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A Biological and Chemical Study of the Tidal James River

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A BIOLOGICAL AND CHEMICAL STUDY OF THE TIDAL JAMES RIVER

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This paper constitutes a final contract report from the Virginia Institute of Marine Science to the Federal Water Pollution Control Administration on work performed under contract PH 86-65-86. The data contained herein are considered final but complete analyses cannot be made until corollary studies are completed.

15 November 1966
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SUMMARY AND RECOMMENDATIONS

The tidal James River is truly a multi-purpose natural resource. Its aesthetic value is of immeasurable importance to the millions of tourists who stand on the shores of Jamestown Island or Carter's Grove, Brandon, Shirley, Westover, Berkeley, or Sherwood Forest plantation each year and gaze out over this historic body of water. The estuarine portion is a major oyster producing area in Chesapeake Bay. In 1966 over 500,000 bushels of shucking oysters were harvested and over 600,000 bushels of seed oysters were caught for replanting in other rivers. This harvest represents only a fraction of past and potential levels because the breeding populations in the lower estuary have been destroyed by the protozoan Minchinia nelsoni, which is often referred to as MSX.

The tidal James also supports significant sport and commercial fin-fisheries. Striped bass, spot, flounder, croaker, trout, shad, and herring are taken in haul seines and gill nets and catfish and carp are taken in fyke nets and traps. All these species plus others of little commercial value are harvested by sport fishermen.

The lower James is heavily utilized for recreational boating and water contact sports but this use is restricted in the upper tidal area because of pollution.

Several industries use the river water for cooling purposes and the City of Hopewell withdraws water from the mouth of the Appomattox River, which exchanges with James River water during each tidal cycle, for its domestic and industrial water supply system. This supply has been plagued by taste and odor problems and threatened by salt water intrusion.

James River water is utilized to a limited extent for agricultural irrigation. This use will undoubtedly increase in the future.

The James is an important waterway for commerce and military activities. The Hampton Roads area is a major port with shipping and shipbuilding facilities located at Newport News, Norfolk, and Portsmouth. Ocean-going ships utilize the waterway to Deepwater Terminal near Richmond. Norfolk is also the site of the largest U. S. Navy complex in the world.

The James River is used for domestic and industrial waste disposal. This is an intended use but in the freshwater reach of the tidal James the assimilation capacity is exceeded and the other potential uses are curtailed. In the estuarine portion hundreds of acres of oyster beds are condemned for direct harvesting. This industry cannot exist in close proximity to concentrations of human activities, and even if all outfalls were removed, most areas would remain condemned. The other intended uses of Hampton Roads are not curtailed.

From the pollution standpoint, the critical area in the James River extends from Richmond to Brandon Point, a distance of 48 nautical miles. The phytoplankton standing crop, as indicated by chlorophyll levels, frequently exceeds 50 $\mu g l^{-1}$, the value proposed as the upper limit for aesthetically desirable water. Values exceeding 100 $\mu g l^{-1}$ were recorded on one cruise. An algal scum was frequently observed during the late summer months.

Dissolved oxygen values of less than 1 mgl^{-1} were measured at Station J-76 near Kingsland Creek and oxygen sag zones were found below Richmond and Hopewell. Three fish-kills were recorded during the study period and channel trawl samplings by the Ichthyology Department indicated that very few fish were able to survive in the degraded environment. Benthic samples indicated that invertebrate forms were very scarce between J-57 and Richmond with only the most tolerant species represented. In some areas the bottom was completely devoid of animal life which suggests the occasional presence of toxic materials.

The phosphorus and nitrogen data indicate that the 48-mile critical area is highly enriched. Nitrate-nitrogen values as high as 231 μg-at l^{-1} and soluble reactive phosphorus values as high as 12.60 μg-at l^{-1} were recorded during the study. The nutrient elements could not be followed through the estuarine portion and the phytoplankton population in the lower area did not reflect that the high level of enrichment existed upstream.

In order to return the upper tidal region of the James to the status of a multi-purpose natural resource, organic loading must be reduced to a level where the river can assimilate the wastes without the development of sub-minimal dissolved oxygen conditions. The proposed hydraulic model studies will yield data which will permit a more accurate prediction of the BOD capacity of the river at different fresh-water discharge rates.

GENERAL HYDROGRAPHY

The James River is the most southerly major tributary stream of the Chesapeake Bay System. It is approximately 400 miles in length and has a drainage area which exceeds 10,000 square miles. Its course cuts through the Coastal Plain, Piedmont, Blue Ridge, and Ridge and Valley physiographic provinces. The mean freshwater discharge is approximately 7,500 c.f.s. but extremes of 329 to 325,000 c.f.s. have been recorded (Virginia, 1960).

The James River is tidal from its mouth at Hampton Roads to Richmond, a distance of approximately 95 miles (Fig. 1). The mean tidal range is 0.79 m at the mouth and 0.98 m at Richmond. The tidal current velocities range between 0.8 and 1.5 knots with the surface ebb velocities in the estuarine portion usually slightly higher than the surface flood velocities. The opposite is true for the velocities of the deeper waters. This factor, in combination with the duration of the current direction, results in a net downstream flow in the upper layer and a net upstream flow in the lower layer. Pritchard (1952) observed a mean velocity in the upper layer of 0.09 m sec^{-1} and a mean lower layer velocity of -0.06 m sec^{-1}. This two-layered system serves to transport the more dense salt water upstream in the lower layer while mixing through the theoretical zone of no net motion contributes dissolved salts to the upper layer.

The average zone of salt-water intrusion extends from the mouth to Jamestown Island, a distance of 35 miles. The location of the

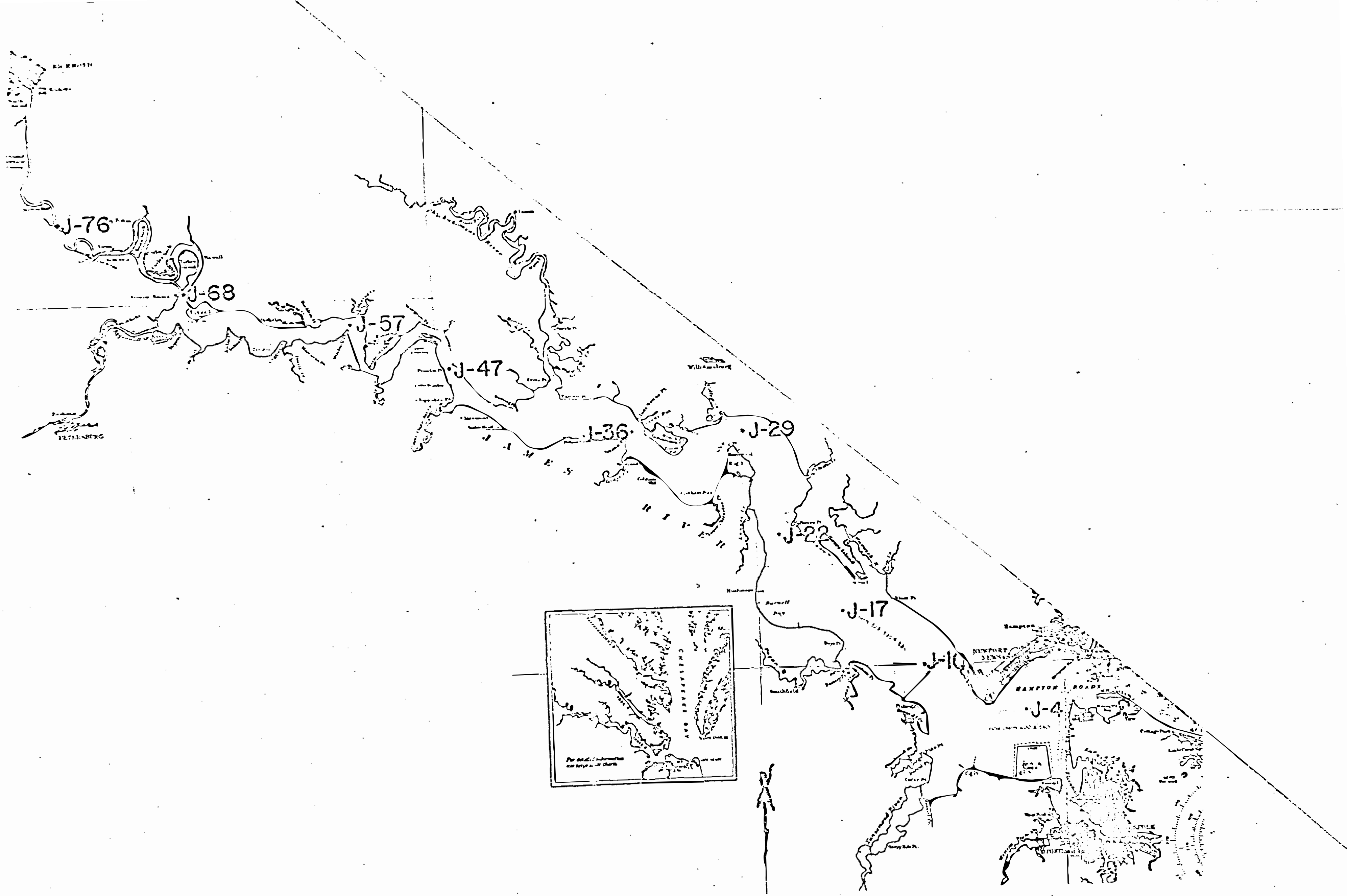


Fig. 1. TIDAL JAMES RIVER AND LOCATION OF SAMPLING STATIONS (Numbers indicate miles from mouth)

transition zone normally moves upstream and downstream as much as 15 miles with extremes in fresh-water discharge. During the extreme drought period of 1965 the fresh-water discharge as measured at Richmond remained between 1,090 and 1,704 c.f.s. from July through January. The salinities increased near the mouth until August when the inflowing waters from Chesapeake Bay provided stability to the system (Fig. 2). The upstream stations showed a significant increase in salinity and the progression of the salt wedge upstream as near steady-state low flow conditions persisted. In December 1965, measurable quantities of dissolved solids of marine origin were detected at Jordan Point, 63.5 miles upstream from the mouth.

The spring run-off pushed the salt wedge downstream and depressed the salinities at the downstream stations. Salinity recovery was quite rapid after the fresh-water crest had passed but the salinity structure was less stable than before the high run-off and was depressed again by the April 1966 freshets.

Water temperatures in the James estuary and tidal river ranged from 0.0 to 29.0°C during the study period (Appendix A) The lowest temperatures were recorded in February during an extreme cold wave. Ice cover extended from J-22 to the Fall Line either as floating shore ice or fresh-water ice. The highest water temperatures were recorded in September 1965. The temperature regime varied from less than 1°C from the mouth to J-76 in July 1965 to more than 7°C in December 1965.

The James River is considered one of the most turbid of Virginia's tidal streams. This is the result of (1) the large drainage basin, and

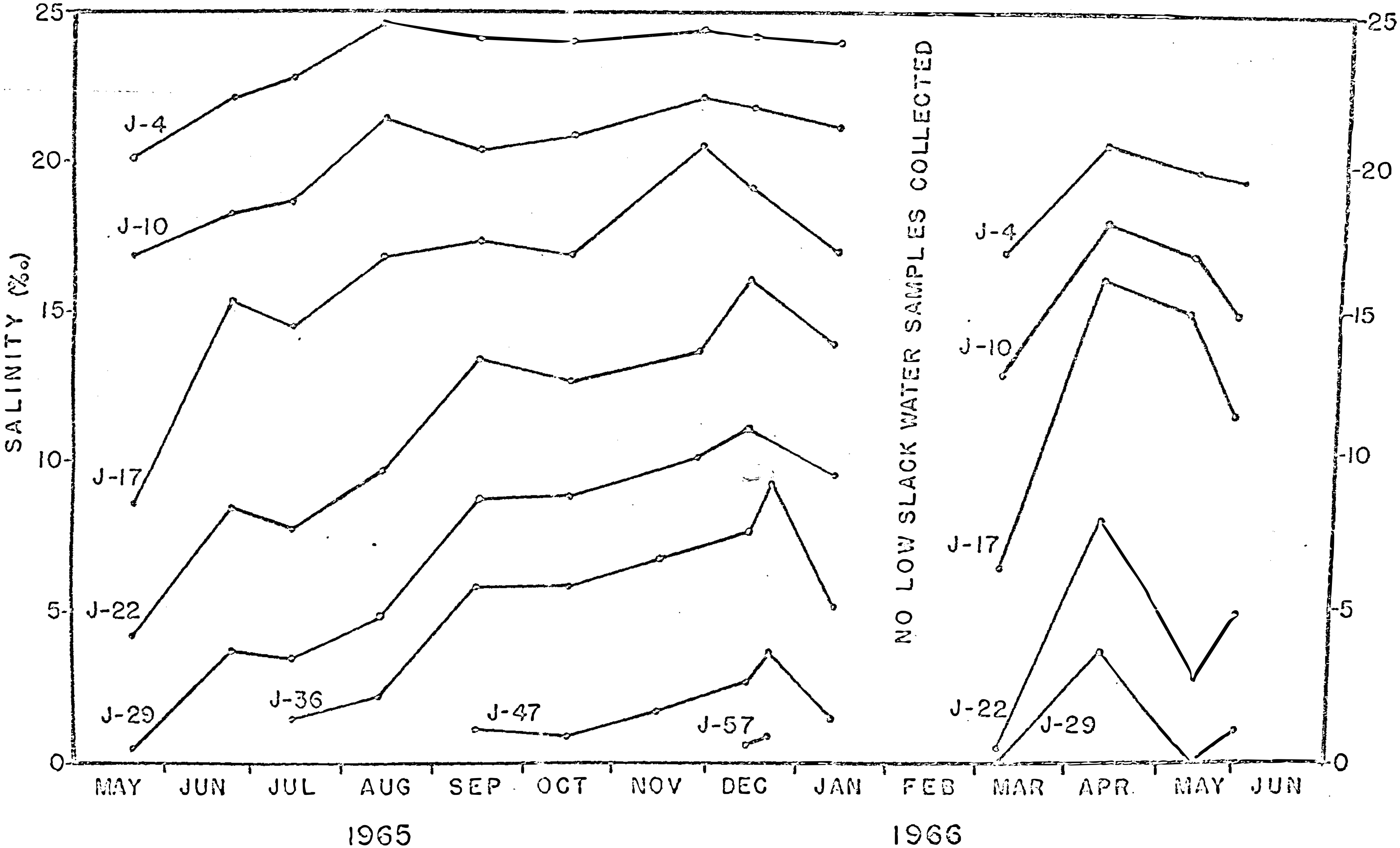


Fig. 2. BOTTOM SALINITY VALUES FOUND AT THE JAMES RIVER ESTUARY STATIONS FROM MAY 1965 THROUGH MAY 1966

(2) the vast shoal areas in the lower estuary. The latter are easily disturbed during periods of high winds and the resulting temporary turbidity reduces the aesthetic value of the estuary and has an adverse biological effect as the settling silt and clay particles mechanically entrap phyto- and zooplankton and remove them from suspension.

The monthly surveys were conducted at slack before flood tide on days when wind conditions permitted small boat operations. The data presented in Appendix A therefore represent minimal suspended solids levels.

The July 1965 data (Fig. 3) are representative of low fresh-water discharge conditions. The salinity at J-4 had reached 21 ‰ and the salt water transition zone was above J-36. The longitudinal distribution of suspended solids was typical of a coastal plain estuary. Our data indicate that the highest inorganic suspensoid level is frequently found in the 0.5-5.0 ‰ zone and the levels then decrease toward the mouth. The organic or loss on ignition fraction is an indication of the plankton concentration in the water but this is more accurately described in the section on phytopigments.

Secchi disk readings which are indicative of the transparency of the water as influenced by suspended solids are given in Table 1.

DISSOLVED OXYGEN

Water samples were collected for dissolved oxygen determinations at two-meter intervals from surface to bottom at each of the ten stations during each sampling run. The chemicals involved in the fixation of

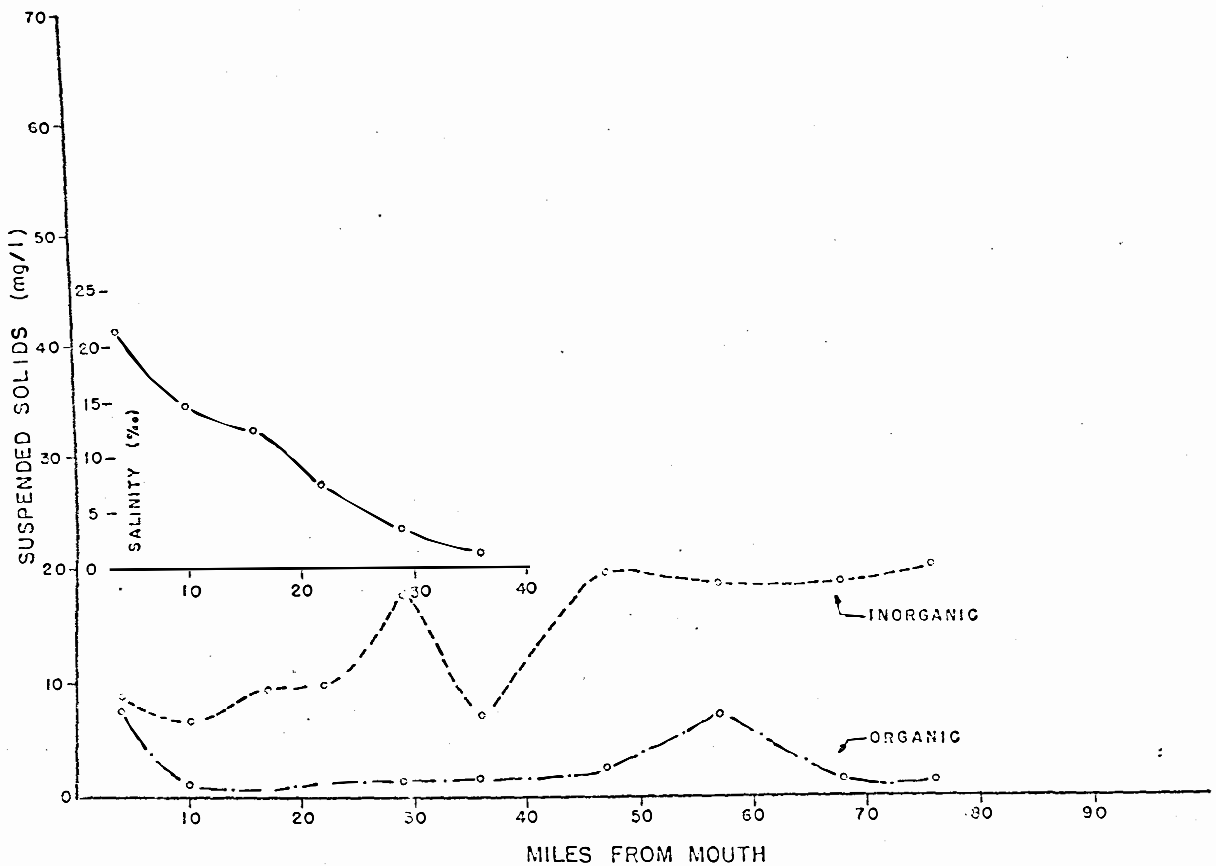


Fig. 3. INORGANIC AND ORGANIC SUSPENDED SOLIDS AS RELATED TO SALINITY AND RIVER MILEAGE--JAMES RIVER, JULY 13-14, 1965 (1 m DEPTH)

Table 1

SECCHI DISK READINGS (m) RECORDED FROM THE TIDAL JAMES RIVER AT TEN STATIONS DURING THE PERIOD FROM MAY 1965 THROUGH MAY 1966

Station	1965 19-20 May	21-22 Jun	13-14 Jul	11-12 Aug	14-15 Sept	14-15 Oct	15-29 Nov	13-14 Dec	1966 10-13 Jan	9-13 Mar	7-11 Apr	9-11 May
J-4	1.5	1.5	1.7	1.4	1.7	2.4	2.4	1.8	1.8		1.6	1.7
J-10	0.8	1.0	1.4	1.5	1.5	1.9	2.1	1.1	1.2		1.5	1.1
J-17	0.7	1.2	1.2	1.5	1.9	1.7	1.8	1.2	1.2		1.2	0.7
J-22	0.6	1.7	1.2	1.7	1.8	1.5	1.5	1.7	1.3		0.9	0.6
J-29	0.5	1.8	0.8	0.9	1.2	1.2	1.5	1.5	0.9		0.5	0.5
J-36	0.3	0.8	0.7	0.9	1.0	0.9	1.2	1.2	0.8	0.3	0.3	0.5
J-47	0.6	0.9	0.6	0.6	0.9	0.8	0.9	0.9	0.6	0.2	0.5	0.6
J-57	0.5	0.8	0.5	0.6	0.5	0.5	0.6	0.5	0.5	0.3	0.5	0.6
J-68	0.5		0.6	0.6	0.4	0.6	0.8	0.6	0.7	0.5	0.6	0.5
J-76	1.2	0.8	0.6	0.9	0.8	0.9	1.2	0.9	0.9	0.7	0.8	0.9

the dissolved oxygen were added in the field and the titrations were made in the laboratory. The results reported in mgl^{-1} are given in Appendix A.

The data indicate that the upper tidal portion of the James River is receiving organic loadings beyond the assimilation capacity during low flow periods. In July 1965, values of less than 4 mgl^{-1} were measured at J-47, J-57, J-68, and J-76. At Station J-76, the dissolved oxygen values were below 4 mgl^{-1} from July 1965 through December 1965 at the time of all cruises except October which was made after a fall freshet.

The Estuarine James, downstream from J-47, does not indicate adverse effects from the upstream or tributary loadings. The values exceeded the levels considered minimal for aquatic life at all stations during every cruise.

The range of dissolved oxygen values found at each of the 10 stations when water temperatures were less than and when they were more than 15°C is given in Figures 4 and 5. Although no determinations were made upstream from Richmond, we may assume that a high level of saturation would be attained as the water flows over the falls. At J-76, values less than 1 mgl^{-1} were measured when water temperatures were less than and when they were more than 15°C. The stream shows a slight level of recovery at J-68 followed by a second oxygen sag zone at J-57 and J-47 below the Hopewell domestic and industrial outfalls. Complete recovery is indicated at J-36 and no evidence of oxygen stress was detected through the estuarine portion.

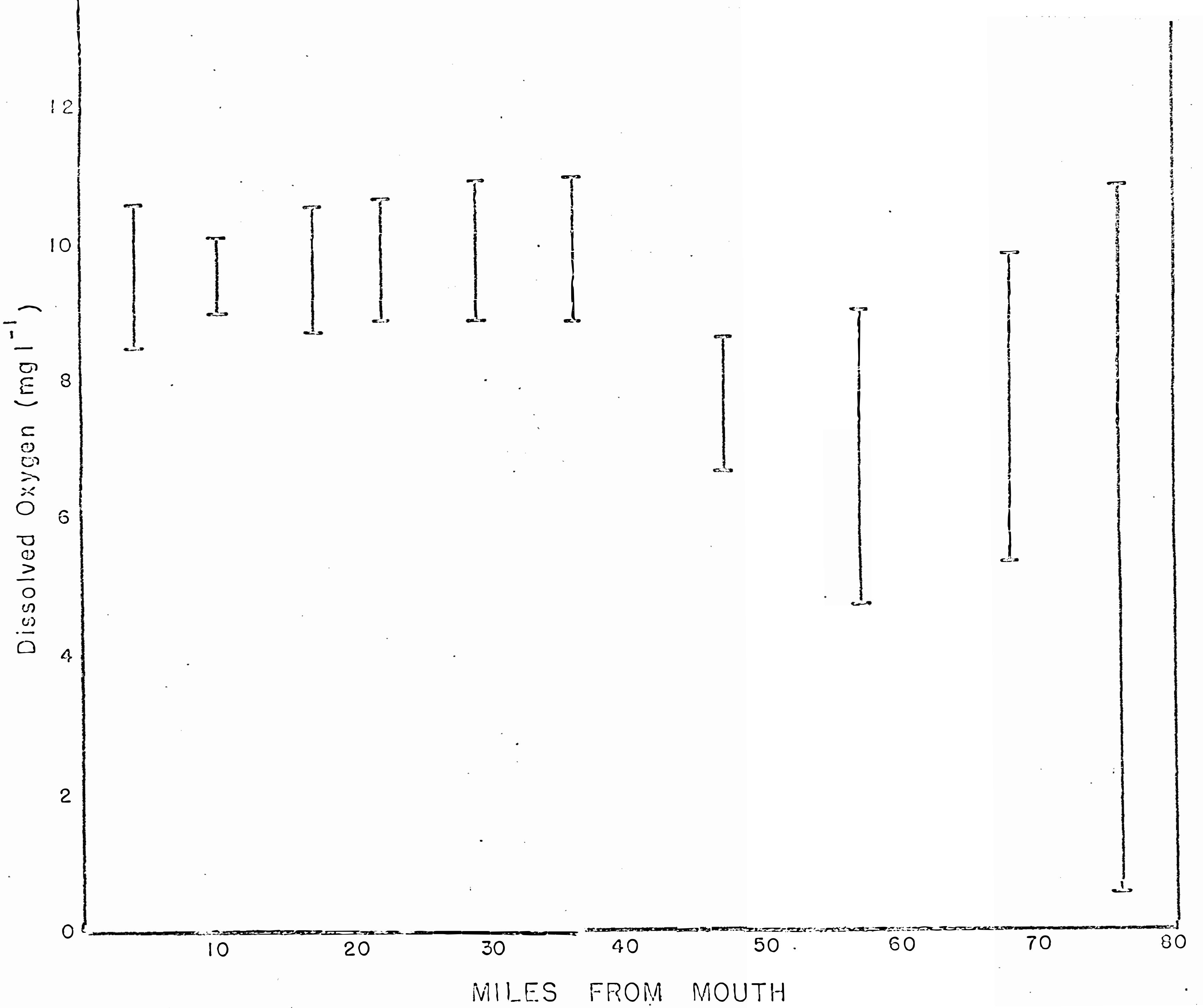


Fig. 4. RANGE OF DISSOLVED OXYGEN VALUES FOUND AT 3 m DEPTH OF JAMES RIVER FROM MAY 1965 THROUGH MAY 1966 WHEN WATER TEMPERATURES WERE LESS THAN 15°C

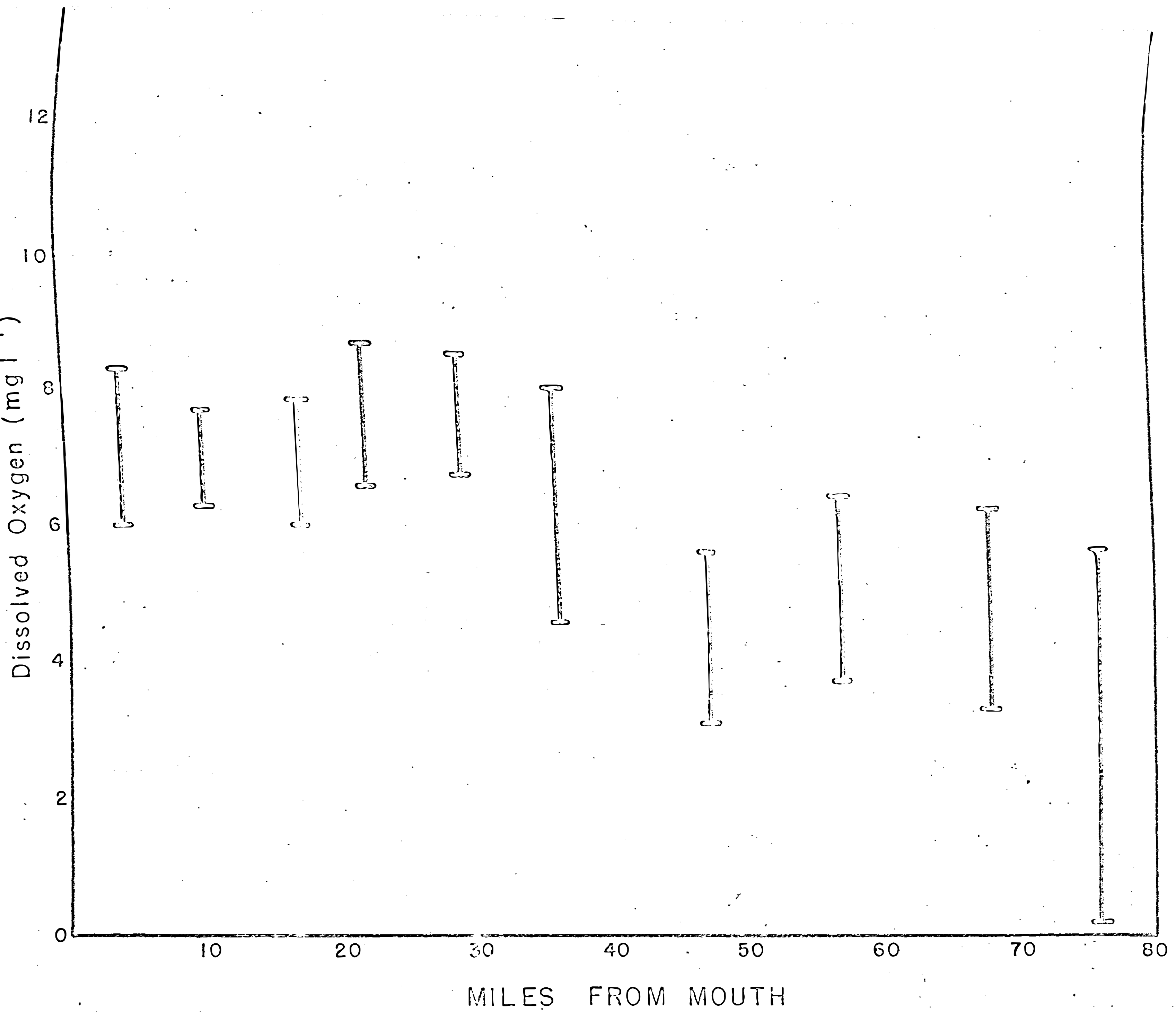


Fig. 5. RANGE OF DISSOLVED OXYGEN VALUES FOUND AT 3 m DEPTH OF JAMES RIVER FROM MAY 1965 THROUGH MAY 1966 WHEN WATER TEMPERATURES WERE ABOVE 15°C

Since dissolved solids affect the solubility of oxygen in water and the sampling program covered stations having salinities ranging from 25 ‰ to freshwater, the data are shown as percent saturation when water temperatures were less than and more than 15°C (Figs. 6 and 7). The two oxygen sag zones are clearly indicated at both temperature ranges. The dissolved oxygen levels were above 80% of saturation during each sampling period from Station J-36 to the mouth.

