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The Physical and Chemical Limnology of Lake McConaughy with Reference to Fisheries Management

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PHYSICAL AND CHEMICAL LIMNOLOGY OF LAKE McCONAUGHY

Nebraska Technical Series No. 9

by
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and
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NEBRASKA GAME AND PARKS COMMISSION
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INTRODUCTION

Lake McConaughy is an important fishery resource of the state of Nebraska. The estimated fishing pressure in 1975 as determined from a postal creel census was 175,872 angler days (Morris 1977). This estimate is inflated compared to an on-site creel census conducted in 1977-78 which showed a total of 69,500 fishing trips annually (Madsen 1980). Not all fishermen were contacted so this estimate is undoubtedly too low. Regardless of which figure is accepted, the reservoir provides many man-days of fishing opportunity. Conservation and management of the fishery resource is necessary to maintain and/or improve its quality.

An important factor in the management of any fishery resource is the limnological characteristics of the water body. This knowledge is a necessity when coldwater species are part of the fishery. Considerable data have been collected on the limnology of Lake McConaughy (Kiener 1951; McCarraher et al. 1971). Prior to 1969 much of the data were temperature and dissolved oxygen profiles at a limited number of locations on the reservoir. After 1969 some additional data were collected but never thoroughly analyzed or published (Van Velson 1978; Morris 1976). As the result of a project designed to develop a model of the eutrophication process in Lake McConaughy (Taylor 1979), a considerable amount of physicochemical data were collected from 1976 through 1978. This paper is directed toward the presentation of these data in conjunction with data from past investigations to provide basic limnological information to those responsible for managing the reservoir's fishery.

DESCRIPTION OF STUDY AREA

Kingsley Dam impounds the North Platte River near Keystone, Nebraska to form McConaughy Reservoir. The dam was constructed by the Central Nebraska Public Power and Irrigation District in 1941 for storage of irrigation water (Table 1).

The reservoir is long and narrow with few embayments (Figure 1 and Table 2). The substrate is muck and silt in the deeper areas with sand predominating near shore. The shoreline is largely sand with occasional patches of rock and gravel. Water level fluctuates 6 to 8 m seasonally with highest levels from October to May. Strong westerly winds are common.

The fishery of the lake is a combination warm, cool, and coldwater population. Major sport species include striped bass *(Morone saxatilis)*, walleye *(Stizostedion vitreum)*, white bass *(Morone chrysops)*, channel catfish *(Ictalurus punctatus)*, rainbow trout *(Salmo gairdneri)*, and smallmouth bass *(Micropterus dolomieui)*. Gizzard shad *(Dorosoma cepedianum)* is the primary forage species. A complete discussion of the fishery can be found in McCarraher et al. (1971). Van Velson (1978) described in detail the life history of the self-sustaining rainbow trout population.

Various aspects of the reservoir's limnology have been described (EPA 1976; McCarraher et al. 1971; Morris 1976; Myers 1973; Rosowski et al. 1976 and 1977; Van Velson 1978). No comprehensive analysis of the lake's limnology, particularly in reference to the fishery, has been reported.

Table 1. Characteristics of Kingsley Dam.

Length, km	5.6
Height above stream bed, m	49.4
Base thickness, m	335.4
Surface outlet elevation, m msl	992.1
Surface outlet capacity, m^3 /sec.	1529.0
Bottom outlet elevation, m msl	953.8
Bottom outlet capacity, m^3 /sec	510.0

Table 2. Physical characteristics of Lake McConaughy.

Surface area, hectares	14,164
Reservoir length, km	35.2
Reservoir width, km	6.4
Maximum depth, m	53
Mean depth, m	22
Volume at maximum pool, m^3	2.4×10^9
Surface elevation, maximum pool, m msl	996.9
Shoreline length, km	169
Shoreline development, ratio of shoreline length to circumference of circle of equivalent area	4.8
Flushing time, years	2.4

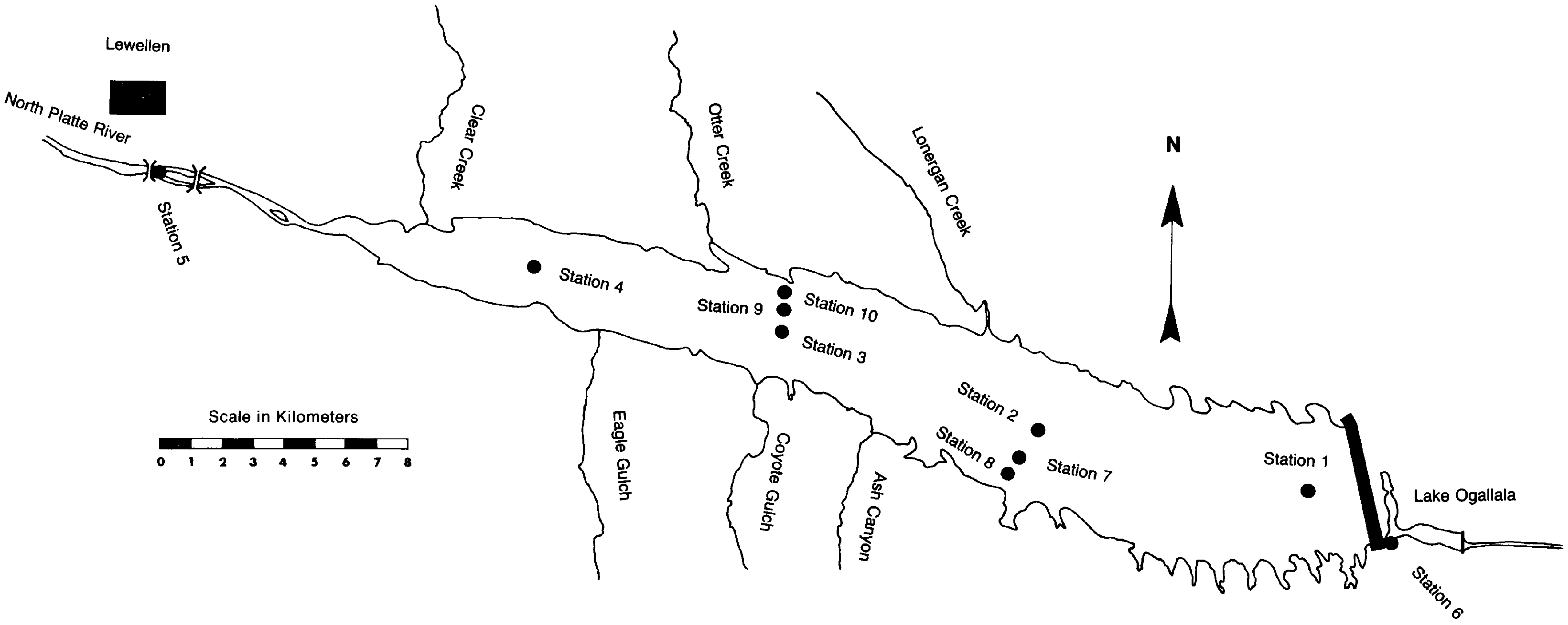

Figure 1. Lake McConaughy and the location of sampling stations.

MATERIALS AND METHODS

Field Sampling

Field samples were collected from August 1976 to August 1978. A bi-weekly schedule was followed during reservoir stratification (April to November) in 1976 and 1977. Monthly samples were collected only at the inlet and outlet during the winter. In 1978 reservoir samples were collected less frequently except during the height of stratification in July and August. Samples were collected from 10 locations (Figure 1). At each reservoir station (stations 1, 2, 3, 4, 7, 8, 9, 10), temperature (°C) and dissolved oxygen (mg/l) were measured at 1 m depth intervals with a YSI Model 57 Dissolved Oxygen Meter. Water samples for laboratory analysis were collected from five depths including a composite from the upper 10 m, mid-thermocline, upper hypolimnion, mid-hypolimnion and near the bottom. At the shallower stations (3 and 4) fewer than five samples were collected because of the lack of a thermocline or a significant hypolimnion. Two 2-liter bottles were filled from each sample depth. One was fixed with 5 ml of concentrated sulfuric acid to stop biological activity. This sample was used for the determination of ammonia nitrogen, Kjeldahl nitrogen, nitrate nitrogen, chemical oxygen demand, and orthophosphate. The other sample was used for the analysis of total alkalinity, chlorides, chlorophylls, specific conductance, calcium hardness, total hardness, total phosphates, total dissolved solids, and turbidity. Hydrogen ion concentration (pH) was determined in the field with a Horizon Ecology Model 5985-40 meter. Water transparency was measured with a secchi disc. At the inlet and outlet (stations 5 and 6) only one depth was sampled. With the exception of secchi disc transparency, which was not measured, determinations were the same as those for the lake samples. All samples were iced immediately and returned to the laboratory for analysis.

