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The Phytoplankton of the Logan River, Utah, A Mountain Stream

William J. Clark
Utah State University

THE PHYTOPLANKTON OF THE LOGAN RIVER, UTAH, A MOUNTAIN STREAM

by

William J. Clark

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INTRODUCTION AND REVIEW OF LITERATURE

The voluminous limnological literature contains few studies of mountain streams. Though there are a few papers on the benthic algae (see Budde 1928, Raabe 1951) only Pennak (1943) reports year-round quantitative data on the phytoplankton. Brinley (1950) gives some phytoplankton information in a summer study of streams in Rocky Mountain National Park.

The comprehensive studies of stream phytoplankton have been done on large rivers by Kofoid (1903, 1908) on the Illinois, Allen (1920) on the San Joaquin, Reinhard (1931) on the Mississippi, Starrett and Patrick (1952) on the Des Moines, Rice (1938) on the Thames in England, and others. The literature on the larger streams is included in the reviews by Blum (1956) and des Cilleuls (1928) and will not be exaustively treated here.

The algae are the basic producers in the aquatic environment. It has been the objective of the present study of the phytoplankton, and of a companion study on factors affecting the productivity of the benthic algae (McConnell 1958), to contribute to our knowledge of the ecology of the algae of the Logan River in particular and of mountain streams in general.

The term phytoplankton is used here to include all the algae found drifting free in the water of the stream.

GENERAL DESCRIPTION OF THE RIVER AND LOCATION OF SAMPLING STATIONS

General description of the river

The Logan River heads just over the Utah-Idaho border in southern Idaho and flows south, then south-west, then west, through the Bear River range of the northern Wasatch mountains, to its junction with the Little Bear River in Cache Valley, Utah. Its total length is approximately 40 miles. Many of the peaks in the water shed are from 9,000 to 10,000 feet above sea level, with the floor of Cache Valley at approximately 4,400 feet.

The river is a swift cascading stream for most of its length, with relatively steep gradients (Figure 1) and main stream velocities of 2 to 5 feet per second for most of the year and 4 to 9 or more feet per second during the spring flood. The average width is about 35 feet, with the width at any particular location dependant upon local canyon configuration. The river is shallow, seldom over two feet deep during the low water period of fall and winter. The average depth at 9 randomly selected transects was 12.3 inches during the winter of 1956-57. Water depths were not measured during the spring flood but were estimated at 2 to 4 feet. There are no full width pools in the canyon section of the river, and only a few half width pools with back eddies.

The dominant rocks of the area are gray blocky limestones and dolomites, and most of the bottom material is composed of

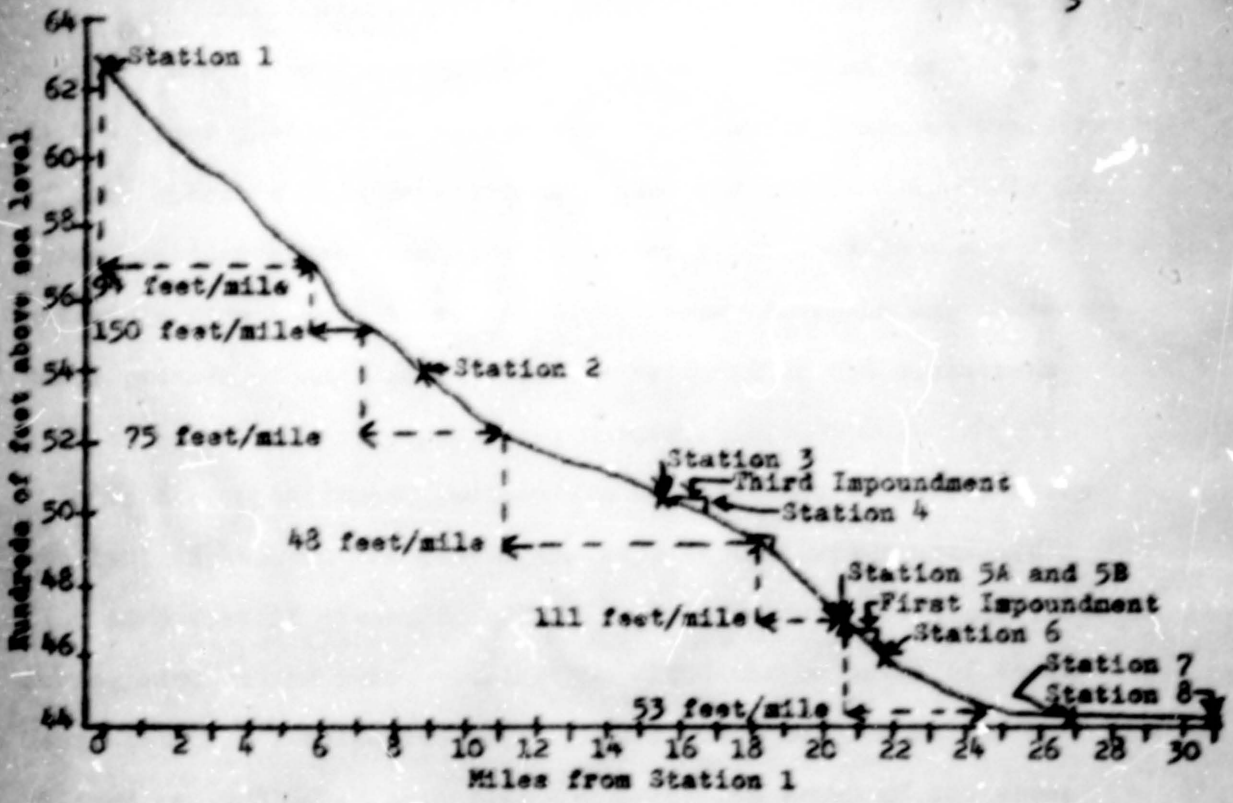

Figure 1. Profile of the Logan River showing location of sampling stations and gradient in feet per mile for representative sections

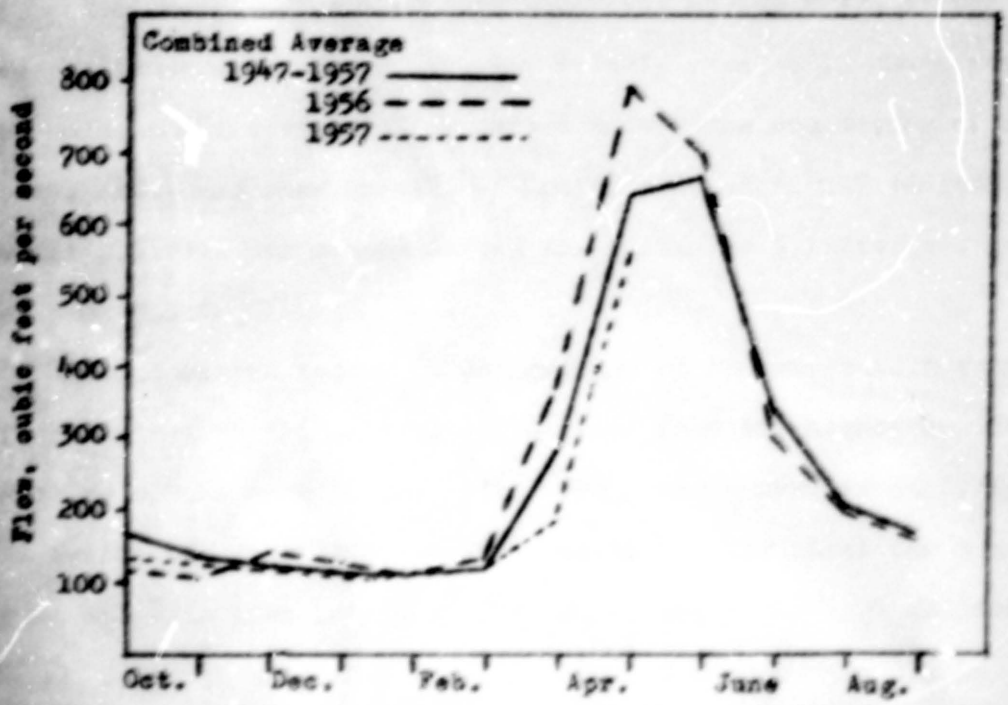

Figure 2. Average monthly flow for the Logan River at the canyon mouth

angular to rounded limestone and dolomite cobbles and boulders. In the upper part of the canyon section, however, rounded boulders of pink quartzite are more abundant than the limestones. Only in a few sections where channel straightening has been done are materials fine enough to be called "gravels" found in any abundance. Small patches of sand and gravel may be found on the downstream side of large permanent boulders, however.

In the upper canyon section and in stretches with very steep gradient throughout the canyon the tops of the larger boulders (1.5 to 3 feet in diameter, a few larger) protrude above the water during most of the year. During the flood the majority of these large boulders are covered by the water and some of them may be shifted and rolled at this time. Most of the rocks of the river bottom however, are fitted firmly in place and are difficult to remove.

The change of gradient and substrate at the mouth of the canyon is abrupt. The river very quickly changes in character, becoming a meandering valley stream with banks and bottom of sand, clay, silt, and some gravel. Velocities at station 7 ranged from under 0.5 feet per second during the summer to 4.7 feet per second at peak flood.

The dominant factor in the regimen of the river is the spring flood caused by the melting of the snow from the higher mountains. Melting of the snow in the valley and lower canyon in early spring increases the flow of the valley section of the river for a short time but this soon subsides. It is not until the high altitude snows begin to melt that the main run-off begins, usually in late

March or early April. The run-off came a little earlier than the average the first spring of the study (1956), and a little later than average the second spring (Figure 2).

The river in the lower part of the canyon has been developed for electric power generation and for irrigation. The first dam, at the mouth of the canyon, is used to provide a head for a high volume, low velocity turbine at the base of the dam. The impoundment of about 11 acres has a considerably reduced volume because of sediment deposits. Much of the area is shallow, and maximum depths were on the order of 10 to 15 feet. One irrigation canal takes water out below this dam and a second canal takes water out about one-fourth mile further downstream.

The second dam is about two miles upstream from the canyon mouth. It is a diversion dam, with the water diverted into a wooden flume and returned to the river through a power plant just above the first dam. The second dam impoundment is very small, really comprising only a short section of slow deep stream. A third irrigation canal takes water out between the second dam and the canyon mouth. Except for the flood period the stream channel between the second dam and the canal diversion carries only enough water for the canal. The stream channel from the canal diversion to the mouth of the canyon is dry at first and then picks up some seepage and spring water.

The third dam, 3.5 miles above the canyon mouth, diverts water into a pipe, this water returns to the river through a power plant just above the second dam. The entire flow is diverted into the pipe except during the flood, and except for flood stage the main channel between the third and second dams carries

only seepage and spring water. The area of the third impoundment is about the same as that of the first, 11 acres, and like the first impoundment it is extensively silted in, with only a channel of deep water through the upper part and an area of deep water near the dam. Maximum depths are 8 to 10 feet.

Location of sampling stations

It was decided to establish stations which would permit the evaluation of changes along the river and during the season, with the effects of the impoundments to be studied by sampling above and below them.

The stations had to meet several criteria. The number of stations were required to be such that collection could be completed during 1 day. Within this numerical limit they should reflect as well as possible the changing conditions of the river. The stations had to be readily accessible the year around, with winter the critical time for accessibility. Access was facilitated by the fact that highway 89 parallels the river for the first 25 miles of the canyon.

Preliminary work indicated 8 stations to be the maximum number which could be run in a single day. The 8 stations were finally located as follows:

Station 1. Red Banks Bridge. Elevation 6,260 feet. This is the highest point at which the river can be reached from the highway in winter without skis or snowshoes. The highway leaves the river completely approximately 2 1/2 miles above this point. The canyon above here is wide, with moderately sloping sides. The river is in general wide (40 to 50 feet) and shallow (usually under 1 foot).

Station 2. Logan Cave. Elevation 5,400 feet. The canyon here is narrow, with high walls which cut off direct sunlight during much of the day. The stream is narrow (25 to 35 feet), and deeper (1 to 2 feet) than the section above Red Banks. Temple Fork, one of the major tributaries, enters between Red Banks and Logan Cave.

Station 3. DeWitt Camp. Elevation 5,050 feet. The canyon here is more open than at Logan Cave but the walls are high and steep. The river is somewhat wider again (35 to 45 feet) and quite shallow, mostly under 1.5 feet. To point out the extreme variability however, just 500 yards upstream from this station there is a 100 yard section of stream with a narrow channel and depths of 2 to 4 feet. The station is approximately 100 yards above the back waters of the third impoundment. Right Hand Fork, a small tributary, enters the river between stations 2 and 3.

Station 4. Outlet of third impoundment. Approximately three-fourths mile from Station 3. The water flows from the surface of the dam through a vertical grill into the pipeline surge chamber. The station is at the grill.

Station 5. Above first impoundment. Elevation 4,690 feet. This station was originally located about 100 yards downstream from the confluence of the main river channel and the power station spillway, and just above the backwaters of the first dam. Preliminary tests indicated that the waters were mixed at this point. However, further tests at the beginning of the second year showed that the mixing was incomplete and erratic, and the station was split. Samples were taken on alternate collecting days thereafter

from the main river channel (5A) and the power raceway (5B) above their confluence. The data for the first year at station 5 were not analyzed since it was considered impossible to interpret .

Station 6. Below first dam. Elevation 4,620 feet. The station is approximately 200 feet downstream from the dam. This station was characterized by an extremely luxuriant growth of moss on the rocks, much more than was found at any other location on the river.

Station 7. Mendon Bridge. Elevation 4,430 feet. This station is about four miles from station 6. It is on the valley floor below the city of Logan. The stream is slower and deeper, with bottom of finely divided material and some gravel. The banks are brushy or undercut. Blacksmith Fork River, a stream about half the size (at that point) of Logan River, enters between Logan City and Mendon Bridge.

Station 8. Boat Landing. Elevation 4,420 feet. This station is about four air-line miles from station 7: however, the river meanders considerably. The station is not on the Logan River proper. It is on the Little Bear River a short distance below the confluence of Little Bear and the Logan River. This station was established to try to trace the fate of the mountain stream plankton. The rivers at this point are just entering the back waters of Cutler Dam, and the water level is controlled by the dam. There is always a definite current however, usually about 1.5 to 2 feet per second.

METHODS AND PROCEDURES

Temperature

Water temperatures were taken in degrees Fahrenheit with pocket thermometers and with maximum-minimum thermometers.

Mounts for the maximum-minimum thermometers were made by pouring concrete over an inverted wooden trough. A section of chicken wire was used as reinforcement, and a wire ring was set in the top of the mount. The concrete was left rough on top. After a few days in the water the mounts became inconspicuous, a desirable characteristic since the stream has heavy fishing pressure, and conspicuous objects in the stream were often stolen, broken, or thrown on the bank by fishermen. The maximum-minimum thermometers were screwed to the top of the trough formed on the under side of the concrete, and the block placed in the edge of the mainstream current. The high water of 1956 displaced several of the blocks despite their weight of about 25 pounds, and 2 were never found. Before the 1957 runoff those blocks which could not be placed in sheltered locations were wired to stakes driven in the bank. No thermometers were lost during the 1957 runoff.

Turbidity

Turbidites were read as parts per million SiO_2 equivalents with a Hellige turbidimeter.

Water velocity

The majority of the velocity measurements were made with an Atlas propeller type current meter. A few were made with a Leopold-Stevens Midget current meter.

Volume of flow

Volume of flow data for stations 5A and 5B and for the total flow at the mouth of the canyon were obtained from the Logan office of the Water Resources Division of the U. S. Geological Survey.

Flow estimates at the other stations were made from stream profiles, and gage height and velocity data collected by project personnel. Profiles of the natural stream bed were made by measuring from a reference line to the stream bottom. Gage heights were recorded at each collection as distance from the reference line to the water surface.

Velocity measurements at each cross section were made several times, at low, medium, and high water stages. Surface velocities were taken at intervals across the stream and a weighted average velocity obtained. The velocities were weighted by the depth of the water at the point of measurement. Cross sectional volume was obtained from the gage height and profile data.

Flows were calculated by the formula

$$F = A\ V\ C$$

where F = flow in cubic feet per second,

A = cross sectional area at the measured gage height,

V = weighted average velocity at the same measured gage height as in A, and

C = a constant, 0.8 for the canyon station with rocks and gravel bottoms, 0.9 for station 7 with a smooth bottom.

Gage height was plotted against discharge volume for each station, and curves were drawn through the points obtained.

Discharge volumes were read from these curves using gage measurements taken on the collection trips.

Water chemistry

Water analyses were done by the United States Department of Agriculture Soils and Water Analyses Laboratory at Utah State University, using standard methods.

Oxygen determinations were made with the Winkler method as given in Welch (1948).

PH determinations were made by Hellige Color Comparetor Kit and with a Beckman pH meter.

Phytoplankton collection and enumeration

The phytoplankton were sampled in two parts; those large enough to be retained by a number 20 silk plankton net--the net plankton--and those too small to be retained by the net--the nannoplankton.

Net plankton. The net samples were obtained by pouring 5 buckets of water of 8 liters each through the net, for a total of 40 liters per sample. The water was taken from the main current. The net, of number 20 silk, was supported from a ring stand with the silk portion of the net suspended inside a galvanized container a little larger in diameter than the net. The net was supported in this manner so that the organisms would not be forced through the meshes by the water as it was poured in.

After the sample had been poured through, the net was lifted out, and the inside washed with water which had passed through the net. The cup was then removed, the excess water drained out through the sides by swirling, and the sample transferred to a

vial. The cup was twice washed into the vial with water which had passed through the net. The samples were immediately preserved by the addition of sufficient formalin to make a 2 to 4 percent solution.

Observations were made occasionally on special collections but analyses of the regular collections did not begin until May 1957.

Enumeration was done under a Bausch and Lomb stereo-microscope with a stand for bottom illumination. A circular counting trough patterned in general after that given by Ward (1955) was used. The trough, cut in a 5 inch circle of one-half inch lucite, had a diameter of 3 1/2 inches, depth of 3 mm. and a flat bottom 2 mm. wide, with the sides sloping at an angle of 50° from the vertical. The sides and bottom of the trough were polished after being turned on a lathe. Ward (1955) recommends an angle of 30° for the sides of the trough and it was intended to follow his recommendation; the 50° angle was cut by mistake. The trough functioned satisfactorily however, so long as care was taken to agitate it as the sample settled so that organisms did not adhere to the sides. The steeper sides as given by Ward are recommended. Ward's trough was specially mounted and driven by a motor. It was felt that such an elaborate device was not necessary for the number of samples in this study, although the motor drive would be a definite advantage for sustained counting. The glass plate was removed from the stage of the stereo-microscope and a plastic plate inserted in its place during counts. A hole was bored in the center of the circle containing the trough, and a pin placed

in the plastic plate to bring the trough to the center of the field. With the pin through the hole the trough could be easily rotated past the field of view with the fingers of 1 hand. The trough could also be easily removed for emptying and cleaning.

The dimensions of the trough were such that the flat bottom filled approximately one-half of the field, with 15X oculars and a 4X objective, or 60 power. The trough was lighted from beneath and the organisms appeared to be much better illuminated and more easily recognised than with top lighting.

The samples were prepared for counting by decanting with an eye dropper from the original sample as much fluid as was consistent with the amount of debris. The general levels were established by experience, the criterion being the maintainance of an amount of debris in the counting trough which would not interfere with counting, and yet concentrating the sample as much as possible to gain added precision. (For a further discussion of this point see the section on counting precision.) Repeated examinations of the decanted fluid showed no algae.

