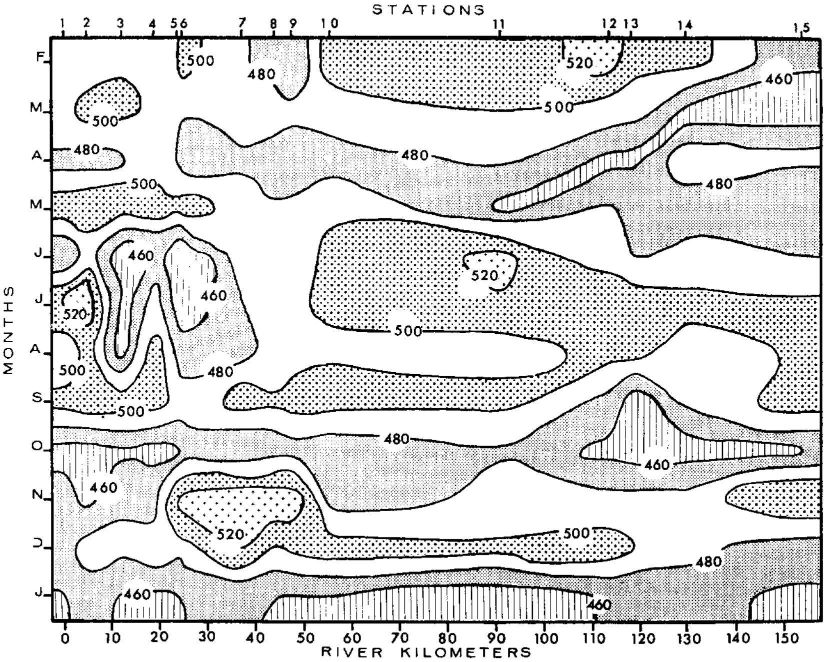

Fig. 15. Mean surface specific conductance in micromhos/cm for all samples taken during each sampling period at each of 15 stations in the Guadalupe River from February, 1969 through January, 1970.

in alkalinity levels. Diel fluctuations of total alkalinity were significant only during periods of high discharge. In general, all stations showed less diel change in August when the lowest discharge was observed in the study area.

Hydrogen ion concentration

Mean surface pH ranged from 7.2 to 8.2 (Fig. 14). A maximum of 8.7 was observed in February at Station 11 and a minimum of 6.8 in August at Station 12. Mean bottom pH ranged from 7.1 to 8.1. A maximum of 8.2 was observed in February at Stations 3 and 8, and a minimum of 6.9 was observed in August at Stations 12 and 13.

Seasonal variations in pH (Fig. 14) correlated to some degree with those of DO and chlorophyll *a* (Fig. 3 and 7). High pH values were recorded in March at Stations 8 through 15 and in the summer at Stations 3 to 6. These high values corresponded with high DO and high chlorophyll *a*. Alkalinity and pH followed the normal correlation pattern except for disturbances resulting from photosynthetic activity. Increased discharge appeared to disrupt most relationships and these were generally distinguished by low pH values.

Bottom pH values were essentially the same as surface values for most diel sampling periods. The most significant difference occurred at Station 3. Station 3 recorded pH values of 0.4 to 0.6 of a pH unit higher on the surface in June, July, and August, which correlated with the high surface chlorophyll and oxygen.

Conductivity

Mean surface specific conductance ranged from 419 micromhos/cm in May at Station 15 to 550 micromhos/cm in November at Station 7 (Fig. 15). Maximum surface conductivity was 600 micromhos/cm in November at Station 5 and the minimum was 360 micromhos/cm in March and May at Station 15. The maximum bottom conductivity was 580 micromhos/cm in September at Station 12 and in November at Station 8, and the minimum was 370 micromhos/cm in March at Station 15.

Seasonal conductivity showed a complex relationship to several parameters. High conductivity values were closely correlated with high alkalinity in February, March, May, September, November, and December (Fig. 13 and 15). Seasonal minima and maxima in alkalinity and conductivity have been found to occur at approximately the same time in lakes of southern Michigan (Hooper, 1956). The low conductivity corresponded to the low alkalinity and high chlorophyll *a* at Stations 3 to 6 during the summer (Fig. 7, 13 and 15). The high conductivity was observed in the summer at the lower stations when a higher pH was present (Fig. 14 and 15). Conductivity generally correlated with pH throughout the year except for lower conductance and higher pH at Stations 3 to 6 in the summer. The utilization of bicarbonate ions and nutrients in photosynthesis accounted for this reduced conductivity. High conductivity was present during periods of low flow except where photosynthesis was actively decreasing the bicarbonate alkalinity (Fig. 7, 10, 13 and 15). Conductivity was adversely affected by periods of high flow as a result of dilution. Bottom surface differences and diel effects were generally insignificant except for those variations caused by flow and photosynthetic activity.

Summary

A study of limnological conditions was conducted on a 168-km

stretch of the Guadalupe River in central Texas for one year beginning in February, 1969. This river stretch was unique in that it had a sequence of five shallow, nonstratified, main-stream reservoirs. Flow through the study area was controlled by releases from these five reservoirs and from Canyon Reservoir, a deep-storage reservoir, located 30 km upstream. Physicochemical properties measured monthly on a diel basis at 16 stations were: dissolved oxygen, chlorophyll *a*, pH alkalinity, specific conductance, water temperature, turbidity, transparency, water velocity, and discharge.

Seasonal and diel changes in limnological conditions were of greater magnitude in impoundments than in lotic areas. Periods of low flow and low velocity resulting in long water retention periods in impoundments coupled with greater solar input associated with long days contributed to the greatest fluctuations. Increased discharge, particularly from Canyon Reservoir, caused more uniformity of conditions throughout the study area so that conditions at all points approached average seasonal conditions.

Longitudinal variations in physicochemical conditions were influenced by the impoundment of water, effluent of sewage disposal plants, reaeration through turbulence, and was greatly affected by seasonal periods of drought and flooding.

High dissolved oxygen in impoundments was accompanied by high chlorophyll *a*, high pH, and low bicarbonate alkalinity. These conditions indicate the importance of bicarbonate ions as a carbon source for phytoplankton in this system.

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