Laboratory Analysis

Total and calcium hardness (mg/l) were determined using the EDTA titrimetric method described in Standard Methods (1971).

Total alkalinity (mg/l) was determined by procedures outlined in Standard Methods (1971).

Chloride concentration (mg/l) was found using the mercuric nitrate method of Standard Methods (1971).

Chlorophyll a, b, and c (μg/l) was determined using the trichromatic method described in Standard Methods (1971).

Specific conductance (μmhos/cm) was found using a Model 31, YSI conductivity bridge.

Turbidity (NTU) was measured with a Hach 2100A turbidimeter.

Total solids (mg/l) was determined by evaporating 75 ml of water in a weighed dish in a Thelco Model 26 drying oven. The increase in weight over the empty dish was considered to be the concentration of total solids. Dissolved solids was determined in a similar manner except the sample was first filtered through a No. 3 Whatman, 11 cm diameter filter to remove particulate solids. The filtrate was evaporated and the dish weighed to obtain the concentration of dissolved solids.

Total phosphate (mg/l) was measured using the ascorbic acid procedure from Standard Methods (1971).

Orthophosphate (mg/l) was measured with a Technicon Auto-analyzer using an automated ascorbic acid method.

Nitrate nitrogen (mg/l) and ammonia nitrogen (mg/l) were also determined on the auto-analyzer.

Chemical oxygen demand (mg/l) was determined using the potassium dichromate method of Standard Methods (1971).

Kjeldahl nitrogen (mg/l) was determined by the procedure described in Methods for Chemical Analysis of Water and Wastes (1976).

Data for all variables were transferred to computer media for processing and analysis.

Statistical Analysis

Analyses included means, standard deviations, and other statistics on each variable for all sampling dates and stations, and for each individual station. Mean values for each variable were broken down by year, station, season, and depth. Resultant values are used throughout the results and discussion section.

Several more complicated analysis of variance (AOV) procedures were also utilized. For purposes of AOV, data were divided into two years, August 1976 through July 1977 and August 1977 through July 1978. Seasons of the year were defined as follows:

Season 1	Winter	January, February, March
Season 2	Spring	April, May, June
Season 3	Summer	July, August, September
Season 4	Fall	October, November, December

Stations remained defined as in Figure 1. Two depth levels were considered. The surface composite and the bottom sample. Variables considered in the analyses were water temperature (^oC), dissolved oxygen (mg/l), total alkalinity (mg/l), pH, total solids (mg/l), total dissolved solids (mg/l), total hardness (mg/l), calcium hardness (mg/l), chlorides (mg/l), specific conductance (μmhos/cm), total phosphate (mg/l), orthophosphate (mg/l), nitrate nitrogen (mg/l), ammonia nitrogen (mg/l), turbidity (NTU), secchi disc transparency (m), chlorophyll a (μg/l), and chemical oxygen demand (mg/l). The following analyses were then made for each variable:

1. A 3-way AOV with year, season, and station as independent variables. Only stations 1-4, surface measurements, were included. The objective was to determine horizontal variations in the reservoir along the major axis while also defining the significance of any yearly or seasonal changes.

2. A 3-way AOV with year, season, and stations as independent variables. Only surface measurements from stations 2, 3, and 7-10 were included. The objective was to determine if the value of measured variables differed horizonitally along transects perpendicular to the long axis of the reservoir. Again yearly and seasonal changes were noted.

3. A 4-way AOV with year, season, station, and depth as the independent variables. Stations were limited to 1, 2, and 3 and depths to top and bottom samples as these were the only stations with sufficient data for analysis by depth. The objective was to describe significant differences between surface and bottom values while accounting for variation due to year, season, and station.

4. A 3-way AOV with year, season, and station as independent variables. Stations 5 (inlet) and 6 (outlet) were the only ones included. The objective was to determine differences in variable values between the inlet and outlet while accounting for yearly and seasonal variability.

Other minor analyses were made as needed.

Graphic presentation of the data was made in isopleth form showing depth and seasonal changes together. In some instances, data did not lend itself to this type of presentation. As a result some graphics are presented as temporal fluctuations in surface values only.

RESULTS

Temperature

Temperature profiles for each sampling date for primary stations are shown in Figure 2. These profiles are similar to those found by previous investigators (Kiener 1951; Kiener 1952; Thomas 1964; McCarraher et. al. 1971; VanVelson 1978) and typical of deeper Great Plains reservoirs. Stratification began in early May each year, but did not become stable until mid-July. The thermocline usually developed between 15 and 20 m from the surface. Profiles were observed to change rather rapidly as a result of extreme changes in air temperature and strong northwesterly winds. These conditions produced very sharp thermoclines such as observed August 16, 1978 (Figure 2). Similar sharp gradients were reported in 1961 (Thomas 1964). The degree of stratification decreased in the upper reservoir stations primarily due to decreased water depth.

The maximum and minimum temperatures observed by station are shown in Table 3. Previous investigators have reported surface temperatures at station 1 as high as 26.7°C (Van Velson 1978). Excessively high temperatures are usually short-lived and confined to the upper 10 m of the water column. A more commonly reported high is 23-24°C, and even temperatures this high are short-lived.

No temperatures were measured under ice cover during this study. However, both inlet (station 5) and outlet (station 6) determinations were 0.0°C or nearly so during ice cover. More recently Ellison and Madsen (1980) reported temperatures of 0.0°C or less in the reservoir during ice cover. This is much lower than normally found under ice cover in most lakes. It is also much colder than water found in other lakes in the vicinity of Lake McConaughy (Ellison and Madsen 1980). They found temperatures uniform throughout with the exception of two bays fed by spring-fed streams. Otter Creek Bay and Lonergan Creek Bay each had temperatures substantially higher than 0.0°C and gradually declining as the distance from the mouth increased. These areas of higher temperatures are relatively small, on the order of 5 ha.

Extremely low winter temperatures may have a detrimental effect on gizzard shad (*Dorosoma cepedianum*), the primary forage species in the lake. Jester (1972) reported that small gizzard shad began succumbing when water temperatures reached 2.8°C. As temperature continued to decline, larger and larger individuals died. At 0°C, few if any gizzard shad can survive (Ellison and Madsen 1980). The only thermal refuge in Lake McConaughy is likely the spring-fed bays. Under conditions of low water levels (which eliminate the bays) and/or extremely low air temperatures, which quickly cool spring waters, the effectiveness of these refuges may be diminished. These factors should be considered when managing the fishery based on the availability and stability of the gizzard shad population.

Surface water temperatures did not vary significantly ($p \leq 0.10$) within the reservoir proper (stations 1-4 and 7-10). Although not statistically significant in the analysis used, there were short term variations which could be significant to fisheries activities. For instance, the upper reservoir warms faster in the spring and cools quicker in the fall than the lower reservoir. Also, the shallower water is more susceptible to short term temperature changes.

The average outlet temperature (10.0°C) was significantly ($p \leq 0.001$) lower than the inlet (15.3°C). The reservoir, consequently, acts as a cooling sink that provides water on the average at a temperature considerably below the mean river temperature. From a fisheries standpoint this is highly significant in relation to the management of Lake Ogallala, a 120 ha lake immediately below the dam.

Yearly differences in temperature were significant ($p \leq 0.10$), perhaps indicating some year to year variations in climatic conditions. As expected, seasonal changes were found to be significant ($p \leq 0.001$) as was the surface versus bottom temperature comparison ($p \leq 0.001$).

Table 3. Minimum and maximum temperatures (°C) recorded by station, Lake McConaughy, 1976-78.