After concentration the volume of the concentrate was measured in graduated centrifuge tubes. The sample was then mixed by alternately filling and expelling a 5 ml. pipette whose point had been broken off to give a large diameter orifice. When the sample was well mixed the pipette was filled and 1 ml. delivered into the counting trough. It was found that the sand and heavier material could be kept from falling to the bottom and entering with the 1 ml. sample by holding the pipette at a low angle. The sample was spread evenly around the trough with a teasing needle,

and the trough agitated slightly for a few moments to shake the organisms into the bottom. The organisms were then counted by revolving the trough past the objective, starting and ending at a line scribed on the bottom of the trough, and keeping count of the organisms on a multiple key counter. In a few cases an organism was too numerous to be easily counted, and the sample was then diluted to a point which facilitated the counting. For the regular collections 3 counts of 1 ml. each were made from each sample. For special collections, such as daily and 24 hour series, 5 counts of 1 ml. each were made from each sample. The counts for each sample were averaged, and the average values used, with the known volumes, to calculate the number of organisms per liter of river water.

Ward (1955) used the trough to count complete samples. Whether the collection volume is adjusted so as to make this possible or whether the samples are sub-sampled as in this case, it appears that the trough has definite advantages over the commonly used Sedgewick-Rafter cell. Among these advantages are quickness and simplicity of use, ease of counting because the eye need scan only a small area, and removal of the problems caused by unequal distribution in the Sedgewick-Rafter cell (Serfling 1949). If counts of only a part of the circle are made however, as suggested by Ward, serious distributional problems arise since random distribution in the trough may be almost impossible to achieve.

It was noticed that the liquid of the 1 ml. samples tended to distribute itself somewhat unequally in the trough due to the non-wetting characteristics of the plastic. Some decrease in the

trough volume would be desirable to remedy this situation. Perhaps the shorter angle on the sides would be sufficient, but probably a decrease in diameter would be necessary. An increase in volume to the next convenient amount of 2 ml. gave too much water for this particular trough.

Nannoplankton. The water for the nannoplankton samples was collected by filling a one-gallon wide mouth glass jar from the main stream current at each station. The jars were taken to the laboratory for separation at the end of the collection trip.

Membrane or millipore filters were used for the major portion of the nannoplankton concentration. The ability of these filters to retain the permit recovery of nannoplankton has been demonstrated (Clark 1956). Two types of filters were used: millipore filters, type RA, diameter 157 mm., manufactured by the Millipore Filter Corporation, price $1.85 each; and membrane filters, coated, coarse porosity, diameter 150 mm., manufactured by Carl Scleicher and Schuell Co. (S. & S. filters), price $.46 each. The "coating" of the membrane filters consists of a rather stiff backing to which the thin (100u) filters are glued. The millipore RA filters have an average pore size of 1.2μ with a range of 0.9 to 1.5μ. The S. & S. coarse grade membrane filters have an average pore size of 0.5μ and a range of 0.3 to 1.2μ. These data are from the manufacturers specifications.

The filters were used with a holder constructed of plastic and copper in which the filters are clamped between the two sections of the holder and supported by a fritted glass disc (Clark 1956).

When in operation, a membrane filter was placed over the fritted glass and the top section placed over the glass and clamped down. A sheet of coarse filter paper was used under the M. F. filters to give better support. Vacuum was supplied by a vacuum-pressure pump, but the system functioned just as well from a regular water aspirator or from the manifold vacuum of an automobile in the field.

Each one-gallon sample was mixed thoroughly and then 3 liters were measured out. The 3 liter sample was passed through the filter, the filter removed, and the plankton washed from the filter into a petri dish with the aid of a pressure atomizer and a fairly stiff artist's brush.

The samples were transferred from the petri dish to labled vials and preserved by the addition of sufficient iodine, in potassium iodide solution, to make a 2 to 3 percent solution.

The membranes became transparent when cleared with a fluid of appropriate refractive index such as cedar oil. Microscopic examination of cleared filters showed that only an occasional organism could be seen on the filters after the cleaning process. No organisms were seen in counts of the regular 30 fields on several concentrates from second cleanings of the filters. Surveys of the haemacytometer plateau in these cases disclosed only a very few organisms. Apparently the filter cleaning process was very effective with the organisms found in the Logan River.

The majority of the separating was done with the S. & S. coarse, coated filters. The S. & S. filters were chosen over the M. F. filters for general use for two reasons: the cost per

filter for the S. & S. was considerably less, and the coated filters were very rugged permitting repeated use. The coated filters were discarded only when filtration times became too slow. With both makes the filters eventually became clogged with fine material. In a typical series of separations, with the S. & S. filter, with the turbidities under 2 p.p.m., the first 3 liter sample passed through in 5 minutes, the sixth sample took 14 minutes.

The M. F. filters are expensive and fragile, seldom lasting for more than 3 samples. They have the advantage of extremely fast filtration rate however, and can be used with more turbid samples. With samples under 2 p.p.m. turbidity, 3 liters pass through the M. F. type RA filters in less than 15 seconds. In one sample series an M. F. filter which had been previously used for some clear samples passed a sample with turbidity of 2.8 p.p.m. in just under 1 minute, and the following sample of 18 p.p.m. turbidity in 1.5 minutes.

The coated S. & S. filters are quite stiff and can be cupped in the hand for washing. The M. F. filters are thin and fragile and attempts at holding them in the hand resulted in breaking of the filter. A holder for the M. F. filters was constructed by forming 2 sheets of plastic into nested tapering troughs. A circle just smaller in diameter than the filters was cut from the inside piece before forming the trough, with the edge of the circle just touching the edge of the plastic. In oporation the M. F. filter was placed on the first piece of the trough, and the second piece placed over the filter so that the edges of the

filter were held down. The organisms could then be washed from the filter through the opening at the edge of the plastic, which became the tip of the trough.

The clogging point was reached suddenly with both makes of filters, and once reached, passage was extremely slow, taking up to 30 minutes for the last liter of a turbid 3 liter sample.

In general it was not practical to filter samples with a turbidity of over 4 to 5 p.p.m. with the S. & S. filters, and then only with new filters. The turbidity limit for the M. F. filters was about 20 p.p.m., and then the filter could usually be used only once. Attempts to clean the filters by soaking and back flushing were not successful. Some increase in filtering speed was noticed after several days of soaking, but the filters reclogged quickly.

Both makes of filters are shipped dry, and once wet must be kept wet. The S. & S. filters were boiled at a slow simmer for 20 minutes before first use, as suggested by the manufacturers for maximum filtration rate.

Since this project began both companies have announced the availability of filters with pore sizes up to 5μ. The development of these membranes as tools for plankton research has only begun. They promise to add much to our knowledge of the very small phytoplankton particularly.

For very turbid samples separation was done with a Foerst plankton centrifuge. At flow rates of 5 minutes per liter or more filtering of the centrifuged water disclosed no spill-over. At a flow rate of 2 1/2 minutes per liter there was 15 percent

spill-over. All of the regular samples were separated at 5 minutes per liter. Exclusive use of the centrifuge would have more than doubled the time required for separation of the samples.

A special Spencer Bright Line Haemacytometer with a cell depth of 300μ was obtained for the nannoplankton counts.

The concentrates were decanted with a dropper, as with the net plankton, to the point of maximum allowable debris. The volume of this concentrate was then determined in a graduated centrifuge tube. During the flood period some samples had to be diluted instead of concentrated to make counting possible. The samples were mixed by filling and expelling a dropper several times, a drop was then introduced at the edge of the cell, filling the cell by capillary action. The counts were made under high dry magnification (about 400X) with a binocular compound microscope. The oblong squares comprising the center millimeter on each side of the scribed area were used. In each case the first field was chosen at random and then every other field counted until 15 fields had been examined. The cell was filled a second time from the same concentrate and 15 fields counted as above, giving a total of 30 fields counted for each sample.

The average number of organisms per field was calculated for each form or group, and this average value used with the known volumes to calculate the number of organisms per liter of river water.

Sensitivity and precision of sampling and enumerating procedures

Sensitivity. First of all, the sample volumes of 40 liters for the net plankton and 3 liters for the nannoplankton were

extremely small fractions of the water mass represented by the sample. The flow volumes in general ranged from about 1,400 to 5,600 liters per second during most of the year, and up to 34,000 liters per second during the spring flood. It was clearly possible to have an organism passing the collection point in considerable total numbers per second and yet have it absent from the collection.

A second artifice of the initial collection was the effect of the 800 to 1,000 percent increase in flow during the spring flood. An organism near the lower threshhold of sensitivity during the rest of the year would disappear from the collections during the flood unless its abundance increased proportionally with the increase in flow. Those organisms remaining constant in numbers per liter during the flood reflected a tremendous increase in total numbers.

To retain equal sensitivity at this point would have meant keeping the sample volume proportional to the volume of flow. With the manpower and facilities available this could only have been done by limiting the study to one or two stations. It was considered more important to cover the series of stations, so long as the sampling bias was recognized. Also, the downstream increase in volume of flow could cause a decrease or disappearance of an organism which was in fact staying constant in actual numbers.

The volume of concentrate remaining after separation and collection varied. It was determined that after standing for several weeks all the organisms settled out in both net and

nannoplankton concentrates. This permitted readjustment of the concentrate volume at the time of counting.

The final degree of concentration was limited by the amount of debris and turbidity present.

For the nannoplankton most concentrate volumes were between 1.5 and 3.5 ml. for the upper six stations, 3.5 to 6 ml. for station 7 and near 25 ml. for the very turbid station 8. During the spring flood increased turbidities gave concentrate volumes of 3.5 to 8 ml. for the upper six stations and 6 to 20 ml. at station 7. At station 8 the turbidities during the flood were little higher than usual and concentrate volumes did not increase. The seasonal effect at this station was a winter decrease in turbidity, giving concentrate volumes of 4 to 15 ml. November through February.

Only a small fraction of the concentrate volume was actually counted. The total volume covered by 30 fields in the special 300u deep haemacytometer amounted to 0.00045 ml. This meant that the organisms had to be present in considerable density in the concentrate to be seen. In terms of minimum sensitivity--the organisms per liter of river water to which one occurrence would be expanded--the values were as follows: Upper 6 stations, non-flood 1,000 to 2,500, flood 2,500 to 6,000; Station 7, non-flood 2,500 to 4,500, flood 4,500 to 15,000; Station 8, winter 3,500 to 11,000, rest of the year 19,000.

The sensitivity could have been kept constant by either keeping the concentrate volume constant or keeping the volume counted in proportion to the concentrate volume. The former

method would have meant choosing the most turbid collections as the standard, to the great detriment of the rest of the data; the latter method would have increased the time involved in counting beyond the capabilities of the project without drastic curtailment of the number of stations or period of collection.

Turbidity was not a problem for the net plankton samples. The turbidity-causing fraction passed through the net. Organic and mineral debris however was a problem, and often made counting difficult. There was no pronounced seasonal or locational trend in the amount of debris present. The stations below the dams were lower in mineral particles, but higher in organic fragments. The organic fragments were more hindrance to counting than were the mineral particles. The amount of debris per unit volume of water rose only a little during the flood, and even then only during the first part of flow increases.

Net concentrate volumes were primarily between 12 to 22 ml. This gave minimum sensitivities of 0.1 to 0.19 organisms per liter for the regular collections with a total of 3 ml. counted per concentrate. For the daily and 24 hour series, with 5 ml. counted per concentrate the minimum sensitivity was 0.08 to 0.11 organisms per liter.

Precision. Since the final figures used in expanding the organisms counted into organisms per liter of river water were means, confidence limits were set to a representative sample of the means using the following formula:

$$M = \bar{x} \pm t_{.05} s_{\bar{x}}$$

where M = population mean,

$\bar{x}$ = sample mean,

$t_{.05}$ = statistic taken from a table such as Table 3.8 in Snedecor (1946), and

$s_{\bar{x}}$ = standard error.

The confidence limits thus obtained were converted to percent of the mean and plotted against the total organisms enumerated in the count (Figures 3 and 4).

The author demonstrated in a previous study (Clark 1956) that for nannoplankton counts made under similar conditions the width of the confidence limits when expressed as percent of the mean is dependent upon the total number of organisms enumerated and independent of the number of fields over which the enumeration was done in the range tested (18 to 72 fields).

The nannoplankton counts of the present study, where 30 fields were enumerated for each count, give very good agreement with the previous study. Total numbers counted of at least 25 are necessary to give confidence limits of near $\pm$ 50 percent, and total numbers of 100 giving about $\pm$ 25 percent.

Agreement of total numbers counted and precision is still very good for the net plankton counts with 5 troughs per count (the daily and 24 hour series), with the relationship of number counted and confidence limits as percent of the mean essentially the same as for the nannoplankton. The points are a little more scattered however and the relationship not quite so precise.

The relationship of total numbers counted and precision, though still very obvious, is quite general for the regular net plankton counts of 3 troughs per count. Very low numbers counted still give very low precision, and high total numbers do not increase the precision much past $\pm$ 50 percent.

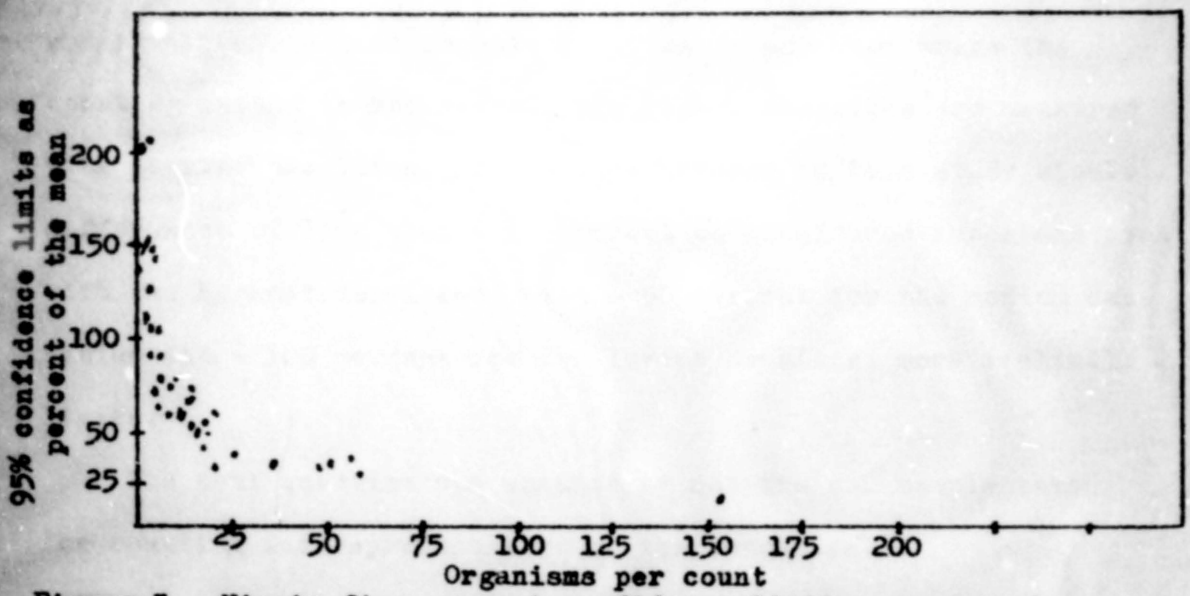

Figure 3. Ninety five percent confidence limits, expressed as percent of the mean number of organisms per count, plotted against the total number of organisms enumerated in the 30 fields covered for each count. Nannoplankton counts.

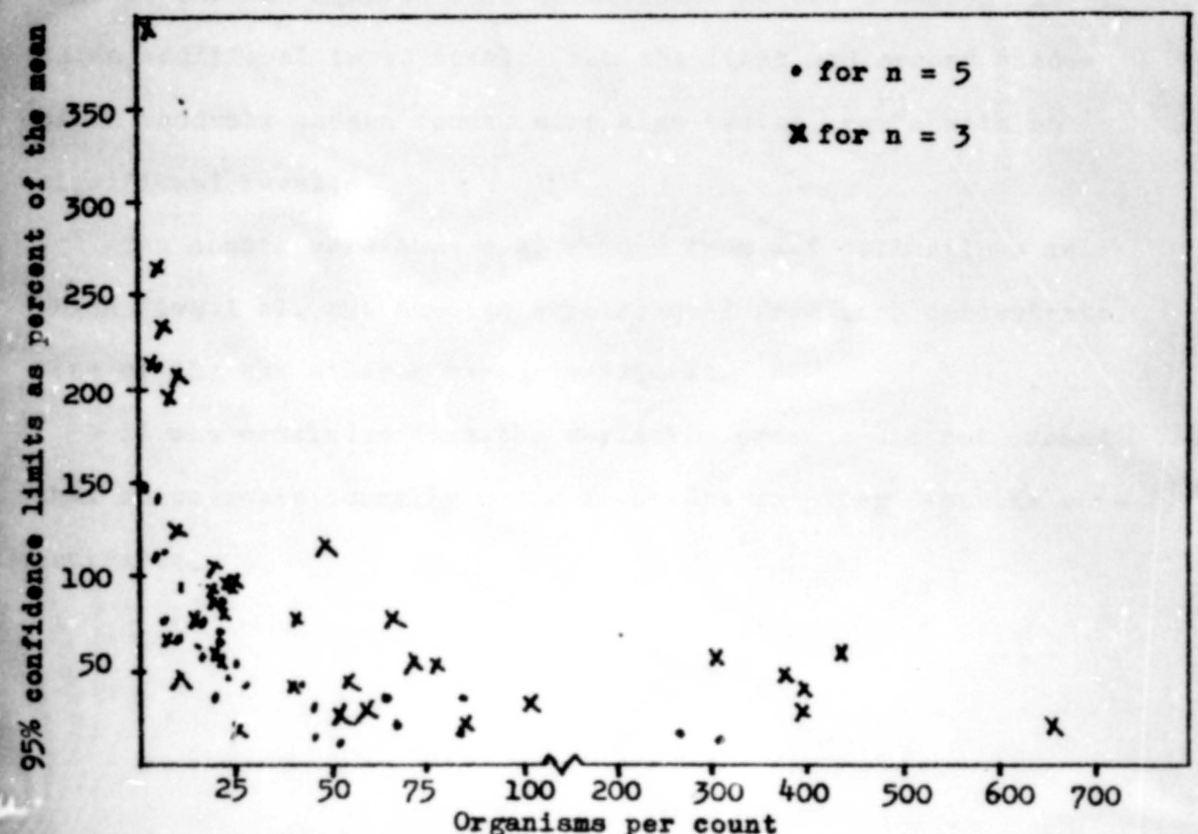

Figure 4. Ninety five percent confidence limits, expressed as percent of the mean number of organisms per count, plotted against the total number of organisms enumerated in the 3 or 5 troughs covered for each count. Net plankton counts.

The effect of this general relationship between total numbers and precision is that in this case, as in any case where the counting method is not varied, the higher densities are measured with greater precision. In no case however in this study should differences of less than ± 25 percent be considered important even with the highest densities; with ± 50 percent for the medium densities and ± 100 percent for the lowest densities more realistic limits.

The next question was whether or not the sub sample taken for counting was representative of the concentrate.

Chi square tests were applied to the counts of 10 nannoplankton forms in 5 replicate counts from the same concentrate. None of the chi squares were significant at the 5 percent level. As an additional test, totals from the first and second slides of 12 randomly chosen counts were also tested, again with no significant results.

Ten counts were chosen at random from net collections in which five 1 ml. sub samples were counted from each concentrate. None of the chi squares were significant.

It was concluded that the variation present did not exceed that which would normally occur in random sampling from the concentrates.

PHYSICAL AND CHEMICAL CHARACTERISTICS OF THE STREAM

Substrate

The bed of the canyon section of Logan River is composed primarily of boulders and cobbles with only small areas of gravels and occasional small patches of sand and/or silt behind large boulders. Occasionally areas of bedrock are exposed. Most of the larger rocks are well fixed in place, and when removed show signs of having stayed in the same position for some time. Rocks of equivalent size when placed on the stream bottom in a new position were moved downstream by the spring flood.

The bottom of the valley section of the river is composed of finely divided materials and the bottom contours change with the erosion and deposition pattern of the currents.