In summary, the dissolved oxygen data collected during the contract period indicate that the organic loadings in the tidal river exceed the assimilation capacity of the stream and sub-minimal environmental conditions resulted. The organic loading in the estuarine portion does not adversely affect the dissolved oxygen levels in the water.

NUTRIENT ELEMENTS

Over-enrichment of natural waters through the introduction of either treated or untreated domestic or industrial wastes has just recently been recognized as a threat to the utility of aquatic systems. The resulting atypical phytoplankton or sessile plant populations may degrade the environment by producing aquatic nuisance conditions, by depleting the dissolved oxygen supply in the water through the processes of respiration, or by changing the composition of the phytoplankton population.

The upper tidal portion of the James River receives large quantities of nutrients in the treated and untreated domestic and industrial wastes

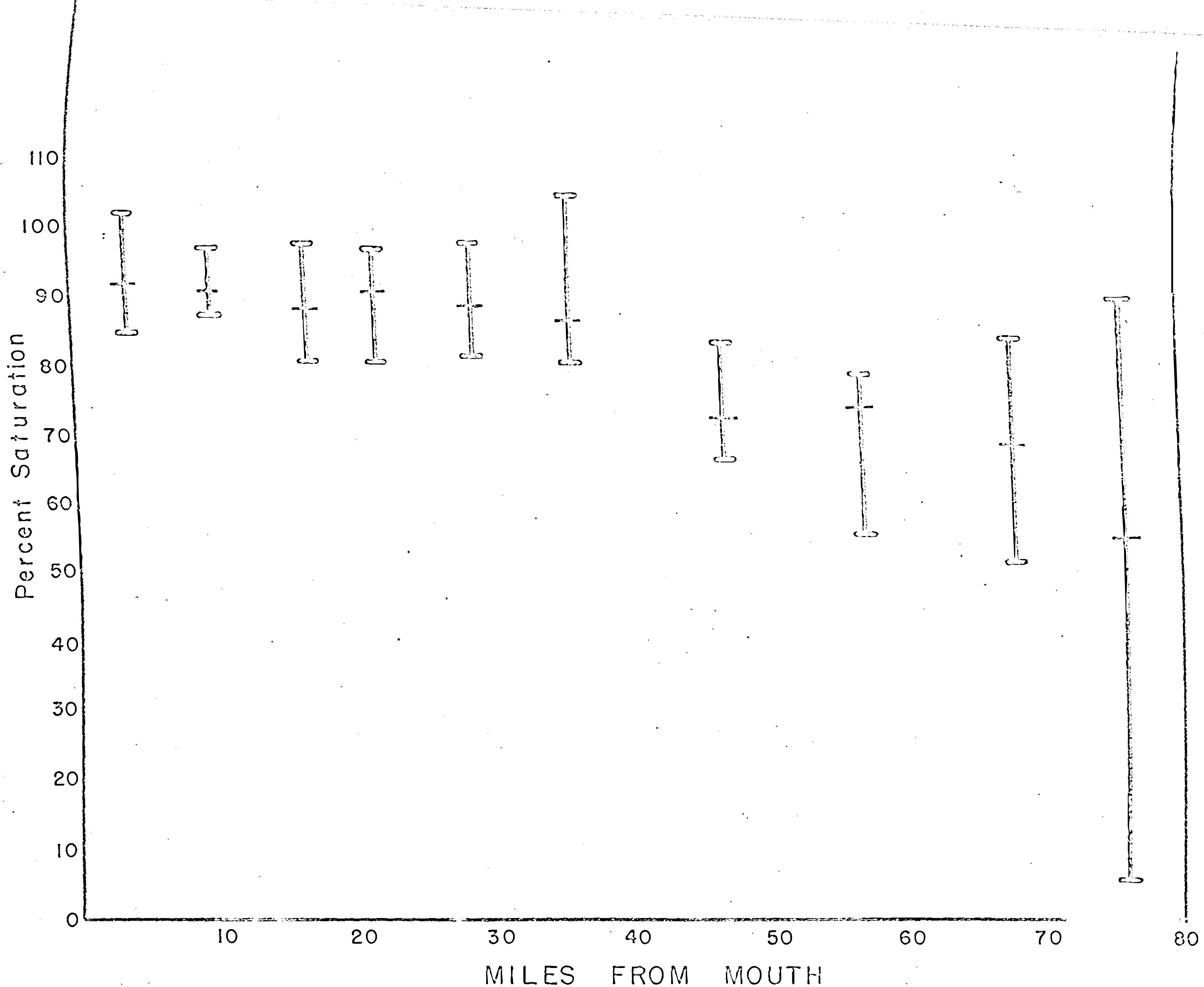


Fig. 6. RANGE AND MEDIAN DISSOLVED OXYGEN PERCENT SATURATION VALUES FOUND AT 3 m DEPTH OF JAMES RIVER FROM MAY 1965 THROUGH MAY 1966 WHEN WATER TEMPERATURES WERE LESS THAN 15°C

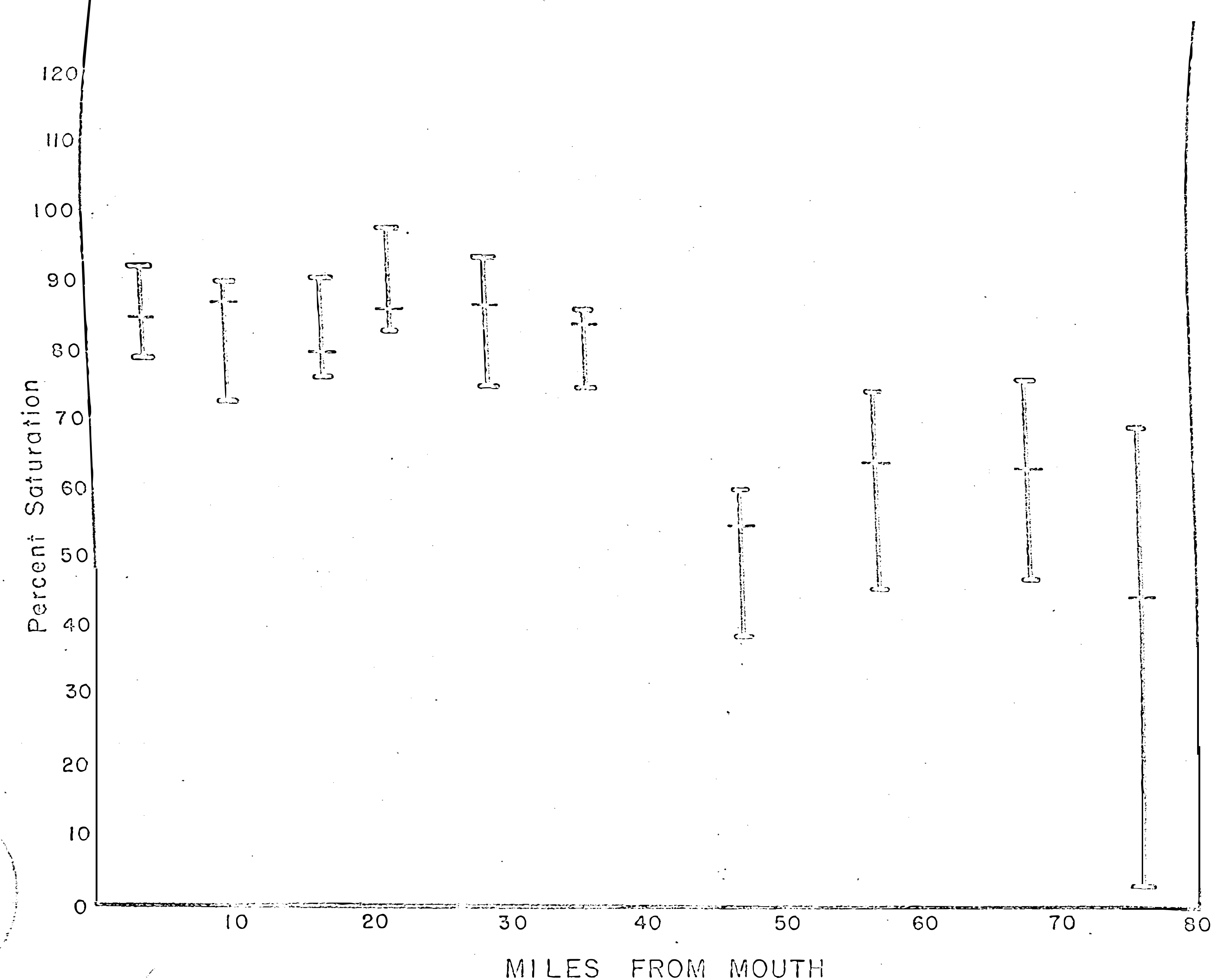


Fig. 7. RANGE AND MEDIAN DISSOLVED OXYGEN PERCENT SATURATION VALUES FOUND AT 3 m DEPTH OF JAMES RIVER FROM MAY 1965 THROUGH MAY 1966 WHEN WATER TEMPERATURES WERE ABOVE 15°C

discharged by Metropolitan Richmond. Calculations based upon a metropolitan population of 500,000 indicate that approximately 2.7 metric tons of phosphorus and 8.2 metric tons of nitrogen in various organic and inorganic forms are discharged into the tidal James each day. During the period from July 1965 to December 1965 when the fresh-water discharge as measured at the Fall Line was approximately 1,000 c.f.s., this produced a direct enrichment of 30 µg-at P l^{-1} and 200 µg-at N l^{-1} if we assume that the upper tidal portion has the hydraulic characteristics of a unidirectional stream.

The City of Hopewell, which is located approximately 30 miles downstream from Richmond, also adds to the nutrient loading of the system. The data indicate a significant increase in the nitrogen content of the river water in the vicinity of the Hopewell domestic and industrial outfalls.

PHOSPHORUS--Water samples collected for phosphorus analyses were immediately iced and returned to the laboratory for processing to isolate the various components. The sample treatments permitted calculations for soluble reactive phosphorus (SRP), particulate reactive phosphorus (PRP), soluble unreactive phosphorus (SUP), and particulate unreactive phosphorus (PUP).

The data on the quantity of the four forms of phosphorus and the total amount present at 1 m and bottom minus 1 m at each of the 10 sampling stations on the James River during the 12 sampling periods are given in Appendix A.

The data indicate that the excess quantity of SRP introduced into the tidal system in the Metropolitan Richmond area is removed from solution either by biotic or abiotic processes in the 40-mile section between Windmill Point (J-57) and the outfalls. In July 1965, the average fresh-water discharge as measured at Richmond was 1,704 c.f.s. or 1.2×10^9 g.p.d. The theoretical phosphorus enrichment was approximately 20 μg-at l^{-1}. The total phosphorus measured at J-76, twenty miles downstream from the city, was 5.88 μg-at l^{-1} at 1 m and 5.60 μg-at l^{-1} at 7 m, indicating a reduction of approximately 75% during a 15$\pm$ day time of passage. The SRP values were relatively high when compared with the downstream values but showed a decrease through the fresh-water section (Appendix B-3). This decrease in SRP can be accounted for in part by an increase in PUP which in a system such as the James is incorporated mainly into plankton cells. Since few fresh-water plankton organisms can survive the salt water environment, we would expect a decrease in PUP in the transition zone and a corresponding increase in SRP. The data indicate a reduction in PUP at J-36 where a salinity of 1 ‰ was measured but the phosphorus could not be accounted for in the other three forms measured. A slight increase in SRP and total phosphorus was measured at Stations J-4, J-10, and J-17 over the value found at J-36.

In September 1965, the average fresh-water discharge at Richmond had decreased to 1,090 c.f.s. and the total phosphorus measured at J-76 had increased to 21 μg-at l^{-1}. Over half of the phosphorus was found to be in the SRP form (12.20 μg-at l^{-1}) and 4.60 μg-at l^{-1} was found in the PUP form (Appendix B-5).

The SRP value decreased from 12.20 µg-at l^{-1} at J-76 to 0.36 µg-at l^{-1} at J-68. Although the PUP value remained relatively constant between the two stations, the standing crop of phytoplankton as indicated by chlorophyll values increased from 85.50 µgl^{-1} to 102.60 µgl^{-1}, the highest value measured on the James River during the contract period.

Analytical difficulties limited the phosphorus data on J-57 to SRP and total, but these values were nearly the same as the values obtained at J-68 on the same cruise.

The data for J-47, as compared to those for J-57, indicate a decrease in total phosphorus from the 6.27 µg-at l^{-1} to 1.35 µg-at l^{-1}. The SRP value increased from 0.20 to 0.49 µg-at l^{-1}. The salinity at this station was 1 ‰.

The SRP values increased from J-36 to the mouth. The increase in the phosphorus form which is considered to be immediately available to phytoplankton was made possible by the absence of a phytoplankton response in the estuarine section. The chlorophyll values were at a relatively constant level from J-22 to the mouth even though the SRP values nearly doubled through the same area (Appendix A).

The fresh-water discharge as measured at Richmond averaged 1,193 c.f.s. during the month of December 1965, a flow of over 6,000 c.f.s. less than the mean value for the month. December was the sixth consecutive month having a mean fresh-water discharge of less than 2,000 c.f.s. The saltwater-freshwater transition zone had moved upstream to beyond J-57 but steady state conditions were still not established. Cruise data from runs on 21 and 27 December indicated that the salinity zone had moved farther upstream to Jordan Point, 63.5 miles from the mouth.

The phosphorus data from the December cruise demonstrate the low dilution factor for the Richmond wastes discharges (Appendix B-8). The total phosphorus value at J-76 was 15.20 µg-at l^{-1}, of which 7.54 µg-at l^{-1} was in the $PO_4^{\equiv}$ form. The total phosphorus in the water decreased to 5.22 at J-68 and 1.68 µg-at l^{-1} at J-47. The values remained nearly constant from J-47 to the mouth with only a slight increase measured in the lower estuary.

In March 1966, the fresh-water discharge at Richmond had increased to 8,563 c.f.s. due to the spring thaw and rainfall. The February average had been 11,345 c.f.s. The hydrographic data (Appendix A) indicate that the system was dominated by the fresh-water component. The freshwater-saltwater transition zone had been pushed downstream to Station J-22 and the surface salinity at J-4 was 16.4 ‰.

The phosphorus data indicate that total phosphorus values were nearly constant through the fresh-water tidal section. The decrease in values in the lower estuary roughly corresponded to the dilution factor of the seawater mixing with the freshwater.

A significant quantity of PRP was found at all stations during the March 1966 cruise. This form consists of phosphate phosphorus which is adsorbed on suspended solids. Higher river turbidities were associated with the spring run-off.

Discussion--The data indicate that the fresh-water tidal James River is highly enriched with phosphorus. Although no water samples were collected for analyses from the river above the City of Richmond, the available wastes discharge data from the metropolitan area indicate a potential level of enrichment comparable to that found.

The phosphorus values measured at Station J-76 were consistently very high except during a period of moderate fresh-water runoff when adequate dilution was provided. A high percentage of the phosphorus measured at this station was in the phosphate form which is immediately available to plant life.

The total phosphorus in the water and the SRP levels decreased significantly through the stations in the fresh-water section in the fall and early winter of 1965 when the fresh-water discharge levels remained below 2,000 c.f.s. and hydrographic conditions approaching steady state were established. A part of the decrease in SRP could be explained through an increase in PUP as the standing crop of phytoplankton increased. The decrease in total phosphorus in the system, however, was too great to be explained by dilution of the James River water by the discharge from the Appomattox River at Mile 65.

During the period from July through December 1965 the total phosphorus in the water column increased from the transition zone to the mouth. This was largely the result of an increase in SRP form in the water column at the estuarine stations. Although the cities adjacent to Hampton Roads discharge treated sewage effluent into the tributaries of the estuary, the nitrogen data for the cruises do not indicate that the effluents are the source of enrichment.

The ca. 985 metric tons of phosphorus discharged into the tidal James by Metropolitan Richmond each year and the unknown quantity entering with run-off water and the other cities in the Tidewater drainage basin must have a rate of removal equal to the rate of accrual in order to prevent an accumulation of the element within the system. An evaluation of the data indicated that the transport was not in the water mass. The loss from solution and suspension far exceeded the volume dilution as indicated by tributary discharge data or salinity values in the estuary.

Sediment samples were taken at fifteen stations located at 5-mile intervals between J-4 and J-75. The top 1 cm was analyzed for total phosphorus. The phosphorus value at J-75 was 1,352 $\mu g\ g^{-1}$ of dried sediment (Fig. 8). The total phosphorus in the sediment samples collected decreased to 310 $\mu g\ g^{-1}$ at J-70 and ranged from 190 to 640 $\mu g\ g^{-1}$. This range of values probably does not represent significant differences between stations since differences in sediment types and adsorptive capacity can be expected in the 65-mile reach downstream from J-75. The data therefore do not indicate that the phosphorus introduced by the upstream sources is being removed from solution through the processes of sedimentation.

A significant quantity of phosphorus is removed from the system by the removal of shellfish. The mean harvest during the last 4 years was estimated at ca. 3 x 10^6 bushels per year. Assuming that the meats contain 0.2% phosphorus and the shells 0.4%, the total removal by the shellfish

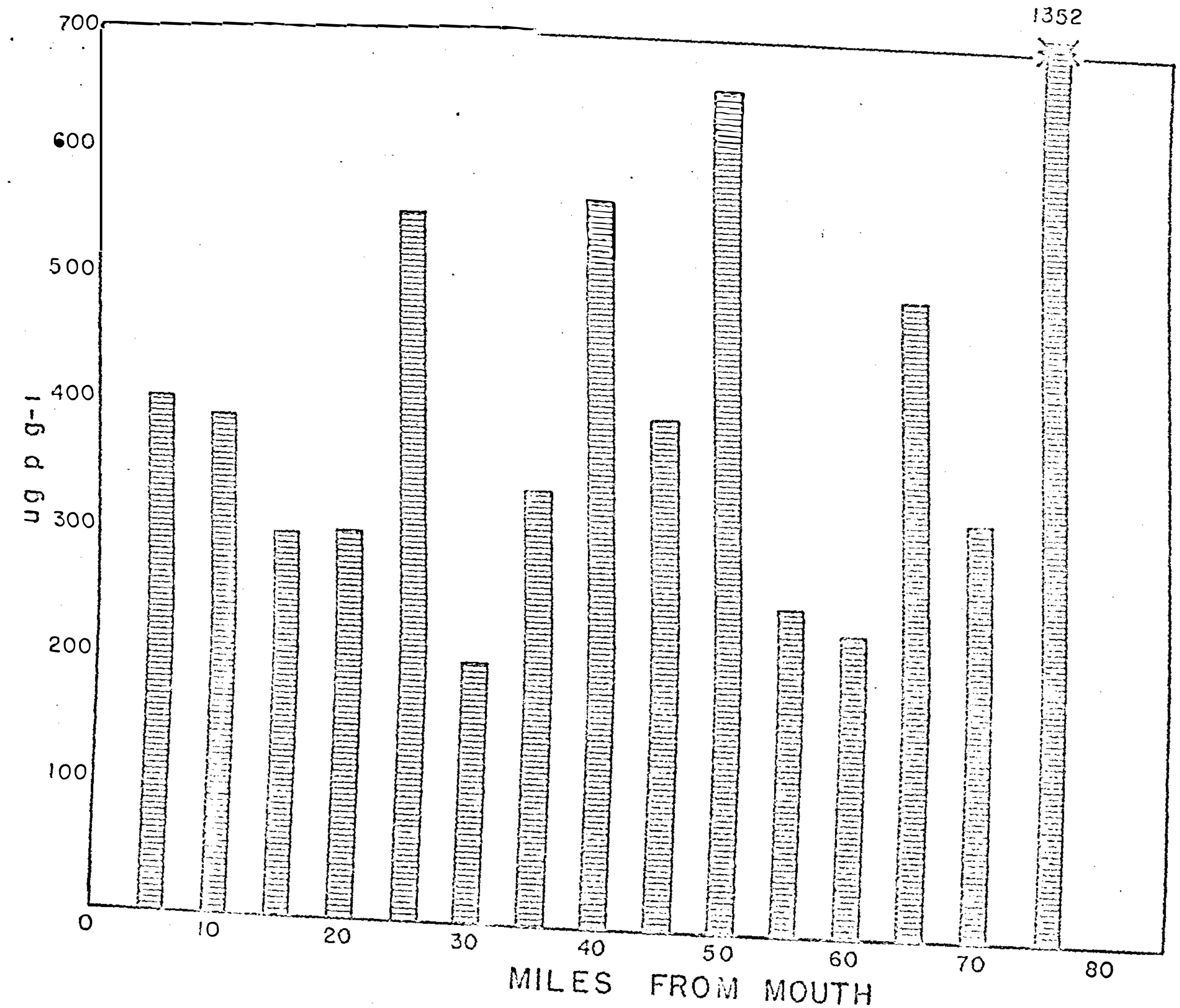


Fig. 8. TOTAL PHOSPHORUS IN TOP 1 cm OF DRIED SEDIMENTS FROM 15 STATIONS ON THE TIDAL JAMES RIVER

industry would only account for 46 metric tons per year, a quantity which would be replaced in only 21 days by the enrichment from the Metropolitan Richmond area.

Although no data are available for the quantity of finfish removed from the system each year by commercial and sport fishermen, the phosphorus removed by this harvest could not exceed that removed by the shellfish

In summary, the available phosphorus data do not permit the development of a quantitative budget for the tidal system. Both the estuarine and fresh-water portions of the James are bordered by extensive tidal marshes. The role of these systems in tidal stream nutrient budgets has not been evaluated. Also, we cannot quantify the role of high rainfall periods and the resulting high flushing rates in washing nutrients from marshes and transporting them out of the tidal system without their entering the biocycle of the estuary.

The phosphorus cycle in open tidal systems is extremely complex and additional studies must be completed before the role of this element in producing aquatic nuisance conditions and degrading the environment can be evaluated.

<u>NITROGEN--Water</u> samples were collected from 1 m and bottom minus 1 m at each of the 10 stations on the tidal James River during the 12 cruises authorized by the contract. The samples were iced and returned to the laboratory for analyses. Ammonia, nitrite, and nitrate analyses were run immediately on returning to the laboratory or, if this were not

possible, the samples were frozen at -18°C. Particulate organic nitrogen (PON) determinations were made on the material retained on a glass filter pad after filtering a known quantity of raw water. The data are given in Appendix A.

The tidal James River is artificially enriched with nitrogen compounds by the wastes from the Metropolitan Richmond area and industrial and domestic wastes from the Hopewell area. The level of nitrogen compounds in the industrial wastes was not determined but one plant produces approximately 1,000 tons of ammonia per day and a loss of the product to the waste stream is unavoidable with the process now employed. This source of enrichment could be identified on all cruises.

The nitrite and nitrate values found at Station J-76 were lower than would be expected from calculations utilizing the level of enrichment from domestic sources and the fresh-water discharge rates at Richmond (Appendix C). Unfortunately, our analyses did not include soluble organic nitrogen, a form which has proven to be extremely significant in recent studies.

The July 1965 data show only 0.90 μg-at $N \cdot NO_2$ l^{-1} and 14.0 μg-at $N \cdot NO_3$ l^{-1} at Station J-76 (Appendix C-8). The nitrite nitrogen level increased to 21.60 and the nitrate nitrogen level to 64.8 μg-at N l^{-1} at J-57 downstream from Hopewell. The nitrite nitrogen value decreased to 4.94 and the nitrate nitrogen value increased to 93.6 μg-at l^{-1} at J-47. Both values decrease from J-47 to the mouth, with the levels at J-4 only 0.03 μg-at $N \cdot NO_2$ and 5.0 μg-at $N \cdot NO_3$ l^{-1}. The PON values ranged from 36.88 to 0.40 µg-at l^{-1} with the highest values in the area below Hopewell where the chlorophyll values indicated the greatest biomass of phytoplankton.

The September nitrite-nitrate values at the 10 stations on the tidal James River followed the same pattern as the July levels (Appendix C-8). The nitrite nitrogen level at Station J-76 was only 0.01 µg-at l^{-1}

The values increased

to 13.00 and 76.0 µg-at l^{-1} at J-57, then decreased to 0.50 and 1.50 at

The September chlorophyll values were the highest recorded during the study period with J-57 and J-68 levels of approximately 100 µg l^{-1}. The available nitrogen was utilized by the phytoplankton and incorporated into plant tissue but the data do not show the inorganic forms returning to solution in the river downstream from the bloom zone.

In December 1965, the fresh-water discharge rate at Richmond had decreased to 1,198 c.f.s. and the fresh-water phytoplankton population had been depressed by low water temperatures. The resulting low dilution and low nitrogen utilization rates were apparent from the data.

The nitrite-nitrate nitrogen values at Station J-76 were 1.70 and 42.20 µg-at l^{-1} The nitrite level increased to 2.05 µg-at N l^{-1} and the nitrate level to 231.00 µg-at N l^{-1} at J-57. The levels decreased toward the mouth to 0.03 µg-at $N{\cdot}NO_2$ and 0.79 µg-at $N{\cdot}NO_3$ at Station J-4 (Appendix C-8).

After the spring run-off, the inorganic nitrogen levels were nearly uniform through the tidal river (Appendix C-10). The nitrate nitrogen value at J-76 was 0.64 μg-at l^{-1} and the nitrate nitrogen value was 16.27 μg-at l^{-1} at the time of the 19 March cruise. The levels did not show the characteristically high increase at the stations in the vicinity of Hopewell and remained at an above average level throughout the estuary. The nitrite-nitrate values at J-4 were 1.43 and 19.20 μg-at N l^{-1} at the 1 m depth.

Discussion--The tidal James River is highly enriched with nitrogen from both domestic and industrial sources. The data indicate that the latter may be the most significant.

The high level of inorganic nitrogen forms in the river downstream from the Hopewell outfalls was utilized by the phytoplankton population and removed from solution before the water mass was transported into the estuarine section. The blue-green algae population cannot survive in the marine environment and theoretically large quantities of available nitrogen should have been available to the estuarine forms. Our data do not indicate that either regeneration, or uptake and a marine phytoplankton response, occurred. Dentrification and loss to the atmosphere is a factor to be considered in the nitrogen cycle and budget of the system. However, supplemental studies conducted in August and September 1966 indicate that soluble organic nitrogen values as high as 50 μg-at l^{-1} may be found in the estuary during the late summer. These data suggest that the freshwater phytoplankton forms die after being transported into the saltwater zone but that the degradation of organic nitrogen to inorganic nitrogen proceeds very slowly and may not occur in the estuary.

PHYTOPLANKTON

A highly enriched system such as the tidal James River is capable of supporting a phytoplankton population of sufficient density to produce aquatic nuisance conditions and degrade the environment. This study was designed to evaluate the available nutrient levels and to measure the phytoplankton response. Water samples were collected on each cruise at the 1 m and bottom minus 1 m for phytopigment analyses. The samples were returned to the laboratory for processing and fluorometric analyses. Water samples for qualitative plankton analyses were collected for the Microbiology-Pathology Department but these data are not available at this time.