Station	Minimum	Maximum
1	1.5	22.5
2	1.0	23.1
3	2.0	24.4
4	4.0	25.3
5	0.0	30.2
6	0.0	19.8
7	1.5	23.8
8	2.0	24.0
9	2.0	23.0
10	3.5	23.0

Table 4. Ranges in chemical and physical characteristics previously reported for Lake McConaughy.

	Minimum	Maximum
Ammonia nitrogen, mg/l	0.01	0.99
Nitrate nitrogen, mg/l	0.00	8.70
Total phosphate, mg/l	0.01	2.30
Orthophosphate, mg/l	0.00	0.96
Turbidity, NTU	1.00	26.00
Total alkalinity, mg/l	145.00	260.00
Specific conductance, μmhos/cm	680.00	790.00
pH	7.50	8.90
Total dissolved solids, mg/l	243.00	575.00
Total solids, mg/l	418.00	739.00
Chemical oxygen demand, mg/l	0.10	108.60
Chlorophyll a, μg/l	0.10	29.30
Chlorides, mg/l	17.00	20.00
Total hardness, mg/l	170.00	440.00
Calcium hardness, mg/l	88.00	280.00

For basic monitoring, the temperature regime in Lake McConaughy can be described reasonably well with profile measurements at station 1 and temperature readings from the inlet and outlet. These stations, however, would not be sufficient to detail early spring warming of upper reservoir waters, temperatures of lake water near feeder streams, or other areas of special interest.

The relationship between the temperature regime and suitability for various species of fish will be discussed after presentation of other physicochemical data.

Dissolved Oxygen (DO)

The temporal and spatial distribution of dissolved oxygen is shown in Figure 3. DO remains quite adequate for fish life at all depths and stations except during summer stratification. Degradation begins in mid-May and becomes quite severe in the hypolimnion by mid-August. Complete depletion of hypolimnetic oxygen was observed in all three summers of this study. Other investigators have reported similar DO patterns in Lake McConaughy except that in some years hypolimnetic depletion was not complete (Van Velson 1978; Thomas 1964).

No significant differences ($p \leq 0.10$) in surface DO were found among stations 1-4 and 7-10. However, surface values were significantly greater ($p \leq 0.001$) on the average than bottom values. The outlet showed a significantly higher DO level than the inlet, probably due primarily to the lower water temperature and in part to the aeration occurring in the outlet structure.

Yearly and seasonal differences were also found to be significant ($p \leq 0.10$) in all AOVs. This would indicate significant temporal changes both within the year and between years. These changes are likely related to water temperature and the depletion of hypolimnetic DO described above.

Total Alkalinity (ALKA)

Total alkalinity (mg/l) ranged from 153 to 279 (Figure 4). The minimum observation was within previously reported ranges, but the 279 mg/l determination was 19 mg/l higher than previously reported for Lake McConaughy (Table 4). All observations were well within the range reported from other Great Plains reservoirs (Table 5).

On the surface a significant difference ($p=0.044$) among stations was found along the major axis, station 4 showing the highest values. No horizontal differences ($p \leq 0.10$) were apparent perpendicular to the long axis (AOV with stations 2, 3, 7-10).

Yearly differences were significant ($p \leq 0.10$), the higher values occurring in year 2. Seasonal changes were apparent (Figure 4) and statistically significant ($p \leq 0.10$). Overall, the lowest recordings occurred in the fall and the highest in the spring.

Total alkalinity at the inlet was significantly higher ($p \leq 0.001$) than at the outlet. Surface values (stations 1-3) were significantly lower ($p=0.007$) than bottom determinations.

Although total alkalinity varied significantly among stations, depths, and years, it always remained in a range compatible to fish production. Total alkalinity provides a measure of the total bases in the water.

Monitoring of total alkalinity on a regular basis is probably unnecessary for fishery purposes. It stays in a compatible range and will not likely change from that pattern within the foreseeable future.

All the alkalinity in Lake McConaughy was due to the bicarbonate ion. A well buffered system is desirable from a fisheries standpoint because it allows biological production to commence uninhibited by drastic chemical changes in the water. Bases provide buffers for various chemical reactions and are particularly important in maintaining pH in a narrow range.

Table 5. Physical and chemical characteristics of various lakes and reservoirs in the mid United States from Montana to Texas.

Lake and Investigator	Min. - Max. Temperature °C	Dissolved Oxygen (mg/l)	Total Alkalinity (mg/l)	pH	Total Hardness (mg/l)	Calcium Hardness (mg/l)	Chlorides (mg/l)	Specific Conductance (µmhos/cm)	Total Phosphate (mg/l)	Orthophosphate (mg/l)	Nitrate Nitrogen (mg/l)	Ammonia Nitrogen (mg/l)	Secchi Disc Transparency (m)
Tuttle Creek Res., Ks. Taylor (1971)	* - 27.9	3.2-8.9	102-232	7.1-8.7				250-580		0.04-1.44	0.01-1.49		0.03-1.42
Viva Naughton Res., Wy. Funk and Gaufin (1971)	2.0-21.0	0.5-14.0	50-120			24-55	0.02-3.22		0.23-0.97	0.0-0.33	0.01-0.98	0.0-0.18	
Waco Res., Tx. Lind (1971)		7.7	145	8.3	169	58		290	0.004		0.2		
Yellowtail Res., Mt. Wright and Soltero (1973)	* - 24.0	0.6-11.6	122-276	7.5-8.8		55-181	6.00-14.50	600-1300		0.0-0.80	0.01-0.90	0.0-0.60	
Missouri R. Mainstem Res. Benson (1968)			136-245	7.0-8.5	139-280	39-73	2.40-13.00	365-876	0.01-3.15		0.17-1.90	0.0-2.30	
Oahe Res., S.D. Selgeby and Jones (1974)	*-23	3.0-11.8	125-190	7.4-9.2		38-60	7.00-10.80	486-969		0.002-0.117	0.03-0.20	0.0-0.155	0.60-6.10
Flathead Lake, Mt. Gaufin et al. (1976)	*-21.0	8.0-11.0	10-86	8.0-8.8			0.32-1.00			0.0-0.20	0.0-0.19	0.01-0.32	

* = minimum temperature "not available"

Hydrogen Ion Concentration (pH)

The hydrogen ion concentration (pH) in the water ranged from 7.6 to 8.85. Temporal variations (surface only) for main stations are shown in Figure 5. All values were within previously recorded ranges (Table 4) and well within the range described for other reservoirs (Table 5).

The pH in year 1 was significantly higher ($p=0.002$) than in year 2. Seasonal differences were also significant ($p=0.04$) with the lowest pH occurring in the summer. Surface pH was higher than bottom pH for stations 1-3. This is a normal occurrence in stratified waters. For surface data, no differences ($p \leq 0.01$) were found within the reservoir proper. Outlet pH was significantly lower ($p = 0.04$) than the inlet pH.

The pH of water is controlled by the chemical constituents present. To promote aquatic life pH should remain in the 7.0-9.5 range and preferably near 8.0. The values found in Lake McConaughy were near optimim for fish production except in the hypolimnion during stratification. Fish do not inhabit this area so the lower values were of little consequence. Given the high total alkalinity values found, pH is unlikely to vary outside the ranges measured in this and previous studies.

Hydrogen ion concentration was very stable in Lake McConaughy and is not likely to pose problems for the fishery. Monitoring on a regular basis is not suggested. However, measurements will be necessary in special cases of high algal blooms or other abnormal water conditions.

Total Solids (TS)

Total solids (mg/l) ranged from 396 to 1300 (Figure 6). The maximum value was considerably higher than the 739 mg/l previously reported (Table 4), but previous data did not include inlet samples. The higher TS concentrations were from the inlet. Within the reservoir, the maximum concentration was 864 mg/l, still above previously reported values.

Yearly and seasonal differences were found to be significant in all analyses ($p \leq 0.01$). Concentrations were higher in year 1 than year 2. Seasonal variation included a winter high followed by a spring low and a rise in summer and fall.

There was also a significant difference ($p \leq 0.01$) along the major axis of the reservoir (surface samples), the primary differences being higher values at station 4. Significant differences ($p=0.032$) also occurred perpendicular to the long axis but no pattern could be established.