Gradient

The average gradient from station 1 to the mouth of the canyon is 73 feet per mile, though 1 section is twice that (Figure 1). The gradient in the valley is 3.5 feet per mile if measured in a straight line, but under 2 feet per mile by stream.

Even the valley gradient exceeds those reported in most plankton studies. Galtsoff (1924) gives .35 to .38 feet per mile for the Upper Mississippi, and 1.3 feet per mile for the 16 mile Rock Island "rapids". Kofoid (1903) gives 1.2 feet per mile as the average gradient for the Illinois, but .137 feet per mile for the lower 227 miles. Starrett and Patrick (1952) report 1.5 to 3.2 feet per mile for the DesMoines. However, the gradient of 220 feet per mile reported by Pennak (1943) for Boulder Creek in

Colorado exceeds even the steepest sections measured on Logan River, though a few of the tributaries may approach it.

Temperature

The temperature data are of 2 types: the single or center line represents water temperatures at the time of plankton collection; the upper and lower lines connect values from maximum-minimum thermometers and represent the temperature range since the last collection trip at each point (Figures 5 and 6). The straight lines at the beginning of the maximum-minimum data on Figures 5C and 5E, and 6C and 6D represent the temperature range from the time the thermometers were lost at the beginning of the spring flood until their recovery. The temperature range over stations 1 through 6 was 32°-60°F, for station 7 the range was 32°-76°F and for station 8, 34°-85°F. The low temperature at station 8 would probably have been near 32°F had maximum-minimum temperature data been available. The temperature range for the upper river was somewhat less than the 32°-69°F reported by Pennak (1943) for Boulder creek. The temperatures of station 7 (32°-71°F) and 8 (34-85°F) are comparable to those given by Kofoid (1903) for the Illinois (32°-89°F), Starrett and Patrick (1952) for the DesMoines (32°-85°F), and Reinhard (1931) for the Mississippi (37°-77°F). Allen (1920) gives a range of 39°-79°F for the San Joaquin, a much higher minimum temperature than those cited here.

Anchor ice was often present at station 1 from late November through January. The river remained open at station 1 and for about 2 miles upstream from it. The river froze over completely above this open stretch, and in many areas for about 5 miles

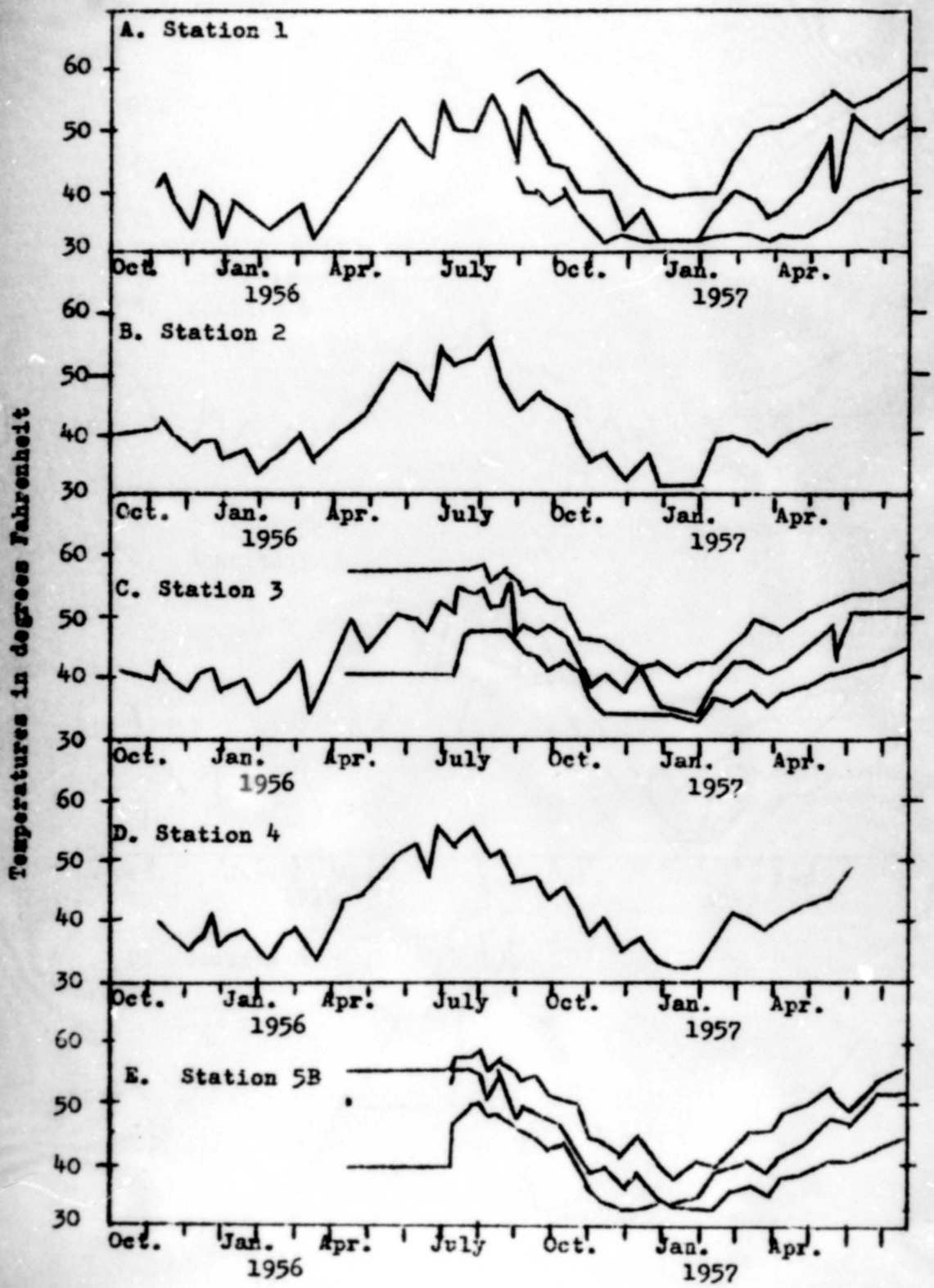

Figure 5. Water temperatures in degrees Fahrenheit at stations on the Logan River, Utah from October 1955 to July 1957. The central line is the water temperature at time of plankton collection. The upper and lower lines show the temperature ranges measured by maximum-minimum thermometers.

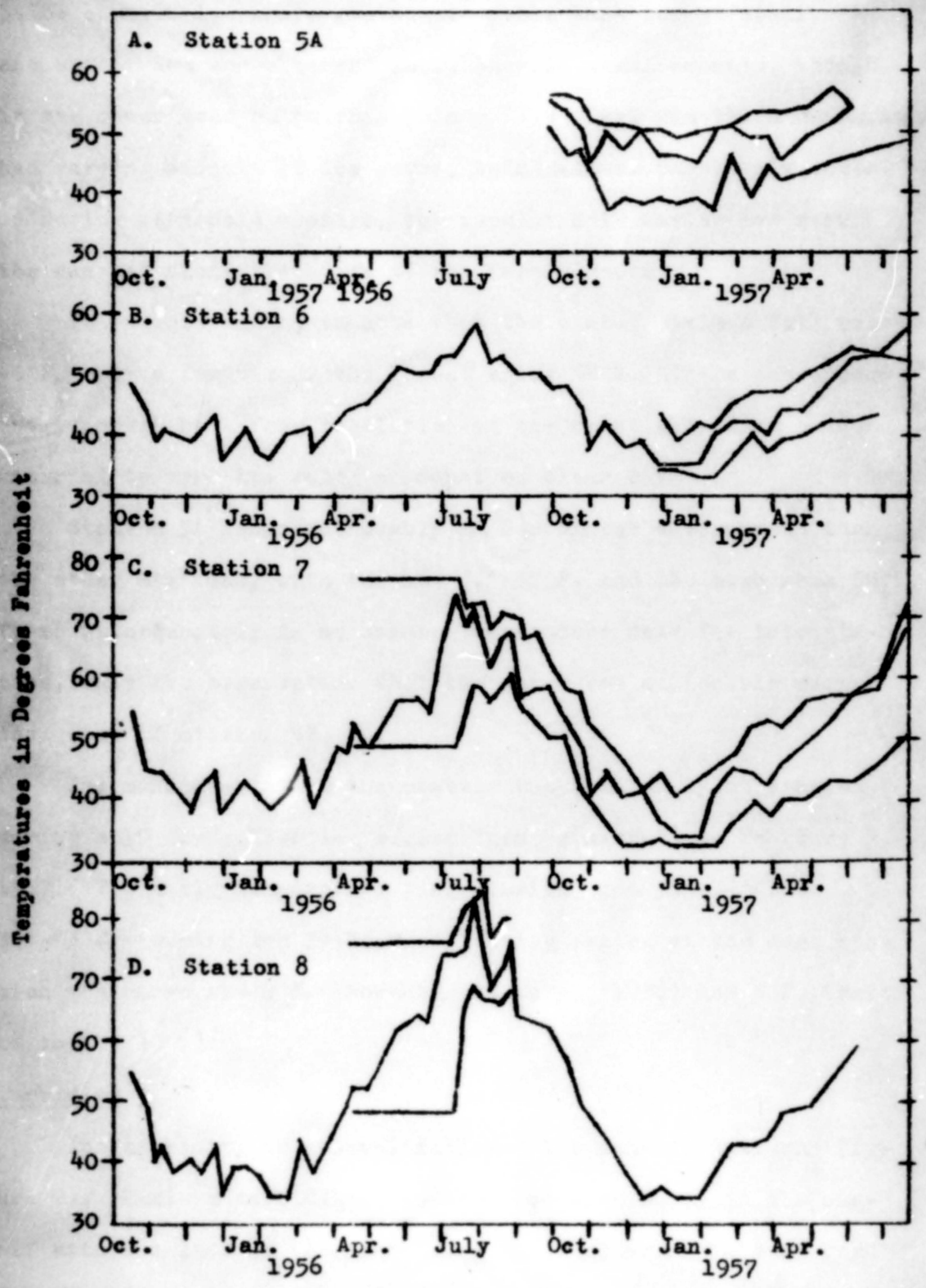

Figure 6. Water temperatures in degrees Fahrenheit at stations on the Logan River, Utah from October 1955 to July 1957. The central line is the water temperature at time of plankton collection. The upper and lower lines show the temperature ranges measured by maximum-minimum thermometers.

below station 1. There was considerable bank ice at station 2 and anchor ice was observed there once in small amounts, though it was never seen below this point. The first and third impoundments had varying amounts of ice cover, being almost completely covered during very cold weather, but usually only having ice near the dam and along the edges of the impoundments.

It is interesting to note that the winter maximum fell below 40°F. only a few times, the lowest being 38°F. There was apparently enough heat from insolation on the relatively dark bottom material to warm the water somewhat on clear days.

Station 5A had a noticeably milder winter environment than the other stations, with the low 37°-39°F. and the high near 50°F. There unfortunately is no summer temperature data for this station, only the observation that the water was noticeably warmer than that of station 5B.

The maximum-minimum thermometer was read daily at station 3 during a 10 day collecting series from January 29 to February 7, 1957. The daily temperature range varied from 36°-39°F. to 33°-43°F. During two 24 hour collecting series at the same station the range was 2°F. (November 29 to 30, 1956) and 5°F. (March 18 to 19, 1957).

Turbidity

The turbidity in general followed the run-off pattern (Figure 7). Maximum turbidities however occurred early in the run-off with the last of the high water quite clear. The very high turbidity peak of April 6, 1957 was obtained on a collection trip taken the day following a night of rain and sleet. The downstream

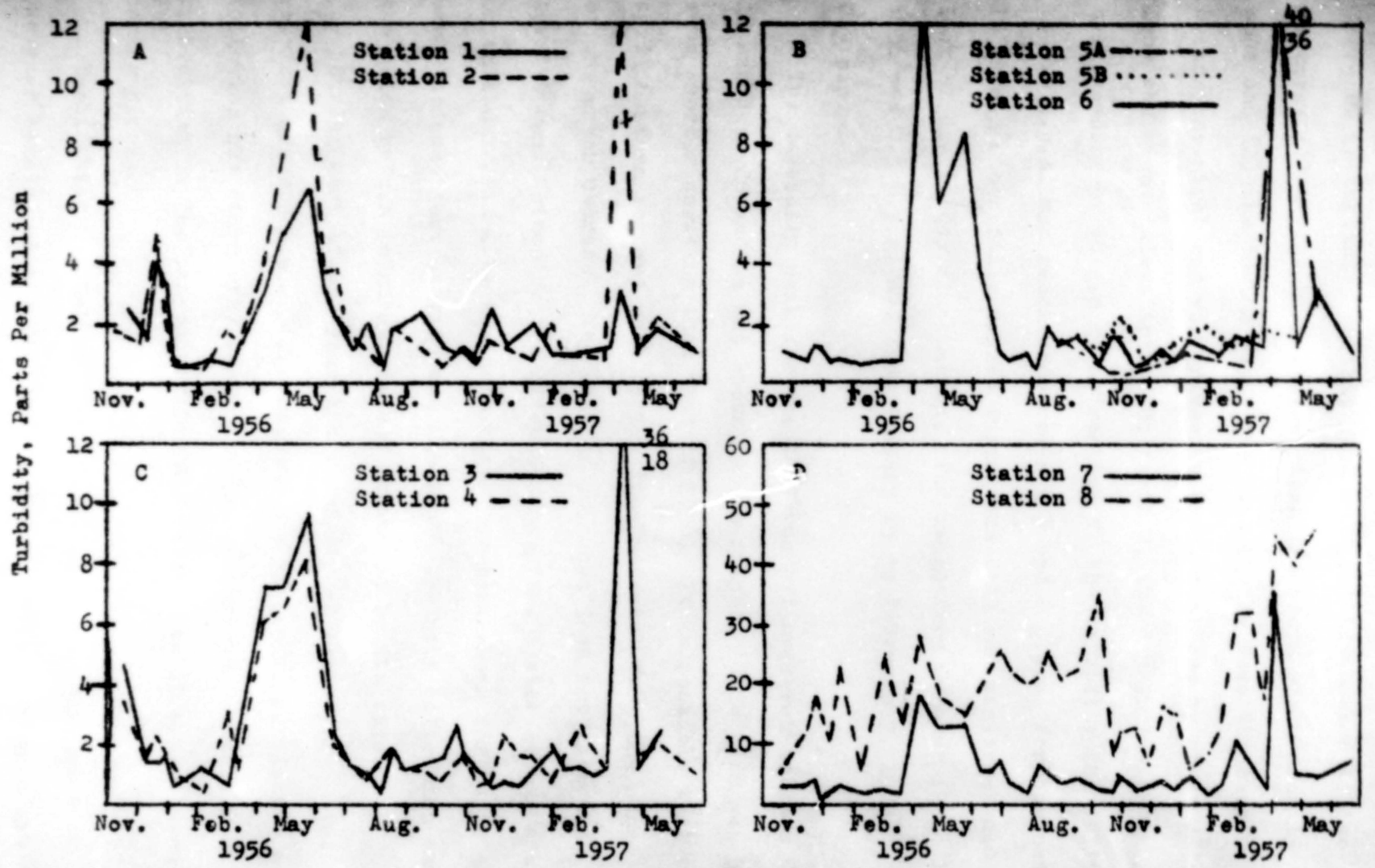

Figure 7. Turbidity, p.p.m. SiO_2 equivalent, at stations on the Logan River from November 1955 to June 1957. Note change of scale in D.

increase in turbidity on this date was probably caused by two factors: (1) at the higher elevations the storm was primarily snow and (2) the turbid water had been moving down the canyon during the night and was gradually being replaced by clean water from the higher elevations. On April 7, the day following the high reading of 18 p.p.m. at station 3, the turbidity had fallen to 3.5 p.p.m. and remained between 2.3 and 4 p.p.m. for the next 10 days. Other daily series during the fall and winter showed a lack of day to day fluctuation. The range from October 12 to 17, 1956 was 0.3 p.p.m. and from January 29 to February 7, 1957, 0.9 p.p.m.

The turbidity peak for the 1957 run off occurred between May 18 and June 25 and is not shown on the graphs. This peak was of much shorter duration than that of 1956. It is possible that the April 6 storm removed much of the fine material from the edges of the water courses. The station 5B graph does not show the April 6 peak, since by the alternate sampling system it was missed on that date. And by the same token the peak shown for 5A is too broad because that station was missed on the next collection and the quick return to normal is not indicated by the data.

During most of the year the turbidity at the upper 6 stations remained under 2 p.p.m. The maximum was 40 p.p.m. at station 6 following the storm previously discussed. Except for this peak, turbidities in the canyon portion did not exceed 15 p.p.m. even during floods.

Turbidities at station 8 remained relatively high most of the year because of the fine material comprising the banks and

bottom, and the fact that the irrigation waste water from surrounding crop lands was very turbid. The maximum turbidity of 46 p.p.m. at station 8 is far below the maximum of 240 p.p.m. reported for the Mississippi by Reinhard (1931).

Water velocity

Because of local changes in gradient a wide range of water velocities could usually be found within a short distance of any 1 point on the river. Among the sampling stations, station 2 had the highest water velocity, with a minimum main stream velocity of 4.5 feet per second and a maximum of 9.2 feet per second during floods. No attempt was made to measure flood velocities in the areas of maximum gradient, but they appeared to be considerably higher than at station 2. Station 1 had a range of 2.5 to 8.6 feet per second; station 3 a range of 2.5 to 7.7 feet per second. the velocity ranges at station 7 (0.4 to 4.7) and station 8 (0.5 to 4.4) are more in line with those of 0.7 to 4.37 for the upper Mississippi (Galtsoff 1924) and 0.6 to 2.5 for the Illinois (Kofoid 1903). (Velocities were not measured in the channel above station 5A, but they appeared to be lower than those of the river above the third dam.)

Volume of flow

Profiles were established at stations 1, 2, 3, and 7, and flow data calculated from gage readings and velocity measurements. The Water Resourced Division of the U. S. Geological Survey maintains recording gages on the three segments of the stream at the canyon mouth which collectively comprise the flow at that point; the river channel--station 5A, the power raceway--station 5B, and

the first irrigation canal. Data from these stations were obtained at the Logan office of the Geological Survey. Flow estimates at station 8 were not attempted since the control of the water level by Cutler Dam prevented the establishment of a reliable gage height discharge volume relationship. Volume of flow data are presented for stations 1, 2, 3, 5A, 5B, 7 and for the total stream flow at the canyon mouth (stations 5A, 5B, and the first irrigation canal combined) (Figure 8). In spite of the difference in altitude, the data for the upper 3 stations do not demonstrate a sequence in starting date of runoff or in date of maximum flow. Observations indicated that there was a slight sequence, with the lower station being earlier, but the 10 to 15 day intervals between collections was enough to mask this sequence. The river does not flow through terrain which gradually increases in altitude, the transition from valley to high mountains is abrupt, with Mt. Logan at 9,700 feet only 4 miles from the canyon mouth. Thus with high terrain paralleling almost its entire length, the river rose and fell almost as 1 unit.

Gages at stations 5A and 5B reflected the manipulation of the flow for power and irrigation. Except during the spring flood, the main channel at the canyon mouth (station 5A) carried only seepage water, some spring water, and occasional overflow from the surge tank at the power station flume terminal. The flow at station 7 reflected fluctuations caused by irrigation demands. This demand began during flood time, and its effect was to remove the slow tapering off in maximum flow which was noticeable at the upper stations.