The relative quantities of phytoplankton in the water at the two depths sampled at each of the 10 stations during the 12 cruises are given in Appendix A.

The chlorophyll data indicate that the fresh-water blue-green algae population has a different response pattern than the estuarine community. In May, June and July 1965, the fresh-water population showed a progressive increase in biomass in the highly enriched area (Appendix D-1). The chlorophyll level at J-57 reached 50 $\mu g\ l^{-1}$ in July. Natural waters having this phytopigment level are noticeably green and are considered objectionable to many users.

The standing crop of phytoplankton as indicated by the chlorophyll levels decreased to very low levels at Station J-47 and then showed a slight increase in the estuary.

During August, September, and October 1965, the fresh-water phytoplankton population reached levels which adversely affected the aesthetic value of the water and produced environmental degradation. The maximum response to the artificial enrichment occurred during the period of high solar radiation levels and high water temperatures in September.

With the exception of a small bloom in the middle estuary in October, the phytoplankton population downstream from J-47 remained at very low levels.

In November, December, and January, the fresh-water discharge levels at Richmond remained very low due to the continued drought (Appendix E); however, the standing crop of phytoplankton in the fresh-water section decreased and chlorophyll values of less than 50 $\mu g\ l^{-1}$ were obtained at J-57 and J-68. The December value at J-57 was approximately 15 $\mu g\ l^{-1}$ (Appendix D-3). This was the only month during the study that measurable seasalts were detected this far upstream.

The phytoplankton standing crop in the lower estuary (J-4 to J-22) increased during the late fall period. Chlorophyll values of between 10 and 20 $\mu g\ l^{-1}$ were measured at all stations in December 1965.

During March, April, and May 1966, the freshwater discharge into the tidal James was the highest recorded during the study period. The effect of the increased dilution and flushing rate was reflected in the chlorophyll values (Appendix D-4). A decrease in run-off in April permitted a buildup of phytoplankton organisms but increased rainfall and fresh-water discharge rates in May again reduced the standing crop.

The phytoplankton standing crop in the middle estuarine section was at a low level during the spring period. Chlorophyll values of less than 15 µg l^{-1} were recorded at all but the J-4 station. When comparisons are made with the upstream stations, the proximity of this station to Chesapeake Bay and the highly enriched Elizabeth and Nansemond rivers may be responsible for the difference in biological characteristics.

NUTRIENT-PHYTOPLANKTON RELATIONSHIPS

Prevailing hydrographic conditions during the contract period provided an excellent opportunity to study the nutrient-phytoplankton relationship as related to water temperature and season. The monthly average fresh-water discharge at Richmond dropped below 2,000 c.f.s. in July 1965 and remained below this level through January 1966 (Appendix E). Although a system such as the tidal James is subjected to freshets, the volume of the basin in relation to the volume of freshwater introduced modified the effects of 2-3 day increases in runoff which are characteristic of drought period hydrographs.

During the summer of 1965, the mean stream flows were as nearly constant and the estuary approached a condition as near to steady state conditions as could be expected in nature. The nutrient dilution factor reached minimal levels and turbidities were low for an estuary such as the James.

The nutrient elements discharged into the system could not be traced through the freshwater or estuarine sections in either inorganic or organic forms. The heavy enrichment in the upper freshwater section (approximately 100 μg-at N l^{-1} and 15 μg-at P l^{-1} at 2,000 c.f.s. discharges) could be detected at J-76 by relating the total phosphorus values to the freshwater discharge at Richmond during the previous 20-day period. During May, June, July, August, and September 1965, the monthly average flows decreased from 5,348 c.f.s. to 1,090 c.f.s. During this same period the total phosphorus in the water column increased from 4 to 21 μg-at l^{-1}; however, the nitrogen in all forms except soluble organic only increased from 68 to 148 μg-at l^{-1} during the June through September period. The standing crop of phytoplankton increased from 17 to 85 μg chlorophyll per liter. The dilution, phosphorus, and chlorophyll values all changed by a factor of 5 during this period. The James River from J-76 to Richmond has a dredged channel and many of the characteristics of a canal. The transport characteristics and nutrient levels would be expected to be directly related to freshwater discharge levels.

A fall freshet provided extra dilution of the waste loading in October but the flows decreased and the total phosphorus values increased again during November, December, and January. The lower water temperatures apparently prevented the blue-green phytoplankton population from attaining the levels recorded in the late summer and fall.

The reach of the James River between Stations J-76 and J-68 is a multichannel system characterized by "curles" which have been cut off by the dredged navigation channel. The volume of the system is more than twice that of the channel and the flushing characteristics are extremely complex. Qualitative dye studies conducted in the hydraulic model indicate that river water transported into the secondary channels and back waters has a long residence time in these systems. The physical and chemical characteristics of the water at J-68 are also affected by the waste loadings from Hopewell and the discharge of the Appomattox River but the steady state-slack before flood tide influence has not been quantified.

The total phosphorus levels at J-68 were frequently less than 50% of the values recorded at J-76. In contrast, the oxidized nitrogen levels were often 10 times higher than the J-76 levels as the result of the Hopewell discharges.

The nitrogen enrichment produced a tremendous phytoplankton response during the summer months. Chlorophyll levels above 100 $\mu g\ l^{-1}$ were recorded in September 1965. The blue-green population decreased as solar radiation and water temperatures decreased. In January 1965, the 1 m chlorophyll level at J-68 was 24 $\mu g\ l^{-1}$.

The total phosphorus levels in the water column remained constant or showed a slight decrease through the remainder of the freshwater section but the available nitrogen values increased at J-57 downstream from Hopewell. A nitrate nitrogen value of 262 μg-at l^{-1} was recorded in November 1965, a period when utilization by plants was low.

The phytoplankton levels at J-57 were extremely high during the late summer period. Floating masses of algae were observed and aquatic nuisance conditions developed; however, blue-green forms cannot tolerate a salt water environment and the population was greatly reduced at J-47 and J-36.

The large quantities of nitrogen and phosphorus biologically combined in the cells of the freshwater organisms would be released to solution after the death and decomposition of the cells. The nutrients would be available for the development of an estuarine phytoplankton population or, if not utilized, would be detected by the analyses for oxidized forms.

The phytoplankton population in the estuarine James did not increase until cool water conditions prevailed in the late fall and early winter. Prior to this period the soluble reactive phosphorus values increased but this only indicates that available phosphorus was not being utilized. During the period when the SRP values were increasing toward the mouth, the nitrite-nitrate nitrogen values in the estuarine section were at very low levels and were decreasing toward the mouth. On 15 September 1965, the SRP value at J-4 was 1.65 µg-at l^{-1} whereas the nitrite plus nitrate nitrogen value was 1.90 µg-at l^{-1}. Theoretically, an N-P ratio of 15:1 is required for optimum phytoplankton reproduction and growth.

The data indicate that during the summer months the nitrogen released at Hopewell is incorporated into phytoplankton in the J-57 - J-68 reach of the James River. Our data do not show that this nitrogen is converted to the oxidized forms after death and decomposition of the cells before the water mass is flushed from the system. Likewise, the reduction in total phosphorus is greater than can be accounted for by seawater dilution and sedimentation.

During the late fall and early winter period, the nitrogen introduced into the James River at Hopewell is not utilized by freshwater phytoplankton and is flushed into the estuarine section. The fall estuarine phytoplankton forms utilize the available nutrients and the phytoplankton biomass increases.

The period of phytoplankton response was indicated by the nitrite levels in the water. During the late spring and summer the estuarine population did not respond to the nutrients present and nitrites were detected at all stations, whereas in the late fall and winter nitrite nitrogen was frequently near the lower limit of detectability at the downstream stations.

The role of temporary turbidity was not evaluated during this study; however, the summer of 1965 was characterized by stable atmospheric conditions which resulted in the severe drought. We do not attribute the low biomass of phytoplankton in the water at the estuarine stations to physical removal by settleable solids.

In conclusion, the freshwater phytoplankton population responded to nutrient levels as influenced by freshwater discharge and to solar radiation and water temperatures. The nutrient cycle from the freshwater to the estuarine section could not be quantified. The nitrogen compounds were apparently lost from the bio-cycle. The N-P ratio more closely approached a 1:1 ratio than the 15:1 ratio which is considered optimum for phytoplankton populations.

The highest estuarine phytoplankton populations were recorded in the late fall and early winter. During this period nitrogen utilization was limited in the freshwater section. High estuarine phytoplankton populations were accompanied by a near depletion of nitrite nitrogen in the water.

LITERATURE CITED

Pritchard, D. W. 1952. Salinity distribution and circulation in the Chesapeake Bay estuarine system. J. Mar. Res. 11(2):106-123.

Virginia Department of Conservation and Economic Development, Division of Water Resources, 1960. Notes on surface water in Virginia. 63 p (mimeo).

APPENDIX A

BIOLOGICAL, CHEMICAL, AND PHYSICAL DATA FROM TEN STATIONS ON THE TIDAL JAMES RIVER

DATA SHEET

RIVER James CRUISE DATE 6 May 1965

Station	Depth (M)	Temp (C)	Salinity (‰)	DO (mgl-1)
J-4	S	17.4	16.70	9.65
	2	17.2	16.68	9.05
	4	17.3	17.00	8.86
	6	17.1	17.40	7.70
J-10	S	19.5	10.77	9.03
	2	18.3	11.88	8.50
	4	18.2	12.29	7.32
	6	18.6	12.69	8.18
J-17	S	19.8	5.62	6.57
	2	19.0	6.64	8.42
	4	18.7	6.92	8.24
	6	18.8	7.37	8.16
J-22	S	20.1	1.67	7.84
	2	19.4	2.40	7.46
	4	19.2	2.67	7.86
	6	19.2	2.72	8.04
	8	19.2	2.78	7.76
	10	19.3	2.99	8.28
	12	19.3	3.13	7.96
J-29	S	20.7	0.23	7.96
	2	20.1	0.22	7.42
	4	19.7	0.21	7.36
	6	19.6	0.22	7.34
	8	19.6	0.23	7.32
J-36	S	20.1	0.11	7.08
	2	20.1	0.09	6.63
	4	20.0	0.09	6.59
	6	20.0	0.09	6.61
	8	20.0	0.09	6.47
	10	19.8	0.10	6.37
	12	19.8	0.10	6.49
J-47	S	20.6		3.46
	2	20.1		3.38
	4	19.8		3.38
	6	19.8		3.18
	8	19.8		3.18
	10	19.7		3.02
J-57	S	21.9		6.81
	2	21.9		6.47
	4	21.7		6.33
	6	21.6		6.17
	8	21.6		6.01
J-68	S	22.4		6.89
	2	22.5		6.83
	4	22.3		5.67
	6	22.3		5.75

6 May 1965 continued

Station	Depth (M)	Temp (C)	Salinity (‰)	DO (mgl-1)
J-76	S	22.7		6.59
	2	22.8		5.81
	4	22.7		5.87
	6	22.6		5.23
	8	22.6		5.69

DATA SHEET

RIVER James CRUISE DATE 19-20 May 1965

Station	Depth (M)	Temp (C)	Salinity (‰)	DO (mgl^{-1})	ALK ($meql^{-1}$)	pH	SS (mgl^{-1})	LOI (mgl^{-1})	ER (mgl^{-1})
J-4	1	20.4	18.47	7.43	1.63	7.4	16.4	8.2	8.2
	3	20.2	18.95	7.47		7.7			
	5	19.6	20.20	7.98		7.8			
	7	19.6	20.04	7.39	1.58	7.7	21.2	10.4	10.8
J-10	1	21.3	12.07	7.15	1.30	7.6	30.3	10.7	19.7
	3	21.0	13.73	6.90		7.5			
	5	20.7	15.84	6.70		7.5			
	7	20.5	16.91	6.76	1.56	7.5	33.7	14.0	19.7
J-17	1	22.6	7.06	7.47	1.01	7.4	26.7	7.0	19.7
	3	22.3	7.95	7.11		7.3			
	5	22.3	8.65	6.95	1.07	7.2	37.3	11.0	26.3
J-22	1	23.0	3.12	7.03	0.82	7.3	26.0	6.7	19.3
	3	22.8	3.83	7.29		7.4			
	5	22.6	4.07	7.21		7.4			
	7	22.4	4.11	7.29		7.3			
	9	22.6	4.09	7.13		7.3			
	11	22.3	4.28	6.91	0.90	7.1	28.3	7.0	21.3
J-29	1	23.4	0.42	7.11	0.65	7.3	44.8	6.8	38.0
	3	23.3	0.42	6.91		7.2			
	5	23.2	0.44	6.91		7.2			
	7	23.0	0.46	6.86	0.66	7.1	71.2	11.2	60.0
J-36	1	24.4		6.50	0.34	7.1	44.0	12.0	32.0
	3	23.9		6.40		7.0			
	5	23.8		6.42		6.9			
	7	23.8		6.30		6.9			
	9	23.9		6.30		7.0			
	11	23.9		6.21	0.56	6.9	72.0	19.0	53.0
J-47	1	25.0		3.64	0.51	6.6	19.6	4.4	15.2
	3	24.5		3.37		6.5			
	5	24.4		3.31		6.5			
	7	24.4		3.29		6.5			
	9	24.5		3.27		6.5			
	11	24.5		3.25	0.49	6.4	36.0	11.0	25.0
J-57	1	25.7		5.81	0.88	7.2	28.5	9.0	19.5
	3	25.5				7.2			
	5	25.4				7.2			
	7	25.2		3.64	0.84	7.0	32.0	7.6	24.4
J-68	1	25.9		4.49	0.93	7.0	28.5	16.5	12.0
	3	25.8		4.31		7.0			
	5	25.8		4.43	1.00	7.0			
	6	25.8		4.45		6.9	34.5	8.0	22.5
J-76	1	26.6		5.91	0.87	7.2	12.8	9.5	3.3
	3	25.6		4.29		7.1			
	5	25.5		4.75		7.0			
	7	25.4		4.43	0.86	7.0	14.3	8.0	6.3

DATA SHEET

RIVER James CRUISE DATE 19-20 May 1965

Station	Depth (M)	TOT. P (μg.at l^{-1})	SRP (μg.at l^{-1})	PRP (μg.at l^{-1})	SUP (μg.at l^{-1})	PUP (μg.at l^{-1})	NO_2.N (μg.at l^{-1})	NO_3.N (μg.at l^{-1})	OPN (μg.at l^{-1})	Chl.a (μgl^{-1})
J-4	1	0.97	0.03	0.15	0.38	0.41	0.23		4.8	4.2
	7	0.68	0.10	0.06	0.17	0.35	0.19			3.0
J-10	1	1.06	0.03	0.22	0.32	0.51	0.33		5.6	12.0
	7	1.37	0.27	0.11	0.08	0.91	0.28		3.9	4.2
J-17	1	1.37	0.27	0.29	0.35	0.46	0.33		4.2	
	5	2.40	0.32	0.24	0.21	1.73	0.33		3.9	5.7
J-22	1	1.89	0.53	0.31		1.05	0.26			2.8
	11	1.12	0.35	0.49	0.27	0.01	0.31		2.8	3.2
J-29	1	2.58	0.32	0.71	0.06	1.49	0.26		5.6	3.5
	7	2.00	0.47	0.75	0.78		0.38		7.1	3.9
J-36	1	1.40	0.62	0.16	0.63		0.98		3.5	2.7
	11	3.97	0.27	1.10	0.70	1.90	0.52		10.4	3.7
J-47	1	1.90	0.41	0.25	0.40	0.84	4.95			2.0
	11	2.67	0.41	0.46	0.59	1.21	5.00		1.6	3.0
J-57	1	2.80	0.18	0.35	0.60	1.67	6.35		5.6	13.4
	7	3.05	0.27	0.45	0.57	1.76	5.72		9.0	11.9
J-68	1	3.57	0.44	0.53	0.37	2.23	0.69		1.4	12.4
	6	2.98	0.44	0.71	0.46	1.37	0.73		7.1	16.3
J-76	1	3.69	0.78	0.34	0.50	2.07	0.39		9.2	16.8
	7	3.72	0.66	0.81	0.92	1.33	0.37		1.4	12.9

DATA SHEET

RIVER James CRUISE DATE 21-22 June 1965

Station	Depth (M)	Temp (C)	Salinity (‰)	DO (mgl^{-1})	ALK ($meql^{-1}$)	pH	SS (mgl^{-1})	LOI (mgl^{-1})	FR (mgl^{-1})
J-4	1	21.9	19.69	7.06	1.58	7.6	7.2	2.6	4.6
	3	21.7		6.76		7.5			
	5	21.5	21.46	6.46		7.4			
	7	21.9	22.22	6.40	1.66	7.3	10.0	2.4	7.6
J-10	1	23.0	15.52	8.11	1.19	7.7	8.3	0.8	7.5
	3	22.5	15.29	7.04		7.7			
	5	22.3	16.62	6.54		7.6			
	7	22.1	18.13	6.30	1.47	7.5	32.0	5.8	26.2
J-17	1	23.3	10.27	7.51	1.02	7.7	9.0	3.6	5.4
	3	22.9	12.04	7.14		7.6			
	5	22.9	15.07	6.40		7.5			
	7	22.7	15.53	6.32	1.32	7.2	21.0	4.0	17.0
J-22	1	23.7	5.60	8.04	0.58	7.7	6.4	4.0	2.4
	3	23.2	6.67	7.49		7.6			
	5	23.2	6.93	7.20		7.5			
	7	23.3	7.53	7.16		7.5			
	9	23.2	8.27	7.04		7.5			
	11	23.4	8.60	6.88	0.67	7.0	10.0	2.3	7.7
J-29	1	23.9	1.86	7.99	0.79	7.6	16.3	1.3	15.0
	3	22.9	2.52	7.46		7.4			
	5	22.8	3.61	7.40		7.3			
	7	23.1	3.81	7.30	0.96	7.2	23.3	3.8	19.5
J-36	1	23.3		7.63	0.52	7.4	12.3	2.0	10.3
	3	23.1		7.46		7.3			
	5	23.1		7.44		7.3			
	7	23.1		7.36		7.2			
	9	23.1		7.42		7.1			
	11	23.3		7.40	0.57	7.0	18.0	2.3	15.7
J-47	1	24.7		5.13	0.50	6.9	6.3	0.8	5.5
	3	24.3		5.15		7.0			
	5	24.1		4.87		7.0			
	7	24.1		4.85		7.0			
	9	24.0		4.83		7.0			
	10	24.1		4.93	0.49	7.2	33.5	5.0	28.5
J-57	1	24.4		6.98	0.76	7.3	20.0	8.7	11.3
	3	24.1		6.42		7.2			
	5	24.1		6.42		7.1			
	7	24.1		6.38		7.1			
	8.5	24.4		6.36	0.73	6.9	44.0	12.5	31.5
J-68	1	25.5		5.37	0.76	7.0	21.5	6.5	15.0
	3	25.5		5.61		7.1			
	5	25.5		5.54		7.0			
	6	25.9		5.57	0.75	6.8	27.5	8.0	19.5
J-76	1	24.6		7.00	0.84	7.2	2.5	0.5	2.0
	3	24.1		5.35		7.1			
	5	24.3		4.39		7.1			
	7	24.1		3.52	0.86	7.1	18.5	3.0	15.5

DATA SHEET

RIVER James CRUISE DATE 13-14 July 1965

Station	Depth (M)	Temp (C)	Salinity (‰)	DO (mgl^{-1})	ALK ($meql^{-1}$)	pH	SS (mgl^{-1})	LOI (mgl^{-1})	FR (mgl^{-1})
J-4	1	26.0	21.29	7.07	1.59	7.7	16.5	8.8	7.7
	3	25.8	21.35	6.73		7.7			
	5	25.6	21.69	6.28		7.6			
	7	25.5	22.79	5.96	1.68	7.5	11.6	9.8	1.8
J-10	1	26.9	14.83	7.15	1.20	7.6	7.5	6.5	1.0
	3	26.7	16.08	6.53		7.6			
	5	26.4	18.70	5.98		7.6			
	7	26.3	18.79	5.90	1.46	7.5	25.0	20.0	5.0
J-17	1	27.0	12.19	6.18	1.04	7.3	9.8	9.2	0.6
	3	26.9	12.47	6.00		7.3			
	5	26.9	13.11	5.88		7.3			
	7	26.8	14.45	5.74	1.22	7.2	31.0	29.0	2.0
J-22	1	27.4	7.22	6.67	0.75	7.2	11.0	9.8	1.2
	3	27.4	7.41	6.57		7.2			
	5	27.3	7.40	6.53		7.2			
	7	27.3	7.44	6.77		7.2			
	9	27.3	7.68	6.45		7.2			
	11	27.3	7.83	6.36	0.78	7.2	28.3	24.0	4.3
J-29	1	27.5	3.42	7.39	0.56	7.3	19.0	17.8	1.2
	3	27.4	3.45	7.27		7.3			
	5	27.4	3.46	7.23		7.3			
	7	27.4	3.49	7.13	0.36	7.3	22.0	18.5	3.5
J-36	1	26.5	1.11	6.33	0.43	6.9	8.5	7.0	1.5
	3	26.3	1.32	6.69		6.9			
	5	26.2	1.31	6.80		6.9			
	7	26.1	1.37	6.57		6.8			
	9	26.1	1.48	6.63	0.47	6.8	42.0	36.3	5.7
J-47	1	27.5	0.13	3.28	0.34	6.4	21.8	19.5	2.3
	3	27.4	0.13	3.36		6.4			
	5	27.3	0.13	3.38		6.4			
	7	27.3	0.13	3.30		6.4			
	9	27.2	0.13	3.36		6.4			
	10	27.1	0.13	3.46	0.34	6.4	27.7	24.0	3.7
J-57	1	27.4	0.14	3.80	0.86	7.0	25.5	18.5	7.0
	3	27.4	0.14	3.64		7.0			
	5	27.3	0.18	3.60		6.9			
	7	27.2	0.18	3.72		7.0			
	8	27.1	0.18	3.82	0.86	6.9	35.0	29.5	5.5
J-68	1	28.2		3.07	0.92	6.8	20.0	18.5	1.5
	3	28.0		3.22		6.7			
	5	27.8		3.36		6.7			
	7	27.7		3.78	0.92	6.7	55.5	44.5	11.0
J-76	1	27.1		1.86	0.87	7.0	21.5	20.0	1.5
	3	26.9		1.84		7.0			
	5	26.9		2.00		6.9			
	7	26.8		2.08	0.83	7.0	26.3	22.7	3.6

DATA SHEET

RIVER James CRUISE DATE 13-14 July 1965

Station	Depth (M)	TOT. P (μg.at 1^{-1})	SRP (μg.at 1-1)	PRP (μg.at 1^{-1})	SUP (μg.at 1^{-1})	PUP (μg.at 1^{-1})	NO_2.N (μg.at 1^{-1})	NO_3.N (μg.at 1^{-1})	OPN (μg.at 1^{-1})	Chl.a (μg1-1)
J-4	1	1.83	0.40	0.10	0.30	1.03	0.03	5.0		11.2
	7	1.93	0.56	0.14	0.44	0.79	0.04	4.4	3.2	4.2
J-10	1	1.93	0.30	0.05	0.40	1.18	0.26	4.5	1.1	9.6
	7	2.62	0.70	0.15	0.58	1.19	0.21	1.2	1.4	7.6
J-17	1	1.73	0.50	0.05	0.30	0.83	0.34	18.8		4.2
	7		0.70		0.20		0.33	21.8	4.3	4.4
J-22	1	1.24	0.16	t	0.19	0.93	0.23	24.6		4.7
	11	2.23	0.30	0.10	0.05	1.78	0.23	26.2	3.6	4.2
J-29	1	1.49	0.06	t	0.24	1.19	0.21	63.6	5.6	4.4
	11	1.34	0.06	t	0.14	1.14	0.20	42.8	2.1	4.9
J-36	1	1.05	0.16	t	0.24	0.65	0.33	63.6	2.4	2.8
	9	2.03	0.16	0.14	0.19	1.54	0.30	68.0	2.1	5.5
J-47	1	2.28	0.70	0.25	0.15	1.18	4.94	93.6	2.4	2.1
	10	2.42	0.65	0.54	0.25	0.98	5.00	96.8	3.6	3.2
J-57	1	4.83	0.35	t	0.50	4.03	21.60	64.8	36.9	49.5
	8	5.40	0.40	t	0.45	4.55	20.64	70.0		55.3
J-68	1	6.54	1.88	0.69	0.44	3.53	3.36	5.6	17.1	37.9
	7	6.72	1.19	0.94	0.35	4.24	5.16	14.0	24.0	41.8
J-76	1	5.88	2.47	0.97	0.34	2.10	0.90	14.0	8.4	5.2
	7	5.60	2.17	1.13	0.60	1.70	0.97	11.6	3.2	4.2

DATA SHEET

RIVER James

CRUISE DATE 11-12 August 1965

Station	Depth (M)	Temp (C)	Salinity (‰)	DO (mgl-1)	ALK (meql-1)	pH	SS (mgl-1)	LOI (mgl-1)	FR (mgl-1)
J-4	1	25.2	23.56	6.26	1.76	7.8	8.4	1.2	7.2
	3	25.2	23.73	6.22		7.9			
	5	24.9	24.40	5.58		7.9			
	7	24.7	24.61	6.04	1.81	7.9	20.2	4.2	16.0
J-10	1	27.0	17.23	6.79	1.31	7.8	9.0	2.7	6.3
	3	26.8	18.67	6.57		7.8			
	5	26.1	21.47	5.74		7.9			
	7	26.0	21.54	5.72	1.60	7.9	35.6	6.3	29.3
J-17	1	27.3	13.95	6.33	1.03	7.7	9.3	2.8	6.5
	3	27.1	15.37	5.82		7.7			
	5	27.2	16.71	5.70		7.7			
	7	26.9	16.94	5.52	1.26	7.7	30.6	3.2	27.4
J-22	1	27.7	8.53	6.63	0.80	7.3	6.8	2.5	4.3
	3	27.7	8.59	6.55		7.5			
	5	27.7	9.49	5.12		7.5			
	7	27.6	9.51	6.41		7.5			
	9	27.7	9.56	6.45		7.5			
	11	27.7	9.70	6.29		7.5			
	12	27.5	9.83	6.31	0.79	7.5	59.5	7.5	52.0
J-29	1	28.0	4.41	7.05	0.46	7.3	13.3	0.6	12.7
	3	27.9	4.35	6.87		7.3			
	5	27.8	4.53	6.89		7.3			
	7	27.6	4.88	6.83	0.50	7.4	62.0	4.0	58.0
J-36	1	27.8	1.73	6.77	0.27	7.1	14.3	2.3	12.0
	3	27.6	1.97	6.73		7.2			
	5	27.7	2.04	6.75		7.3			
	7	27.6	2.05	6.69		7.3			
	9	27.4	2.13	6.69		7.3			
	11	27.4	2.22	6.67	0.38	7.3	48.7	5.1	43.6
J-47	1	28.2	0.20	3.17	0.19	6.8	18.7	1.0	17.7
	3	28.0	0.20	3.09		6.6			
	5	28.0	0.21	3.15		6.7			
	7	28.0	0.21	3.45		6.6			
	9	28.0	0.21	3.33		6.5			
	11	27.9	0.21	3.31	0.18	6.5	28.5	7.0	21.5
J-57	1	28.5	0.15	4.38	0.82	7.5	20.4	10.0	10.4
	3	28.4	0.15	3.92		7.5			
	5	28.3	0.15	3.84		7.4			
	7	28.3	0.15	3.86		7.4			
	9	28.4	0.15	3.81	0.72	7.4	30.0	8.5	21.5
J-68	1	29.4		6.39	0.96	7.5	22.0	6.8	15.2
	3	29.2		5.62		7.6			
	5	29.0		5.48		7.5			
	7	29.1		5.38	0.98	7.6	55.0	13.0	42.0
J-76	1	29.2		2.75	0.92	6.9	15.6	4.4	11.2
	3	28.9		1.04		7.0			
	5	28.9		0.74		7.1			
	7	28.9		0.66		7.2			
	[illegible]	[illegible]		0.66	0.90	7.3	18.8	4.0	14.8