Depth was found to be non-significant ($p \geq 0.01$) in determining TS. TS was much higher ($p \leq 0.001$) at station 5 than at station 6.

The range of the total solids found was well within the tolerance range of all fishes. The water can be considered reasonably hard, typical of Great Plains reservoirs. Variations found were not particularly significant to the fishery and are not likely to ever be limiting.

Total Dissolved Solids (TDS)

Total dissolved solids are closely related to total solids, and as a result patterns were similar (Figure 7). The maximum value of 842.7 mg/l was considerably above the maximum previously reported value of 575 mg/l, but the minimum of 359 mg/l was within previously reported ranges (Table 4).

Yearly differences were significant ($p \leq 0.10$) with year 2 being the lowest. Seasonal differences ($p \leq 0.001$) were similar to TS.

Along the major axis, TDS at the surface were significantly different ($p=0.005$), the highest mean concentration being found at station 4. There were no significant variations ($p \leq 0.10$) perpendicular to the long axis or due to depth. TDS was significantly higher ($p \leq 0.001$) at the inlet than at the outlet.

TDS has been used as an index to the productive capability of a lake. Ryder (1965) described a morphoedaphic index obtained by dividing TDS by mean depth. Jenkins and Morais (1971) expanded the development of this index by relating it to total standing crop of all fishes, standing crop of game fishes, and harvest of game fish. All regression equations that he developed were parabolic with maximum standing crops and harvests found at intermediate values of the morphoedaphic index (Figure 8). The morphoedaphic index for Lake McConaughy is 23.3. This value falls very near the peak on all 3 curves. Using the equations for these lines, the following predictions were made:

Total standing crop, all fish	246 kg/ha
Standing crop of game fish	77 kg/ha
Harvest of game fish	35 kg/ha

Values for the standing crop estimates do not seem unreasonable, but the predicted harvest of 35 kg/ha is much higher than the 5.1 kg/ha observed in a 1977-78 creel census (Madsen 1980). Another relationship developed by Jenkins and Morais (1971) may help explain why. He derived the equation log harvest in kg/ha = -0.4687 + 0.8935 log hours/ha to describe the relationship between total harvest and angler effort. Using the observed effort on Lake McConaughy in 1977-78 of 21.6 hours/ha, a harvest of 5.3 kg/ha was predicted. Of these two predictions of harvest, one predicts harvest potential based on productivity while the other predicts harvest as a result of angler effort. This leads to the observation that harvest potential is not being realized on Lake McConaughy due to inadequate fishing pressure. This seems very possible in light of its location and observed low level of pressure.

From this total discussion it can be concluded that Lake McConaughy should be a highly productive body of water due to a near optimim morphoedaphic index. Furthermore, the productive potential is not being realized due to inadequate fishing pressure. Regardless of whether these predictions are accurate or not, the levels of TDS found in this study are indicative of high productivity.

Total Hardness (TH)

Annual variations in surface total hardness (mg/l) at each of six stations are shown in Figure 9. The minimum and maximum observations were 164 and 315 mg/l, respectively. The minimum value fell 6 mg/l below the previosuly reported value of 170 mg/l (Table 4).

No significant differences ($p \leq 0.10$) were found between years. Significant ($p \leq 0.01$) seasonal changes showed a high in the winter, lower concentrations in spring and summer and an increase in the fall.

TH showed statistically significant ($p=0.063$) variations among stations 1-4 for surface samples. As with TS and TDS the highest values were at station 4. Perpendicular to the long axis, no significant differences ($p \leq 0.10$) were found. TH was significantly ($p \leq 0.001$) greater on the bottom than on the surface. TH was also greater ($p \leq 0.01$) at the inlet than the outlet.

TH is an indicator of the productive capability of the water. In this case, all values fell in a range not limiting to fishes and indicative of high productive capability. TH is not likely to change significantly in future years so monitoring on a regular basis is not necessary.

Calcium Hardness (CHRD)

Graphic representation of surface measured CHRD is shown in Figure 10. The minimum value of 96 mg/l was within previously reported limits, but the maximum of 293 mg/l was 13 mg/l higher than the previous high (Table 4). All values were high compared to those reported from other reservoirs (Table 5).

Yearly differences were significant ($p \leq 0.01$), lower concentrations being found in year 1. Significant ($p \leq 0.01$) seasonal patterns showed a high in winter, a drop in spring and summer, and an increase toward fall.

Station differences along the major axis and perpendicular to it were not apparent ($p=0.162$ and 0.999, respectively). Bottom concentrations were significantly higher than surface values ($p \leq 0.001$). The inlet showed greater values ($p \leq 0.001$) than the outlet.

Comments relative to the fishery would be similar to those for TH.

Chlorides (CL)

The distribution of chlorides (mg/l) is shown in Figure 11. The minimum and maximum values recorded were 13.4 and 23.2 mg/l, respectively. The maximum value was higher than any previously reported for Lake McConaughy (Table 4) and also higher than reported for other area reservoirs (Table 5). Within the reservoir, no station or depth differences were found ($p \leq 0.10$). Yearly changes were noted, however, as chlorides were significantly higher in year 2 ($p \leq 0.10$). The inlet versus outlet analysis showed higher values in year 1 ($p=0.005$), significant seasonal changes ($p=0.023$), the higher concentrations occurring in summer, the lowest in winter, and significantly higher values at the inlet.

The values of CL found were within tolerable ranges for freshwater fish and indicative of a productive aquatic ecosystem. Significant changes are not expected and as a result, further monitoring is not suggested.

Specific Conductance

The specific conductance of 336 samples ranged from 460 to 920 μmhos/cm (Figure 12). Both the high and low values were outside those previously found (Table 4). Previously collected data were concentrated in the summer months and few samples have ever been taken. As a consequence, the values previously obtained were likely not very representative of the total picture in Lake McConaughy. Values obtained were within ranges reported on other reservoirs (Table 5). No yearly changes were evident ($p \leq 0.10$).

Seasonal differences ($p \leq 0.10$) were found in all analyses, the highest values occurring in summer and fall, the lowest in the spring. No station or depth differences were found within the reservoir ($p \leq 0.10$). However, the inlet had significantly higher conductivity ($p = 0.008$) than the outlet.

Specific conductance is a measure of the conductive capacity of the water which is dependent on the amount of ionizable substances present. Actually, it is simply another method for assessing the potential productivity of the water. Values found indicate a productive environment suitable for freshwater fishes. Further monitoring of this parameter is not needed.

Total Phosphate (TPO_4)

The seasonal and spatial distribution of total phosphate (mg/l) is shown in Figure 13. Concentrations found ranged from 0.01 to 2.55 mg/l, the upper value being slightly higher than any previously recorded (Table 4). Along the major axis, surface TPO_4 varied significantly between stations ($p \leq 0.01$), the highest values being recorded at station 4. No differences were noted perpendicular to the long axis ($p \leq 0.10$). There was a significant difference between surface and bottom samples ($p = 0.10$), the bottom being higher. Seasonal changes were evident from within the reservoir analyses ($p \leq 0.10$), the highest concentrations occurring in the fall. Relative to the inlet and outlet, the inlet concentration was significantly higher ($p = 0.001$) by approximately 0.3 mg/l. Significant seasonal differences at the inlet and outlet showed the lowest concentrations in the fall and winter, the highest in spring and summer ($p \leq 0.10$).

Orthophosphate (OPO_4)

Orthophosphate distribution patterns are shown in Figure 14. The range of values measured was 0.0 to 0.66 mg/l, both near the range previously reported (Table 4). When analyzing for differences along the major axis, no seasonal changes ($p \leq 0.10$) were noted, but station differences were significant ($p = 0.022$). As with TPO_4, the highest values were at station 4. No differences were found among stations perpendicular to the long axis. However, seasonal differences were noted in this analysis ($p=0.039$), the highest values being found in fall and winter. Depth was a significant factor ($p=0.006$) in the depth analysis, the bottom showing higher values. Season and station were also significant in this analysis ($p \leq 0.10$). The inlet showed a significantly higher OPO_4 value than the outlet ($p=0.023$).