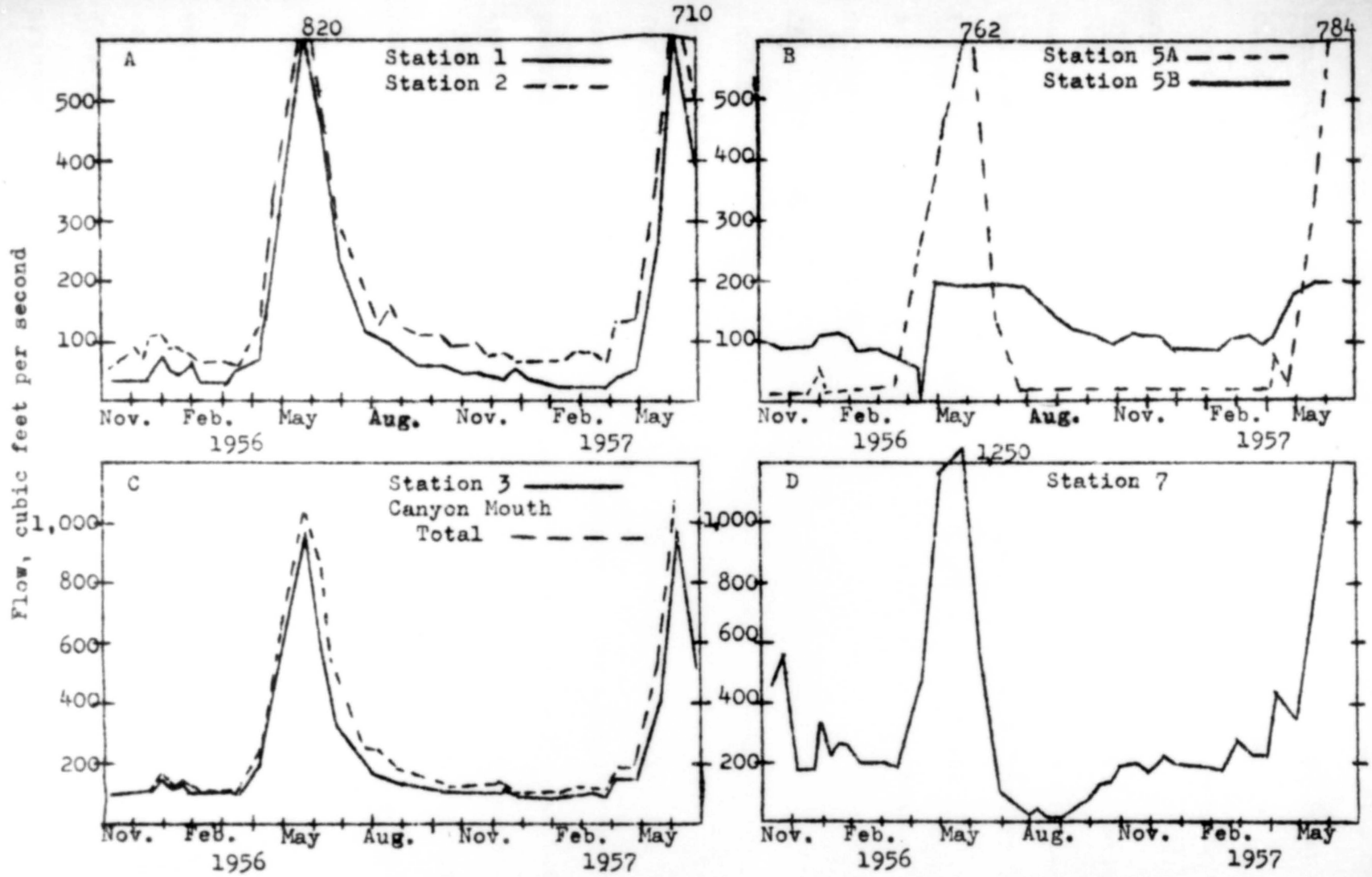

Figure 8. Volume of flow in cubic feet per second at stations on Logan River from November 1955 to June 1957. Note change of scale for C and D.

Peak flow volumes were 10 times the winter minimum flow. Examination of records from the stations at the mouth of Logan Canyon showed diurnal fluctuations in flow only during the first part of the spring flood and even then they were occasional and amounted to 10 percent fluctuations at most.

There was little fluctuation in the daily series at Station 3; during the 8 days from October 12 to 19, 1956, the gage readings had a range of one-half inch, between January 29 and February 7, 1957 the range was 1 1/4 inches, and between April 6 and 15, 3 1/4 inches. The full range of gage readings at this station during the study was 32 inches.

Water chemistry

General. The results of 3 series of chemical analyses are given in Table 1. Much of the first analyses must be discounted for comparative purposes since, as is noted in the table, the sample stood for some time before analysis. The analyses show in general; a downstream increase in total dissolved solids (T.D.S.), little difference in any one series between the upper three stations for most constituents, and significantly higher values at the lower 2 stations in several cases (nitrate nitrogen, phosphate, sulfate).

The January and April 1957 analyses appear to be significantly different in several cases: sodium and nitrate nitrogen were higher in the April analysis; bicarbonate, t.d.s., calcium and magnesium were higher in the January analysis. Since water levels were not significantly different at the 2 collection dates, presumably some other factor or factors was responsible. The

Table 1. Chemical analyses of water from the Logan River, Utah. Electrical conductivity (E. C.) in Micromhos per centimeter; other figures in parts per million.

Date and Location	EC	TDS	Ca	Mg	Na	K	Cl	SO_4	CO_3	HCO_3	PO_4	NH_4 N	NO_3 N
September 12, 1956													
Station 1	350	146	40*	17*	1	0.4	4	2	0-10	206*	0.3*	.015*	0.12*
Station 3	360	142	38*	17*	2	0.4	2	2	0-10	200*	0.2*	.19*	0.04*
Station 6	370	140	33*	17*	2	0.4	4	3	0-10	178*	0.08*	0*	0.005*
Station 7	510	184	29*	23*	4	1.2	6	12	0-10	245*	0.67*	0*	0.23*
Station 8	570	242	37*	28*	14	3.3	14	27	0-10	255*	2.5*	.04*	0.30*
January 1957													
Station 1	360	180	55	20	2	2.0	5	4	0-10	255	0.03	0	0.14
Station 3	370	196	50	20	3	2.0	5	6	0-10	236	0.02	0	0.12
Station 6	380	196	51	21	3	2.0	6	8	0-10	240	0.02	0	0.12
Station 7	420	204	55	23	4	2.0	6	15	0-10	260	0.02	0	0.20
Station 8	490	272	59	23	9	3.0	13	21	0-10	287	0.11	0	2.90
April 5, 1957													
Station 1	340	178	45	16	12	2.0	4	4	18	217	.009	0	1.6
Station 2	340	182	47	15	15	2.0	6	5	0-10	221	.018	0	2.0
Station 3	360	212	48	17	15	2.0	6	6	0-10	232	.009	0	1.8
Station 6	370	206	49	18	16	2.0	6	8	0-10	236	.009	0	2.2
Station 7	420	230	49	21	23	2.0	8	15	0-10	255	.01	0	4.7

* Sample stood before analysis; values are approximate or questionable.

data available permit only a general outline of the chemistry of the stream. More detailed work would be required to evaluate seasonal or downstream changes.

It appears that the impoundments do not add to the river water significant amounts of the materials tested for in these analyses.

Dissolved oxygen. Dissolved oxygen content in the canyon portion of the stream varied around the saturation point.

PH. The pH was not extensively tested. The average value was 7.6.

THE PHYTOPLANKTON

The general algal flora of the stream

Submerged vascular aquatics were almost completely absent from the river itself, though they were abundant in the first and third impoundments. Moss covered the rocks of the river bottom for several hundred yards below the first dam, and to a lesser extent at the outlet raceway of the powerhouse above the first impoundment. Patches of moss were occasional in other sections of the canyon portion of the river.

The most obvious algae were the banks of Spirogyra and Zygnema in the first and third impoundment; the brown streamers of Palmella Myosurris on the rocks in the canyon--most prevalent in the late fall and winter--and the brighter green thalli of Prasiola mexicana which were most abundant during the decline of the spring flood, large amounts being exposed by the falling water level. Cladophora was abundant below the first dam in conjunction with the moss, particularly in late winter and spring, but it was not often seen above the third dam. Vaucheria was seen occasionally in the upper river between stations 1 and 2 and was abundant in the winter in the river channels between the dams. Ulothrix was widespread though never abundant and reached a maximum in late wihter.

Upon close examination most of the rocks of the river bed were found to be covered with blue-green algae; some of these formed conspicuous crusts of calcium carbonate, while others were

very inconspicuous, their extent being realized only by extraction of their pigments (McConnell 1958). Predominant among the blue-greens were Phormidium incrustatum and Schizothrix fasiculata.

Diatoms were rarely obvious in the canyon section of the river. Occasionally they would be noticed as a brown scum on the rocks or bottom in the infrequent backwaters. In the valley section of the river the diatoms were present at low water as a brown coating and as brown streamers attached to rocks or twigs. Diatoms were present in scrapings from almost every habitat except perhaps the exposed front face of rocks in the main current. Diatoms were found on the blue green crusts, and large numbers of spicules were left when portions of the crust were dissolved.

It is difficult to compare the diatoms and blue-greens quantitatively but it appears to be quite possible that the blue-greens are the dominant photosynthetic group in the river.

The algae which have been identified from the river are listed in Table 2. No attempt has been made to compile a complete list. The collections of encrusting forms and diatoms examined and sent away for identification were quite representative however, and in these 2 groups the important species are certainly present, though many rare or occasional species are just as certainly missing.

The following forms were identified from the net plankton at station 8 on the Little Bear River below its junction with the Logan River but not from the Logan River itsself: Comphonema parvulum (Kutz.) Grun., Navicula cari Ehr., Nitzschia amphibia Grun., N. angustata (W. Sm.) Grun., N. fonticola Grun., N. hungarica Grun., N. tryblionella Hantzsch, N. vermicularis (Kutz.)

Table 2. Algae identified from the Logan River, Utah during 1955 and 1956.

Chrysophyta

Xanthophyceae

Vaucheria sp.

Chrysophyceae

Dinobryon Sertularia Ehr.
Palmella Myosurus (Ducluz.) Lyngb.
[=Hydrurus foetidus (Vill.) Trevis.]

Bacillariophyceae

Achnanthes exigua Grun.
A. minutissima Kutz.
Amphicampa hemicyclus (Ehr.) Karsten
Amphora ovalis Kutz.
A. ovalis Kutz. var. pediculus Kutz.
A. perpusilla Grun.
Caloneis amphisbaena (Bory) Cleve
Ceratoneis arcus Kutz.
Cocconeis pediculus Ehr.
C. placentula Ehr.
Cymatopleura solea (Breb.) W. Sm.
Cymbella affinis Kutz.
C. cistula (Hempr.) Grun.
C. prostrata (Berk.) Cleve
C. tumida (Breb.) v. Heurck
C. tumidula Grun.
C. vertricosa Kutz.
Denticula tenuis Kutz.
Diatoma anceps (Ehr.) Grun.
Diatoma hiemale (Lyngb.) Heib.
D. hiemale (Lyngb.) Heib. var. mesodon? (Ehr.) Grun.
D. vulgare Bory
Epithema sorex Kutz.
Eunotia lunaris (Ehr.) Grun.
E. pectinalis (Kutz.) Rabenh.
Fragilaria capucina Desmaz.
F. Harrissonii W. Sm.
Gomphoneis herculeanum (Ehr.) Cleve
Gomphonema acuminatum Ehr. var. coronatum (Ehr.) Cleve
G. constrictum Ehr.
G. gracile Ehr.
G. intricatum Kutz.
G. olivaceum (Lyngb.) Kutz.
Hantzschia amphioxys (Ehr.) Grun.
Melosira Roeseana Rabenh.
M. varians C. A. Ag.

Table 2. (Cont.)

Meridion circulare Ag.
Navicula anglica Ralfs
N. bicapitellata Hust.
N. bacillum Ehr.
N. cryptocephala Kutz.
N. cuspidata Kutz. var. ambigua (Ehr.) Cleve
N. dicephala (Ehr.) W. Sm.
N. lanceolata (Ag.) Kutz.
N. minima Grun. var. atomoides (Grun.) Cleve
N. pupula Kutz.
N. rhynchocephala Kutz.
N. Rotaeana (Rabh.) Grun.
N. viridula Kutz.
N. vulpina Kutz.
Neidium dubium (Ehr.) Cleve forma constricta Hust.
N. iridis (Ehr.) Cleve
Nitzschia acuminata (W. Sm.) Grun.
N. apiculata (Greg.) Grun.
N. Heufleriana Grun.
N. linearis W. Sm.
N. palea (Kutz.) W. Sm.
N. sigmoidea (Ehr.) W. Sm.
N. sublinearis Hust.
Pleurosigma Spencerii W. Sm.
Rhoicosphenia curvata (Kutz.) Grun.
Stauroneis Smithii Grun.
Surirella angustata Kutz.
S. ovalis Breb.
S. ovata Kutz.
Synedra acus Kutz.
S. rumpens Kutz.
S. ulna (Nitzsch) Ehr.

Myxophyta

Myxophyceae

Amphithrix jantnina (Mont.) B. and F.
Calothrix parietina (Nag.) Thur.
Entophysalis Lemaniae (Ag.) Dr. and Daily
E. rivularis (Kutz.) Drouet
E. rivularis f. papillosa (Kutz.) Dr. and Daily
Lyngbya versicolor (Wartm.) Gom.
Nostoc parmelioides Kutz.
N. sphaericum (L.) Vauch.
Phormidium incrustatum (Nag.) Gom.
P. subfuscum Kutz.
P. uncinatum (Ag.) Gom.
Schizothrix fasiculata (Nag.) Gom.

Table 2. (Cont.)

Chlorophyta

Chlorophyceae

Cladophora glomerata (L.) Kutz.
Chlorotylium cataractum Kutz.
Closterium acerosum (Schrank) Ehr.
C. Ehrenbergii Menegb.
C. litorale Gay
Mougeotia sp.
Odegonium spp.
Palmellococcus? sp.
Pediastrum spp.
Prasiola mexicana J. G. Ag.
Spirogyra spp.
Stigeoclonium sp.
Ulothrix zonata (Web. and Mohr) Kutz.
Volvox spp.
Zygnema spp.

Pyrrophyta

Dinophyceae

Ceratium hirundinella (O. F. M.) Schrank

Grun., Eudorina elegans Ehr., and Pledorina sp. None of these forms was abundant in the plankton. The data is insufficient to permit conclusions as to differences in species composition of the 2 streams. These forms are listed as a possible beginning in that direction.

The composition of the phytoplankton

Net plankton. The intention was to include in the net plankton only those organisms which would be completely retained by the net. This goal was only partially attained. One diatom, Nitzschia sigmoidea, was included with the net plankton because its large size--up to 500u long--would not permit its free movement in the haemacytometer used for nannoplankton counting. A check of nannoplankton samples for November and December of 1955, when these samples were taken from water which had passed through the plankton net, disclosed that from 40 to 60 percent of the N. sigmoides were passing through the net. Though up to 500μ long, the diatoms width of 10-15μ permitted passage through the 60-70μ openings in the number 20 silk net. The tiny Closterium litorale was also found to be passing through the net, and in the same percentage as N. sigmoidea. The calculated densities for these 2 organisms were doubled on the basis of this information. The other organisms included in the net plankton were: the other Closterium species C. Ehrenbergii and C. acerosum, Ceratium hirundinella, Pediatrum, the Volvocales (combined in enumeration, almost entirely Volvox), and the filamentous forms Ulothrix, Palmella Myosurus (actually a thallus included here for convenience), Cladophora, Spirogyra, Zygnema, and Vaucheria. In enumerating, the filamentous forms were recorded as number of field length fragments

(field diameter 4.3 mm.), the Volvocales and Pediastrum as number of colonies, and the remaining forms as number of individuals. Only cells which appeared to be alive and in good condition were counted--this applies also to the nannoplankton.

In presenting the general data on the net plankton the organisms are divided into 3 groups; the diatoms, the filamentous forms (including Palmella), and the non-filamentous forms comprising the remainder. Data on the 3 groups and on the total net plankton are presented.

Nannoplankton. Included in the nannoplankton are all the diatoms but N. sigmoidea, the trichomes of the benthic blue-green algae, and a spherical, green, multi-chloroplast form tentatively identified as a species of Palmelococcus. Even if the author were a skilled diatom taxonomist it would not have been possible to identify with certainty all the diatoms as encountered in the counting cell. The approach used was to place the common forms into morphologically distinct groups. In many cases the genus and in some cases the species could be determined with reasonable confidence. Collections were sent to Paul Conger and Dr. Francis Drouet for identification, and re-examination of the samples with the help of the identifications permitted most of the remaining groups to be named. Where identification was doubtful a question mark is added, where several species were lumped they are discussed under the genus.

In discussing the general data on the nannoplankton the data are presented as diatoms, non-diatoms and total.

The diatoms and Palmelococcus were enumerated as individuals. The blue-greens were enumerated as trichome fragments. The

fragments were rarely longer than 150u.

Variations in phytoplankton abundance

The presentation of plankton data presents problems to which no completely satisfactory solution has yet been found. The first impulse is to publish the data in detail. Kofoid (1903, 1908) and Allen (1920) for example did so, with the tables running to over 150 pages in each case. From the experience of the author and from the comments of others it appears that these detailed tables are seldom consulted, the desired information being obtained from summary graphs and discussions of the individual groups. The data for this study are presented by these latter 2 means; figures presenting the data in groups as previously given, and discussions of the important individual forms within each group.

The magnitude of the variations in plankton numbers makes the use of a linear scale in graphs impractical. The "spherical curve" method as given by Ruttner (1953) is utilized here. In this method of presentation a figure is drawn whose diameter corresponds to the cube root of the number of organisms per liter. Organisms per liter is the basic unit for the net plankton, and thousands of organisms per liter for the nannoplankton.

The effect of this method of presentation is to drastically reduce the heights of the peaks, and yet give low numbers a significant magnitude, points which must be kept constantly in mind in interpreting the figures.

Diurnal variation. Before the results of samples taken at intervals of 10 to 15 days apart can be adequately interpreted some information is needed on the magnitude of variation which might be expected between samples. There are few references to

diurnal variability in stream plankton. Allen (1920) reports on one 12 hour series of samples--7 A.M. to 7 P.M.--which shows a considerable increase in blue-greens between 1 P.M. and 7 P.M., with diatoms also increasing somewhat during this time. His tests were made on a side canal however and not in the main river and in addition covered a period of changing tide so that his data are hardly applicable to stream conditions. Blum (1954) gives data showing a diurnal cycle for 1 organism Nitzschia palea (Kutz.) W. Smith, with the maximum near noon (11 A.M. - 2 P.M.) and maximum values of 800 to 2,200 cubic units per liter, 6 to 20 times the night and early morning values of 66 to 350 units per liter. The other organisms present did not exhibit a diurnal variation but were quite erratic, varying from 2.7 to 21 units per liter. The collections were made in a polluted section of the stream in which the N. palea was the dominant benthic algae. Blum states that the N. palea was abundant in the plankton only in the region in which it was an abundant benthic form, indicating a benthic source for the cells, which he states were probably raised into the plankton by formation of oxygen bubbles during the mid-day period of maximum light.