DATA SHEET

RIVER James CRUISE DATE 11-12 August 1965

Station	Depth (M)	TOT. P (μg.at l^{-1})	SRP (μg.at l^{-1})	PRP (μg.at l^{-1})	SUP (μg.at l^{-1})	PUP (μg.at l^{-1})	NO_2.N (μg.at l^{-1})	NO_3.N (μg.at l^{-1})	OPN (μg.at l^{-1})	Chl.a (μgl^{-1})
J-4	1	2.13	1.10	0.00	0.40	0.63	0.06	<1.0	2.5	4.9
	7	2.13	1.06	0.00	0.49	0.58	0.04	<1.0		5.2
J-10	1	2.00	0.75	t	0.40	1.12	0.01	<1.0	1.4	5.9
	7	2.88	1.20	t	0.49	2.17	0.10	<1.0		8.3
J-17	1	1.66	0.62	t	0.44	0.64	0.25	2.0	3.5	3.7
	7	2.44	0.94	0.26	0.26	0.98	0.16	1.5	6.9	6.6
J-22	1	1.24	0.35	t	0.23	0.66	1.00	12.2	4.5	3.3
	12	2.88	0.40	0.35	0.25	1.88	0.84	9.1	8.4	4.9
J-29	1	1.33	0.17	0.05	0.27	0.84	0.66	27.3	4.2	5.4
	7	2.65	0.22	0.31	0.22	1.90	0.78	23.2		4.9
J-36	1	1.25	0.17	t	0.36	0.76	0.32	46.4	9.0	6.1
	11	2.17	0.13	0.09	0.32	1.63	0.32	40.0	7.0	5.2
J-47	1	1.85	0.62	0.13	0.23	0.87	3.80	78.0	1.4	2.7
	11	2.00	0.45	0.25	0.35	0.95	3.60	120.0		2.8
J-57	1	4.90	0.35	t	0.71	4.02	16.00	40.0	53.2	57.3
	9	5.48	0.40	t	0.62	4.56	15.50	37.0	61.6	40.1
J-68	1	4.50	0.25	0.05	0.60	3.60	5.60	15.8	28.4	78.9
	7	6.70	0.25	0.23	0.50	5.72	6.04	1.0	57.6	86.2
J-76	1	10.60	4.50	1.60	0.90	3.60	0.11	14.9	20.2	47.3
	8	10.96	4.30	2.20	0.90	3.56	0.11	0.4	30.0	43.7

DATA SHEET

RIVER James

CRUISE DATE 14-15 September 1965

Station	Depth (M)	Temp (C)	Salinity (‰)	DO (mgl-1)	ALK (meql-1)	pH	SS (mgl-1)	LOI (mgl-1)	FR (mgl-1)
J-4	1	25.2	23.82	5.99	1.75	7.9	28.5		
	3	25.1	23.87	5.97		7.8			
	5	25.1	24.01	5.97		7.6			
	7	25.7	24.15	5.85	1.81	6.6	33.9		
J-10	1	25.0	19.92	6.35	1.36	7.8	27.8		
	3	25.0	20.31	6.21		7.8			
	5	25.5	20.35	5.93		7.8			
	7	25.1	20.47	6.13	1.45	7.8	23.4		
J-17	1	25.8	16.63	6.23	1.09	7.7	19.2		
	3	25.7	17.12	5.97		7.7			
	5	25.3	17.12	5.97		7.7			
	7	25.2	17.42	5.95	1.15	7.8	27.4		
J-22	1	25.7	12.58	6.81	0.77	7.7	18.9		
	3	25.7	12.93	6.69		7.7			
	5	25.7	13.02	6.57		7.7			
	7	25.7	13.20	6.63		7.7			
	9	25.7	13.45	6.47		7.7			
	11	25.9	13.49	6.45	0.86	7.7	19.3		
J-29	1	26.0	8.47	6.85	0.50	7.5	12.2		
	3	25.9	8.60	6.71		7.5			
	5	26.0	8.74	6.71		7.5			
	7	26.0	8.78	6.81	0.53	7.7	15.2		
J-36	1	25.7	5.08	6.59	0.40	6.9	15.4		
	3	25.7		6.77		7.0			
	5	25.7		6.65		7.0			
	7	25.7		6.49		7.0			
	9	25.6	6.00	6.87	0.36	6.9	21.2		
J-47	1	26.1	1.01	4.48	0.19	6.6	21.8		
	3	26.3		4.46		6.7			
	5	26.6		4.44		6.7			
	7	25.9		4.48		6.6			
	9	25.8		4.48		6.7			
	10	25.9	1.06	4.58	0.19	6.9	18.2		
J-57	1	26.0	0.22	5.41	0.70	7.6	8.2		
	3	26.0		5.27		7.6			
	5	26.0		5.35		7.5			
	7	26.0				7.5			
	8	26.0	0.23	4.99	0.69	7.5	59.6		
J-68	1	26.6		6.49	1.01	7.9	27.6		
	3	26.7		6.29		7.9			
	5	26.7		6.27		7.9			
	7	26.7		6.15	1.03	7.9	38.0		
J-76	1	26.5		0.34	0.95	6.9	12.4		
	3	26.4		0.18		6.9			
	5	26.5		1.19		6.9			
	7	26.8		0.80	0.96	7.0	15.4		

DATA SHEET

RIVER James

CRUISE DATE 14-15 September 1965

Station	Depth (M)	TOT. P (μg.at l^{-1})	SRP (μg.at l^{-1})	PRP (μg.at l^{-1})	SUP (μg.at l^{-1})	PUP (μg.at l^{-1})	NO_2.N (μg.at l^{-1})	NO_3.N (μg.at l^{-1})	OPN (μg.at l^{-1})	Chl.a (μgl^{-1})
J-4	1	2.60	1.85	0.01	0.39	0.35	0.50	1.4	2.3	2.7
	7	2.54	1.85	t	0.30	0.39	0.49	1.5	6.0	2.6
J-10	1	2.29	1.52	0.09	0.43	0.25	0.61	2.2	2.7	3.2
	7	2.85	1.65	0.05	0.44	0.71	0.61	2.5	4.6	3.5
J-17	1	1.80	1.30	t	0.30	0.24	0.79	2.8	0.8	2.2
	7	2.04	1.45	t	0.30	0.29	1.70	3.0	1.4	1.7
J-22	1	1.41	0.65	t	0.32	0.44	1.78	3.8	3.5	4.5
	11	1.57	0.80	t	0.26	0.54	1.50	4.4	3.0	3.2
J-29	1	1.15	0.30	0.07	0.35	0.43	2.83	13.0	3.5	5.8
	7	1.06	0.40	t	0.15	0.54	3.00	12.6	2.3	1.8
J-36	1	1.15	0.55	t	0.00	0.79	2.22	30.1	2.8	5.2
	9	1.26	0.55	t	0.01	0.76	2.90	26.6		2.3
J-47	1	1.35	0.49	0.06	0.26	0.54	1.15	74.4		3.0
	10	1.57	0.49	0.26	0.06	0.76	1.13	74.4		2.6
J-57	1	6.27	0.20	t	0.60	7.60	13.00	76.0	68.8	91.8
	8	8.20	0.30				9.00	83.2		63.4
J-68	1	6.90	0.36	t	0.60	6.30	13.50	40.2	29.2	102.6
	7	7.70	0.40	t	0.64	7.06	13.20	39.8		120.1
J-76	1	21.20	12.20	2.80	2.10	4.60	0.01	2.0	33.3	85.5
	7	21.60	12.60	2.60	1.90	4.50	0.09	1.8		63.4

DATA SHEET

RIVER James

CRUISE DATE 14-15 October 1965

Station	Depth (M)	Temp (C)	Salinity (‰)	DO (mgl^{-1})	ALK ($meql^{-1}$)	pH	SS (mgl^{-1})	LOI (mgl^{-1})	FR (mgl^{-1})
J-4	1	18.8	23.70	7.11	1.66		10.4	4.1	6.3
	3	18.8	23.91	7.15					
	5	18.8	23.98	7.07					
	7	18.7	24.09	7.03	1.69		12.0	5.0	7.0
J-10	1	18.6	19.46	7.74	1.29		12.2	6.0	6.2
	3	18.6	19.90	7.54					
	5	18.6	20.47	7.37					
	7	18.8	20.92	7.17	1.43		15.2	5.8	9.4
J-17	1	18.4	15.69	8.20	0.93		17.0	5.0	12.0
	3	18.5	16.58	7.86					
	5	18.5	16.78	7.66					
	7	18.7	16.06	7.68	1.07		21.0	6.0	15.0
J-22	1	18.6	11.43	8.84	0.62		14.8	7.4	7.4
	3	18.5	12.03	8.72					
	5	18.5	12.46	8.50					
	7	18.5	12.57	8.66					
	9	18.5	12.71	8.52					
	11	18.8	12.83	8.54	0.72		13.6	3.8	9.8
J-29	1	18.6	7.77	8.62	0.41		16.6	4.6	12.0
	3	18.5	8.01	8.56					
	5	18.7	8.40	8.56					
	7	19.0	8.79	8.52	0.47		24.8	5.6	19.2
J-36	1	18.1	4.50	8.02	0.23	7.2	14.4	t	
	3	18.2	4.92	8.04		7.2			
	5	18.2	5.20	8.04		7.2			
	7	18.2	5.44	8.02		7.2			
	9	18.1	5.91	7.86	0.30	6.9	15.0	t	
J-47	1	19.4	0.90	5.53	0.34	7.0	19.4	4.3	15.1
	3	19.2	0.90	5.61		7.1			
	5	19.1	0.92	5.79		6.9			
	7	19.1	0.94	5.47		6.9			
	9	19.1	0.96	5.49		7.0			
	11	18.9	0.96	5.55	0.33	7.1	25.0	2.8	22.2
J-57	1	18.9	0.23	5.71	1.02	7.3	31.6	13.6	18.0
	3	18.6	0.24	5.75		7.3			
	5	18.7	0.24	5.45		7.2			
	7	18.7	0.24	5.83		7.2			
	9	19.1	0.24	5.77	1.06	7.2	80.0	22.5	57.5
J-68	1	19.0		5.53	1.07	7.5	21.2	3.6	17.6
	3	19.0		5.59		7.5			
	5	19.1		5.45		7.6			
	7	19.7		5.55	1.08	7.6	32.4	7.2	25.2
J-76	1	18.2		4.29	0.69	7.2	13.7	5.0	8.7
	3	17.8		4.33		7.1			
	5	17.9		4.25		7.2			
	7	19.8		4.33	0.71	7.3	16.3	3.2	13.1

DATA SHEET

RIVER James

CRUISE DATE 14-15 October 1965

Station	Depth (M)	TOT. P (µg.at l^{-1})	SRP (µg.at l^{-1})	PRP (µg.at l^{-1})	SUP (µg.at l^{-1})	PUP (µg.at l^{-1})	NO_2.N (µg.at l^{-1})	NO_3.N (µg.at l^{-1})	OPN (µg.at l^{-1})	Chl.a (µgl^{-1})
J-4	1	2.66	1.90	0.20	0.42	0.14	0.80	5.1	0.8	2.8
	7	2.58	1.90	0.20	0.33	0.15	0.80	5.7	2.0	2.5
J-10	1	2.23	1.45	0.15	0.40	0.23	0.54	4.3	3.7	4.4
	7	2.44	1.72	0.10	0.26	0.36	0.70	6.2	0.8	2.7
J-17	1	2.16	0.85	0.25	0.53	0.53	0.11	2.3	4.6	12.2
	7	1.92	1.06	0.06	0.38	0.42	0.33	4.0		2.8
J-22	1	3.07	0.87	0.24	0.95	1.01	0.09	2.4	13.3	45.9
	11	1.48	0.32	0.08	0.55	0.53	0.10	3.3	3.6	6.8
J-29	1	1.16	0.15	t	0.34	0.72	0.48	14.4	15.0	8.9
	7	1.64	0.06	t	0.43	1.21	0.28	4.3	5.8	7.6
J-36	1	1.09	0.10	t	0.40	0.59	0.80	44.4	10.0	2.3
	9	1.18	0.15	0.03	0.17	0.83	0.78	35.2	1.4	2.0
J-47	1	2.16	0.22	0.14	0.43	1.37	4.67	96.8	3.2	8.6
	11	2.16	0.20	0.20	0.40	1.36	4.40	95.3	3.4	10.1
J-57	1	5.63	0.00	0.36	0.69	4.58	44.20	125.8	51.1	89.0
	9	7.68	0.10	0.50	0.60	6.48	38.50	126.0	5.3	82.4
J-68	1	5.81	0.67	0.68	0.54	3.92	6.50	36.8	22.0	81.0
	7	4.60	0.63	0.79	0.50	2.90	6.99	40.0	22.0	35.9
J-76	1	5.83	2.28	1.32	0.59	1.64	0.62	50.7	4.2	2.9
	7	6.12	2.19	1.86	0.61	1.46	0.64	51.0	1.6	3.3

DATA SHEET

RIVER James CRUISE DATE 15 & 29 November 1965

Station	Depth (M)	Temp (C)	Salinity (‰)	DO (mgl-1)	ALK (meql-1)	pH	SS (mgl-1)	LOI (mgl-1)	FR (mgl-1)
J-4	1	11.2	23.50	8.72	1.62	8.0	11.1	4.0	7.1
	3	11.3	24.03	8.54		8.0			
	5	11.4	24.53	8.32		7.5			
	7	11.2	24.36	7.16	1.65	6.7	10.2	2.6	7.6
J-10	1	10.6	20.07	9.23	1.36	8.2	11.2	4.0	7.2
	3	10.8	20.15	9.15		8.2			
	5	11.0	20.40	8.96		8.2			
	7	8.1	22.32	8.22	1.53	8.2	11.6	3.3	8.3
J-17	1	11.0	17.72	9.29	1.16	8.2	13.4	5.6	7.8
	3	11.0	19.82	8.60		8.2			
	5	11.0	20.74	8.74		8.2			
	7	10.9	20.77	8.64	1.43	8.3	12.5	5.3	7.2
J-22	1	10.4	12.29	9.52	0.79	8.0	9.2	2.0	7.2
	3	10.3	13.27	9.40		8.1			
	5	10.5	12.89			8.1			
	7	10.5	13.58	9.33		8.2			
	9	9.9	13.84	9.23	0.86	8.3	8.3	1.8	6.5
J-29	1	10.1	9.29	9.65	0.64	7.5	8.4	1.2	7.2
	3	10.1	9.47	9.53		7.6			
	5	10.1	9.51	9.53		7.6			
	7	10.0	10.20	9.19	0.58	7.6	17.0	6.2	10.8
J-36	1	13.6	5.70	8.91	0.29	7.3	13.4	t	13.4
	3	13.3	6.02	8.83		7.2			
	5	13.4	6.20	8.77		7.3			
	7	13.3	6.33	8.81		7.3			
	9	13.1	6.54	8.75		7.2			
	11	13.1	6.91	8.71	0.35	7.0	13.4	t	13.4
J-47	1	13.7	1.54	6.81	0.37	7.0	14.6	t	14.6
	3	13.7	1.62	6.69		7.0			
	5	13.7	1.66	6.77		7.0			
	7	13.6	1.68	6.87		7.0			
	9	13.6	1.70	6.93		7.0			
	11	13.7	1.75	6.93	0.26	7.3	27.4	1.7	25.7
J-57	1	13.6	0.28	4.75	0.99	7.4	20.8	2.8	18.0
	3	13.6	0.29	4.73		7.3			
	5	13.6	0.29	4.85		7.4			
	7	13.6	0.33	4.83	0.96	7.6	35.6	1.2	34.4
J-68	1	14.1	0.19	4.99	1.00	7.3	17.6	t	17.6
	3	14.1	0.19	5.35		7.3			
	5	14.0	0.20	5.40	1.01	7.5	23.5	2.0	21.5
J-76	1	14.1		0.59	0.90	7.1	5.2	t	5.2
	3	14.1		0.55		7.0			
	5	14.0		0.48	0.92	7.2	5.7	t	5.7

DATA SHEET

RIVER James CRUISE DATE 15 & 29 November 1965

Station	Depth (M)	TOT. P (µg.at l^{-1})	SRP (µg.at l^{-1})	PRP (µg.at l^{-1})	SUP (µg.at l^{-1})	PUP (µg.at l^{-1})	NO_2.N (µg.at l^{-1})	NO_3.N (µg.at l^{-1})	OPN (µg.at l^{-1})	Chl.a (µgl^{-1})
J-4	1	2.15	1.10	0.12	0.50	0.43	0.15	1.0		7.3
	7	1.90	0.95	0.12	0.47	0.36	0.20	0.8		6.0
J-10	1	2.12	0.96	0.12	0.42	0.62	0.05	0.9	8.5	11.3
	7	2.40	1.10	0.20	0.60	0.50	0.08	0.9	7.6	15.3
J-17	1	2.15	0.80	0.18	0.42	0.75	0.10	1.0		19.8
	7	2.22	1.00	0.18	0.68	0.36	0.05	1.0		17.3
J-22	1	1.40	0.40	0.08	0.38	0.54	0.12	8.2		7.4
	9	1.11	0.50	0.05	0.30	0.26	0.11	5.1	1.1	3.1
J-29	1	0.90	0.24	0.04	0.27	0.35	0.21	19.7	0.6	3.0
	7	1.02	0.30	0.03	0.24	0.45	0.20	19.8	1.1	1.3
J-36	1	1.10	0.05	0.51	0.37	0.17	0.35	54.0	3.5	2.0
	11	0.99	0.12	0.08	0.40	0.39	0.26	42.0	1.1	1.5
J-47	1	1.67	0.27	0.20	0.35	0.85	2.44	154.0	8.9	4.8
	11	2.10	0.30	0.24	0.27	1.29	2.51	138.0	4.2	4.4
J-57	1	3.25	0.10	0.18	0.60	2.37	33.00	262.0		36.1
	7	4.25	0.05	0.19	0.55	3.46	29.60	262.0	24.3	37.6
J-68	1	5.22	0.75	0.42	0.51	3.54	19.40	83.5		39.4
	5	5.05	0.57	0.45	0.51	3.52	19.60	98.0	23.7	25.4
J-76	1	17.80	11.72	1.18	2.28	2.62	6.50	10.0		5.0
	5	18.20	11.25	1.30	2.45	3.20	7.00	9.6	15.7	4.1

DATA SHEET

RIVER James | CRUISE DATE 13 & 14 December 1965

Station	Depth (M)	Temp (C)	Salinity (‰)	DO (mgl-1)	ALK (meql-1)	pH	SS (mgl-1)	LOI (mgl-1)	FR (mgl-1)
J-4	1	9.0	24.19	5.39	1.80		16.0	7.0	9.0
	3	8.8	24.22	8.41					
	5	8.7	24.27	4.98					
	7	8.9	24.24	6.40	1.82		21.0	4.8	16.2
J-10	1	8.9	21.09	7.27	1.51		22.1	7.3	14.8
	3	8.8	21.46	8.95					
	5	8.8	21.64	7.89					
	6	9.0	21.88	7.58	1.61		31.6	8.6	23.0
J-17	1	8.7	18.50	10.41	1.28		22.0	9.2	12.8
	3	8.7	19.08	10.25					
	5	8.7	19.06	10.21					
	7	8.9	19.17	10.08	1.37		24.0	8.2	15.8
J-22	1	8.3	14.62	10.35	1.00		16.3	7.3	9.0
	3	8.4	15.11	10.50					
	5	8.4	15.39	10.06					
	7	8.3	15.51	9.30					
	9	8.4	15.84	10.31					
	11	8.5	16.20	10.37	1.10		13.7	3.7	10.0
J-29	1	8.7	10.48	9.90	0.70		15.7	3.2	12.5
	3	8.5	10.84	9.75					
	5	8.5	11.07	9.44					
	6	8.7	11.24	9.46	0.75		22.6	5.3	17.3
J-36	1	8.6	6.51	10.08	0.50	7.6	10.4	2.0	8.4
	3	8.5	7.01	10.16		7.5			
	5	8.5	7.11	10.06		7.6			
	7	8.5	7.17	10.23		7.5			
	9	8.4	7.22	9.92		7.2			
	11	8.5	7.71	9.94	0.56	7.1	15.4	2.9	12.5
J-47	1	8.9	2.49	9.46	0.56	7.6	21.2	2.2	19.0
	3	8.9	2.51	9.61		7.6			
	5	9.0	2.49	9.65		7.6			
	7	9.2	2.58	9.69		7.6			
	9	10.0	2.62	9.44	0.58	7.7	52.0	4.4	47.6
J-57	1	8.5	0.47	8.06	0.86		30.5	0.5	30.0
	3	8.7	0.58	8.10					
	5	8.6	0.45	8.26					
	7	8.8	0.49	8.02					
	9	8.8	0.44	8.47	0.96		56.0	8.0	48.0
J-68	1	9.8	0.20	8.12	1.00		20.8	2.4	18.4
	3	9.8	0.20	7.79					
	5		0.25	8.95	0.98		26.0	4.8	21.2
J-76	1	15.0	0.20	3.72	0.82		7.2	2.0	5.2
	3	16.2	0.20	3.99					
	5	16.4	0.20	5.66					
	7	16.6	0.19	3.66	0.86		8.0	3.0	5.0

DATA SHEET

RIVER James CRUISE DATE 13 & 14 December 1965

Station	Depth (M)	TOT. P (μg.at l^{-1})	SRP (μg.at l^{-1})	PRP (μg.at l^{-1})	SUP (μg.at l^{-1})	PUP (μg.at l^{-1})	NO_2.N (μg.at l^{-1})	NO_3.N (μg.at l^{-1})	OPN (μg.at l^{-1})	Chl.a (μgl^{-1})
J-4	1	1.90	0.52	0.20	0.43	0.75	0.03	0.7		14.0
	7	1.93	0.55	0.20	0.47	0.71	0.04	0.8	4.9	13.8
J-10	1	2.20	0.47	0.24	0.45	1.04	0.03	0.8		16.0
	6		0.52	0.21			0.04	0.9	2.1	13.1
J-17	1	1.80	0.22	0.14	0.35	1.09	0.04	0.9		18.4
	7	1.80	0.30	0.20	0.27	0.03	0.09	0.8	4.9	16.2
J-22	1	1.38	0.22	0.08	0.18	0.90	0.15	10.1		14.0
	11	1.45	0.16	0.11	0.26	0.92	0.09	4.0	4.3	15.3
J-29	1	1.10	0.30	0.09	0.25	0.46	0.40	32.5		2.8
	6	1.26	0.36	0.11	0.21	0.58	0.32	26.6	2.9	2.8
J-36	1	1.21	0.11	0.09	0.35	0.66	1.26	58.2		4.6
	11	1.02	0.12	0.10	0.32	0.48	0.85	47.6	4.5	1.8
J-47	1	1.68	0.24	0.11	0.18	1.15	0.48	164.0	3.5	2.1
	9	3.42	0.20	0.29	0.26	2.67	0.41	152.0	8.1	2.7
J-57	1	4.20	0.13	0.13	0.53	3.41	2.05	231.0	17.1	14.8
	9	5.20	0.16	0.19	0.46	4.39	2.05	228.4	22.1	16.2
J-68	1	5.22	0.60	0.23	0.71	3.68	0.90	102.5	6.2	31.7
	5	5.40	0.51	0.16	0.61	4.12	0.82	100.0	15.8	27.6
J-76	1	15.20	7.00	0.54	3.20	4.46	1.70	42.2	14.0	1.7
	7	17.00	7.10	0.74	3.30	5.86	1.80	52.2	4.4	1.6

DATA SHEET

RIVER James CRUISE DATE 10 & 13 January 1966

Station	Depth (M)	Temp (C)	Salinity (‰)	DO (mgl-1)	ALK (meql-1)	pH	SS (mgl-1)	LOI (mgl-1)	FR (mgl-1)
J-4	1	5.9	23.79	9.82	1.64		15.0	2.8	12.2
	3	5.8	23.92	9.84					
	5	5.8	24.03	9.70					
	7	5.8	24.05	9.76					
	9	5.7	24.03	9.84	1.70		24.0	3.8	20.2
J-10	1	5.4	20.04	10.38	1.01		19.6	3.0	16.6
	3	5.4	20.65	10.10					
	5	5.2	20.95	10.02					
	7	5.5	21.66	9.94	1.48		21.1	4.5	16.6
J-17	1	5.1	16.87	10.64	1.18		15.0	2.2	12.8
	3	5.0	16.98	10.54					
	5	5.0	17.31	10.30					
	6	4.9	17.28	10.16	1.19		22.3	6.0	16.3
J-22	1	5.2	13.07	10.72	0.81		13.5	2.5	11.0
	3	5.3	13.50	10.62					
	5	5.4	13.67	10.60					
	7	5.4	13.78	10.58					
	9	5.3	13.90	10.60					
	11	5.3	14.15	10.50	1.00		18.5	3.0	15.5
J-29	1	5.0	8.66	11.08	0.65		20.5	1.5	19.0
	3	5.0	9.07	10.86					
	5	4.9	9.45	10.76					
	6	4.9	9.77	10.70	0.71		30.6	6.3	24.3
J-36	1		4.86	11.18	0.48		28.5	11.0	17.5
	3		5.04	10.96					
	5		5.21	10.94					
	7		5.34	10.94	0.53		46.5	13.5	33.0
J-47	1	7.1	1.35	9.24	0.71		27.2	6.0	21.2
	3	7.1	1.45	9.40					
	5	7.1	1.48	9.32					
	7	8.8	1.49	9.40	0.69		30.5	6.0	24.5
J-57	1	6.6	0.30	9.10	0.98		44.0	8.0	36.0
	3	6.6	0.30	9.02					
	5	6.6	0.31	8.96					
	7	7.0	0.31	8.94	0.88		56.5	19.0	37.5
J-68	1	7.7	0.20	7.06	0.81		26.0	10.0	16.0
	3	7.7	0.19	7.10					
	5	7.8	0.19	6.70					
	7	8.0	0.19	7.14	0.61		29.5	5.5	24.0
J-76	1	7.7	0.18	6.10	0.70		7.0	2.5	4.5
	3	7.7	0.19	6.12					
	5	7.8	0.18	5.98					
	7	8.2	0.18	6.00	0.90		10.5	3.0	7.5

DATA SHEET

RIVER James CRUISE DATE 10 & 13 January 1966

Station	Depth (M)	TOT. P (μg.at l^{-1})	SRP (μg.at l^{-1})	PRP (μg.at l^{-1})	SUP (μg.at l^{-1})	PUP (μg.at l^{-1})	NO_2.N (μg.at l^{-1})	NO_3.N (μg.at l^{-1})	OPN (μg.at l^{-1})	Chl.a (μgl^{-1})
J-4	1	2.01	0.95	0.18	0.41	0.42	0.10	1.4		7.6
	9	2.08	0.92	0.20	0.44	0.52	0.06	1.4	11.0	6.1
J-10	1	1.80	0.60	0.16	0.32	0.72	0.10	2.2	4.8	12.4
	7	1.81	0.82	0.22	0.41	0.36	0.13	1.8		4.9
J-17	1	1.45	0.46	0.18	0.42	0.39	0.22	7.3	1.4	8.9
	6	1.50	0.48	0.21	0.30	0.51	0.18	7.1	9.6	6.0
J-22	1	1.26	0.50	0.15	0.17	0.44	0.60	21.6	3.5	5.4
	11	1.50	0.50	0.22	0.25	0.53	0.46	17.4	6.0	4.7
J-29	1	1.36	0.44	0.16	0.13	0.63	1.93	45.2	0.6	2.7
	6	1.70	0.44	0.28	0.19	0.79	1.48	40.0	11.3	2.7
J-36	1	1.54	0.15	0.20	0.42	0.77	4.32	82.0		3.8
	7	2.31	0.80	0.02	0.52	0.97	5.00	94.0		3.8
J-47	1	2.18	0.28	0.20	0.42	1.28	11.30	165.0	2.3	4.4
	7	2.47	0.35	0.31	0.53	1.68	9.20	167.0	8.5	4.0
J-57	1	5.20	0.06	0.29	0.74	4.11	10.50	151.0	17.1	14.2
	7	5.40	0.28	0.45	0.64	4.03	10.50	153.0		51.7
J-68	1	5.99	1.10	1.48	0.68	2.73	3.20	55.0	11.4	26.7
	7	6.68	1.56	1.15	0.75	3.22	3.10	52.0	8.5	22.8
J-76	1	11.88	4.10	1.12	2.14	4.52	2.10	45.0	2.0	2.7
	7	12.28	4.10	1.39	2.30	4.49	2.05	44.5	1.3	3.2