TPO_4 and OPO_4 are both indexes of the amount of phosphorous available in the water. Given the tests used in this study, TPO_4 is likely a better indicator of the amount of phosphorous in the system than OPO_4.

Phosphorous is a necessary nutrient for algal production in an aquatic ecosystem. This production is necessary to produce fish biomass, but can also create problems through depletion of DO in the hypolimnion (discussed later) and other detrimental characteristics of eutrophication. Algal production in Lake McConaughy is phosphorous limited (EPA 1976) and, therefore, any attempts to limit the eutrophication process should be directed at phosphorous reduction. An annual net accumulation of nearly 200,000 kg of TPO_4 occurs in Lake McConaughy. Where this phosphate goes is uncertain. It is possible that as much phosphate is bound up by the sediments as enters the lake each year. If this is the case, then an equilibrium condition has been reached and further eutrophication is unlikely. A more probable situation is that some of the phosphate is tied up, but a portion of it becomes active in the biological system, increasing algal production. If this is undesirable, then limiting net phosphorous accumulation would be desirable. One approach to reducing phosphorous loading would be to reduce the concentration in inflow waters. This would be practical if a substantial portion of the phosphorous present was from point sources. However, this is not the case as nearly all of the phosphorous in inflowing waters is from nonpoint sources such as agricultural runoff (Myers 1973). To limit the concentration would be impractical from a fishery management standpoint. Some progress may be obtained, however, through federally mandated programs directed at reducing sources of nonpoint pollution. A simple reduction in inflow concentration, if accomplished, still may not reduce algal production due to the reservoir of phosphorous in the sediments that could be recycled into the water column (Latterell et al. 1971).

A second approach to reducing net loading is a result of summer stratification. Phosphorous is released from sediments primarily under anaerobic conditions which occur during this time (Wildung and Schmidt 1973). By releasing water from the hypoliminion during mid to late summer, phosphorous rich water would be discharged, minimizing loading.

Neither of the above techniques is likely to reduce eutrophication significantly. As will be discussed later, reducing eutrophication may not be necessary.

TPO_4 and OPO_4 are monitored regularly by the Nebraska Department of Environmental Control at the inlet and outlet of Lake McConaughy. This data, along with other variables measured, should be obtained regularly and trends assessed.

Nitrate Nitrogen (NO_3-N)

Nitrate nitrogen was found to vary from 0.0 to 2.8 mg/l (Figure 15). These values were well within the previously reported range (Table 4). Along the major axis, seasonal ($p \leq 0.001$) and station ($p=0.016$) effects were both significant. The highest surface values were found in winter, the lowest in the summer. Station 4 showed higher values than the remaining stations.

No station differences ($p \leq 0.10$) were noted perpendicular to the major axis, though seasonal variations were evident ($p \leq 0.001$). Bottom samples were not significantly different from surface samples ($p \leq 0.10$). Significantly higher ($p \leq 0.001$) concentrations were found at the inlet than at the outlet. In this analysis, significant seasonal effects ($p=0.002$) showed the highest value in the fall and the lowest in summer.

Nitrate nitrogen is also an important plant nutrient necessary for algal production. If a system is nitrate limited it becomes desirable to limit this nutrient. However, Lake McConaughy is not nitrate limited at this time, hence control of nitrates would not result in improved water quality. An annual loading of about 1.3 million kg occurs. This will not become significant unless the nitrogen-phosphorous ratio decreases significantly causing nitrates to become limiting. Due to the chance that this could conceivably occur, it is still desirable to limit nitrates where possible. The primary method for limiting nitrates would be through reduction of inflow concentrations. As with phosphorous, this would depend on reducing nonpoint sources of pollution. Nitrates can also be reduced through hypolimnetic withdrawal of water during stratification.

The Nebraska Department of Environmental Control records of NO_3 N determinations should be obtained along with the phosphate data.

Ammonia Nitrogen (NH_3 N)

Ammonia nitrogen values ranged from 0.0 to 1.2 mg/l (Figure 16). The maximum value is somewhat higher than the previously reported maximum of 0.99 mg/l (Table 4). No significant differences ($p \leq 0.10$) due to station or season were found along the major axis. However, yearly differences were significant ($p=0.026$), year 2 showing higher values. No station differences were noted perpendicular to the major axis, but seasonal and yearly differences were significant ($p=0.039$, $p \leq 0.001$). The highest NH_3 N values occurred in the summer. Bottom NH_3 N concentration was higher than the surface ($p=0.025$) at stations 1-3. In contrast to most other variables, NH_3 N was significantly higher at the outlet than the inlet ($p \leq 0.001$).

Ammonia nitrogen is an indicator of the respiration and hence the production occurring in a lake. Low values are common because NH_3 N is reduced to NO_3 N very quickly. Concentrations of NH_3 N found were not detrimental and rather inconsequential. Further monitoring of this parameter is probably unnecessary at this time.

Turbidity (TURB)

Temporal and spatial differences in turbidity (NTU) are shown in Figure 17. The maximum of 315 NTU was considerably higher than any previously reported value (Table 4). Along the major axis, turbidity increased significantly ($p \leq 0.001$) from station 1 to station 4. Perpendicular to the major axis a significant difference was found ($p \leq 0.001$). The highest values were at stations 3, 9, and 10, the upper transect, while the lowest values were at stations 2, 7 and 8. As expected, bottom samples showed a higher turbidity than surface samples ($p = 0.012$). In all of the above analyses, seasonal differences ($p \leq 0.10$) were noted. Summer turbidity was the highest in all cases. As expected, the inlet showed a significantly higher TURB than the outlet ($p \leq 0.001$).

Secchi Disc Transparency (SECCHI)

Secchi disc readings were taken only in the main reservoir at the surface (Figure 18). A highly significant ($p \leq 0.001$) difference in secchi disc transparency was evident along the major axis, the highest readings being at station 1, the lowest at station 4. Significant ($p \leq 0.001$) seasonal changes showed highest values in the spring and the lowest in the fall. Perpendicular to the major axis, analyses showed station 2, 7, and 8 to be higher than 3, 9, and 10.

Water clarity found in Lake McConaughy, whether measured in turbidity units or by secchi disc, was not limiting to fishes in most cases. Sufficiently high turbidity was occasionally found at stations 4 and 5 to limit sight feeding fishes. However, the phenomenon was not widespread and was not high enough to cause physical harm to the fish. The above indexes showed a gradient from the lower reservoir to the upper with the clearest water near the dam and the most turbid near the inlet. Turbidity in the upper reservoir was due to a combination of suspended inorganic material and phytoplankton. In the lower reservoir, phytoplankton was the primary source of turbidity. In the spring and early summer when zooplankton populations were high, water clarity was high. As the summer progressed, higher water temperatures and predation reduced zooplankton, then phytoplankton became more abundant, reducing water clarity to a lower level which persisted into fall.

Water clarity characteristics are not likely to change significantly in the near future. Some increase in turbidity could occur as a result of continued eutrophication and the introduction of new forage fishes. Forage fish depend heavily on zooplankton for food which would result in higher phytoplankton density. However, no significant problems are visualized as a result of either factors.

Chlorophyll a (CHA)

Chlorophyll a concentrations ranged from 0.0 to 150.4 μg/l (Figure 19). The maximum value was considerably higher than previously reported (Table 4), but sampling in this study was more intensive and widespread than in previous studies. Significant differences ($p \leq 0.001$) along the major axis were due mainly to a very high mean value at station 4. Seasonal patterns showed significantly higher ($p \leq 0.021$) levels in spring and summer. No significant station differences were found in the analysis testing differences perpendicular to the major axis. Bottom CHA concentrations were higher than surface values at stations 1-3 ($p=0.094$). Significantly higher mean values were found at the inlet than at the outlet ($p=0.010$). Yearly differences were evident in some of the AOVs ($p \leq 0.10$).

CHA is indicative of algal concentrations. The purpose in its determination in this study was to show seasonal variations and variations along the major axis. Results indicate that variability is high, and that to adequately assess CHA would require several sampling sites at frequent time intervals. Although indicative of the eventual supply of food for fish, the major fluctuations in CHA are dampened considerably several steps up the trophic pyramid. The primary purpose for future monitoring would be to assess trends in the eutrophication process. As noted above, an intensive effort would be necessary in order to establish trends.