Two 24 hour collections were made during the present study; November 29-30, 1956, and March 18-19, 1957 (Figures 9A and 10A). The 24 hour collections were made at station 3, the lowest station on the unmodified river. Two points are immediately apparent: first, there was no general diurnal cycle; second, the densities fluctuated very little, less than the range reported by Blum (1954) for the phytoplankton other than N. palea. For the net plankton (Figure 9A) the diatoms varied from 3.9 to 9.0 cells per liter

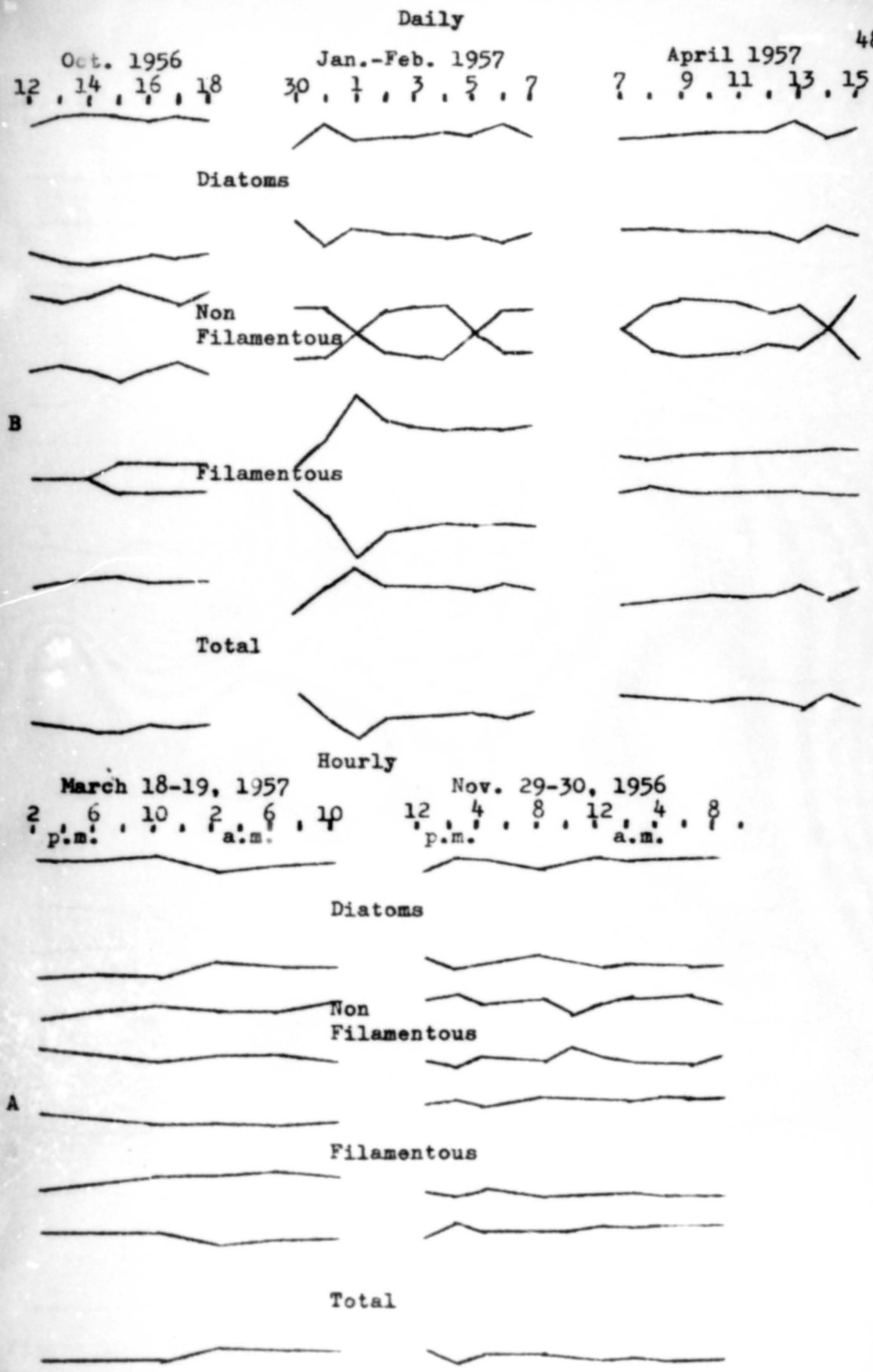

Figure 9. Variations in net phytoplankton density in 24 hour and daily series of collections on the Logan River, Utah (Station 3, DeWitt Camp). The diameter of the figures in centimeters, cubed, equals organisms per liter.

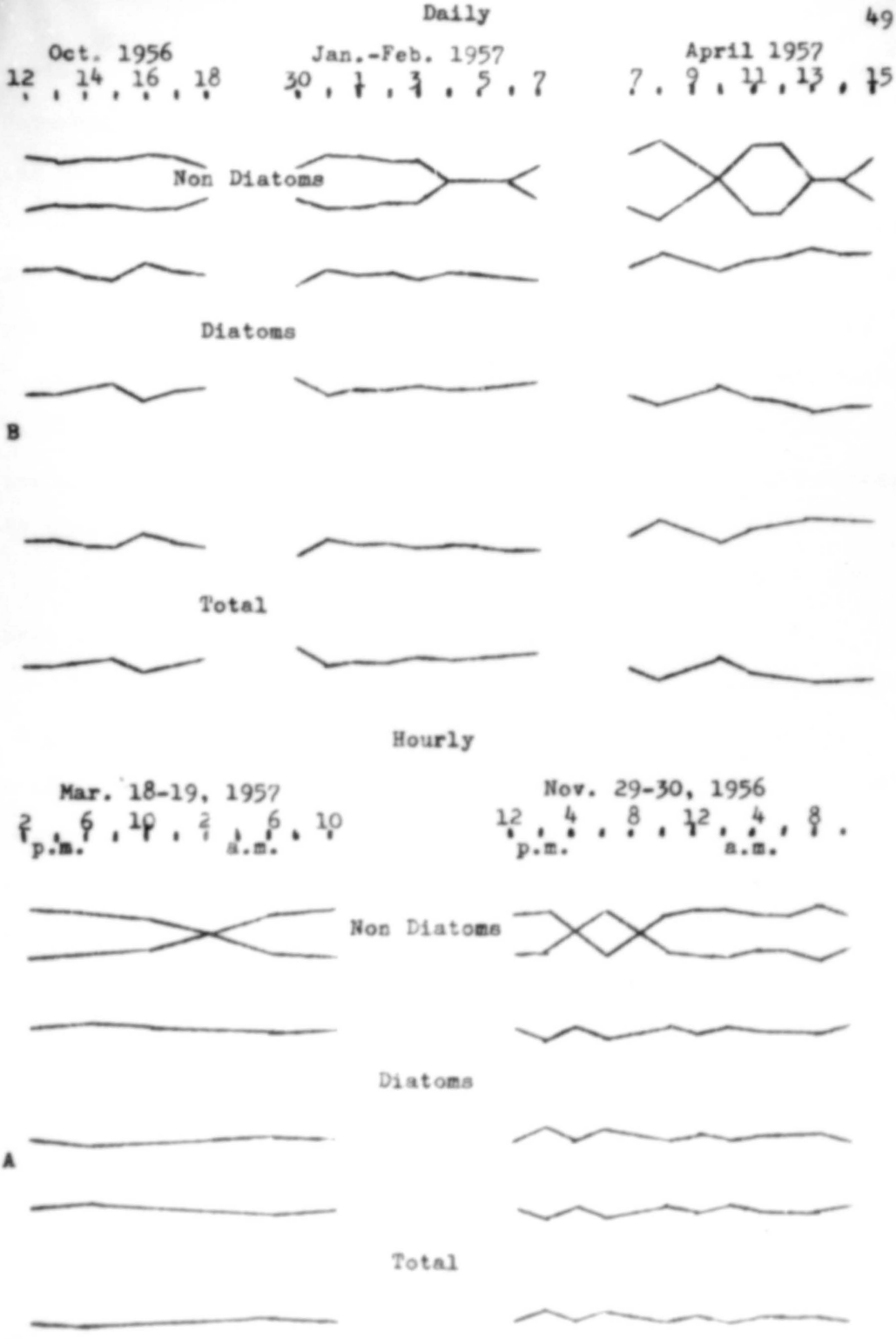

Figure 10. Variations in nannoplankton density in 24 hour, and daily series of collections on the Logan River, Utah (Station 3, DeWitt Camp). Twice the diameter of the figures in centimeters, cubed, equals thousands of organisms per liter.

during the March series and from 3.2 to 6 cells per liter in the November series. Corresponding ranges for the other groups in the net plankton are as follows: Non-filamentous, March, 0.12-1.1, November, 0.22-2.0; filamentous forms, March, 0.51-213, November, 2.9-5.0; total, March, 5.1-10.6, November, 7.6-13. For the nannoplankton groups the ranges are as follows: Non-diatoms, March, 0-4,000 cells per liter, November, 0-5,300 cells per liter; diatoms, March, 38,000-65,000 cells per liter, November, 28,000-58,000 cells per liter; Total, March, 40,000-68,000 cells per liter, November, 32,000-62,000 cells per liter.

Most of the variability shown here falls within the 50-100 percent which has been assigned to sampling error.

The net plankton filamentous forms consisted predominantly of Palmella myosurus in the March series, with some Mougeotia and a little Cladophora. In the November series only P. myosurus was present. The only form present in the non-filamentous group other than the 3 Closterium species was a lone occurrence of Ceratium hirundinella in the November series.

The non-diatom group of the nannoplankton consisted in both series of blue-green fragments only.

Daily variation. Three daily series of collections were made at station 3: October 12-18, 1956; January 30, 1956-February 7, 1957; and April 7-15, 1957 (Figures 9B and 10B). The general levels were quite different from series to series, but each was representative of its season. Variation was much greater than in the 24 hour series. Maximum values were 2 to 4 times minimum values, and in 1 case (the filamentous forms in the January 1956-February 1957 series) the maximum was 20 times the minimum. The

changes in density were not violent however. In only 1 case were the maximum and minimum values found on consecutive collections, and in this case (nannoplankton diatoms, October 1956 series) the maximum was not quite twice the minimum. Changes in density usually occurred over a period of several days.

Only one or two days out of the 25 represented in the 3 series would be grossly misleading as a representative of the period covered. It appears that in the upper river at least the regular collections can be expected to give a fairly accurate picture of the period they represent. Individual differences between consecutive collections of less than 2 or 3 fold should not be considered significant. Sharp increases or decreases involving only 1 collection should be suspect, they may represent that day only. Trends established by several collections are probably valid.

In all but one or two cases the variation in abundance of the individual forms was equal to or less than that of the group. In the exceptions, as in the totals, the greater range was caused by 1 large sample in the series.

What effect the impoundments and diversions have on the diurnal and daily variation is unfortunately not known.

Seasonal variations. One of the consistent relationships seen in almost all of the plankton studies on the larger rivers is the association of the plankton maximum with the falling water level after the spring flood peak. Kofoid (1908) and Rice(1938) comment particularly on this relationship, and Kofoid further points out that the majority of the minor pulses during the year were also

at times of falling water level. Kofoid attributes this correlation of falling water level and plankton maxima to a return of plankton to the river from flooded areas as the water level falls. The flooded backwater areas provided good conditions for reproduction, which was aided by activation of spores and resting stages left by previous floods. The data of Reinhard (1931) also demonstrates the relationship of plankton maxima to falling water levels. Starrett and Patrick (1952) give data for a station just below a dam however and their data show that water level and plankton production are not closely correllated. The plankton increase began during the period of falling water level but continued into the summer with the actual maximum coming some 2 months later. Pennak's (1943) data on the Colorado mountain stream show no definite relationship between flow and numbers. The diatom density in particular is very erratic. The greatest pulse came during the beginning of the spring flood and the second greatest came during the winter period of low flow.

The data for the present study (Figures 11 to 17) show no consistent seasonal trend. The pattern varies from station to station even within the groups.

For the net plankton diatoms (Figure 11, note that for Figures 11 and 13 the scale is half that of the other figures) the spring flood was a period of minimum density at the upper 3 stations, with maximum density coming in the late summer and fall. Densities were low and erratic at stations 4 and 6, and no trends were apparent. Stations 7 and 8 present a marked contrast. Maximum density at station 7 occurred during the summer, at which time station 8 was at its minimum. Maximum

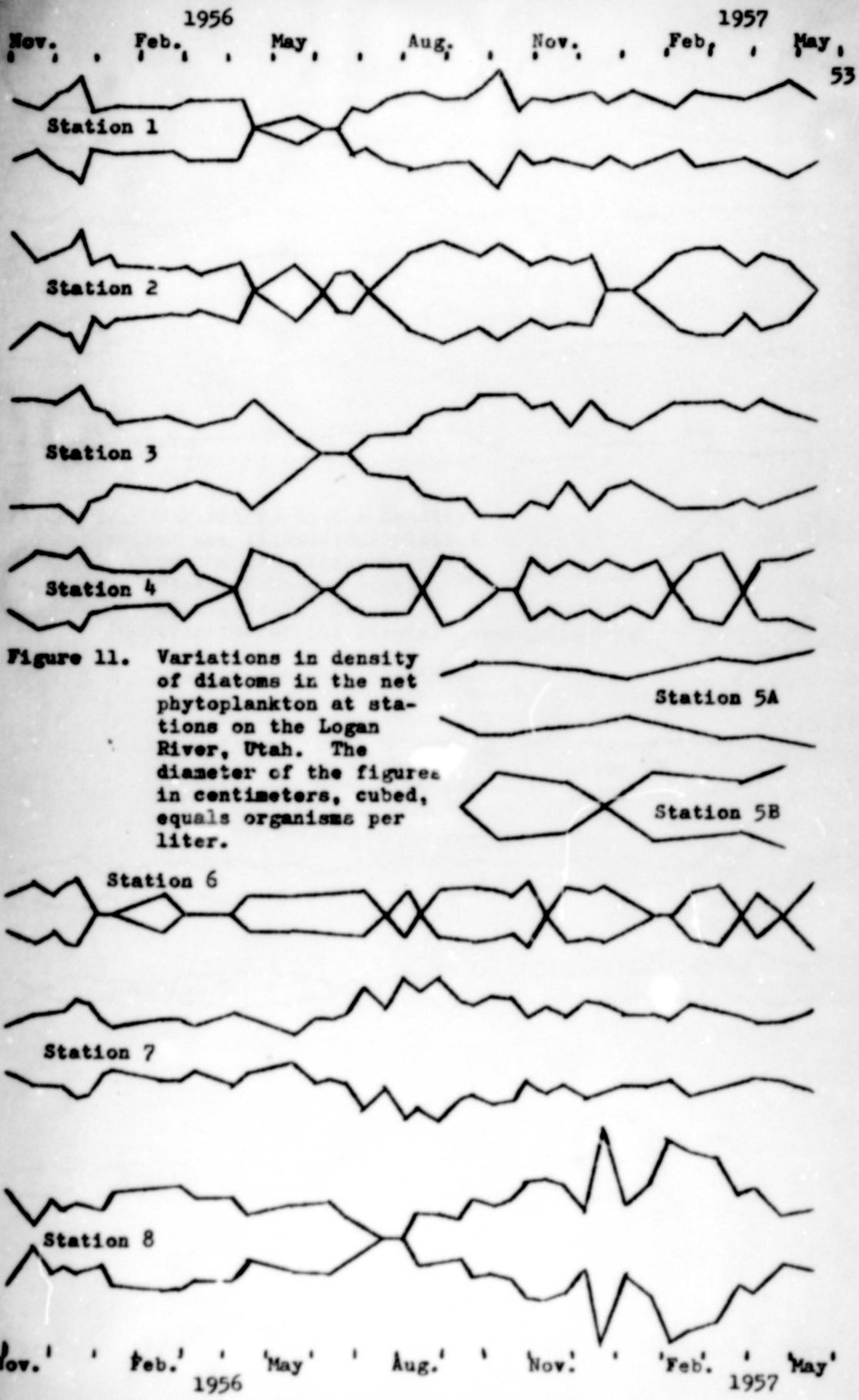

Figure 11. Variations in density of diatoms in the net phytoplankton at stations on the Logan River, Utah. The diameter of the figures in centimeters, cubed, equals organisms per liter.

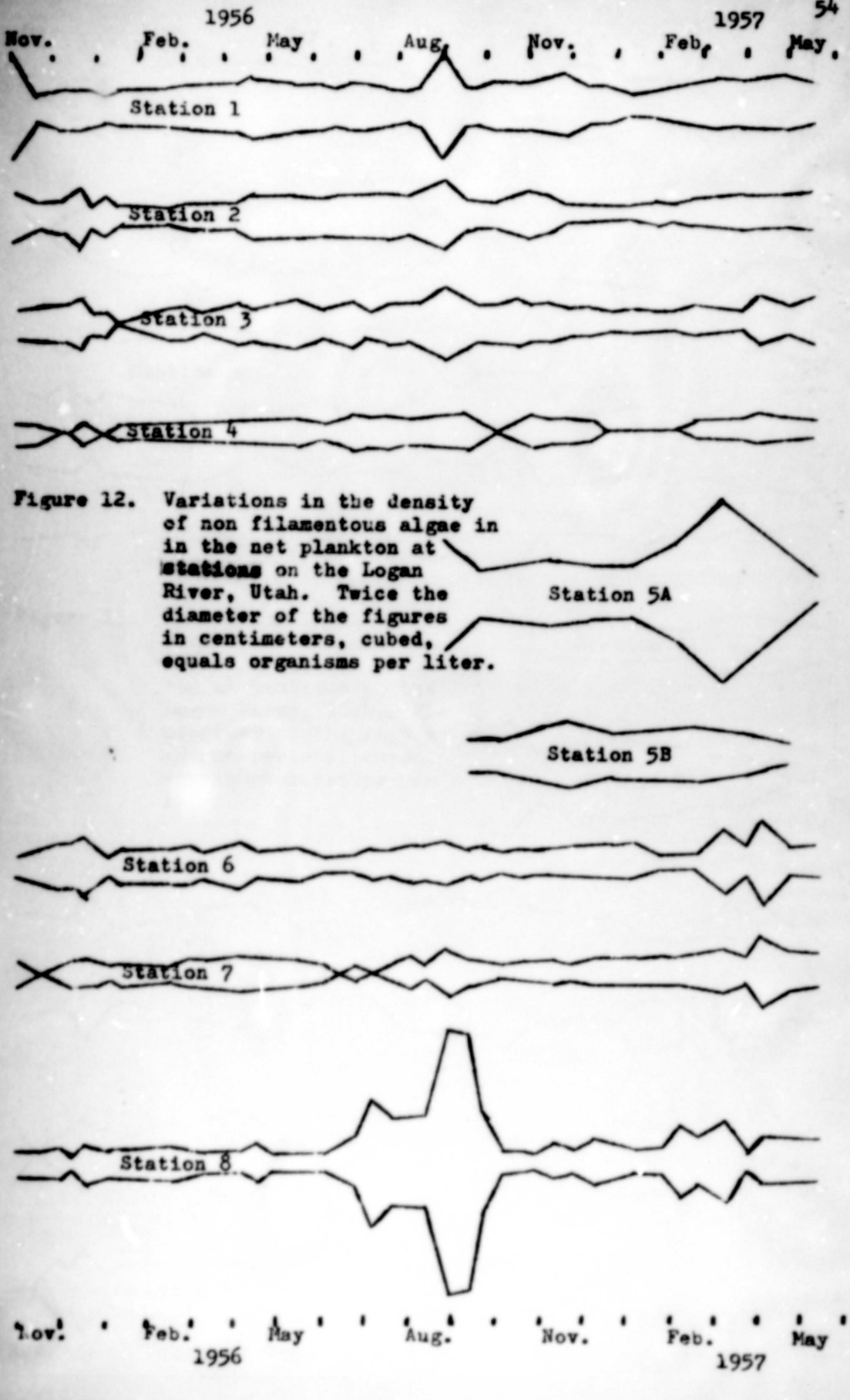

Figure 12. Variations in the density of non filamentous algae in in the net plankton at stations on the Logan River, Utah. Twice the diameter of the figures in centimeters, cubed, equals organisms per liter.