DATA SHEET

RIVER James CRUISE DATE 9 & 13 March 1966

Station	Depth (M)	Temp (C)	Salinity (‰)	DO (mgl^{-1})	ALK ($meql^{-1}$)	pH	SS (mgl^{-1})	LOI (mgl^{-1})	FR (mgl^{-1})
J-4	1	6.8	16.39	10.33	1.40	8.0	26.6	7.3	19.3
	3	6.8	16.78	10.58		7.9			
	5	6.8	17.70	10.56		7.3			
	7	6.8	17.33	10.45	1.42	6.7	33.0	10.6	22.4
J-10	1	7.4	9.41	9.81	1.08	7.8	23.2	12.0	11.2
	3	7.3	10.14	9.68		7.8			
	5	7.3	11.10	9.77		7.9			
	7	7.5	13.12	9.87	1.24	7.9	35.0	10.6	24.4
J-17	1	7.9	3.17	9.50	0.78	7.7	33.2	6.4	26.8
	3	7.7	3.57	9.46		7.7			
	5	7.7	4.21	9.48		7.7			
	7	8.2	6.60	9.48	0.95	7.9	38.4	8.2	29.2
J-22	1	8.5	0.28	9.48	0.59	7.5	53.0	9.0	44.0
	3	8.3	0.35	9.42		7.5			
	5	8.2	0.40	9.42		7.6			
	7	8.2	0.45	9.58		7.6			
	9	8.2	0.47	9.50		7.7			
	11	8.3	0.58	9.42	0.61	7.9	90.5	7.5	83.0
J-29	1	9.0	0.11	9.56	0.44	6.4	49.0	3.0	46.0
	3	8.5	0.11	9.56		4.0			
	5	8.5	0.11	9.56		7.6			
	7	8.5	0.11	9.56	0.53	7.7	74.0	21.0	53.0
J-36	1	7.6	0.08	9.62	0.53	7.3	58.0	8.0	50.0
	3	7.6	0.07	9.68		7.2			
	5	7.4	0.07	9.68		7.2			
	7	7.3	0.07	9.62		7.2			
	9	7.0	0.08	9.62		7.3			
	11	7.0	0.10	9.99	0.42	7.2	87.0	5.0	82.0
J-47	1	8.4	0.06	8.41	0.50	7.5	68.0	t	68.0
	3	8.4	0.06	8.55		7.5			
	5	8.4	0.06	8.37		7.6			
	7	8.2	0.06	8.43		7.6			
	9	8.2	0.06	8.39	0.48	7.6	90.0	13.0	77.0
J-57	1	8.3	0.06	8.59	0.52	7.6	40.0	5.0	35.0
	3	8.2	0.06	8.63		7.6			
	5	8.3	0.06	8.53		7.8			
	7	8.3	0.07	8.55	0.50	7.7	93.0	20.0	73.0
J-68	1	8.5	0.06	9.79	0.55	6.9	32.5	5.5	27.0
	3	8.8	0.07	9.83		6.7			
	5	8.3	0.07	9.79		6.3			
	6	8.3	0.07	9.91	0.52	6.0	44.0	4.0	40.0
J-76	1	7.7	0.07	10.70	0.59	7.6	12.5	2.5	10.0
	3	7.6	0.07	10.86		7.7			
	5	7.5	0.06	10.88		7.6			
	7	7.7	0.07	10.98	0.65	7.7	29.0	9.0	20.0

DATA SHEET

RIVER James

CRUISE DATE 9 & 13 March 1966

Station	Depth (M)	TOT. P (μg.at l^{-1})	SRP (μg.at l^{-1})	PRP (μg.at l^{-1})	SUP (μg.at l^{-1})	PUP (μg.at l^{-1})	NO_2.N (μg.at l^{-1})	NO_3.N (μg.at l^{-1})	OPN (μg.at l^{-1})	Chl.a (μgl^{-1})
J-4	1	1.90	0.16	0.12	0.31	1.31	1.43	19.2	2.3	22.5
	7	1.98	0.11	0.16	0.34	1.37	1.20	20.0	14.1	11.2
J-10	1	1.94	0.51	0.09	0.39	0.95	2.15	26.4	2.3	6.0
	7	1.98	0.30	0.15	0.34	1.19	1.88	23.2		11.2
J-17	1	2.78	0.64	0.12	0.32	1.70	1.89	35.6	2.3	4.0
	7	2.58	0.58	0.16	0.32	1.52	2.12	35.0	8.7	4.9
J-22	1	3.80	0.68	0.18	0.42	2.52	0.95	36.8	3.5	3.9
	11	5.80	0.60	0.24	0.36	4.60	0.98	68.0	17.4	5.4
J-29	1	3.84	0.68	0.14	0.50	2.52	0.60	25.0	2.3	4.8
	7	4.60	0.76	0.22	0.74	2.88	0.73	33.1	10.5	7.4
J-36	1	4.42	0.60	0.19	0.50	3.13	0.70	26.8	3.5	4.5
	11	6.60	0.47	0.29	0.64	5.20	1.88	24.0	36.8	5.5
J-47	1	4.44	0.55	0.20	0.57	3.12	0.51	21.2	4.5	4.1
	9	5.90	0.60	1.06	1.15	3.09	0.90	22.8	-	5.0
J-57	1	3.80	0.42	0.31	0.53	2.54	1.31	21.6	9.3	6.1
	7	6.40	0.47	0.62	0.88	4.43	1.31	22.2	22.5	6.9
J-68	1	3.80	0.55	0.41	0.45	2.39	0.44	18.2	2.3	2.9
	6	4.30	0.63	0.61	0.57	2.49	0.48	17.2	14.0	4.0
J-76	1	3.60	1.11	0.21	0.79	1.49	0.65	16.2	2.3	1.6
	7	4.60	1.00	0.30	0.74	2.56	0.64	16.2	16.5	1.8

DATA SHEET

RIVER James CRUISE DATE 7 & 11 April 1966

Station	Depth (M)	Temp (C)	Salinity (‰)	DO (mgl-1)	ALK (meql-1)	pH	SS (mgl-1)	LOI (mgl-1)	FR (mgl-1)
J-4	1	11.2	19.75	10.38	1.54	8.0	27.3	16.3	11.0
	3	11.1	19.86	10.13		8.0			
	5	11.1	20.06	10.08		7.9			
	7	11.2	20.34	10.04		7.8			
	9	11.0	20.69	10.04	1.49	7.8	31.6	12.3	19.3
J-10	1	11.5	14.86	9.77	1.26	8.0	23.6	7.2	16.4
	3	11.4	16.08	9.69		8.0			
	5	11.4	16.72	9.50		8.1			
	7	11.4	18.22	9.62	1.45	8.4	24.6	7.6	17.0
J-17	1	11.8	9.66	9.04	1.01	7.6	19.6	10.0	9.6
	3	11.7	11.18	8.95		7.6			
	5	11.6	12.85	9.10		7.6			
	7	11.6	13.80	9.08		7.7			
	9	11.6	14.38	8.91		7.6			
	11	11.7	16.25	8.70	1.27	7.7	26.3	9.3	17.0
J-22	1	11.9	5.37	9.18	0.78	7.5	22.8	5.2	17.6
	3	11.7	5.86	8.87		7.5			
	5	11.7	6.39	9.02		7.6			
	7	11.7	7.35	8.89		7.6			
	9	11.9	7.60	8.91		7.5			
	11	11.7	8.10	8.85	0.93	7.6	18.0	2.0	16.0
J-29	1	12.3	1.72	9.06	0.59	7.4	48.5	7.0	41.5
	3	12.4	1.95	8.85		7.4			
	5	12.1	2.13	8.97		7.4			
	7	12.2	3.88	9.00	0.67	7.4	79.0	9.5	69.5
J-36	1	11.4	0.44	9.78	0.54	7.5	86.0	14.6	71.4
	3	11.3	0.43	9.51		7.5			
	5	11.3		10.36		7.5			
	7	11.2	0.24	10.69		7.5			
	9	11.4	0.27	9.55	0.52	7.4	177.0	29.0	148.0
J-47	1	12.2	0.10	8.20	0.60	7.3	37.0	5.5	31.5
	3	12.3	0.10	7.49		7.5			
	5	12.3	0.10	7.57		7.5			
	7	12.3	0.11	7.78		7.8			
	9	12.4	0.27	7.84	0.59	7.9	60.0	14.0	46.0
J-57	1	12.5	0.17	8.67	0.82	7.5	43.0	13.5	29.5
	3	12.5	0.12	8.51		7.5			
	5	12.5	0.12	8.47		7.5			
	7	12.6	0.12	8.34		7.5			
	9	13.3	0.12	8.36	0.77	7.4	56.0	15.0	41.0
J-68	1	13.5	0.12	7.80	0.75	7.4	34.5	11.0	23.5
	3	13.4	0.12	7.65		7.5			
	5	13.6	0.12	7.53		7.5			
	7	13.9	0.12	7.40	0.74	7.8	40.0	11.0	29.0
J-76	1	13.4	0.13	7.15	0.79	7.6	18.0	7.0	11.0
	3	13.4	0.27	6.28		7.7			
	5	13.4	0.23	6.64		7.8			
	7	13.9	0.13	6.76	0.80	7.9	20.5	3.0	17.5

DATA SHEET

RIVER James CRUISE DATE 7 & 11 April 1966

Station	Depth (M)	TOT. P (μg.at 1^{-1})	SRP (μg.at 1^{-1})	PRP (μg.at 1^{-1})	SUP (μg.at 1^{-1})	PUP (μg.at 1^{-1})	NO_2.N (μg.at 1^{-1})	NO_3.N (μg.at 1^{-1})	OPN (μg.at 1^{-1})	Chl.a ($\mu g1^{-1}$)
J-4	1	2.23	0.15	0.08	0.32	1.68	0.60	2.8	17.1	21.6
	9	2.43	0.15	0.12	0.28	1.88	0.47	2.0	8.5	13.3
J-10	1	1.53	0.23	0.08	0.24	0198	1.37	13.7	6.2	12.3
	7	1.25	0.23	0.10	0.24	0.68	0.85	6.3	7.0	7.2
J-17	1	1.41	0.55	0.08	0.20	0.58	2.04	21.6	0.4	5.4
	11	1.11	0.38	0.08	0.26	0.39	1.26	12.6	9.0	3.2
J-22	1	1.78	0.53	0.08	0.34	0.83	2.12	26.6		3.8
	11	1.70	0.50	0.10	0.30	0.80	2.15	22.1	1.7	3.7
J-29	1	2.75	0.70	0.12	0.18	1.75	1.83	29.4	10.2	2.3
	7	4.20	0.60	0.38	0.20	3.02	1.94	29.4	5.2	3.2
J-36	1	4.60	0.75	0.18	0.27	3.40	1.20	35.2	16.2	3.0
	9	4.40	0.78	0.58	0.34	2.70	1.49	34.4	10.2	5.4
J-47	1	3.07	0.60	0.06	0.23	2.18	1.15	40.2	21.4	4.4
	9	3.88	0.66	0.09	0.38	2.75	1.17	40.8	8.9	6.1
J-57	1	4.10	0.34	0.06	0.58	3.12	3.14	40.8	15.8	36.4
	9	4.59	0.23	0.10	0.41	3.85	2.80	40.4	20.6	33.0
J-68	1	4.20	0.40	0.06	0.43	3.31	1.10	16.2		25.7
	7	4.86	0.38	0.12	0.37	3.99	1.05	17.4		28.6
J-76	1	7.20	0.87	0.14	0.73	5.46	0.68	7.2		25.7
	7	7.99	0.80	0.17	0.69	6.33	0.65	7.2	9.2	27.6

DATA SHEET

RIVER James

CRUISE DATE 9 & 11 May 1966

Station	Depth (M)	Temp (C)	Salinity (‰)	DO (mgl^{-1})	ALK ($meql^{-1}$)	pH	SS (mgl^{-1})	LOI (mgl^{-1})	FR (mgl^{-1})
J-4	1	16.4	17.26	8.52	1.40		22.0	7.4	14.6
	3	16.2	17.62	8.34					
	5	16.0	19.02	8.10					
	7	16.0	19.57	7.85					
	9	16.0	19.76	7.89					
	11	15.6	19.86	7.85	1.50		21.5	6.2	15.3
J-10	1	16.6	7.68	8.44	0.90		17.6	4.8	12.8
	3	17.0	11.49	7.73					
	5	16.8	13.81	7.71					
	7	16.5	17.08	7.63	1.41		17.2	5.5	11.7
J-17	1	16.8	4.40	7.73	0.98		21.2	4.8	16.4
	3	16.8	5.92	7.22					
	5	17.0	11.96	7.18					
	7	17.0	13.74	7.33					
	9	17.3	13.94	7.18					
	11	16.8	15.12	7.00	1.27		19.2	5.5	13.7
J-22	1	17.3	1.03	7.95	0.56		29.0	5.5	23.5
	3	17.1	1.43	8.02					
	5	17.3	2.19	7.93					
	7	17.5	2.34	7.95					
	9	17.5	2.77	8.40	0.49		32.0	5.2	26.8
J-29	1	18.0	0.19	7.08	0.23		41.5	5.5	36.0
	3	17.9	0.20	7.18					
	5	17.8	0.20	7.22					
	7	18.1	0.20	7.16	0.61		60.5	10.5	50.0
J-36	1	19.8	0.14	7.25	0.91		34.0	5.5	28.5
	3	19.5	0.14	7.10					
	5	19.5	0.15	7.25					
	7	19.5	0.16	7.00					
	9	19.6	0.17	6.94	0.79		40.5	8.0	32.5
J-47	1	18.2	0.09	5.40	0.63		25.0	4.0	21.0
	3	18.1	0.09	5.57					
	5	18.2	0.09	5.44					
	6	18.3	0.09	5.20	0.64		37.5	6.0	31.5
J-57	1	18.7	0.09	6.09	0.85		23.5	3.0	20.5
	3	18.7	0.09	6.19					
	5	18.7	0.09	6.09					
	7	18.6	0.09	6.48	0.89		32.4	4.8	27.6
J-68	1	18.6	0.08	6.03	0.83		39.5	7.5	32.0
	3	18.5	0.08	6.03					
	5	18.1	0.08	6.09					
	7	17.9	0.08	6.07	0.74		48.5	7.0	41.5
J-76	1	18.5	0.08	5.59	0.66		17.0	3.5	13.5
	3	18.6	0.08	5.63					
	5	18.5	0.08	5.65					
	7	18.1	0.08	5.67	0.61		23.2	5.6	17.6

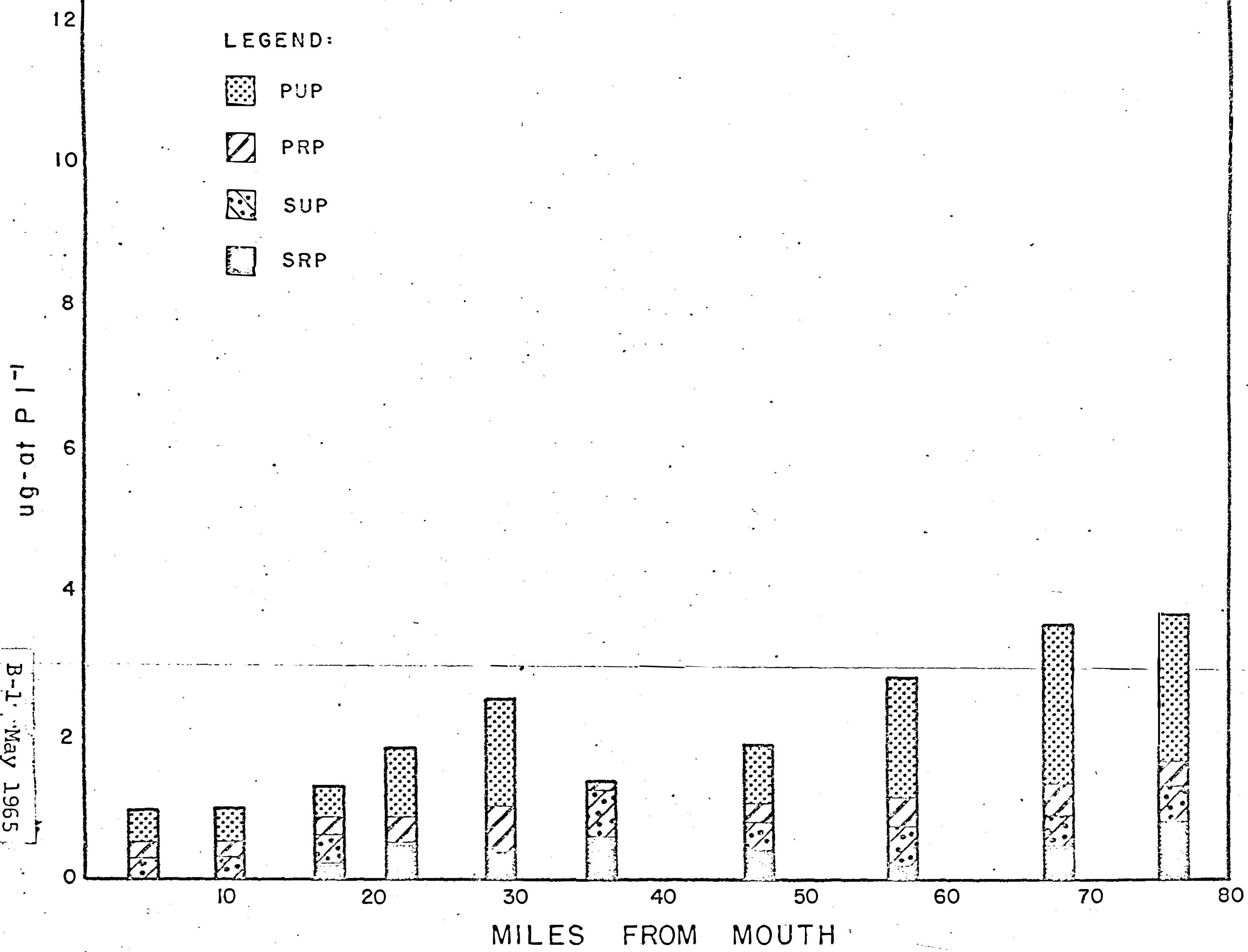
DATA SHEET

RIVER James CRUISE DATE 9 & 11 May 1966

Station	Depth (M)	TOT. P (µg.at l^{-1})	SRP (µg.at l^{-1})	PRP (µg.at l^{-1})	SUP (µg.at l^{-1})	PUP (µg.at l^{-1})	NO_2.N (µg.at l^{-1})	NO_3.N (µg.at l^{-1})	OPN (µg.at l^{-1})	Chl.a (µgl^{-1})
J-4	1	1.41	0.20	0.05	0.40	0.76	0.53	8.2	6.6	11.2
	11	1.33	0.20	0.08	0.24	0.81	0.39	3.8	8.6	8.6
J-10	1	1.54	0.45	0.06	0.40	0.63	1.19	33.8	8.9	5.7
	7	1.05	0.41	0.05	0.34	0.25	0.54	8.6	7.0	4.2
J-17	1	1.90	0.55	0.07	0.20	1.08	2.10	48.0	6.6	6.7
	11	1.44	0.71	0.06	0.25	0.42	0.63	12.1	3.5	2.1
J-22	1	2.07	0.60	0.09	0.36	1.02	5.09	78.0	6.3	4.0
	9	2.00	0.45	0.09	0.25	1.21	2.92	57.0	2.2	3.2
J-29	1	2.60	0.50	0.08	0.35	1.62	6.80	79.4	6.9	5.0
	7	3.40	0.45	0.22	0.27	2.46	6.50	80.0	11.2	5.9
J-36	1	1.12	0.50	0.12	0.40	0.10	4.12	50.0	10.8	12.5
	9	2.73	0.55	0.11	0.25	1.82	4.64	61.2	12.2	8.9
J-47	1	3.40	0.90	0.11	0.60	1.79	1.37	19.2	2.3	10.1
	6	3.60	0.81	0.12	0.39	2.28	1.28	19.6	14.0	11.7
J-57	1	3.38	0.60	0.10	0.60	2.08	1.14	14.4	5.7	17.2
	7	3.60	0.55	0.12	0.42	2.51	1.04	14.5	13.2	15.3
J-68	1	3.81	0.57	0.14	0.33	2.77	0.40	8.4	10.2	
	7	5.20	0.73	0.22	0.39	3.86	0.40	9.4	17.2	8.4
J-76	1	3.60	1.12	0.12	0.58	1.78	0.42	11.2	13.4	4.0
	7	3.81	1.10	0.15	0.50	2.06	0.41	10.4	8.4	3.1

APPENDIX B

SOLUBLE REACTIVE PHOSPHORUS (SRP), PARTICULATE REACTIVE PHOSPHORUS (PRP), SOLUBLE UNREACTIVE PHOSPHORUS (SUP), AND PARTICULATE UNREACTIVE PHOSPHORUS (PUP) LEVELS AT TEN STATIONS ON THE TIDAL JAMES RIVER (1 m depth)



12
10
8
6
4
2
0
ug-at P l^-1
LEGEND:
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PRP
SUP
SRP
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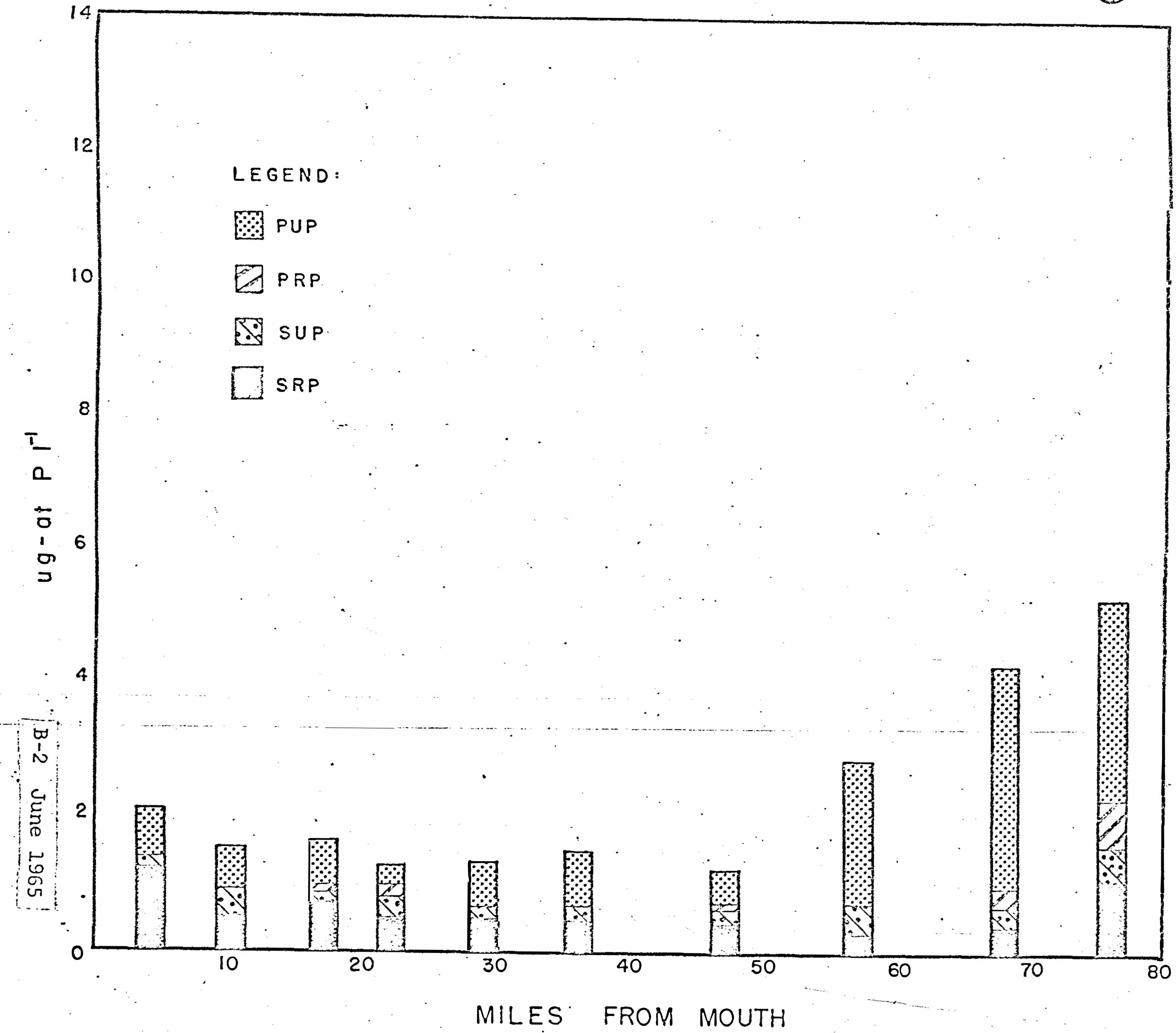
20
30
40
50
60
70
80
MILES FROM MOUTH

B-1 May 1965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SUP
SRP
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10
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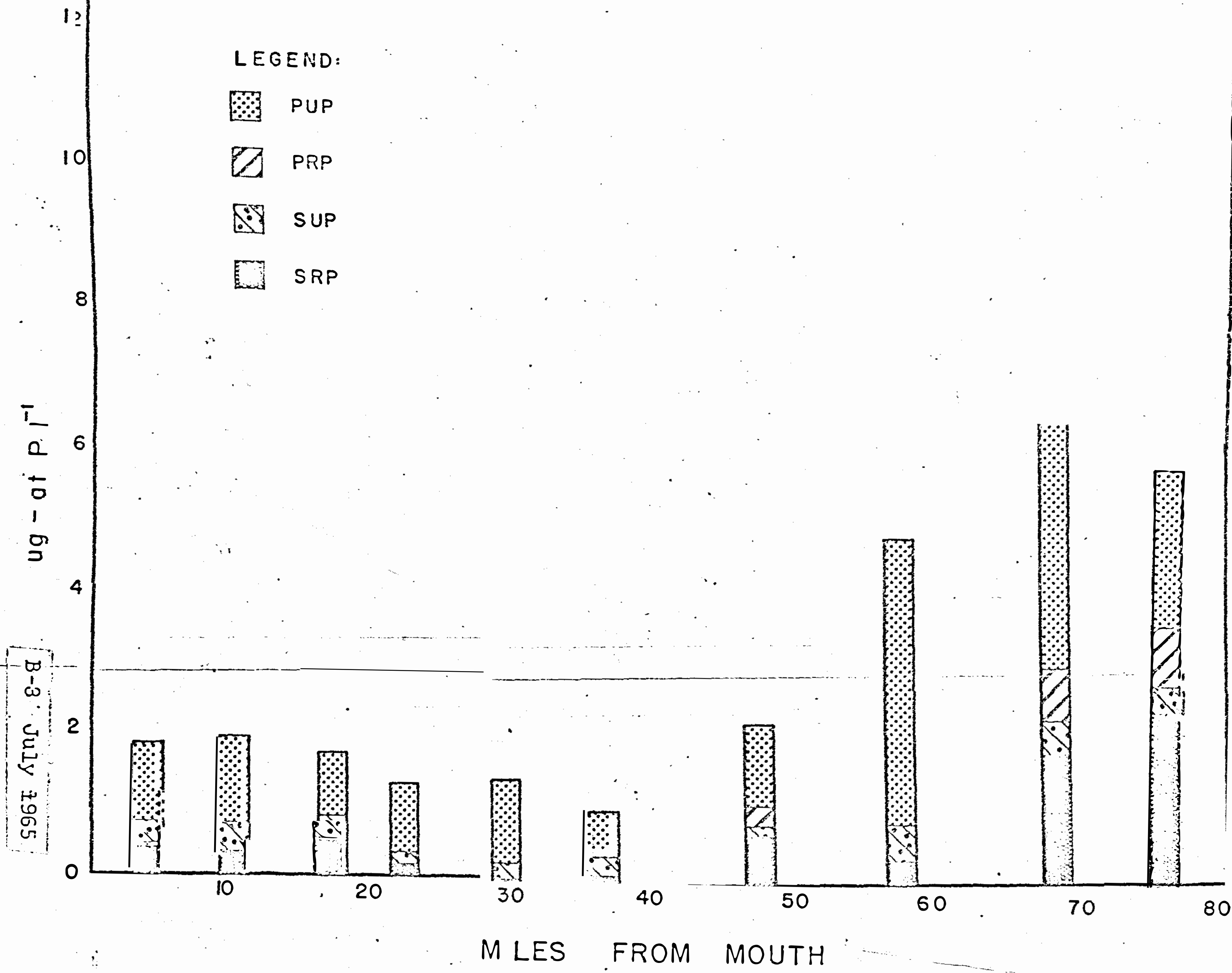
40
50
60
70
80
MILES FROM MOUTH