Chemical Oxygen Demand (COD)

Seasonal values of COD at the main stations are shown in Figure 20. All values were within the previously recorded range (Table 4). Along the major axis, the lowest mean value was found at station 2, with significantly ($p=0.039$) higher values at station 4. No differences were noted perpendicular to the long axis ($p \leq 0.10$). Depth was not an important factor in determining COD ($p \leq 0.10$). The inlet showed a significantly ($p \leq 0.001$) higher COD concentration than the outlet. Seasonal changes were also significant in this analysis ($p = 0.011$), COD being highest in the summer and lowest in the fall and winter.

COD was measured to obtain an estimate of the oxidation demand present in the water. It was not found to be excessive in any case and is not a limiting factor. Further consideration of COD in fisheries related activities would be necessary only if intensive eutrophication studies are undertaken.

Future Fishery Related Water Quality Studies

Reference has been made throughout the discussion to future monitoring of water quality parameters. Some general comments are in order relative to future studies. With minor exceptions, physical and chemical parameters were uniform within the main reservoir (stations 1, 2, 3). Station 4, being strongly influenced by the inlet and extremely shallow water conditions, was generally different from the main reservoir. These observations indicate that future needs could be satisfied with samples from the inlet, outlet, station 4, and the main reservoir. Samples from various depths may be necessary in the main reservoir depending upon the variables being measured.

From a fishery standpoint, temperature and dissolved oxygen profiles and secchi disc readings in the main reservoir should be taken regulary to allow establishment of any trends that may develop. Data from the Nebraska Department of Environmental Control should be obtained to assess trends in nutrient concentration. Total alkalinity, pH, total dissolved solids, and specific conductance, although not expected to change, should be determined every few years to detect any trends.

Water Quality and the Fishery

The chemical and physical characteristics of Lake McConaughy indicate that the lake is eutrophic. The lake has a near optimum morphoedaphic index for the production of fish. In some years the lake could be classified, by normally accepted criteria, as a warmwater fishery. It has previously been described as a "two-story reservoir" (Taylor 1979), one which contains both warm and coldwater habitat. This is appropriate in some years, but in many years complete degradation of hypolimnetic DO eliminates the classically defined coldwater habitat (21°C, 3 mg/l DO). The reservoir is not truly warmwater either, because epilimnetic temperatures seldom exceed 24°C and are most often between 21°C and 24°C. This rather low maximum temperature coupled with the deep thermocline and the morphometry of the lake make it best suited for cool water pelagic species such as walleye and white bass. The present fishery bears this out, as walleye and white bass have emerged as dominant game fish from a myriad of introductions in past years.

Considerable concern has developed over the continued capability of Lake McConaughy to support coldwater species, primarily McConaughy strain rainbow trout. In the late 1960's and early 1970's, the trend appeared to be toward rapid eutrophication (Van Velson 1978). As a consequence, a study was initiated to develop a predictive model of the eutrophication process in Lake McConaughy. This effort was in general, a failure and is described by Taylor (1979). Even without the model, it should be possible to make some assessment of the future for trout in Lake McConaughy.

Using accepted criteria for the definition of coldwater fishery habitat (21°C, 3 mg/l DO), Figure 21 was constructed to show trends in coldwater availability in Lake McConaughy since 1951. There have been times when classic coldwater has been nonexistent. This has happened sporadically for many years and does not seem to be more severe in recent years.

Past studies have indicated that the McConaughy rainbow trout has adapted to this environment and has developed a selective advantage over domestic strain hatchery rainbows (Van Velson 1978). Vancil et al. (1979) suggested that some of the advantage gained may be due to the tolerance of higher temperatures. Burdick et al. (1954) reported tolerance of DO levels below 2 mg/l for rainbow trout held at 21.7°C (71.1°F). This would seem to indicate that, under favorable DO conditions, rainbows could tolerate temperatures higher than 21.7°C. Other evidence in the literature also suggests that rainbows can tolerate water warmer than 21°C. If this is true of normal strain rainbows, then the McConaughy rainbow should easily tolerate temperatures up to 24°C. Figure 21 shows the trend in available habitat for trout given criteria of 24°C or less at DO of 3 mg/l or greater. Obviously, using these criteria, trout may not have been severely stressed in the past.

Using the more liberal criteria, eutrophication of Lake McConaughy and its relationship to coldwater fishery habitat becomes inconsequential. The availability of suitable habitat may not be dependent upon the maintenance of DO below the thermocline. Instead, maintenance of sub 24°C temperatures at some level in the epilemnion may be the critical factor. This is not related to chemical characteristics of the water, but rather to climatic conditions. Historically, sub 24°C water has been maintained throughout the summer. Provided that the climate does not shift to a warmer one, similar conditions will be maintained indefinitely.

Continued eutrophication in Lake McConaughy is not a certainty, but a strong probability. As stated earlier, this may be of little consequence to the coldwater fishery. It could however, if severe enough, begin to alter the characteristics of the lake sufficiently to cause changes in the fishery. Typically, as a lake eutrophies, algal concentrations increase, the species composition of the algae changes, and water becomes more turbid. Certain fish species are more adaptable to these conditions than others (Haines 1973). The more adaptable species are generally less desirable such as carp (*Cyprinus carpio)*, various catfishes, and miscellaneous rough fishes. These are undesirable changes for Lake McConaughy. Therefore, support should be given any program which could have a positive impact on reducing the rate of eutrophication in the lake.

Lake McConaughy is unique in that it is neither a true warmwater, true coldwater, or true "two-story" lake. It could be more aptly described as a one story coolwater lake. The prognosis for the future of the lake fishery is bright. Chemical and physical characteristics should remain near optimum levels for the foreseeable future. Conditions are best suited for coolwater species with acceptable conditions for appropriately adapted coldwater species and traditional warmwater species such as channel catfish. Future fishery management plans should give consideration to the inherent instability of the gizzard shad as a forage fish.