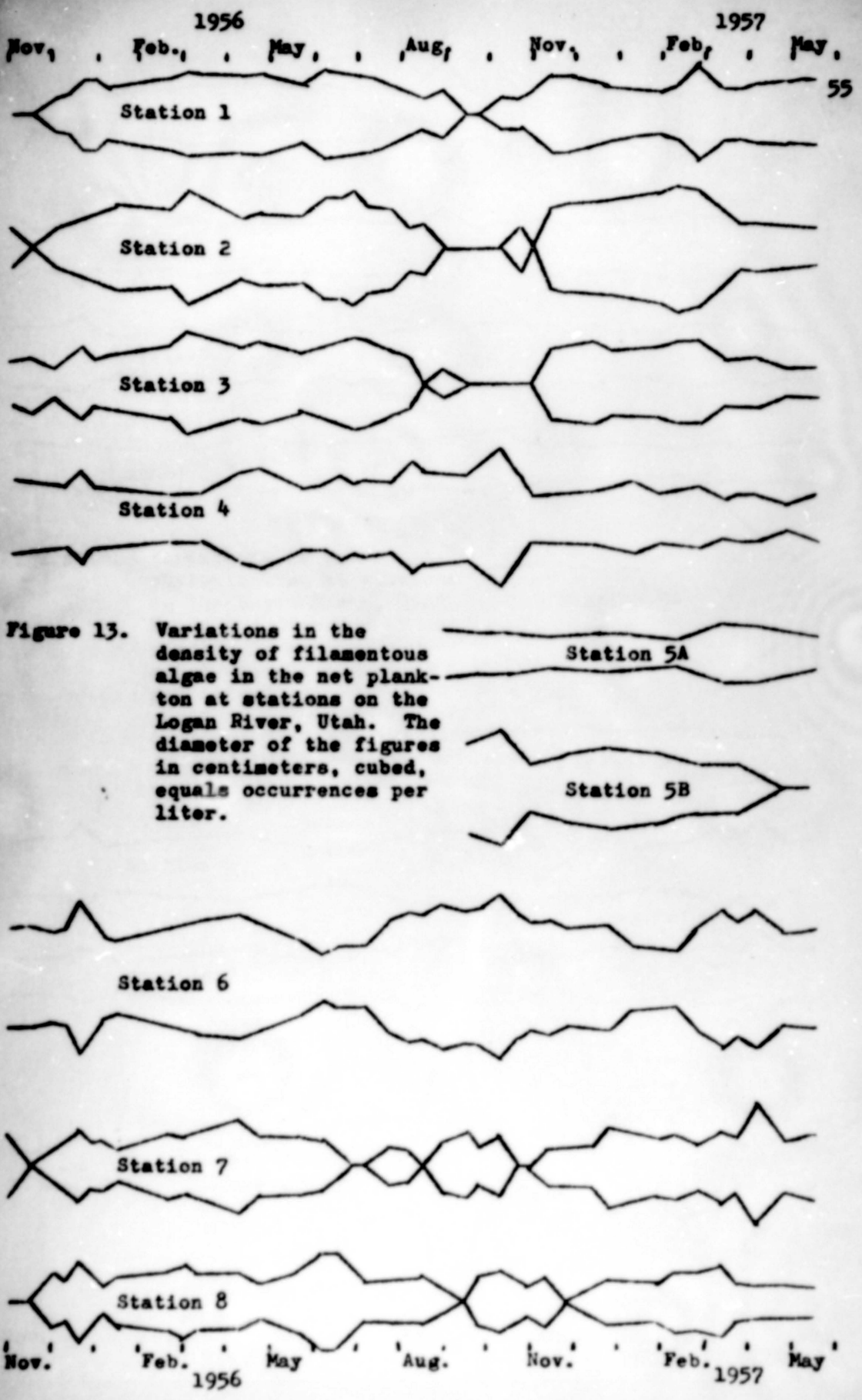

Figure 13. Variations in the density of filamentous algae in the net plankton at stations on the Logan River, Utah. The diameter of the figures in centimeters, cubed, equals occurrences per liter.

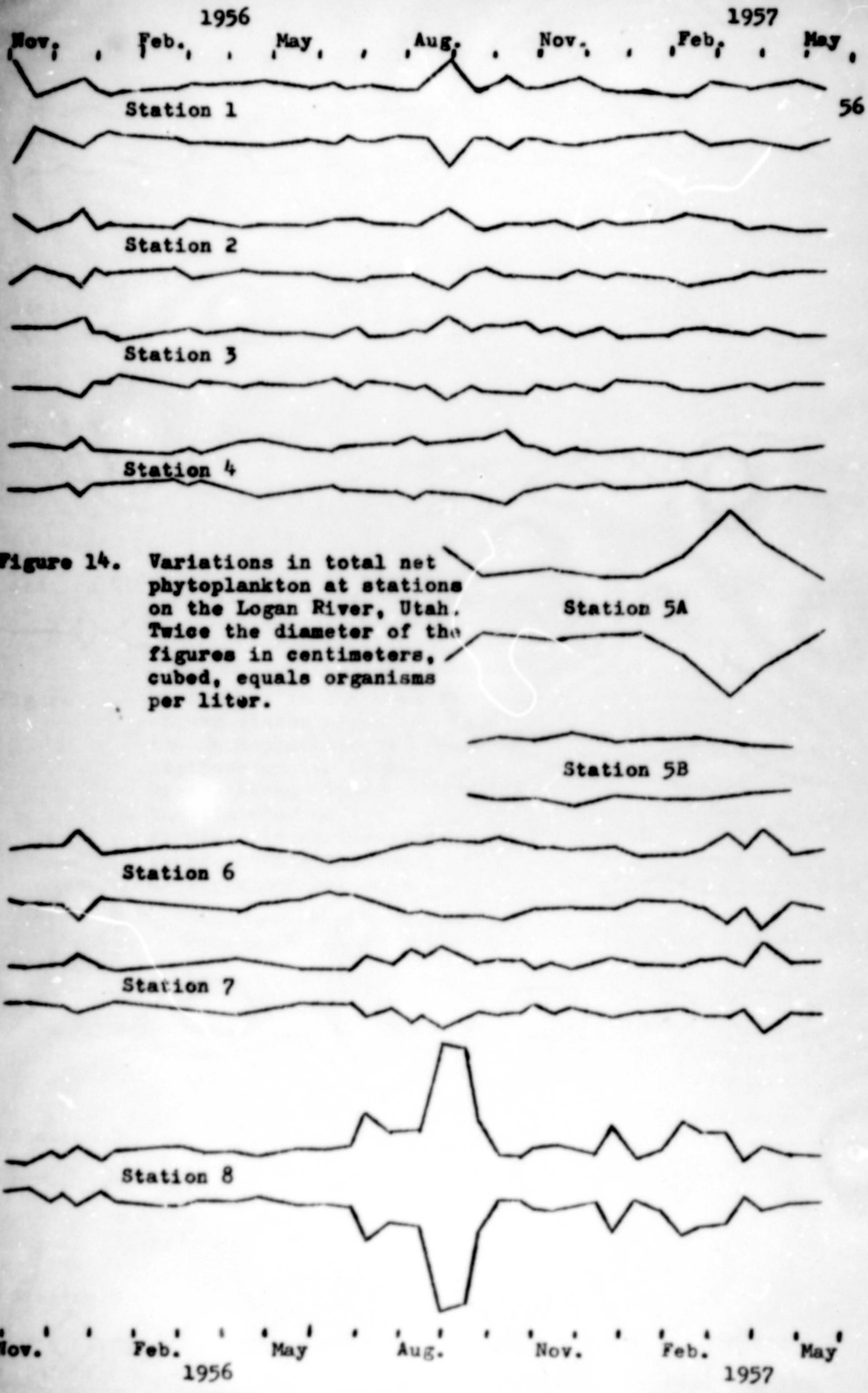

Figure 14. Variations in total net phytoplankton at stations on the Logan River, Utah. Twice the diameter of the figures in centimeters, cubed, equals organisms per liter.

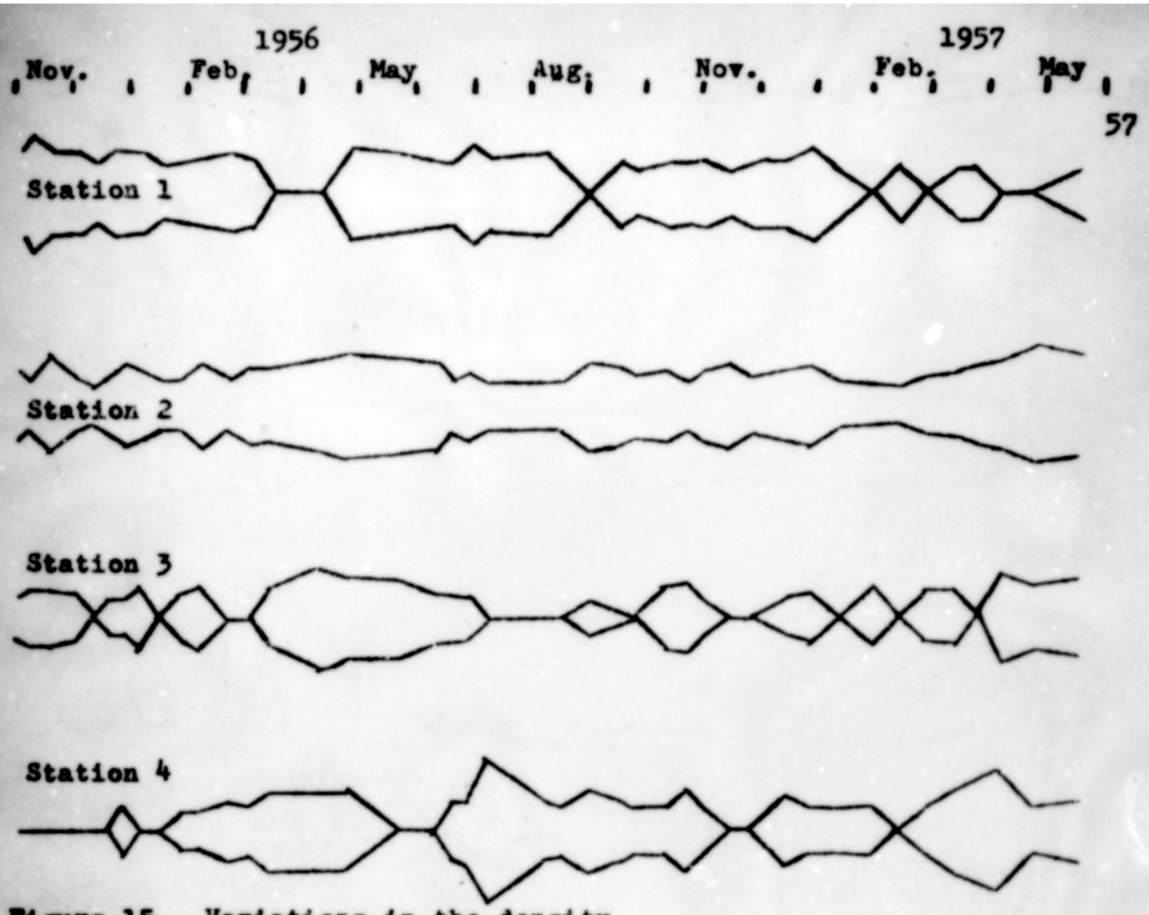

Figure 15. Variations in the density of non-diatom algae in the nannoplankton at stations on the Logan River, Utah. Twice the diameter of the figures, in centimeters, cubed, equals thousands of organisms per liter.

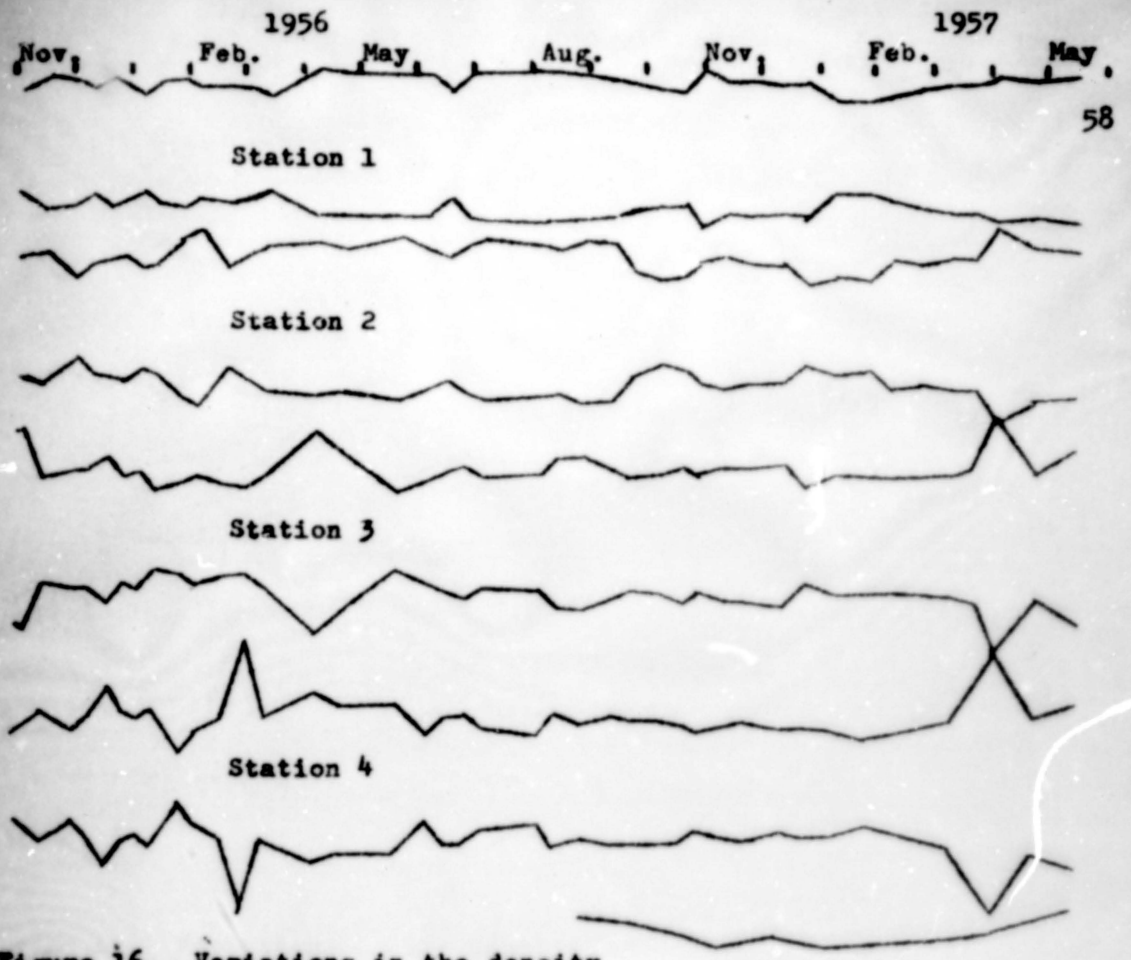

Figure 16. Variations in the density of diatoms in the nannoplankton at stations on the Logan River, Utah. Twice the diameter of the figures, in centimeters, cubed, equals thousands of organisms per liter.

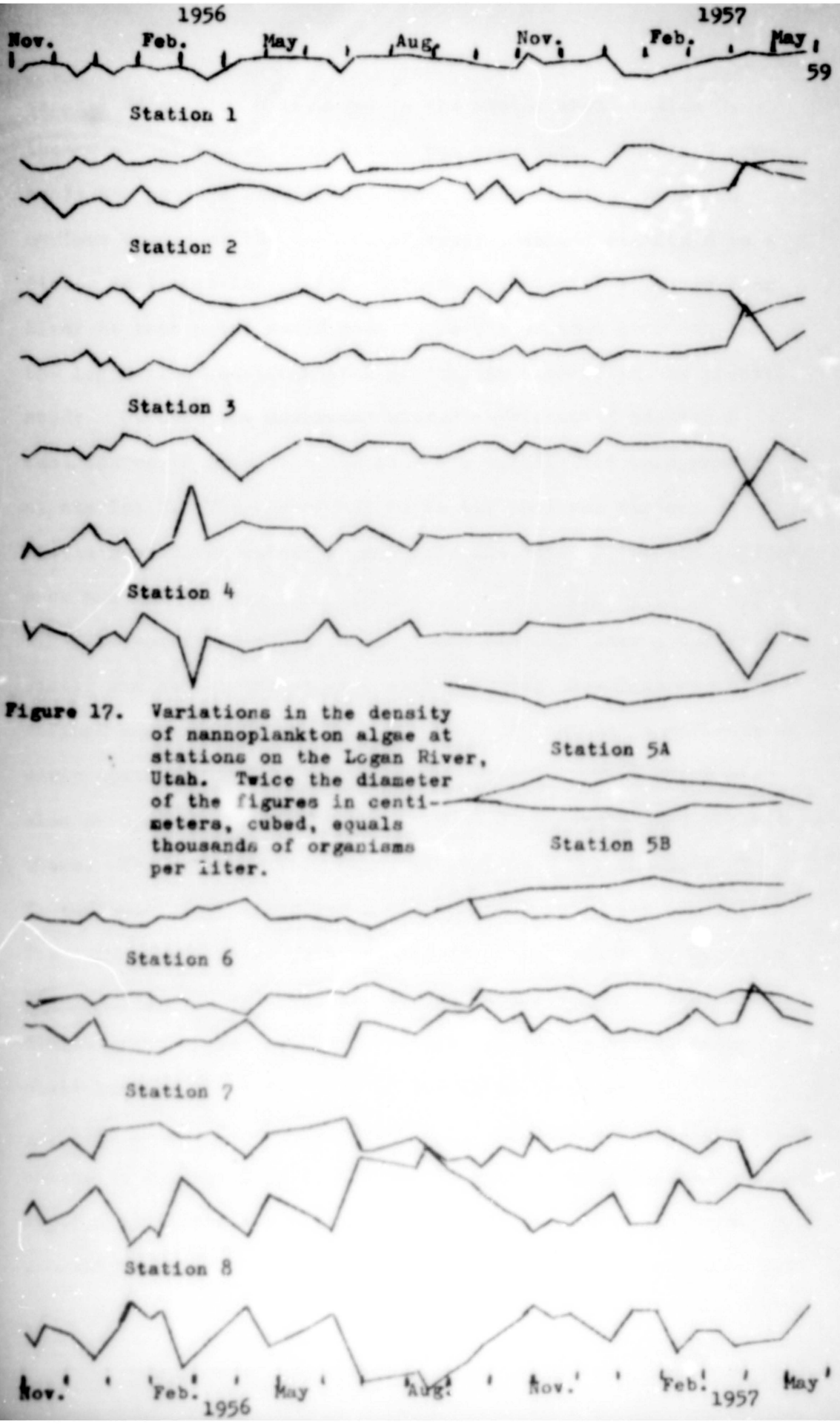

Figure 17. Variations in the density of nannoplankton algae at stations on the Logan River, Utah. Twice the diameter of the figures in centimeters, cubed, equals thousands of organisms per liter.

density at station 8 occurred in the winter when station 7, though not at its minimum value, was very low. Station 7 presents the pattern seen in the large river studies, with the maximum coming at the decline of water levels. Station 8 is a direct contradiction of this pattern; although the Little Bear River at that point would seem to be the closest approach to the large river environmental conditions covered in the present study. Perhaps the decreased winter turbidity at station 8 contributed to this, but the same low turbidities were present at station 7. The answer may be in the upstream history of Little Bear River water; at any rate the reasons for the difference are not obvious.

The non-filamentous forms of net plankton show a definite winter minimum at the upper 4 stations, but they have no well defined maximum (Figure 12). The peak at station 5A reflects an early spring pulse of Closterium Ehrenbergii. This pulse was also present at stations 6 and 7, with C. Litorale also present there. The corresponding pulse at station 8 was composed of C. acerosum, with the other 2 Closterium species not present. The very large summer pulse at station 8 was caused by Ceratium hirundinella and Volvocaceae, predominantly Volvox. The non-diatom group showed no definite seasonal trends at the lower stations with the exceptions of the forms mentioned.

The filamentous forms (Figure 13) present a variable picture, caused in a large part by changes in species composition. At the upper 3 stations, where Palmella Myosurus was the only form present in large numbers, there was a definite fall minimum, but

no pronounced maximum. The picture was the same at station 4 for Palmella, but the low period was filled by a Spirogyra and Zygnema maximum from the third impoundment. Station 6 reflected primarily Spirogyra and Zygnema; Palmella was never abundant. Two minima were present, 1 during the spring flood and 1 during mid-winter.