B-2 June 1965



LEGEND:
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PRP
SUP
SRP
ug - at P l⁻¹
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4
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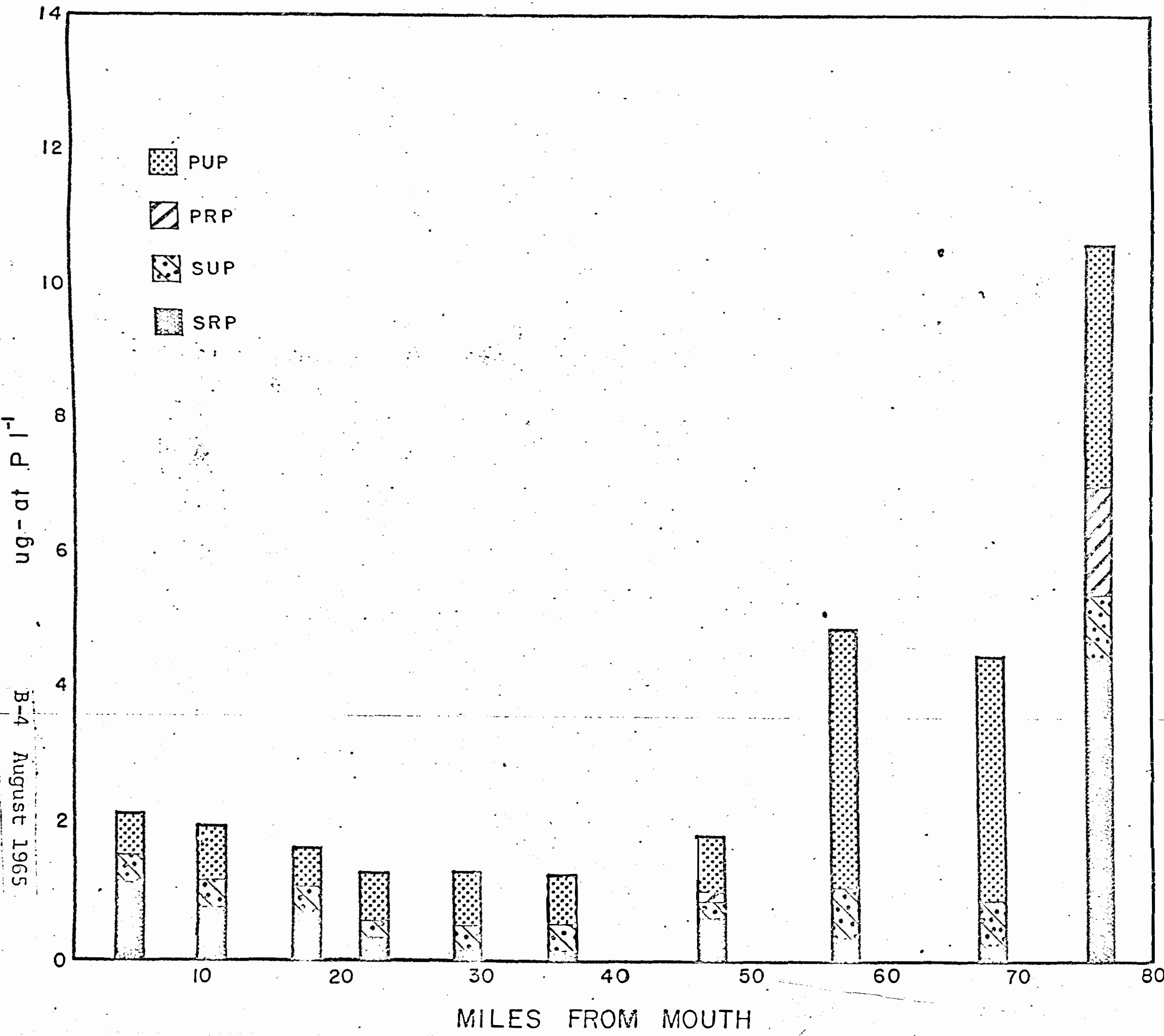
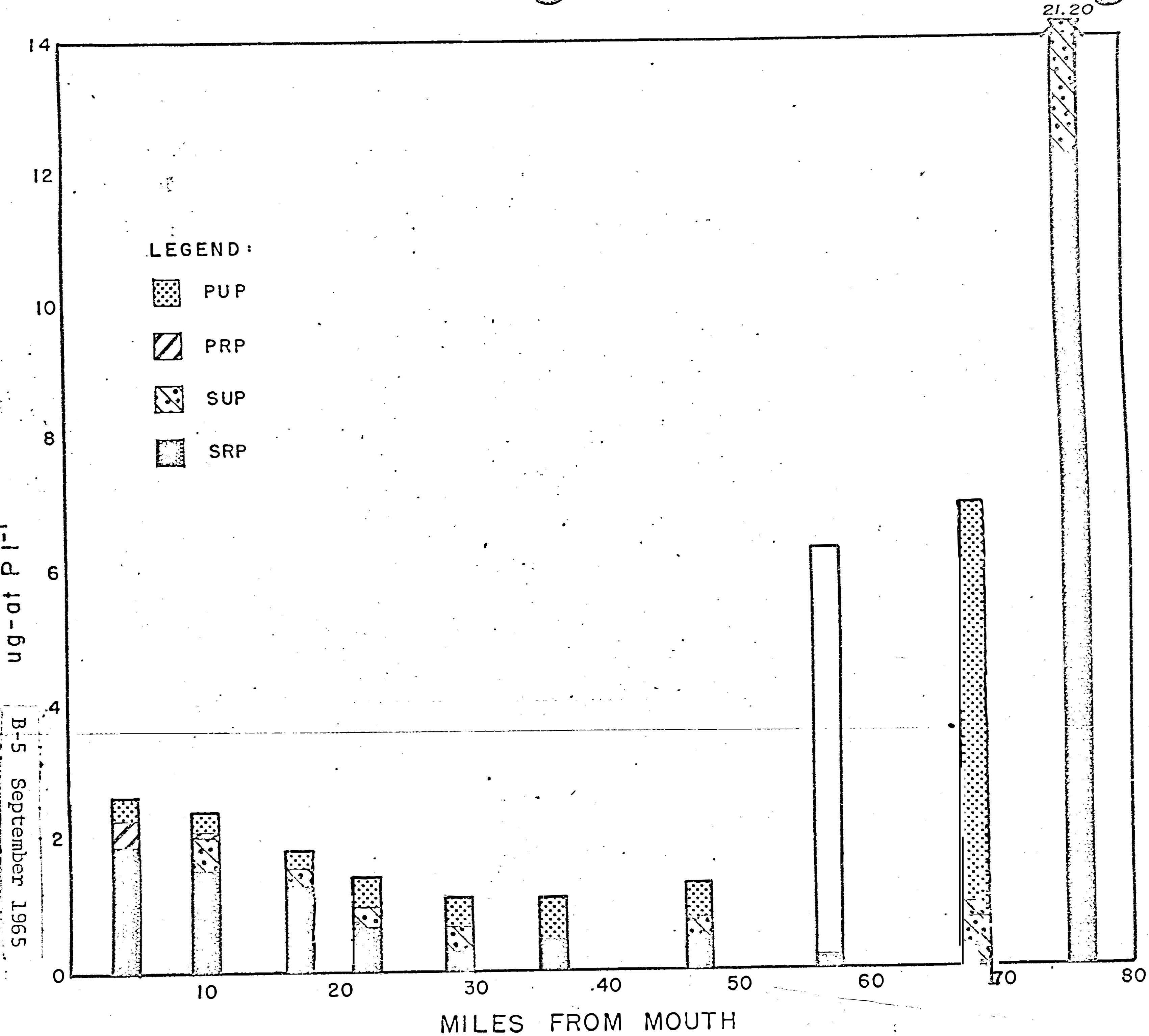
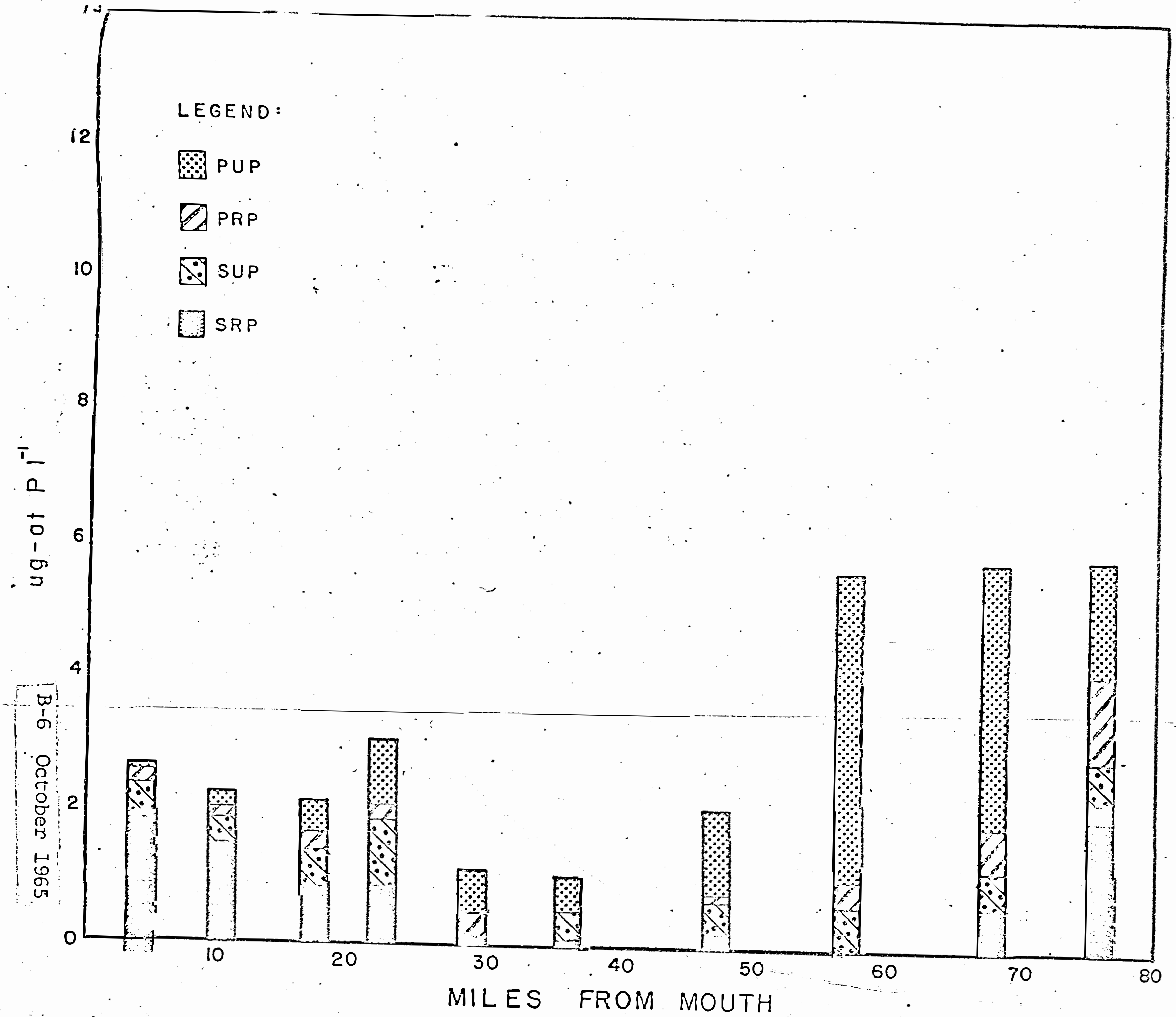
0
10
20
30
40
50
60
70
80
M LES FROM MOUTH
B-3 July 1965



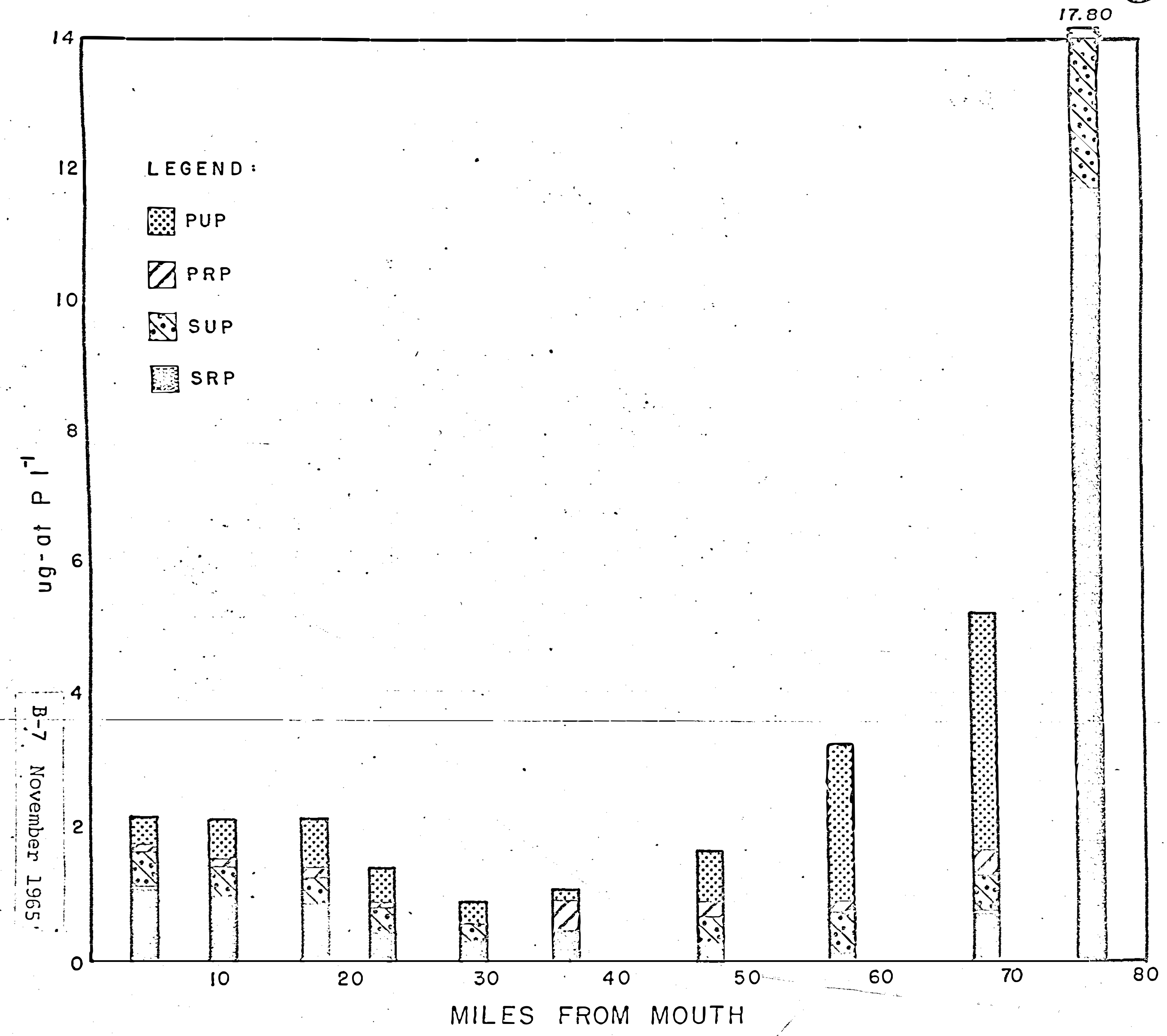
B-4 August 1965



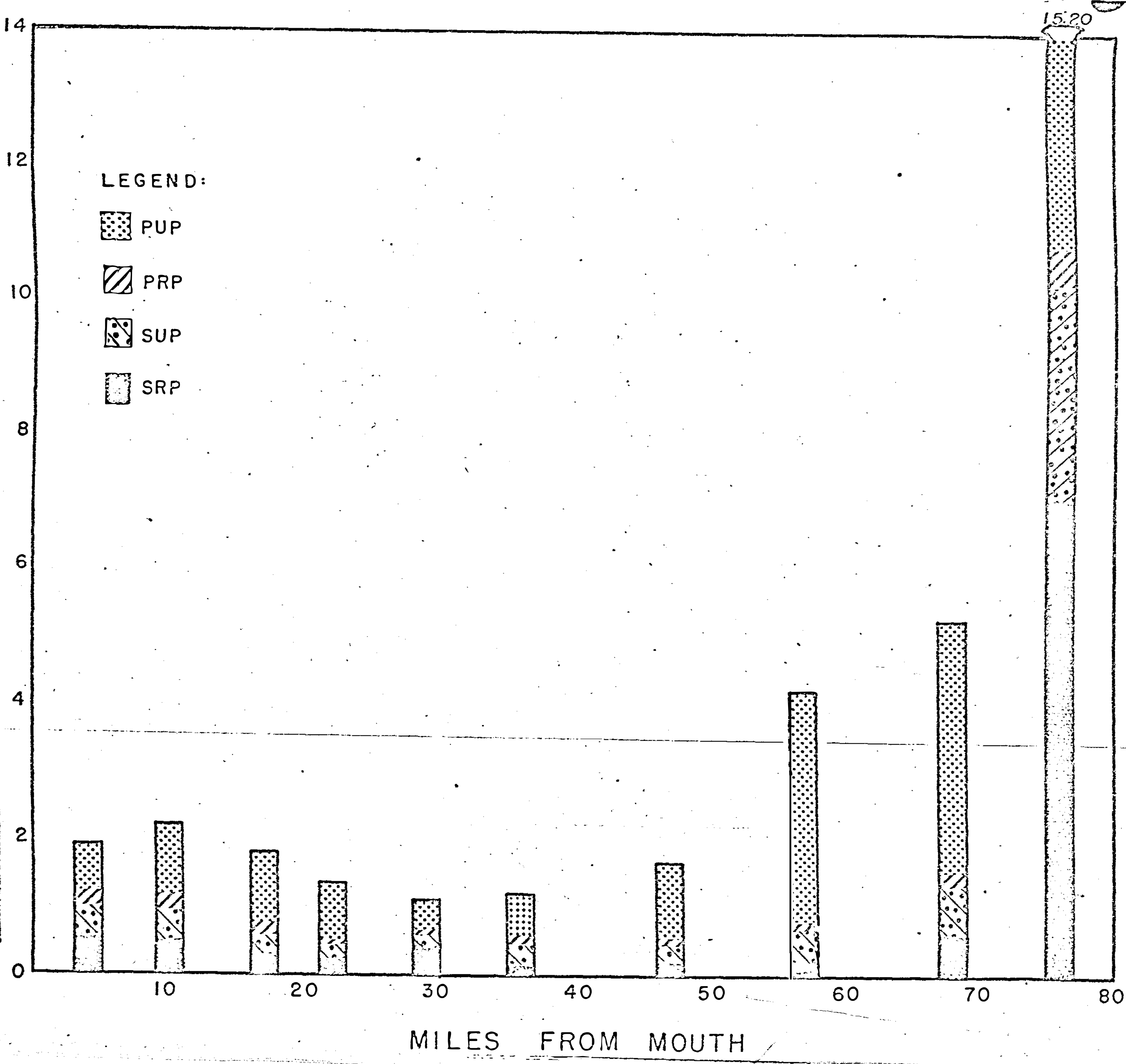
B-5 September 1965



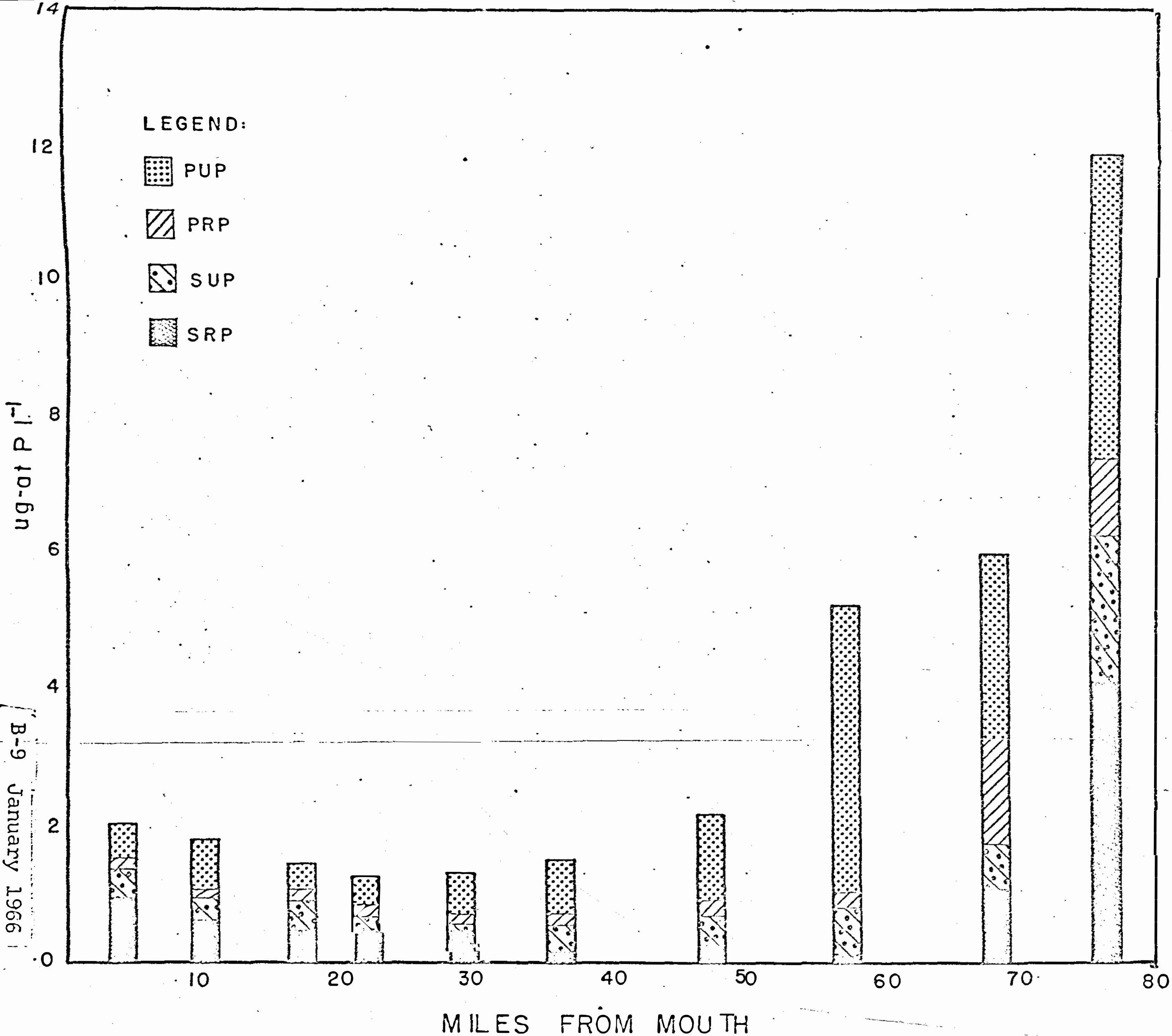
B-6 October 1965



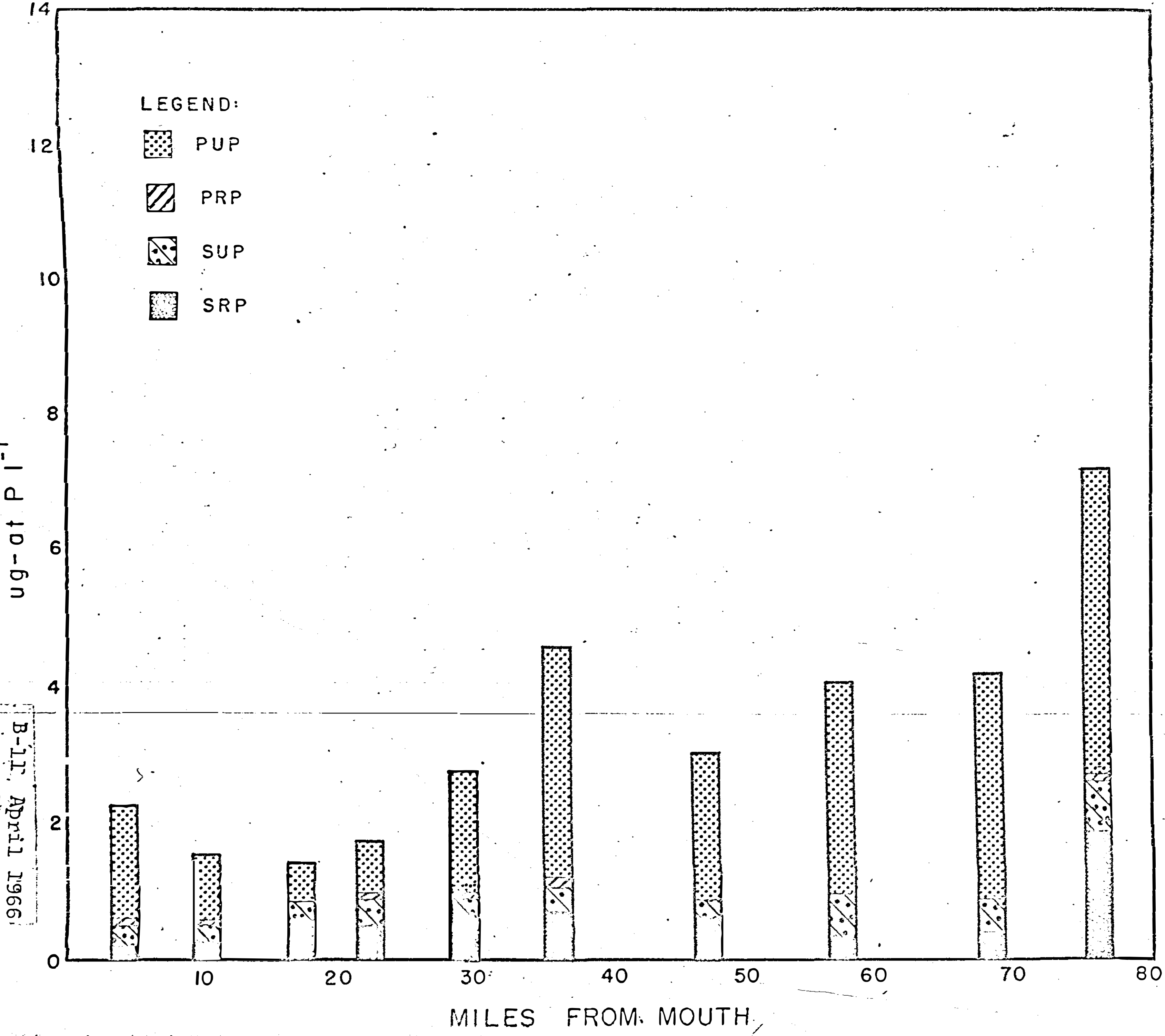
B-7 November 1965



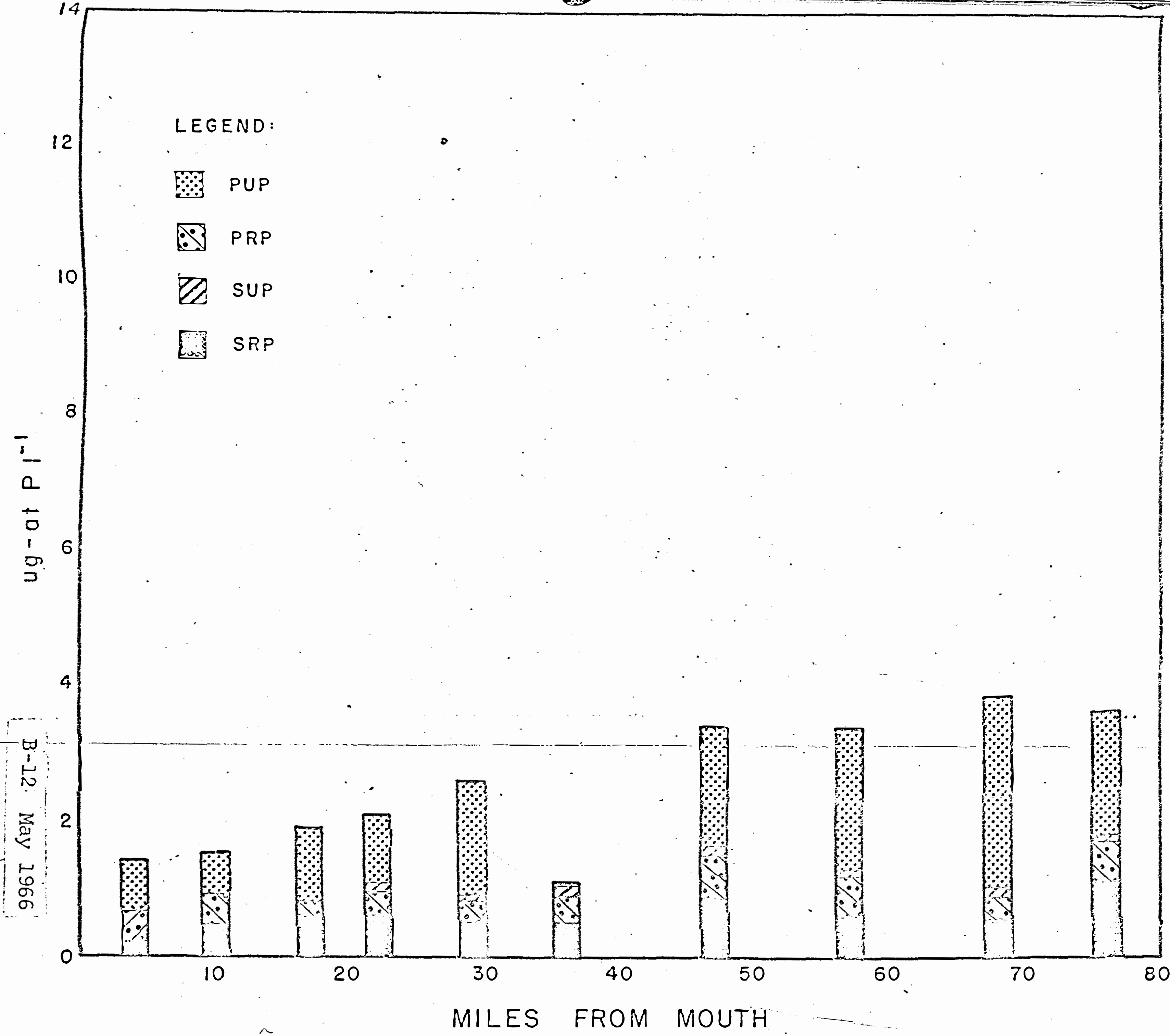
B-8 December 1965



B-9 January 1966



B-11, April 1966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PRP
SUP
SRP
ug-at P l-1
14
12
10
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4
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0
10
20
30
40
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80
MILES FROM MOUTH
B-12 May 1966