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APPENDIX

Figures 2-21

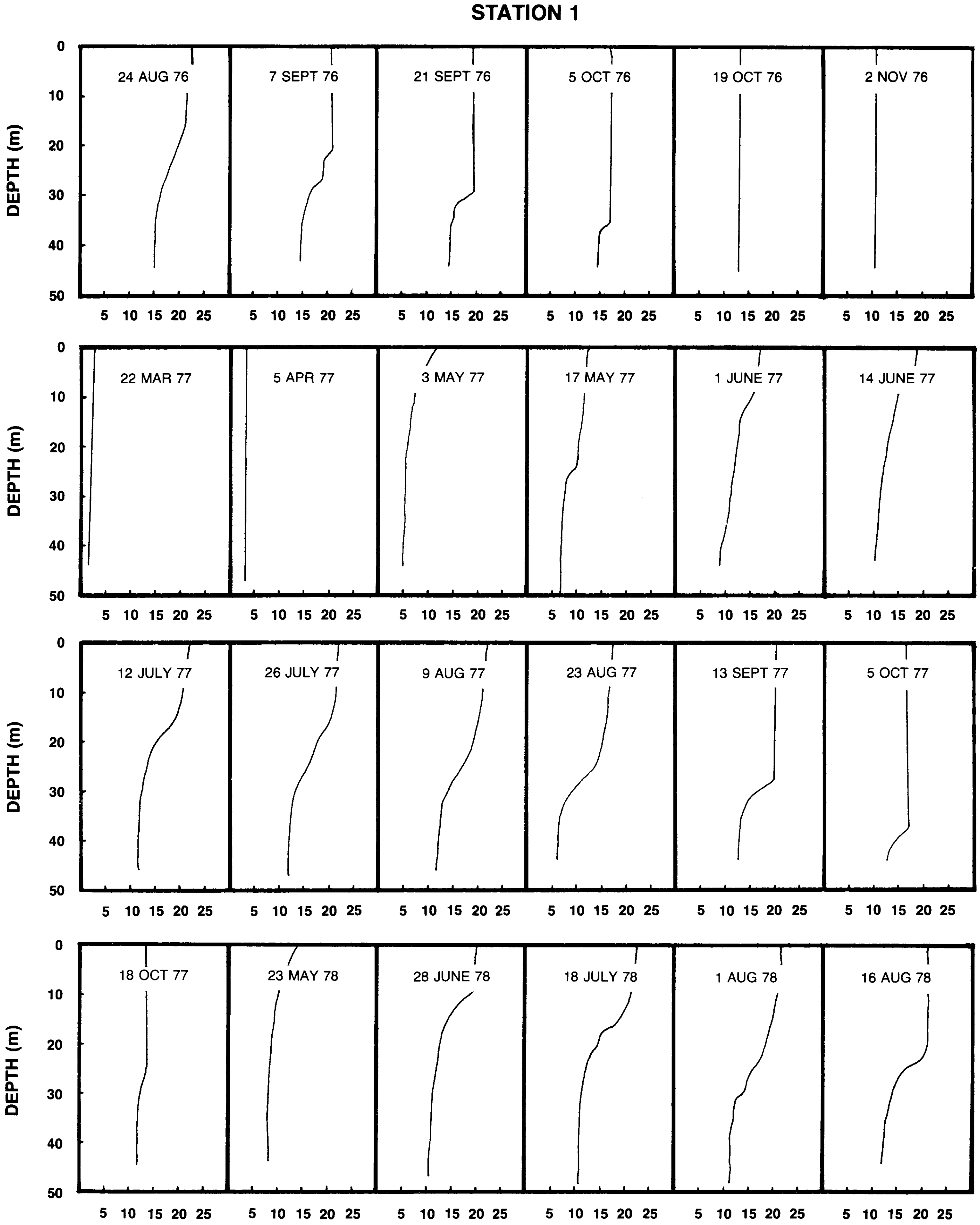

Figure 2. Temperature (^{o}C) profile at station 1.

STATION 2

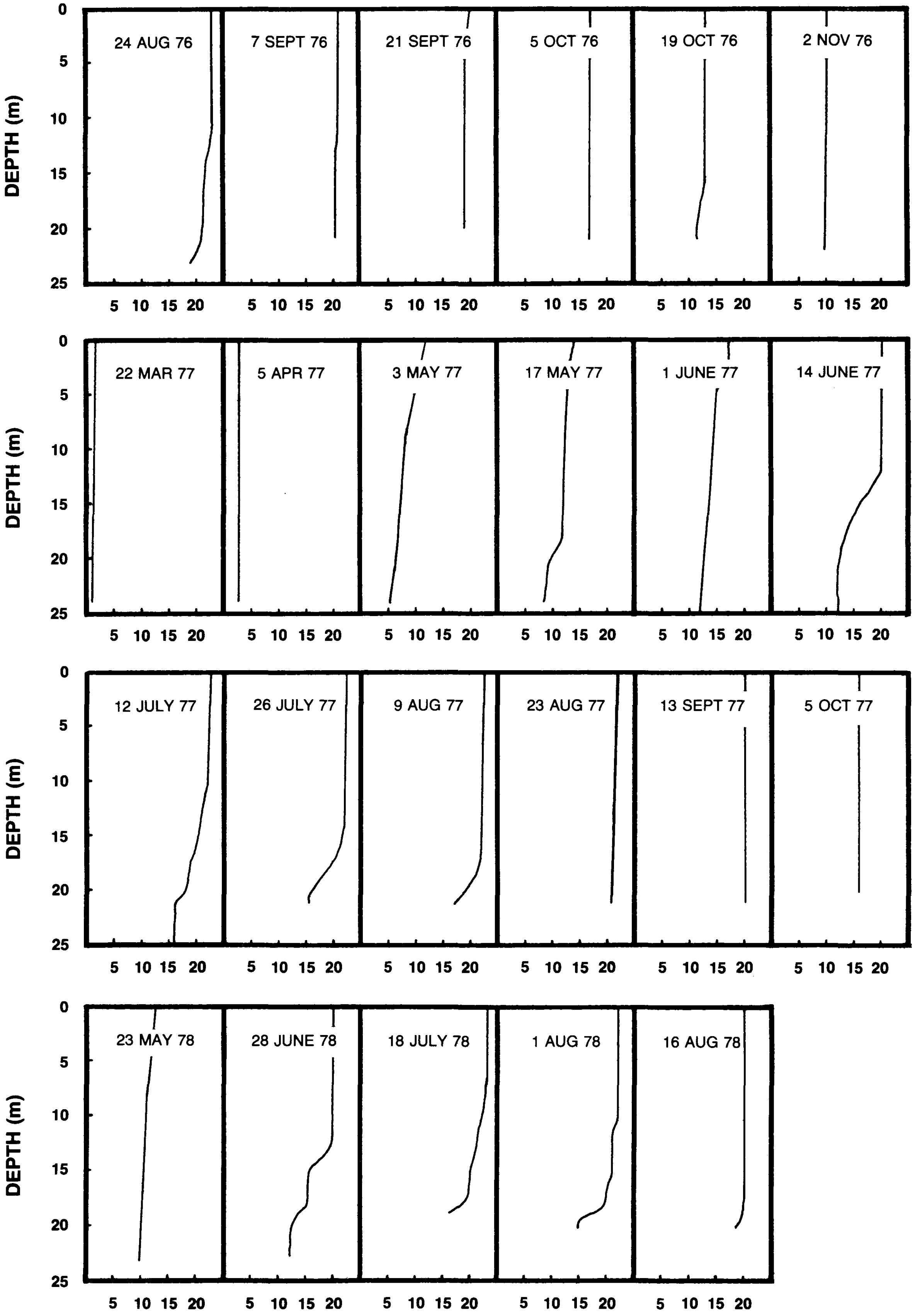

Figure 2. Continued. Temperature (°C) profile at station 2.