The 3 groups comprising the net plankton combined to give little seasonal variation in the net plankton totals (Figure 14). Only the very large pulses of Ceratium and Volvox during the summer and of the Closterium species during the late winter and early spring were apparent.

The non-diatom nannoplankton were always low in density and erratic in occurrence. This group consisted entirely of blue-green fragments at the upper 3 stations. The pattern was not consistent from station to station, even here.

The nannoplankton diatoms were remarkably uniform in density. Minimum values occurred in the winter at the upper 4 stations and maximum values during the spring flood. The peaks in early June at stations 3, 4, and 5 were from collections taken following the rain and sleet storm mentioned in the section on physical and chemical data. They reflected an unusual one-day condition. Station 8 showed a pattern similar to the one discribed for large rivers. The maximum density began to develop in June during the decline of the spring flood and persisted until September.

The diatom numbers were so much greater than the non-diatoms that the nannoplankton totals (Figure 17) are essentially those of the diatoms.

Station to station variation. The net plankton diatoms (Figure 11) showed a slight increase from stations 1 to 3, then a drastic drop in passage through the third impoundment. The diatoms were somewhat more abundant at stations 5A and 5B. Density was again very low below the first dam (station 6). The diatoms increased again at stations 7 and 8, with maximum numbers higher than those of stations 1 through 3.

The non-filamentous forms of net plankton (Figure 12) showed a gradual decrease from station 1 to station 4, a marked increase at stations 5A and 5B, and a decrease again at station 6, with stations 7 and 8 at approximately the same level as station 6 except for large single organism pulses.

The filamentous forms (Figure 13) showed no definite trend in the upper stations. The density at station 6 however was considerably higher than at any other station, with a marked decline at station 7 which was continued at station 8.

The general picture here masks 2 very pronounced sequences. Palmella was the only filamentous form present in any numbers at the upper 3 stations. Palmella was always much less than Zygnema and Spirogyra below station 3, and occurred only occasionally at stations 7 and 8. The Spirogyra and Zygnema were contributed almost entirely by the impoundments, and judging from the decrease at station 7 the fragments did not persist in good condition for any distance.

The density at station 4 was significantly lower than those of stations 1 through 3, showing the net effect of the third impoundment to be a decrease in net plankton. The density at

station 6 was higher than that of station 4 and equal to or greater than the density of the upper 3 stations. Two factors contribute to this: the high density of Closterium spp. at station 5A, some of which passed through the impoundment, and a greater contribution of filamentous algae from the first impoundment than from the third.

The non-diatom nannoplankton showed a general downstream decrease in density. The nannoplankton diatoms were remarkably even from station to station, with perhaps a slight decrease from stations 1 to 4. Station 6 was noticeably the lowest in density, there was an increase at station 7 and a further increase to the maximum at station 8. The nannoplankton totals reflected essentially the same picture as the diatoms since diatom numbers were many times greater than the non-diatoms.

Data on individual forms or groups

Only the more common and morphologically distinct groups were separated during the enumeration. Many of the forms listed in Table 2 will not be mentioned in this section; they were either included in the unidentified group, or if they were morphologically very similar to one of the groups or forms which are described, they were probably included with that group.

The data for the individual counts are summarized for percent occurrence and average density per occurrence in Table 3 for the net plankton and Table 4 for the nannoplankton.

Net plankton. Nitzschia sigmoidea. Synedra ulna and Nitzschia vermicularis may have been accidentally included on occasion, N. vermicularis at station 8 only. The description previously

Table 3. Percent occurrence (upper figure) and average density per occurrence (lower figure) for net plankton algae collected on the Logan River, Utah with a No. 20 silk plankton net.* For the filamentous forms the density figure is appearances per liter of river water; for Pediastrum and the Volvocales the figure is number of colonies per liter; and for the remaining forms the figure is number of cells per liter.

Organism	Collection Station								
	1	2	3	4	5A	5B	6	7	8
Nitzschia sigmoidea	92 2.28	90 2.94	92 5.18	79 1.22	100 2.04	78 1.62	69 1.06	100 3.88	93 7.54
Closterium litorale	72 .98	63 2.06	88 1.40	40 .40	90 1.86	44 .82	36 .58	48 1.30	12 .36
C. Ehrenbergii	98 3.14	80 1.25	88 1.18	60 .60	100 52.10	100 4.79	100 2.77	78 .89	40 .29
C. acerosum	22 .20	10 .16	22 .21	10 .15	0 0	0 0	2 .16	43 .29	88 2.34
Ceratium hirundinella	18 14.93	17 3.30	18 2.38	15 .75	10 7.81	33 .69	12 .63	5 2.01	36 112.97
Pediastrum	0 0	0 0	2 .12	5 .19	10 .18	0 0	0 0	10 .19	26 2.72
Volvocaceae	2 .18	0 0	0 0	11 .39	0 0	11 .20	0 0	0 0	38 24.24
Palmella Myosurus	78 1.51	80 3.68	75 2.17	68 .65	40 .25	22 .19	48 .55	36 .45	12 .31
Spirogyra	45 .57	12 .26	20 .23	85 2.00	60 .38	78 2.48	93 5.87	74 .88	78 1.15
Zygnema	10 .18	7 .33	2 .29	60 .95	20 .21	44 .77	98 2.19	40 .68	21 .17
Ulothrix	12 .19	2 .23	2 .13	22 .20	0 0	0 0	12 .32	14 .22	7 .23
Vaucheria	0 0	2 .13	15 .23	0 0	40 .39	55 .60	55 .57	14 .92	5 .24
Mougeotia	20 .41	5 .06	5 .16	8 .18	0 0	11 .18	2 .12	0 0	5 .24
Cladophora	0 0	20 .19	18 .67	5 .28	0 0	0 0	19 .22	19 .19	2 .15

* Stations 5A and 5B based on 9 and 10 collections respectively during the period September 1956 to April 1957. All other stations based on 39 to 42 collections during the period November 1955 to April 1957. This applies also to Table 4.

Table 4. Percent occurrence (upper figure) and average density per occurrence in thousands of organisms per liter (lower figure) for nannoplankton algae collected on the Logan River, Utah.

Organism	Collection Station								
	1	2	3	4	5A	5B	6	7	8
Blue greens	78	100	62	45	9	22	57	19	0
	7.6	8.3	5.2	5.9	1.0	2.0	2.6	5.9	0
Palmellococcus	tr.	tr.	tr.	33	54	56	28	14	4
				7.0	2.5	3.0	2.0	7.5	5.5
Achnanthes minutissima	95	98	93	95	100	100	90	81	0
	13.1	12.6	14.7	32.5	24.6	11.8	14.2	17.2	0
Amphora perpusilla	62	69	66	50	54	56	38	21	2
	3.5	5.6	10.4	5.0	3.5	3.2	2.4	8.4	18.0
Cocconeis spp.	40	38	46	76	100	89	69	40	8
	3.8	2.6	4.6	9.6	5.0	4.2	3.7	4.5	14.0
Cymbella spp.	50	57	80	45	54	78	35	31	2
	3.2	4.4	7.9	2.0	2.0	1.6	3.3	7.6	9.0
Diatoma hiemale v. mesodon	26	26	32	10	45	11	17	2	0
	2.5	6.8	8.2	3.0	3.6	3.0	2.3	6.2	0
Diatoma spp.	7	19	24	17	27	0	12	31	7
	2.3	4.5	2.1	2.9	4.3	0	1.4	11.3	11.0
Fragilaria capucina	60	26	20	45	27	11	33	71	31
	3.8	4.8	4.2	7.7	23.0	4.0	4.0	14.7	26.0
Fragilaria Harrissonii	48	26	34	28	27	67	34	5	2
	2.8	6.7	5.9	7.2	1.7	2.8	4.8	3.5	18.0
Meridion circulare	17	26	7	26	0	0	0	19	2
	6.7	4.4	4.0	2.0	0	0	0	8.3	3.0
Navicula minima	33	45	34	5	0	22	2	2	14
	4.9	4.2	3.7	1.5	0	1.0	3.0	6.0	12.6
N. viridula	48	24	10	17	27	22	12	40	12
	2.5	3.3	2.5	1.4	1.0	4.5	1.8	28.2	16.4
Navicula sp.	52	71	83	57	73	67	57	83	28
	4.0	4.9	4.2	4.3	5.3	2.3	2.9	14.0	14.8
Navicula spp.	88	86	85	74	73	56	71	78	21
	6.6	9.4	8.4	6.3	5.0	2.8	4.0	15.4	20.2

Table 4 (Cont.)

Organisms	1	2	3	4	5A	5B	6	7	8
Surirella ovata	60	57	36	14	0	22	5	67	19
	3.6	3.6	3.3	4.2	0	2.0	3.0	8.3	24.5
Surirella angustata	33	28	36	28	18	0	17	40	10
	2.8	6.2	4.0	3.4	3.0	0	2.2	13.4	29.5
Synedra acus	33	14	12	2	0	0	10	24	76
	4.9	4.3	3.0	2.0	0	0	1.7	8.0	80.0
S. rumpens	67	60	73	43	73	67	55	74	24
	4.7	4.5	4.7	5.8	5.6	2.0	2.7	9.6	21.3
S. ulna	79	28	41	17	64	11	21	33	52
	4.6	3.5	6.5	2.0	3.0	1.0	2.7	4.5	34.6
Unidentified	78	64	46	33	27	22	33	43	76
	4.2	4.0	3.3	3.6	5.0	2.0	2.4	8.8	61.0

given of the net plankton diatoms are of this species, and need not be repeated.

Closterium Ehrenbergii. C. Ehrenbergii had fairly high density at station 1, decreased somewhat at stations 2 and 3 and showed a marked drop in passing through the third impoundment, as indicated by the station 4 data. The increase at station 5B was the result of contributions from a slow water area in the main channel above the second impoundment. The second impoundment is short and has a moderate current throughout which results in less settling action than at the third or first impoundments. C. Ehrenbergii was most abundant at station 5A. A pulse of 304 organisms per liter on March 12, 1957 raised the average density at station 5A considerably, though even without this pulse the density was well above the other stations. Passage through the first impoundment again resulted in a considerable decrease, which continued at stations 7 and 8, with occurrence spotty and density very low at station 8. C. Ehrenbergii had in general its highest density in fall and winter and lowest in the summer.

Closterium litorale. This form was considerably lower in density than C. Ehrenbergii at station 1, but slightly higher at stations 2 and 3. There were 2 periods of minimum occurrence at these upper stations, during the spring flood and at mid winter. There was a sharp drop in passing through the third impoundment; with the low densities and occurrence continuing at station 5B. Station 5A showed a density almost equal to that of the upper river. There was a sharp decrease in occurrence and density below the first impoundment. The occurrences of C. litorale at station 7 were during the winter predominantly. The few occurrences at

station 8 were not concentrated on any one period.

Closterium acerosum. Occurrences were scattered at the upper 4 stations, though most of the occurrences at station 3 came in the fall. It is probable that the lack of this algae at stations 5A and 5B was a result of the less intensive sampling, since occurrence was very low. Density and occurrence increased somewhat at station 7 and markedly at station 8. At both of these stations the period of maximum density was fall and winter, with summer the low period.

Ceratium hirundinella. Ceratium was of low occurrence, though of high density, when present. At stations 1 through 6 practically all the occurrences came in September and October of 1956. At station 7 the occurrences were during the period July through October 1956, and at station 8 during September and October 1955 and April through October 1956. Station 1 had 1 sample of 50 organisms per liter September 1956, and Station 8 samples of 804, 795, and 58 organisms per liter on September 1, 17, and 26, 1956, respectively. With the exception of these pulses the densities were of a similar order of magnitude. The September 1 pulse was present at the other stations, though to a lesser degree.

Pediastrum. Pediastrum species were present a few times at stations 3, 4, 5A, and 7. With one or two exceptions the occurrences were during the period June-October. Pediastrum was at highest density at Station 8 during this period.

Volvocaceae. The volvocaceae were treated as a group, with Volvox spp. the most common, and the only form occurring in the

Logan River proper. Eudorina and Platydorina occurred occasionally at station 8, on the Little Bear River. There were only 7 occurrences of the group in the upper 7 stations; 1 at station 1, 5 at station 4, and 1 at station 5B. Four of the 5 occurrences at station 4 were consecutive collections in November and December 1956. Density was greatest at station 8 during July, August and September, with only a few occurrences outside the period June through October.

Palmella Myosurus. Palmella was one of the most abundant net plankton forms. It was primarily a late winter and spring form, being almost absent from the drift from mid August to November. In the upper river it was the only one of the group present in any numbers, the data for the upper 3 stations on Figure 13 representing Palmella almost entirely.

Data from the third impoundment outlet show that the Palmella fragments passed through the impoundment, but in very reduced numbers. Its density was further reduced at the 2 stations above the first impoundment. The density increased somewhat below the first impoundment, with the source apparently the 200 yards of river from the dam to the station. The density was again very low at station 7, and only occasional occurrences were recorded at station 8. At both of the lower stations Palmella was present only during the winter and during the spring flood.

Spirogyra. Spirogyra was the second most abundant filamentous form. Reproductive stages were not collected so that species are not known. It was obvious that several species were involved.

In the upper river occurrences were primarily during the spring flood, with only occasional occurrences at other times. Beaver Creek joins the Logan River about 2 1/2 miles above station 1. This creek flows through a series of beaver dams just before entering Logan River, and there are many areas of quiet water in side channels. This was apparently the source of the Spirogyra, Zygnema, Closterium Ehrenbergii, and Ceratium which appear at station 1 but decrease rapidly thereafter.

The large contribution of Spirogyra from the third impoundment was shown in the great increase in both occurrence and density at that station. Occurrences were fairly even throughout the year but density was least just after floods and greatest during the summer and fall. The data for station 4 (Figure 13) represent primarily Spirogyra. The high density at station 4 was reflected also at 5B, augmented probably by the second impoundment. Station 5A, though showing only slightly less occurrence than 5B, had very low abundance. The first impoundment contributed considerable Spirogyra, with the maximum density for this form recorded at station 6. The high period was again in the late summer and fall. Station 7, though showing fairly high occurrence had low density, indicating a relatively quick deterioration of the filaments. The increase in density at station 8 was probably a result of the contribution from quiet water habitats in the lower valley.

Zygnema. Zygnema was of sporadic occurrence in the upper river, and frequent occurrence though of low density at stations 4 and 5B. The first impoundment contributed considerable Zygnema,

and as with Spirogyra the highest density was in late summer and early fall. Both occurrence and density dropped considerably at stations 7 and 8.

Other filamentous forms. Mougeotia was present at station 1 only during the flood, and sporadically at the other stations. Vaucheria was most frequently seen at stations 5, 6, and 7 but was nowhere abundant. Ulothrix was seen only occasionally, with perhaps somewhat greater frequency in the winter months. Cladophora was also very sparse with somewhat higher occurrence in the spring and summer.

Nannoplankton. Blue greens. Several blue green forms are listed from the river. The dominant form in the drift appeared to be Phormidium incrustatum. The trichome fragments were most abundant at the upper stations, and particularly at station 2. They were relatively less abundant at the lower stations, with station 5A showing practically none, and no occurrence at station 8. Peak densities varied from station to station, with that of station 1 coming in fall and winter and station 2 during the spring flood. Apparently stream conditions immediately upstream from the station had the dominant influence. Data for the first 3 stations (Figure 15) represent blue greens entirely.

Palmellococcus. This form first appeared in abundance at station 4, where it was most abundant during the summer months. It was occasionally present at the upper stations but was not differentiated there in the counts. There was no pronounced density peak. The first impoundment did not significantly decrease the abundance of Palmellococcus though occurrence was

lower. Occurrence decreased still further at stations 7 and 8, but when present at these stations abundance was high.

Achnanthes minutissima. A. minutissima was the dominant form though some Rhoicosphenia curvata was probably included. This was the most abundant group at 6 of the 8 stations, being absent from station 8 and only slightly less abundant than Cocconeis at station 4. It was one of the few groups to show an increase in density during passage through the third impoundment. On 2 occasions extremely high densities were recorded at station 4; 103,000 organisms per liter December 22, 1955, and 388,000 organisms per liter on March 3, 1956. These figures were 10 to 20 times greater than densities recorded for station 3. Many of the other collections at station 4 were significantly higher than those of station 3. This high density did not persist, with numbers at station 5B only one-third as great in average, and with no major pulses. The river channel, station 5A, contributed a density second only to station 4. The increase noted through the third impoundment was not repeated through the first impoundment, the average figure for station 6 represented close to an average between stations 5A and 5B when their respective flow volumes were considered. The density increased slightly at station 7 and this species was not recorded at station 8. There was no definite peak period at the upper stations. At stations 6 and 7 there was a definite period of low density in the summer.

Amphora perpusilla. This species had a gradual increase in density from stations 1 to 3, then a sharp drop in passing through the third impoundment. Occurrence declined through the remaining stations until it was seen only once at station 8, at

the beginning of the spring flood. There were no definite periods of peak density at any station. Density was fairly high in the occurrences at stations 7 and 8.

Cocconeis spp. Two species were present, C. pediculus and C. placentula, with C. pediculus predominating. Occurrence was fairly low and density erratic at the upper three stations, with both density and occurrence increasing sharply through the third impoundment. Both species were found to be abundant on filamentous algae in the third impoundment. Occurrence was high at both stations 5A and 5B. The high density at station 4 did not persist to station 5B however. The first impoundment provided a slight decrease in both density and occurrence, in contrast to the effect of the third impoundment. Occurrence decreased sharply at stations 7 and 8, but when present density was high.

Cymbella spp. Several species were present, with C. tumidula and C. ventricosa predominating. This group showed a consistant increase in density and occurrence from stations 1 to 3; a sharp drop in both density and occurrence in passage through the third impoundment, and declining occurrence and increasing density thereafter.

Diatoma hiemale var. mesodon? Occurrence was low in the upper river, with density increasing from station 1 to station 3. There was a sharp drop in both density and occurrence in passage through the third impoundment. There was practically no change from station 4 to station 5B. Occurrence was highest at station 5A, but density here was not significantly higher than at 5A. There was no drastic decrease in either density or occurrence in passage through the first impoundment. Only 1 occurrence was

recorded at station 7, though the density was fairly high. This form was not found at station 8.

Diatoma spp. This group was predominantly D. vulgare, with D. ancops and D. hiemale also present. The group had no high occurrences and the densities were erratic. The major points of interest are the complete disappearance between stations 4 and 5B, and the high density though low occurrence at stations 7 and 8.

Fragilaria capucina. Both occurrence and density were erratic. There was some increase in passage through the third impoundment, but the increase did not persist to station 5B. Station 5A had low occurrence, but very high densities. There was, if anything, a decrease in density in passage through the first impoundment, though occurrence increased somewhat. There was an increase in both occurrence and density at station 7. At station 8 occurrence declined again but density increased still more.

Fragilaria Harrisonii. Both occurrence and density were erratic, with almost complete absence in the lower 2 stations.

Meridion circulare. At the upper 3 stations occurrence was very low though density was fairly high. The effect of the third impoundment was obscure, occurrence increased but density decreased. There were no occurrences at stations 5A, 5B, and 6, but the form reappeared a few times at station 7 with fairly high density. There was only 1 occurrence at station 8.

Navicula minima. Occurrence was low with density fairly high at the upper 3 stations. There was considerable decrease in both in passage through the third impoundment. There were no occurrences at station 5A and only 2 each at stations 5B, 6, and 7.

The appearance at station 8 came in 1 tremendous pulse consisting of occurrences in 7 consecutive collections from June 28 to September 17, 1956. The peak density on August 18, 1956, was 330,000 cells per liter.

Navicula viridula. Occurrence decreased steadily from stations 1 to 3, and remained low at the remainder of the stations except for station 7. Most of the occurrences at station 7 were in the fall and early winter, with a pulse during September 1956--including 1 collection of 148,000 organisms per liter--accounting for most of the increase in density.