APPENDIX C

NITRITE AND NITRATE NITROGEN LEVELS AT TEN STATIONS ON THE TIDAL JAMES RIVER

(1 m depth; note the semi-log scale)

C-1 -May 1965

C-2 -June 1965

C-3 -July 1965

C-4 -August 1965

C-5 -September 1965

C-6 -October 1965

C-7 -November 1965

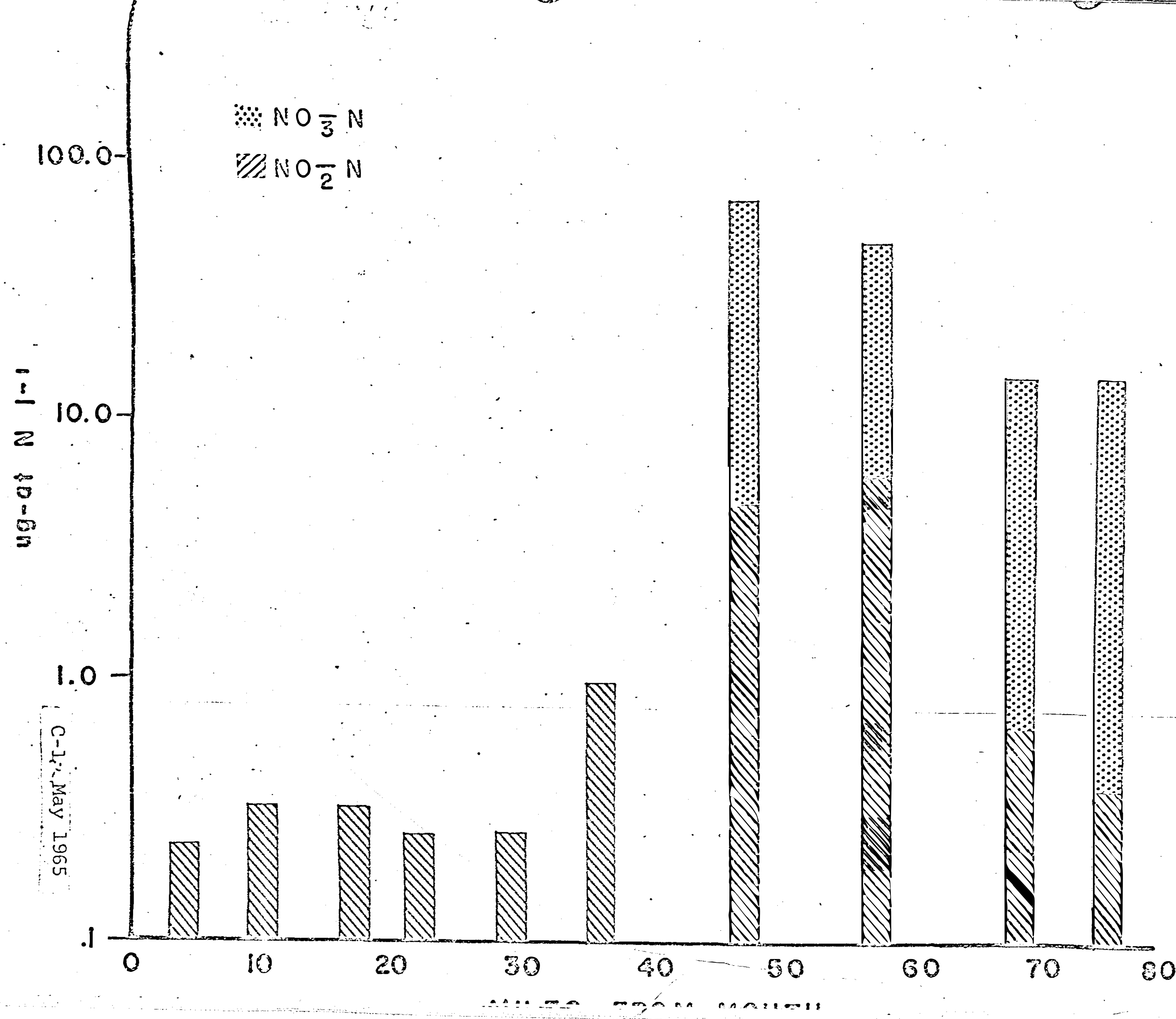
C-8 -December 1965

C-9 -January 1966

C-10 -March 1966

C-11 -April 1966

C-12 -May 1966



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NO2 N
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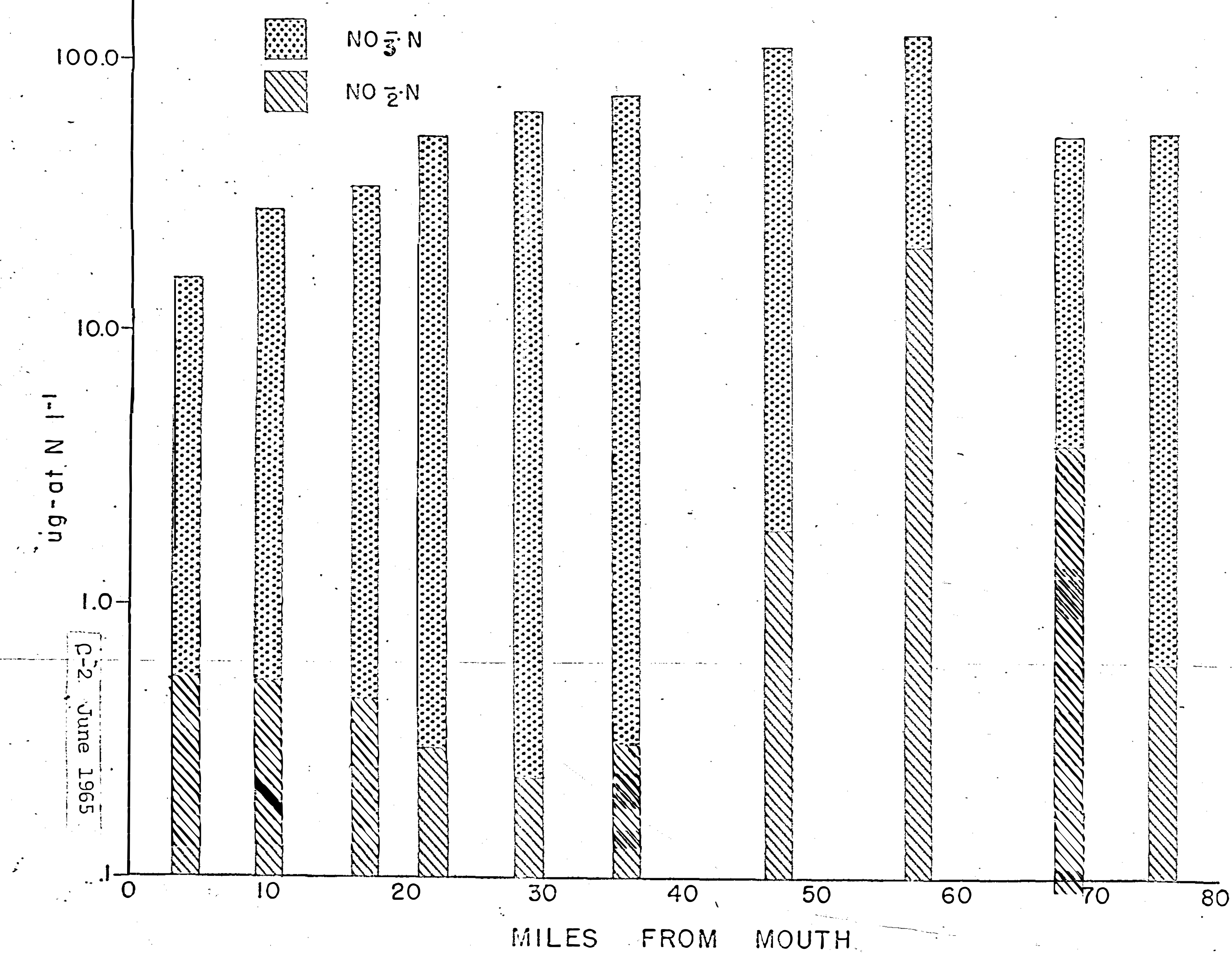
1.0
.1
ug-at N l-1
0
10
20
30
40
50
60
70
80
May 1965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NO_2^--N
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1.0
.1
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C-2 June 1965
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10
20
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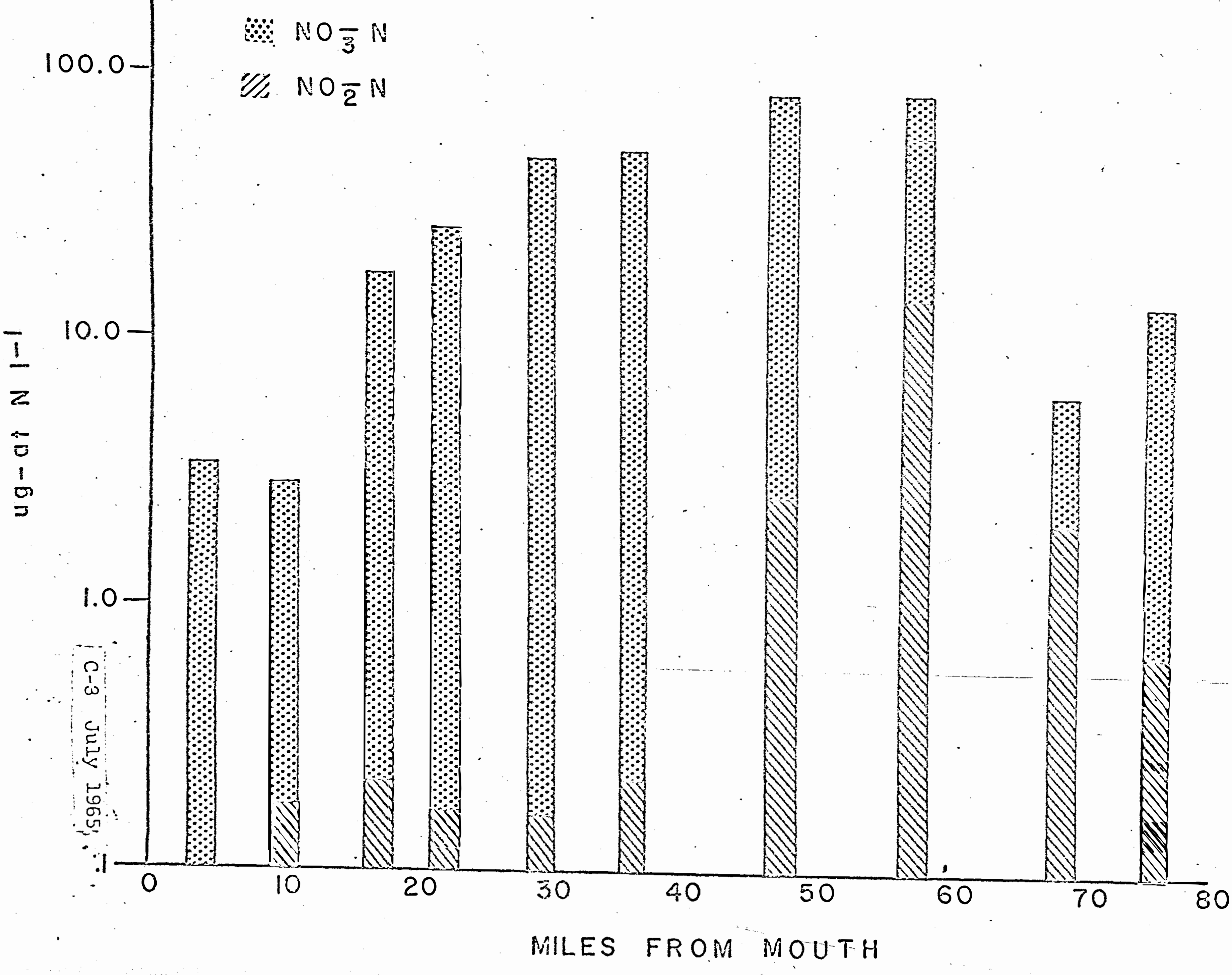
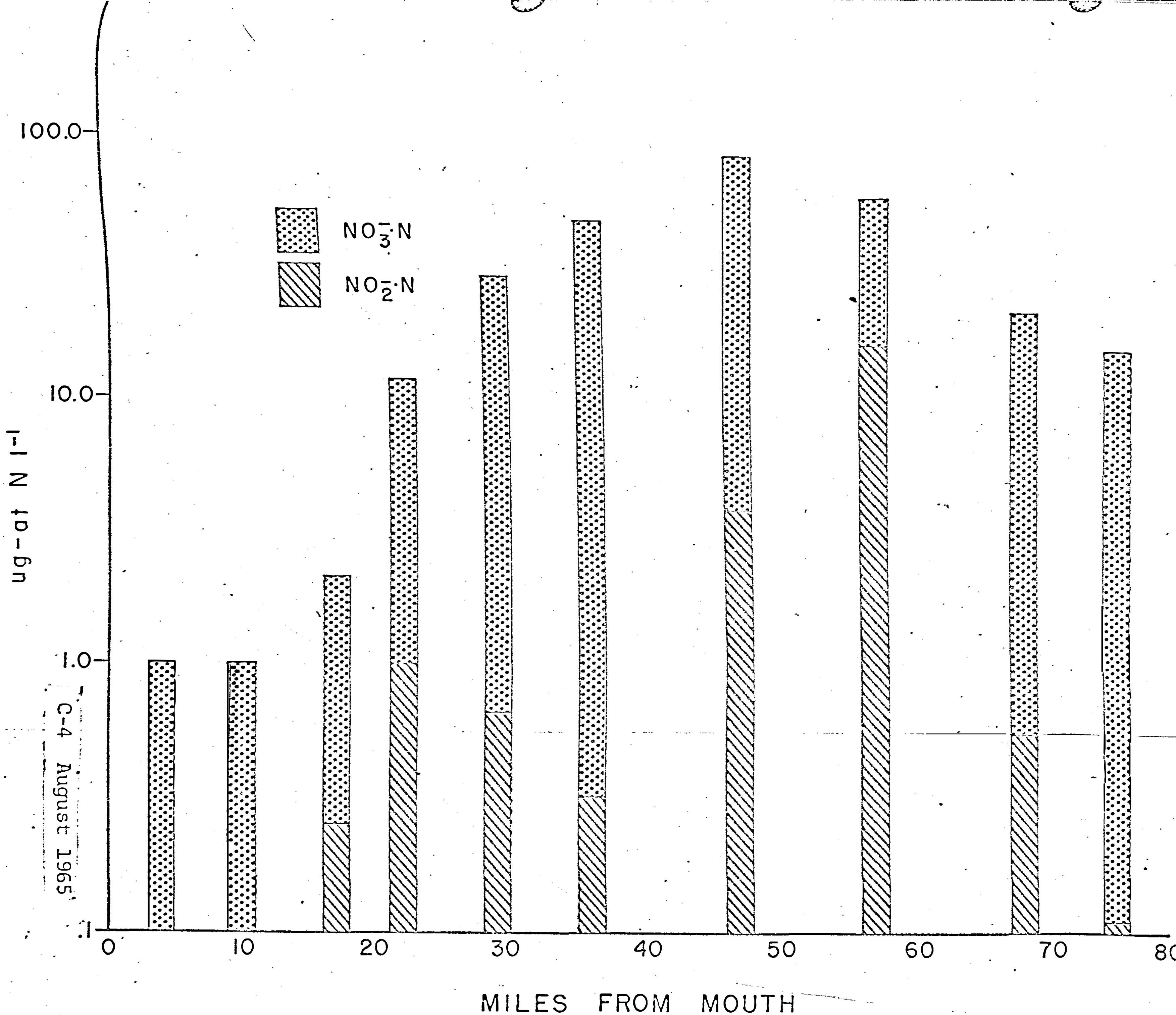
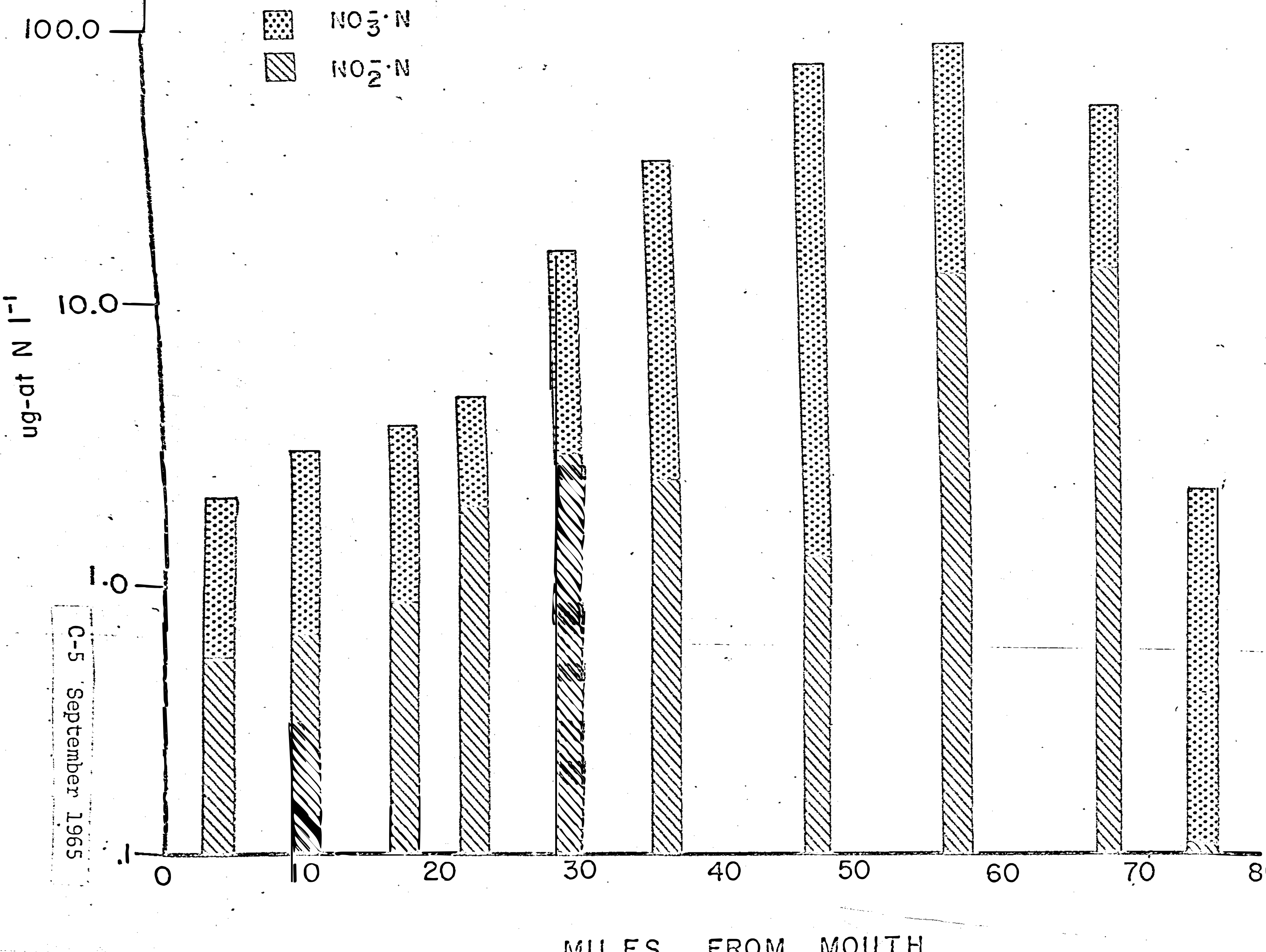
60
70
80
MILES FROM MOUTH



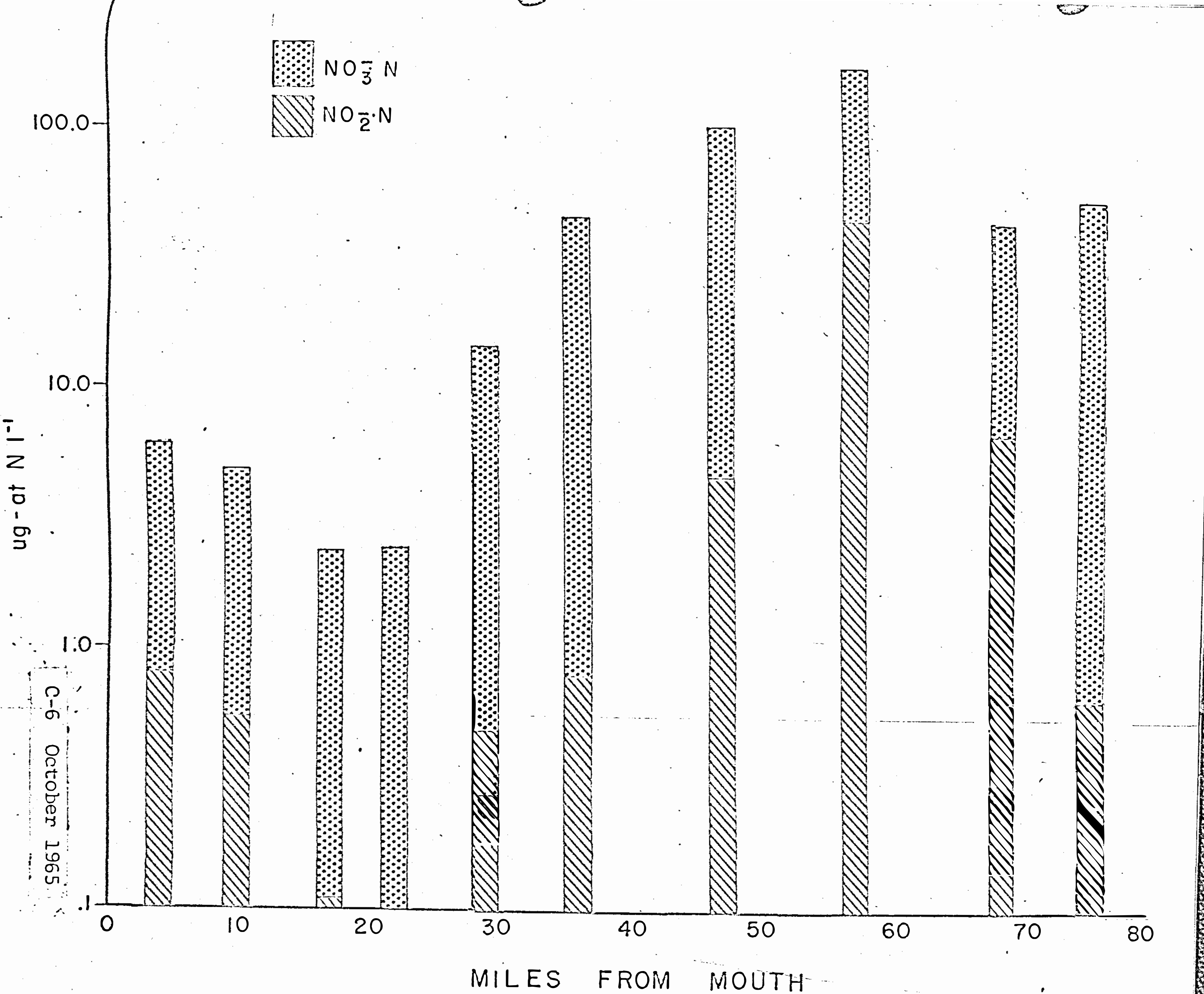
NO_3^- N
NO_2^- N
100.0
10.0
1.0
.1
ug-at N l-1
0
10
20
30
40
50
60
70
80
MILES FROM MOUTH
C-3 July 1965



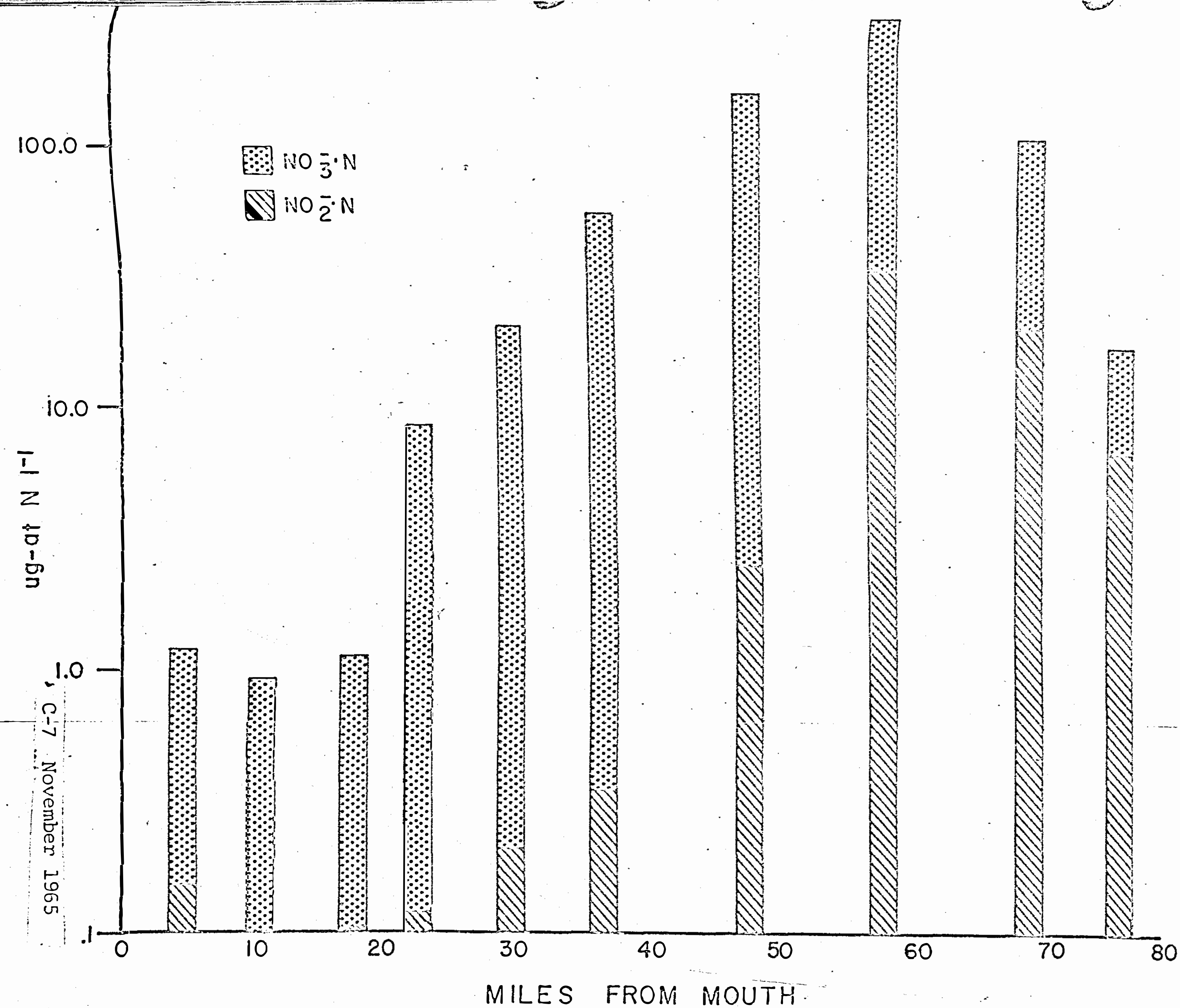
C-4 August 1965



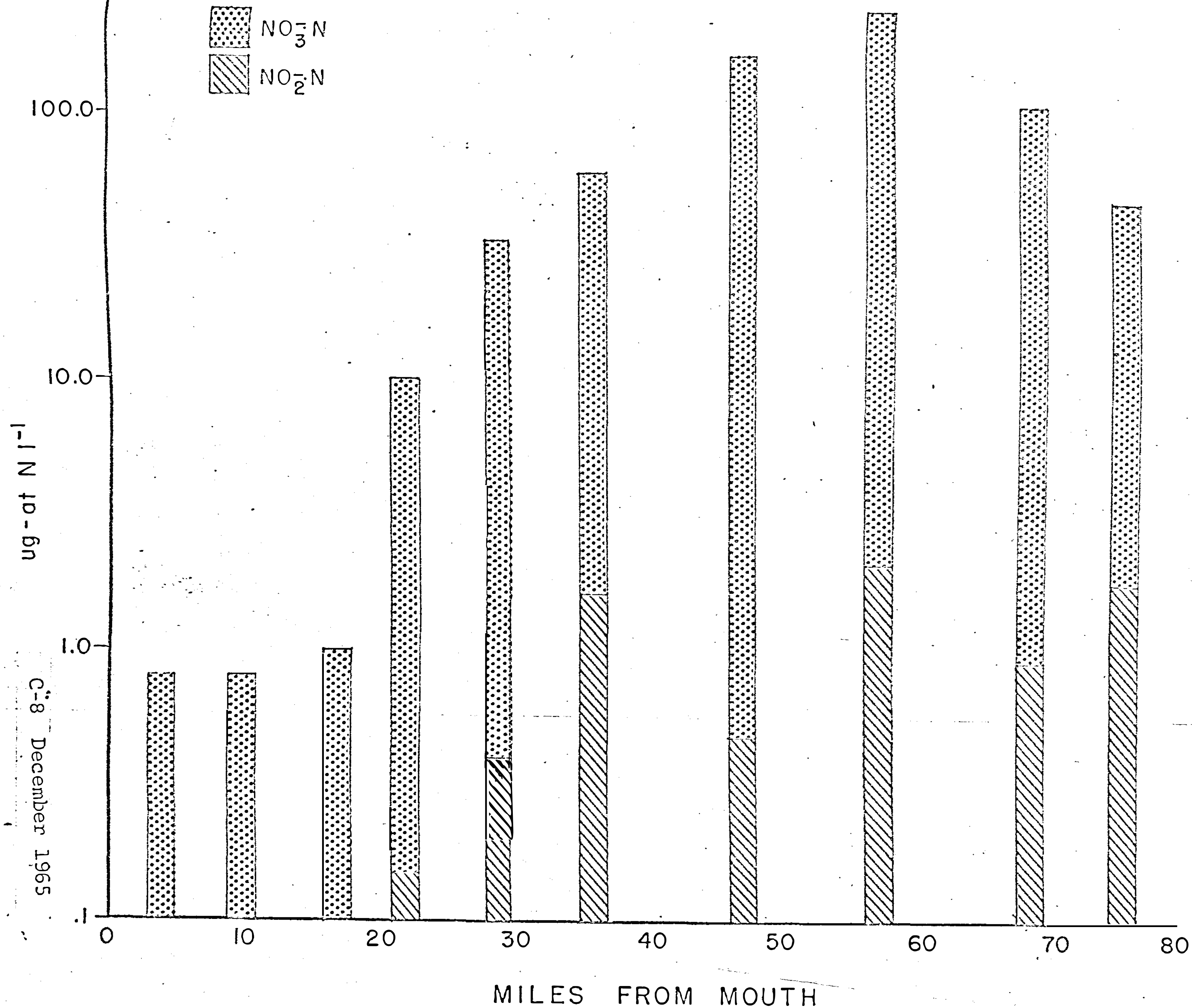
C-5 September 1965



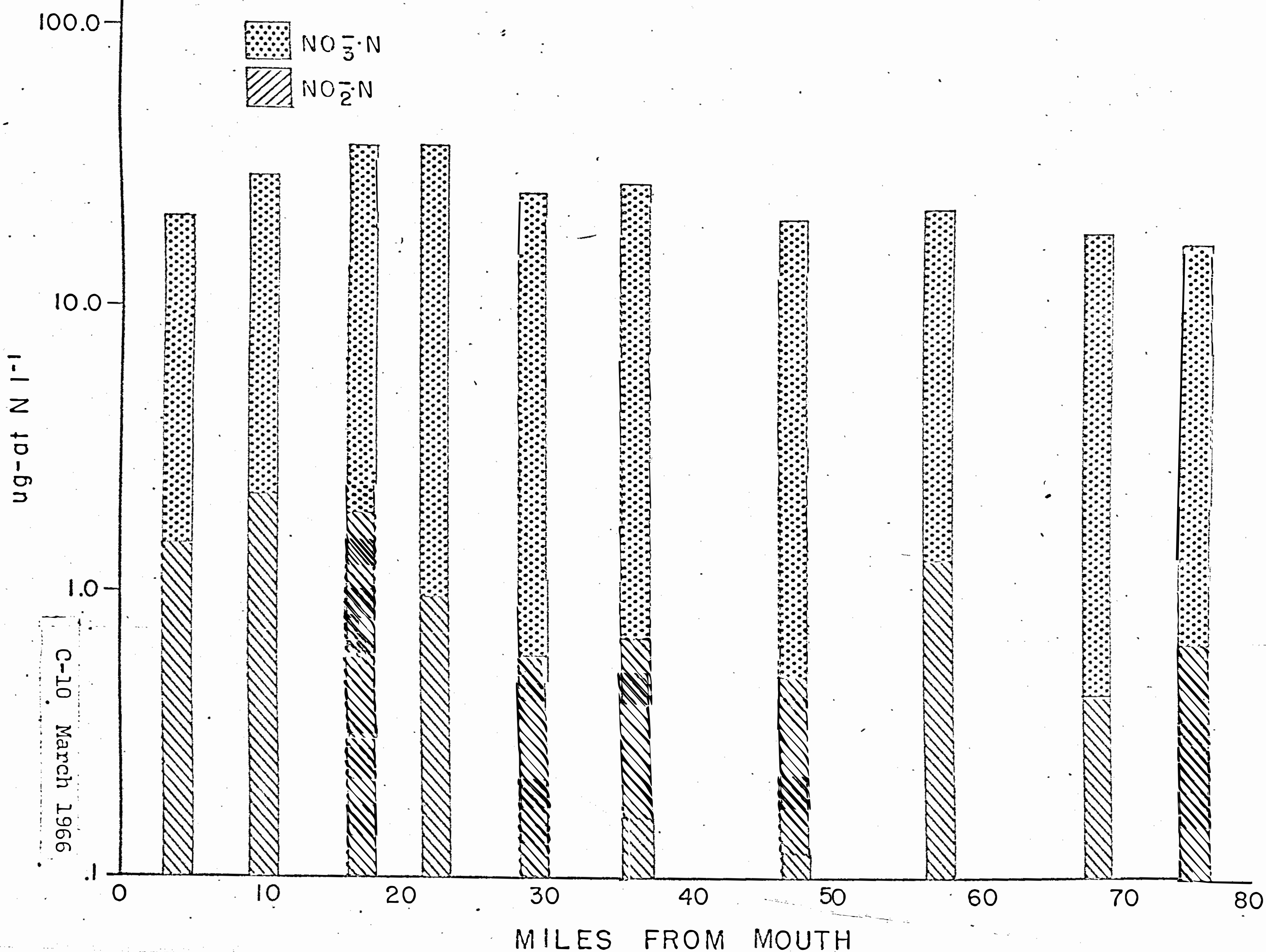
NO3· N
NO2· N
100.0
10.0
1.0
.1
ug-at N l-1
0
10
20
30
40
50
60
70
80
MILES FROM MOUTH
C-6 October 1965



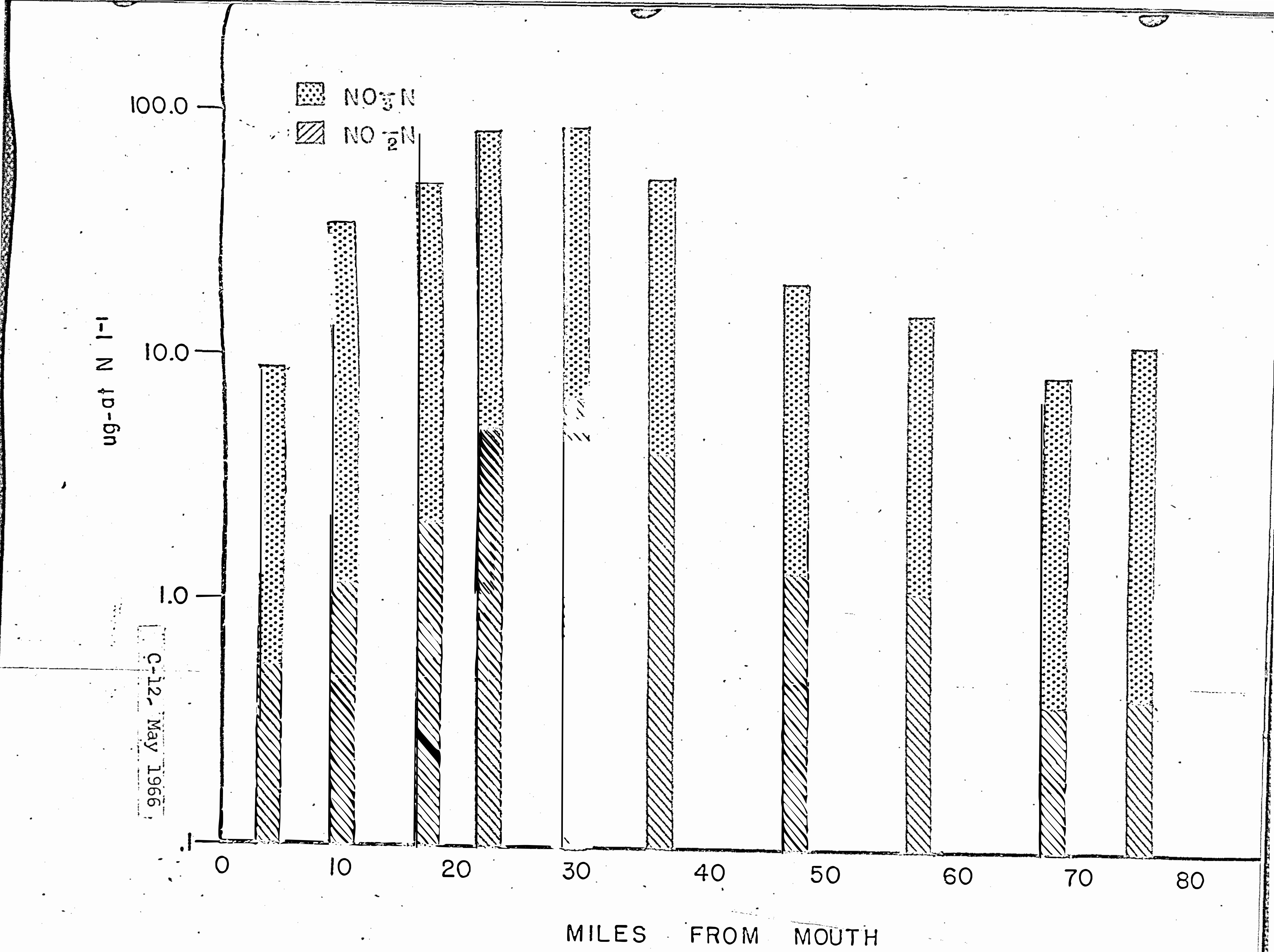
C-7 November 1965



C-8 December 1965



C-10 March 1966



NO_3^-N
NO_2^-N
100.0
10.0
1.0
.1
ug-at N l-1
C-12, May 1966
0
10
20
30
40
50
60
70
80
MILES FROM MOUTH

APPENDIX D

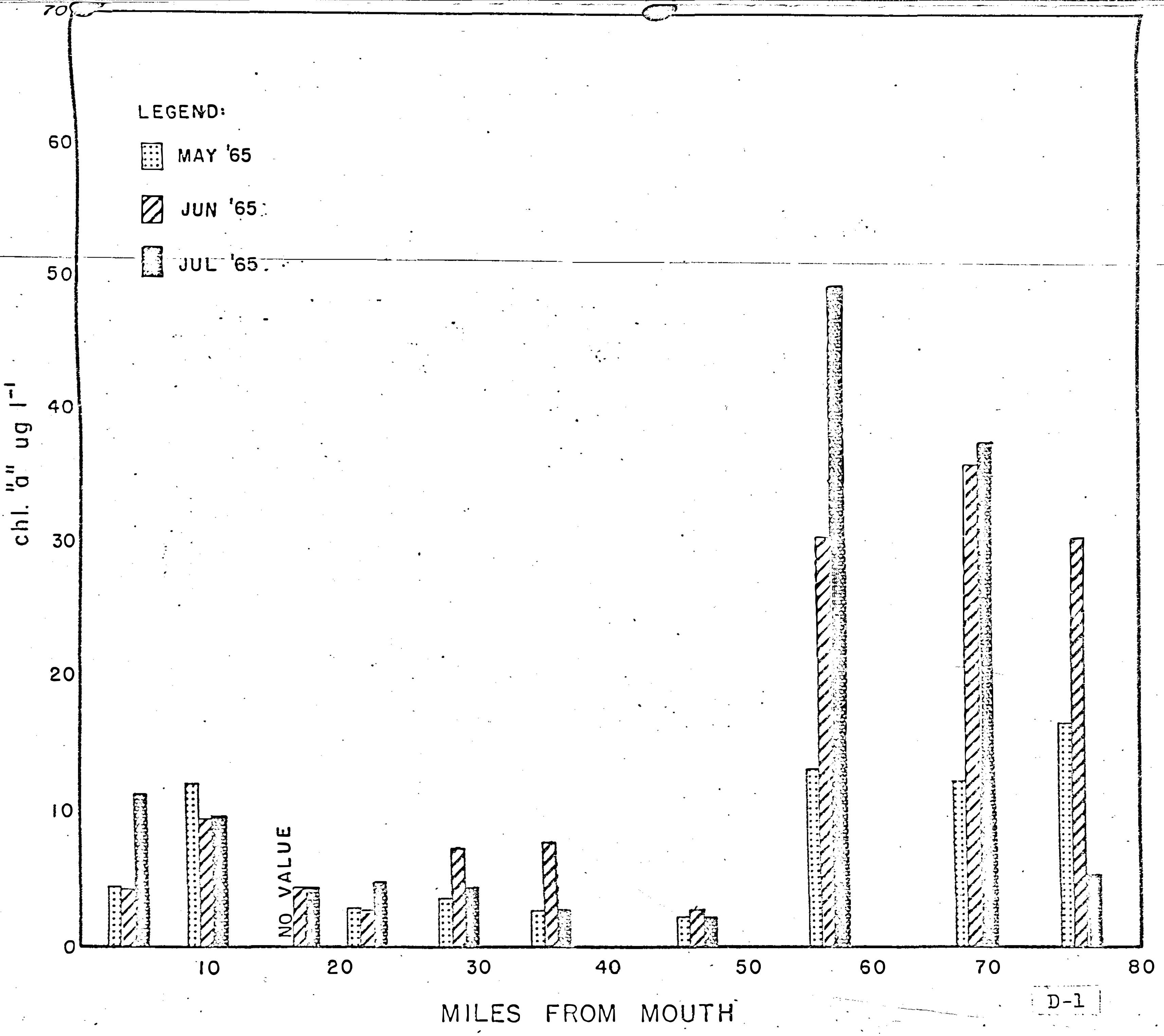
CHLOROPHYLL LEVELS AT TEN STATIONS ON THE TIDAL JAMES RIVER (1 m depth)

D-1 -May, June, July 1965

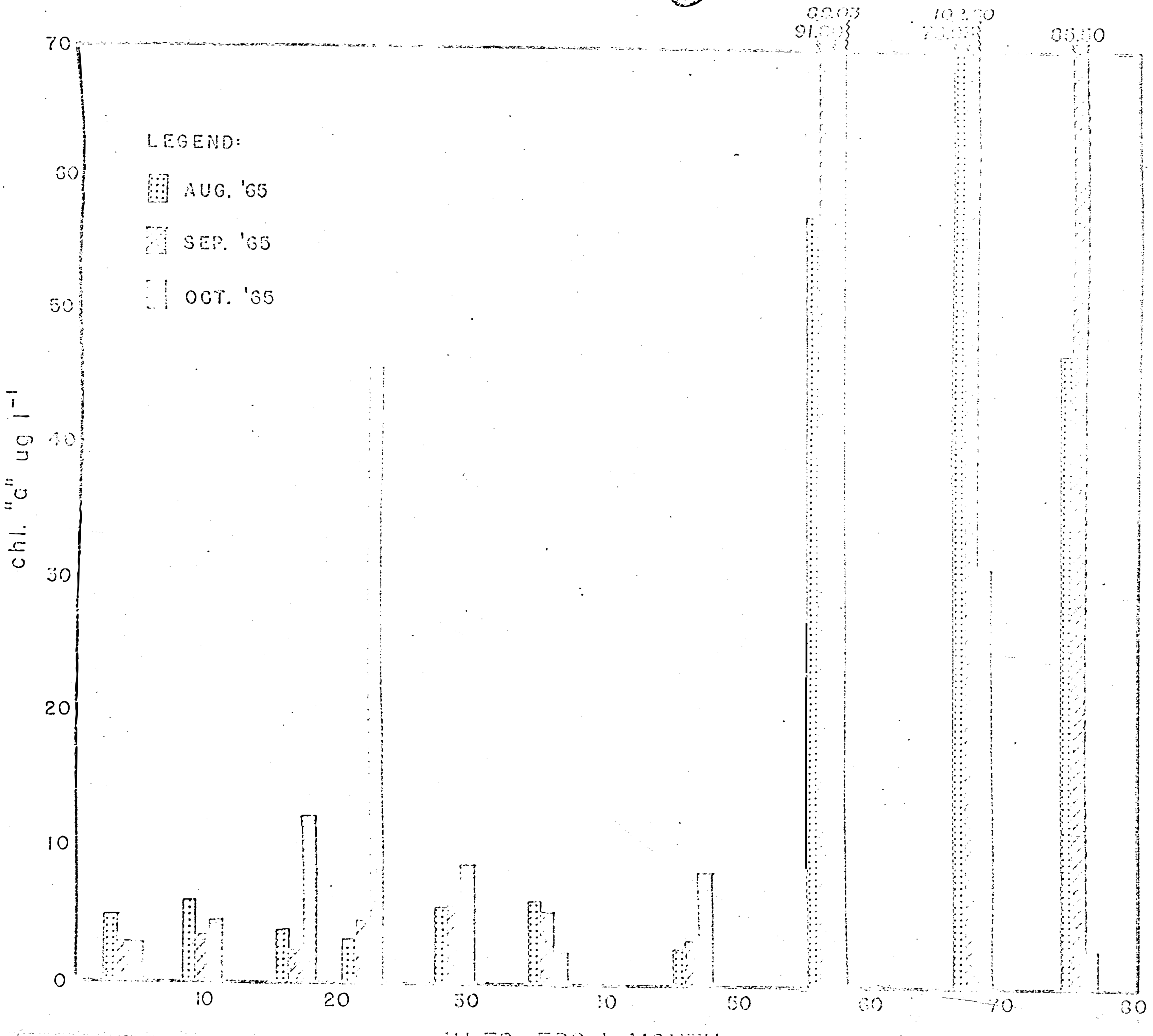
D-2 -August, September, October 1965

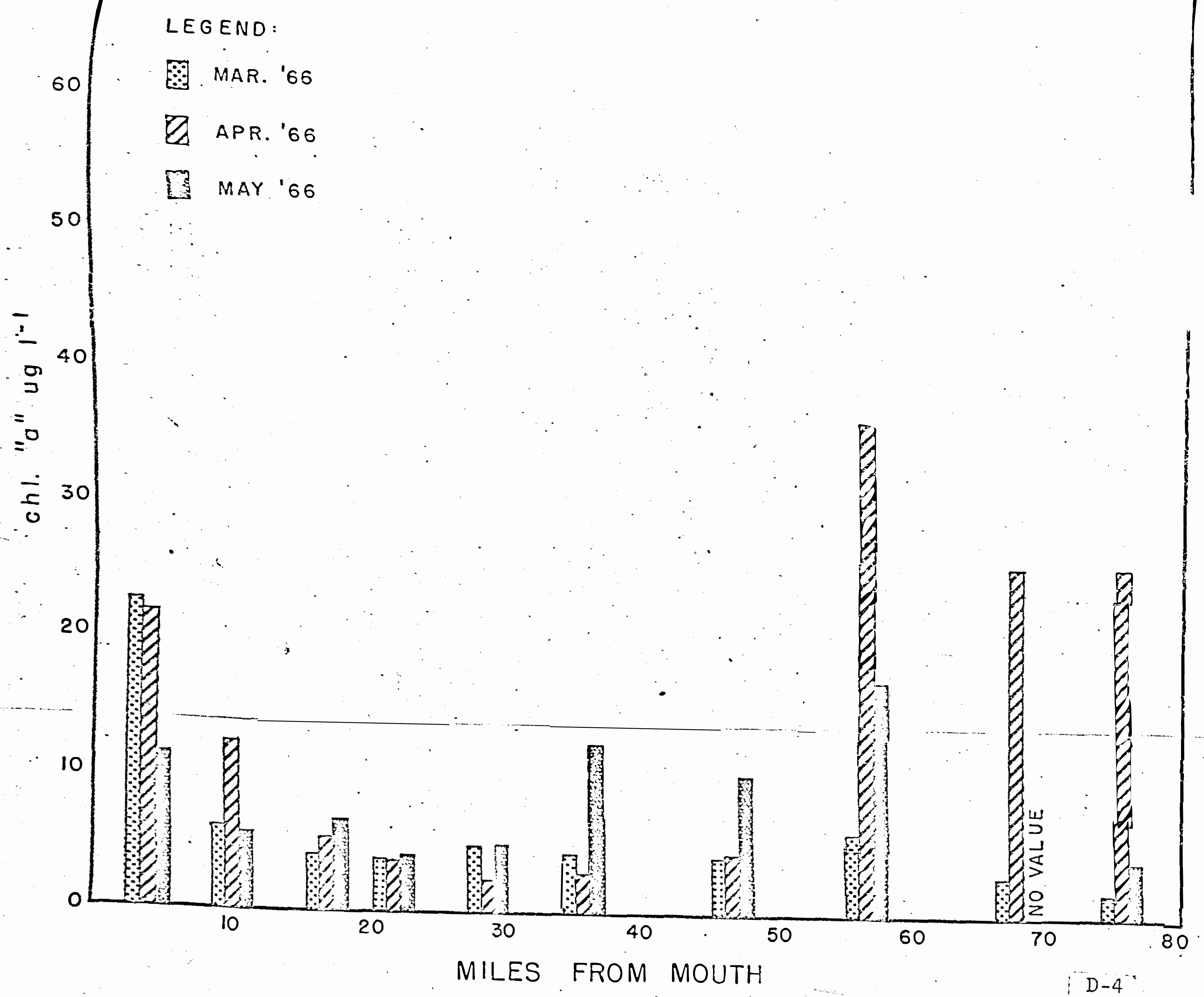
D-3 -November, December 1965, January 1966

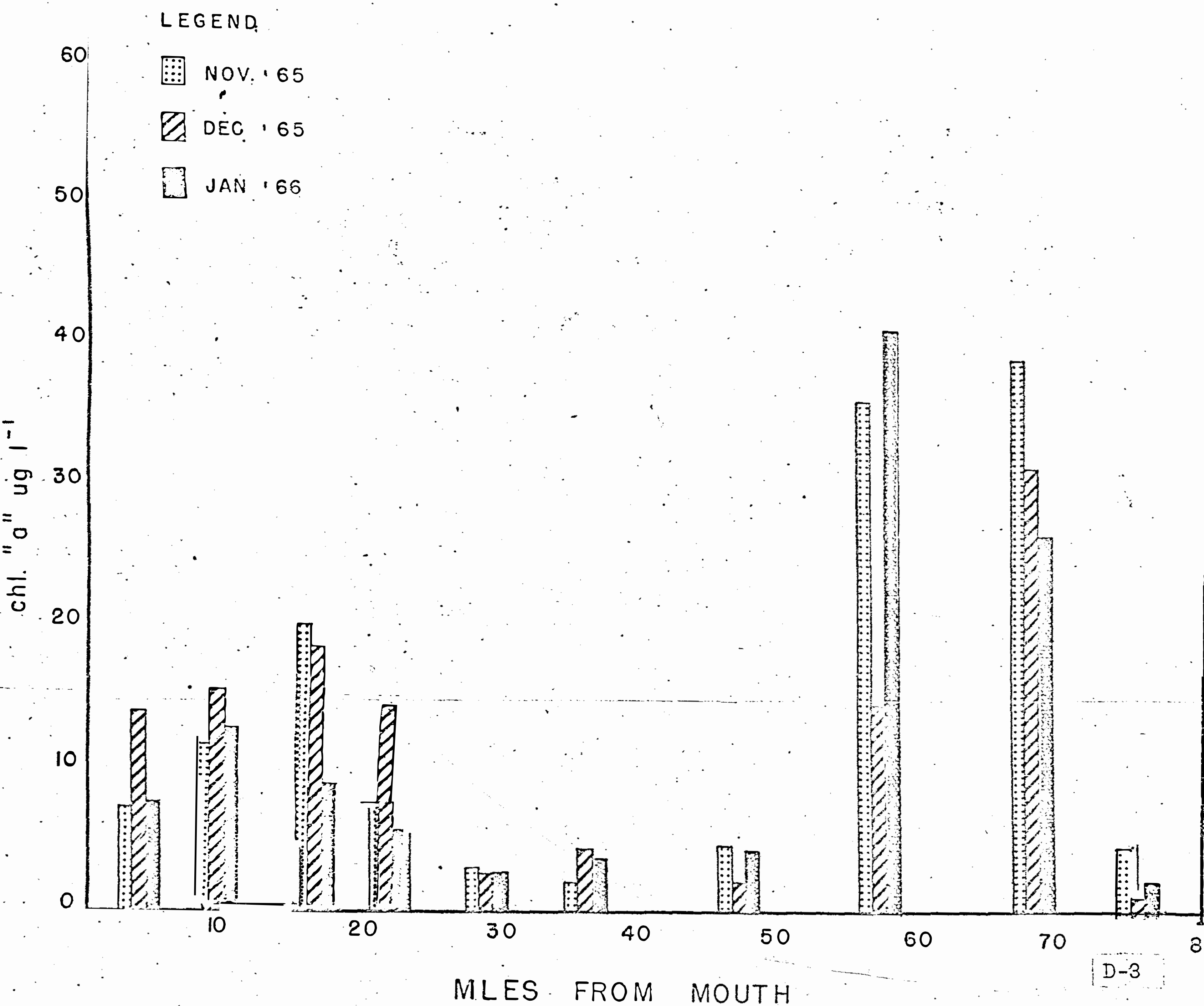
D-4 -March, April, May 1966



LEGEND:
MAY '65
JUN '65
JUL '65
chl. "a" ug l⁻¹
70
60
50
40
30
20
10
0
NO VALUE
10
20
30
40
50
60
70
80
MILES FROM MOUTH


LEGEND:
AUG. '65
SEP. '65
OCT. '65
chl. "a" ug l⁻¹
70
60
50
40
30
20
10
0
10
20
30
40
50
60
70
80
89.03
91.09
102.70
86.50


LEGEND:
MAR. '66
APR. '66
MAY '66
chl. "a" ug l⁻¹
0
10
20
30
40
50
60
NO VALUE
10
20
30
40
50
60
70
80
MILES FROM MOUTH


LEGEND
NOV. '65
DEC '65
JAN '66
chl. "a" ug l-1
0
10
20
30
40
50
60
10
20
30
40
50
60
70
80
MLES FROM MOUTH

D-3

APPENDIX E

APPENDIX E

AVERAGE AND 1965-6 MONTHLY MEAN FRESHWATER DISCHARGES OF THE JAMES RIVER AT RICHMOND, VIRGINIA

Month	Discharge (c.f.s.)[1]	1943-64 Mean	Deviation from Mean
I-65	8,985	9,081	-96
II-65	14,189	11,294	+2,895
III-65	14,204	14,168	+36
IV-65	9,032	12,029	-2,997
V-65	5,348	8,136	-2,788
VI-65	2,432	5,036	-2,604
VII-65	1,704	3,387	-1,683
VIII-65	1,191	3,436	-2,245
IX-65	1,090	3,472	-2,382
X-65	1,686	3,425	-1,739
XI-65	1,266	4,548	-3,282
XII-65	1,193	7,375	-6,182
I-66	1,598	9,081	-7,483
II-66	11,345	11,294	+51
III-66	8,563	14,168	-5,605
IV-66	3,591	12,029	-8,438
V-66	7,682	8,136	-454
VI-66	2,261	5,036	-2,775
VII-66	1,380	3,387	-2,007
VIII-66	812	3,436	-2,624
IX-66	3,026	3,472	-446

From unpublished data sheets provided by Virginia Department of Conservation and Economic Development.