Navicula sp. Occurrence was erratic and density fairly constant at stations 1 through 5A. There was a reduction in density from station 4 to 5B, with little change in passage through the first impoundment and an increase at stations 7 and 8. There was no definite period of abundance at station 7, but half of the occurrences at station 8 came in 6 consecutive collections February 23 to May 23, 1956.

Navicula spp. Several species were included in this group, with N. cryptocephala and N. lanceolata predominating. Occurrence and density showed no definite trend at the upper 3 stations. There appeared to be a significant decrease in density through the third impoundment and a further decrease to station 5B. There appeared to be no significant change in passage through the first impoundment, but both density and occurrence increased at station 7. At station 8 occurrence was lower but density higher. There was a definite increase in density during the spring flood and during the summer and early fall.

Surirella ovata. Occurrence and density were fairly constant at stations 1 through 3. The occurrences at station 4 came only during the spring flood. Occurrence and density were definitely higher in winter at station 7 and 8, with few occurrences in spring and summer. There was no definite maximum period at the upper 3 stations.

Surirella angustata. The data for S. angustata are very similar to those for S. ovata, except that the flood period provided few occurrences at station 4--the majority coming in the fall and winter. Peak abundances were found during the spring flood at stations 1 through 3, and during the winter at the other stations.

Synedra acus. The data here present a strange pattern; steady decrease through stations 1 to 4, absence from stations 5A and 5B and a steady increase through stations 6 to 8. At stations 1 through 3 occurrences were primarily in October, November and December, and at station 6 during June, July, August, September and October. At station 8 there was a succession of pulses: November 1955 through January 7, 1956; February 8 through March 16, 1956; June 9 through September 26, 1956; November 13, 1956 through February 11, 1957; and April 6 through May 18, 1957. The greatest density was 315,000 cells per liter on July 7, 1956.

Synedra rumpens. The only significant variation in the upper 4 stations was a drop in occurrence at station 4. There was considerable drop in density between stations 4 and 5B. Most of the occurrences at station 7 were in summer and fall. Station 8 had 1 pulse from June 19 to August 18, 1956, but other occurrences were scattered.

Synedra ulna. Fall and winter were the periods of highest density at station 1. At all other stations except 8 the occurrences were scattered. There were 2 pulses at station 8; February 8 through March 13, 1956, and June 19 through September 1, 1956. The other occurrences at this station were well scattered. S. ulna showed a marked drop in occurrence and density in passage through the third impoundment in contrast to the other Synedra species covered.

Unidentified forms. Included here were all forms never abundant enough to warrant separate treatment. The density of unidentified forms was fairly constant except for stations 7 and 8; particularly station 8, where many seasonal forms appeared which were not present in the upper river.

DISCUSSION

Source of the phytoplankton

Henson first proposed the term plankton in 1877 to include all the minute animals, plants and debris found floating in the waters of the sea (Welch 1952). As Welch also points out the term was soon extended to cover such assemblages when found in any body of water. Modern usage as given in both Welch (1952) and Ruttner (1953) confines the term plankton to the organisms only, with the non-living fraction termed trypton and the total assemblage called seston. Seston by this usage is then equivalent to the original meaning of plankton as proposed by Henson. The modern literature for the most part follows Ruttner and Welch, as does the present paper. Starrett and Patrick (1952) however use the term plankton as originally proposed by Hensen, including in it both living and non-living material.

The plankton organisms of the sea and the fresh water lakes are the result of evolution over a long period of time of organisms which are adapted for the pelagic life. Exchange of the water in these environments is very slow. No significant fraction of the plankton population is lost, and reproduction from the same stock continues in a more or less stable environment.

The water of a stream is in continual movement, carrying with it any plankton it contains. It is a one-way trip for the plankton, and unless a method of transporting the cells from the mouth of the stream back to the source is postulated there is no opportunity to pass on to succeeding generations the advantages

of selection on the trip down. Those forms from the benthos or from other sources which are adapted for survival in flowing water make up the plankton of a stream. Evolution of the stream plankton is dependant upon evolution of the source floras. There is no opportunity for the evolution of a stream plankton whose species through selection have become peculiarly adapted to life in flowing waters. Thus there cannot be said to have developed a specialized stream plankton in the same sense that there has been developed a specialized lake or marine plankton.

The plankton of a river, then, consists of organisms which have been projected into the flowing water, with their survival depending on how well they are adapted to this new environment.

Water flowing from a lake would carry with it plankton from the lake and Kreiger (1927) considers this a major source. Several studies have demonstrated however that this plankton usually decreases rapidly after entering the stream (Chandler 1937, Reif 1939, Eddy 1932). Kofoid (1903) however considers the reservoirs an important source of plankton for the channel. He was dealing with a river of very low gradient however, which at times apparently was not far removed from lake conditions.

There are a few small lakes in the Logan River watershed. Many have only intermittent outflow, and the outflow from the others traverses several miles of stream before entering the river. None of the lake plankton persisted to the river.

The impoundments, except for their contribution of filamentous algae, were in general detrimental to the plankton. Only Cocconeis, Achnanthes minutissima, Fragilaria capucina and Synedra rumpens showed significantly higher densities at the outlet of

the third impoundment, most other forms decreased. The decreases may have been caused by settling out, by straining out in the abundant beds of submerged aquatics as Chandler (1937) and Reif (1939) show for reduction of lake plankton which enter streams, or by physiological effects of the slower water. For much of their length the three impoundments resemble slow, weed-filled streams.

There are reasonably large backwaters in both the first and third impoundments, but perhaps the exchange of water is too fast to permit the development of a plankton population. Starrett and Patrick (1952) give data from above and below an impoundment the exact size of which is not given but which from their station description must be less than 2 miles long. They give data for July through September only, and during this period total diatoms decreased in 3 of 5 collections and increased only slightly in the other 2. Microcystis increased during the period of peak abundance but decreased slightly during the last 2 collections.

The role of tributaries and backwaters as sources of the phytoplankton has been discussed by many. Fritsch (1902) considers tributaries and backwaters to be the orginal source of the cells, which later multiply in the stream.

Later Fritsch (1903) points out that it is not a matter of direct contribution of the backwaters to form the stream plankton, since the 2 are of very different composition. Kofoid (1908) concludes that the source of the phytoplankton is not immediately from the tributaries but from impounding backwaters, and in low water from the channel itself. Budde (1930) considers the plankton maxima to begin in the quiet waters off the river. Rice (1938)

and Reinhard (1931) and Butcher (1932) emphasize the stream bottom as the source of the phtoplankton cells, the first 2 authors pointing out that tributary plankton almost invariably decline in the main stream. Blum (1954) gives good evidence that the benthos are the source of phytoplankton cells.

Backwaters--other than the impoundments--do not exist on the Logan River. The highest major tributary, Beaver Creek, passes through a series of beaver dams just before entering the river, and there are many beaver channels with quiet water. This tributary contributed some Spirogyra and Closterium, and was probably the source of the Ceratium found at the upper stations. Only the Ceratium persisted past Station 1, which is 2 miles below the entrance of the creek, the other forms disappearing before station 2 was reached. The other tributaries in the upper canyon, Spawn Creek, Temple Fork and Right Hand Fork, had phytoplankton populations similar to that of the main stream, though somewhat lower in density.

Two areas which were functionally "tributaries"--the old river channel in the areas of water diversion--contributed large numbers of Closterium Ehrenbergii to the stream during non-flood periods. The lower channel, above station 5A, also contributed high densities of Achnanthes minutissima and Fragilaria capucina. All 3 forms were much reduced in density below the first impoundment, which prevented evaluation of their fate as main stream plankton.

The tributaries were in general not a source of main stream phytoplankton.

All the evidence points to the benthic algae of the river bottom as the main source of the phytoplankton in the canyon portion of the river. All of the forms abundant enough to be enumerated were found in benthic collections, and those forms contributed by the impoundments or tributaries were benthic in those environments.

Only station 8 on the Little Bear River had forms which could not be traced to the benthos, the Volvocaceae and Ceratium. There are 2 possible source for these forms; a large dam only a few miles upstream from the sampling point, and many backwater areas.

The benthos was not sampled extensively, but some samples were examined from all parts of the river. It appeared that in general a form abundant in the plankton was also abundant in the benthos. The notable exception to this general statement was Achnanthes minutissima. This little diatom which had the highest density in the plankton was dominant in only one benthic collection. Synedra acus, which increased drastically in density at stations 7 and 8, was also very abundant in the benthos at those stations. Ruttner (1953) states that a "true" stream plankton, the Potamoplankton, could only develop in a very long river, confining the term to those forms which reproduce as plankton, and terming the remainder of the forms tychoplankton, forms transported and living but doomed to death.

Eddy (1934) after examining several small streams reports that little true plankton was found in any of them, and makes that generalization about small swift streams in general. He states that the first plankton organisms usually appear after

the water becomes 6 to 10 days old. He does state that occasional bottom diatoms are found in the small streams.

Using the broader meaning of the term, an abundant phytoplankton population was present in the Logan River, even at the upper station where the water age was under 10 hours. The total elapsed time from source to canyon mouth for the water of the Logan River probably averaged under 24 hours. Pennak (1943) also found abundant phytoplankton in a mountain stream whose water was estimated to be less than 15 hours old at the collection station. Lackey (1943) found an abundant phytoplankton in a small stream.

The effect of physical and chemical conditions

The environmental factors may be so interrelated as to prevent separation of their individual effects. Unless the factor is limiting to some degree there may also be considerable variation without effect. The data is discussed with these acknowledged limitations.

Temperature. Kofoid (1903) considers temperature to be of paramount importance in general plankton production; with production in the river below 45°F. only 9 percent of that above 45°F. He states elsewhere however (Kofoid 1908) that temperature does not seem to be a factor in controlling diatom abundance, citing the situation where the major pulse is in the spring when the water temperature is about 60°F., but that no corresponding pulse is seen in the fall when the temperature comes down to 60°F. again. The data of Reinhard (1931), Allen (1920), and Starrett and Patrick (1952) all show pronounced plankton minima during the periods of low temperature. The data from the present study

show a general trend toward minimum plankton numbers during the low temperatures, but not differences of the order of magnitude shown by the studies cited. There were also notable exceptions: Palmella Myosurus was at near maximum density during the cold weather; Nitzschia sigmoidea was also, though fairly low in density, not at its minimum density during the low temperature period. Three stations varied somewhat in their temperature picture. Station 5A, the river channel at the mouth of the canyon, which carries only seepage and some spring water except during the flood, had a winter temperature minimum several degrees above those of the other stations. The non-filamentous net plankton group, which showed a definite minimum at the upstream stations (Figure 12) had no such minimum at station 5A. There was also no pronounced minimum in this group at station 5B, and this is believed to be the result of plankton added to the river from the flow of the river channel above the second impoundment in which conditions are very similar to those of station 5A. Closterium Ehrenbergii and C. litorale were the species affected, the other phytoplankton did not react to the change in winter minimum temperature. The other 2 stations with unusual temperature data were stations 7 and 8, where the maximum temperatures were 15°F. to 20°F. higher than the other stations. Very large plankton pulses were recorded during the periods of high temperature, but they were not caused by forms abundant in the canyon portion of the stream. The organisms with high density pulses were Ceratium hirundinella, Closterium acerosum, Pediastrum and the Volvocales. Only Navicula minima and the Synedra species of the upper stream plankton showed a marked increase during the

summer high temperatures. Many of the upper river species recorded densities at station 8 which were up to several times higher than those from the upper river. Occurrences were usually low and scattered however and the minimum sensitivity for station 8 was also several times that of the canyon stations.

The minimum temperatures appear to be somewhat limiting for most forms, and a few forms increase with the higher summer maximums at the valley stations; but, for most of the phytoplankton the temperature does not seem to be the major limiting factor in this environment. Pennak's (1943) data also show little correlation between temperature and phytoplankton production.

Turbidity. High turbidities at the upper stations were associated with the spring flood. Differences in turbidity at these stations during the rest of the year were not significant. The highest phytoplankton densities were found however at station 8, where the lowest turbidity was very nearly equal to the maximums at the canyon stations. A net diatom pulse was associated with a period of low turbidity at station 8 during the winter of 1956-57, but there was no corresponding nannoplankton diatom increase. The high turbidity at this station did not prevent several phytoplankton pulses from developing. If turbidity is high enough to cut off a significant portion of the light it would certainly be limiting. The constant mixing of the river waters which would bring the cells near the surface occasionally might act to reduce the effect of an absolute turbidity measurement over what it would be in still water. The high turbidity may be a factor in the reduction of some of the canyon forms at stations 7 and 8, but there is no clear cut evidence of this.

Water velocity. High water velocity is in itself considered by Kofoid (1903) to have no demonstrable influence on the plankton. Allen (1920) has been quoted often as stating that water currents above a moderate speed are detrimental to plankton production. He states in another place however that his definition of a "flood" condition is one which keeps a distinct current in the river at Stockton, California, his collection point. He is considering in effect the high water which is accompanied by the increased current as are several others (Reinhard 1931, Rice 1938) who so state. The real effect of current must be judged from regions of varying velocity and not from the seasonal changes.

The areas of lower water velocity in the Logan River (the impoundments) had a different algal composition from the fast water areas, and some of these algae were carried with the water as it left. The filamentous forms added to the stream plankton dropped rapidly in density as they progressed downstream. Factors associated with the higher velocity were then detrimental to this group.

Only 3 of the forms prevalent in the higher velocity areas of the stream increased in passage through the slower water of the third impoundment without known recruitment from the benthic algae in the impoundment; Achnanthes minutissima, Fragilaria capucina and F. Harrissonii. All 3 had decreased again at the next station below the dam. For these forms it might be said that the decreased velocity was benificial. Passage through the lower velocity waters of the third impoundment was either definitely detrimental or neutral for all other phytoplankton. Settling out or straining out by aquatic plants would probably remove many of

the cells initially, but if conditions were favorable they should reproduce as benthos since this was probably their original source. That they did not do so argues that there is a physiological factor associated with the slower renewal of the water at the cell surface which is detrimental. Thus the physiological action of the slower water may reduce the phytoplankton secondarily by reducing the benthos which is its principal source.

Volume of flow. Almost every plankton study on the larger rivers contains comments on the detrimental effect of floods or high water on the plankton population. In this respect the Logan River differed markedly. Only the net plankton diatoms (Nitzschia sigmoidea) showed a minimum density during spring floods, most of the other groups remained at or near maximum densities. Pennak (1943) also reports no correlation between stream flow and phytoplankton numbers in a mountain stream. This difference may be a measure of the contribution of cell division while in passage, to the plankton numbers of these larger streams; the younger flood waters of the mountain streams not having that contributio[illegible]

Water chemistry. The water chemistry was not treated extensively, only general characteristics were established. There was a general increase in dissolved nutrients at stations 7 and 8, but how much this contributed to the differences in composition and abundance cannot be determined. The chemical factor was confounded with higher temperature, higher turbidity, lower velocity, outside water sources, and increased water age.

Light. Light, though obviously an important factor to plant production has not been discussed in this study. The effect of

light on the general productivity of the Logan River is comprehensively covered by McConnell (1958).

SUMMARY AND CONCLUSIONS

1. The Logan River flows as a cascading mountain stream for about 35 miles through the Bear River Range of the northern Wasatch Mountains, and then for 6 miles as a meandering valley stream across the floor of Cache Valley, to its junction with the Little Bear River. There are 3 small impoundments on the river, one at the canyon mouth, one 2 miles upstream and one 3 1/2 miles upstream from the canyon mouth.

2. Eight sampling stations were established on the river; 6 in the canyon section (3 above the impoundments) and 2 in the valley section, with the second valley station on the Little Bear River just below its junction with the Logan River.

3. All 8 of the stations were occupied on the same sampling day, and sampling was conducted at intervals of 10 to 15 days from November 1955 to June 1957.

4. The phytoplankton were sampled by a number 20 silk bolting cloth net for the larger organisms and by membrane filter or plankton centrifuge for the nannoplankton.

5. In addition to phytoplankton collections, measurements of water temperature, turbidity, and water depth were made at each collection, with water velocity measurements and chemical determinations made at representative intervals.

6. The larger phytoplankton were enumerated with a circular counting chamber and a stereo-microscope. The nannoplankton were enumerated with a haemacytometer and a compound microscope.

7. The Logan River contains an abundant phytoplankton population, with phytoplankton here defined as including all the algae floating free with the water.

8. Diatoms dominate the phytoplankton in both number of species and number of individuals.

9. The phytoplankton is almost entirely derived from the benthic algae of the river bottom.

10. None of the diatoms are quantitatively sampled with a number 20 silk plankton net. The number 20 silk net removed only 40 to 60 percent of Nitzschia sigmoidea, an extremely large diatom, and from 10 to 40 percent of the other forms.

11. Only 40 to 60 percent of the Closterium litorale cells are removed by the number 20 silk plankton net. Only a small percentage of the trichome fragments of blue-green algae are removed by the net.

12. The Foerst plankton centrifuge, at a flow rate of 5 minutes per liter or better, removes essentially all the phytoplankton.

13. Millipore or membrane filters are very efficient in removing and permitting recovery of the phytoplankton from water samples, at all but the highest Logan River turbidities (up to 20 p.p.m.). The membrane filter system is several times faster than the Foerst centrifuge.

14. There is no evidence of a diurnal fluctuation in phytoplankton density in the river above the impoundments. The condition below the impoundments was not tested.

15. Day to day variations in phytoplankton density (above the impoundments) are in general not of large magnitude.

16. There is only a small probability that samples taken from the river above the impoundments at weekly or 10 day intervals would not be generally representative of the interval. This probability exists however, and a large magnitude variation in only 1 sample should be suspect in the absence of other evidence.

17. There is no pronounced seasonal phytoplankton maximum in the canyon section of the river. Summer phytoplankton pulses are present at the valley stations but are caused primarily by organisms not common in the canyon section.

18. The impoundments are in general detrimental to the phytoplankton. Fragments of filamentous algae are added to the stream phytoplankton by the impoundments, but these fragments soon deteriorate. A few species of the stream phytoplankton increase in numbers in passage through the impoundments, and some show no effect, but the majority of the phytoplankton have lower density at the outlet than at the inlet.

19. Very low water temperatures have a general but not drastic limiting action on phytoplankton density. One species however, Palmella Myosurus, is at near maximum density during the cold weather. There is evidence that an increase of the winter minimum from near 32°F. to 38°F. reduces the winter minimum for Closterium Ehrenbergii and C. litorale. Maximum summer temperatures in the canyon section are not accompanied by phytoplankton pulses. Maximum summer temperatures at the valley stations, which are 15°F. to 20°F. higher than at the canyon stations, are accompanied by pulses of organisms not common in the canyon section of the river.

20. High turbidity has no obvious limiting action. The highest turbidity is found at stations in the valley which have the maximum phytoplankton densities.

21. Low water velocity is judged to be detrimental to the phytoplankton forms found in the river, based on the effect of passage through the impoundments. High water velocity in the river is detrimental to the filamentous forms from the impoundments.

22. There is a general direct relationship between increased dissolved nutrients and maximum phytoplankton densities.

23. The up to 10 fold increase in volume of flow during the spring floods is not accompanied by a general decrease in phytoplankton density. Many forms are near maximum density during the flood, and only 1 group, the net plankton diatoms, shows a definite density minimum during the flood.

24. The valley stations are characterized in general by higher phytoplankton densities than the canyon stations and by definite yearly cycles in density. The majority of the pulse forming species at the valley stations were not abundant at the canyon stations.

25. The differences between the canyon and valley environments are associated with concurrent differences in temperature range, turbidity, water velocity, water chemistry and the addition of large, inadequately sampled water volumes from other streams. It is not possible with the data available to single out any one or two limiting factors which might be responsible for the differences in phytoplankton composition and numbers between the two environments.

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