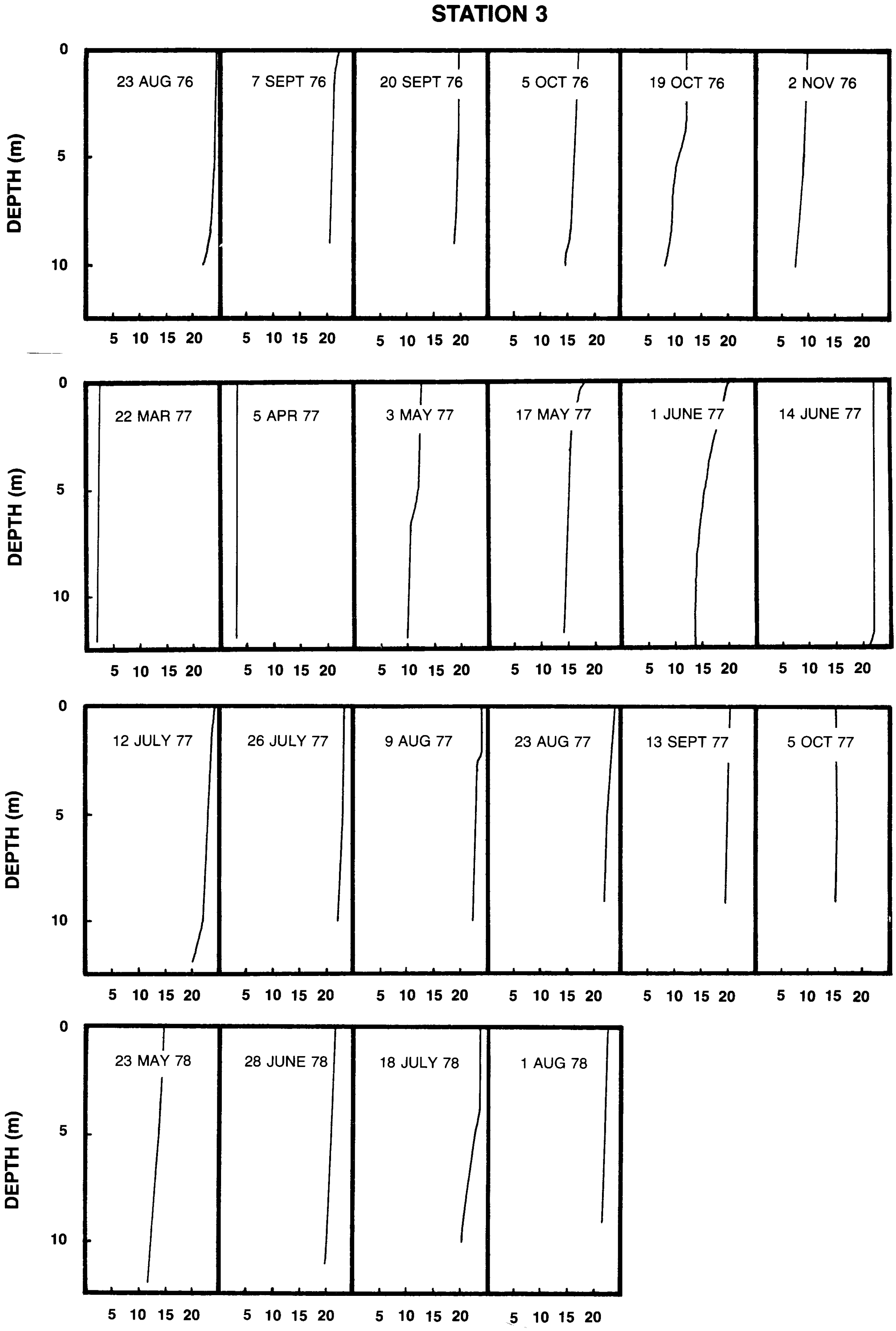

Figure 2. Continued. Temperature (°C) profile at station 3.

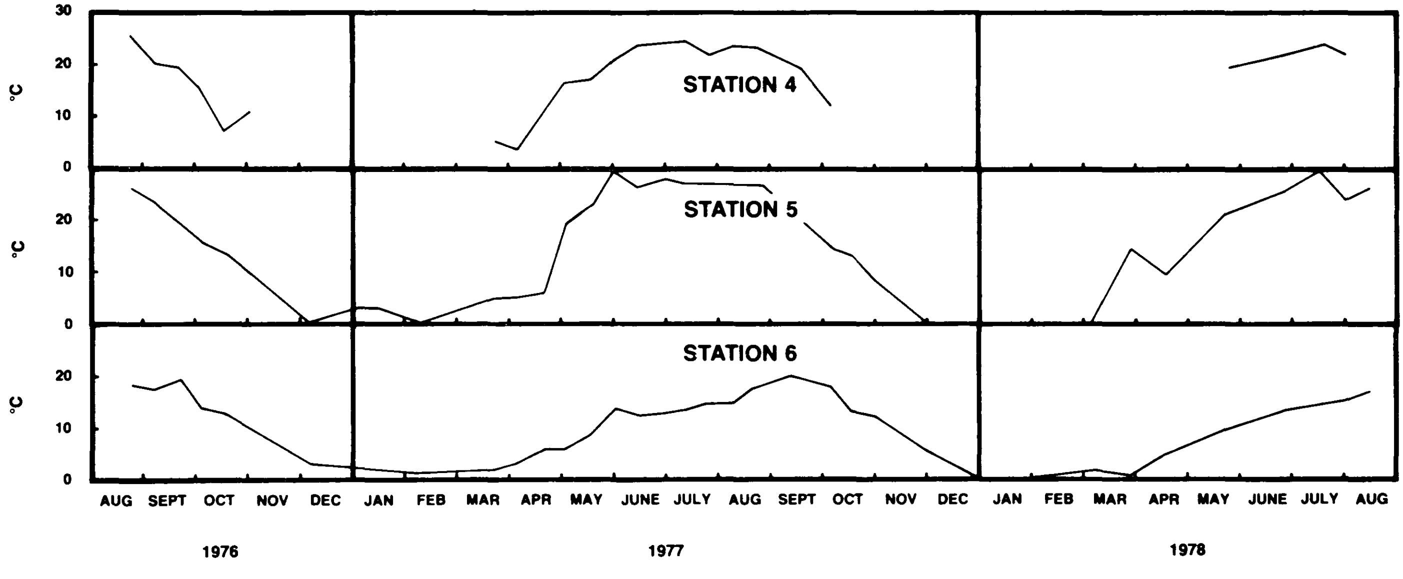

Figure 2. Continued. Temperature (°C) profile at stations 4, 5 and 6.

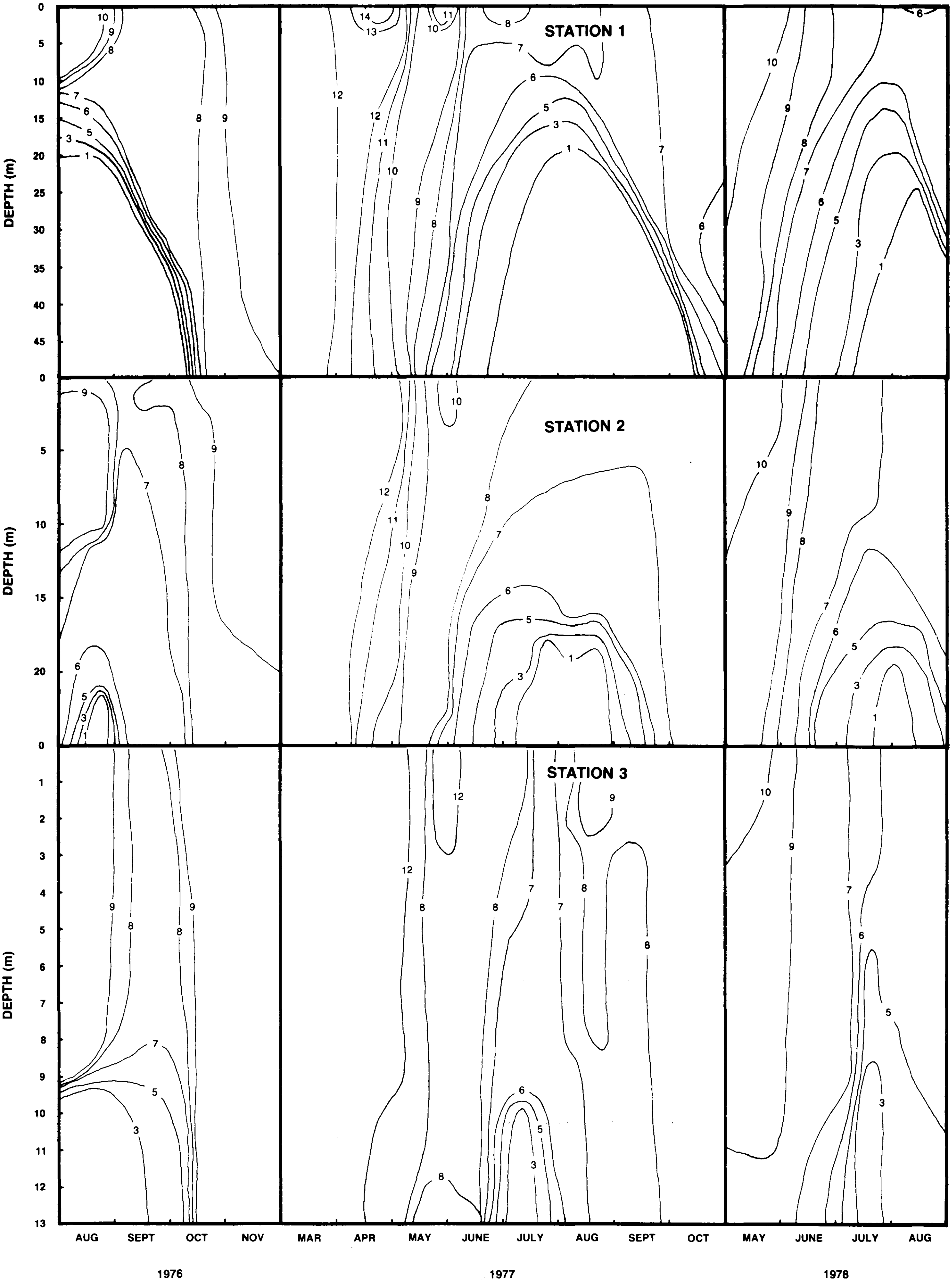

Figure 3. Dissolved oxygen (mg/l) profile at stations 1, 2, and 3.

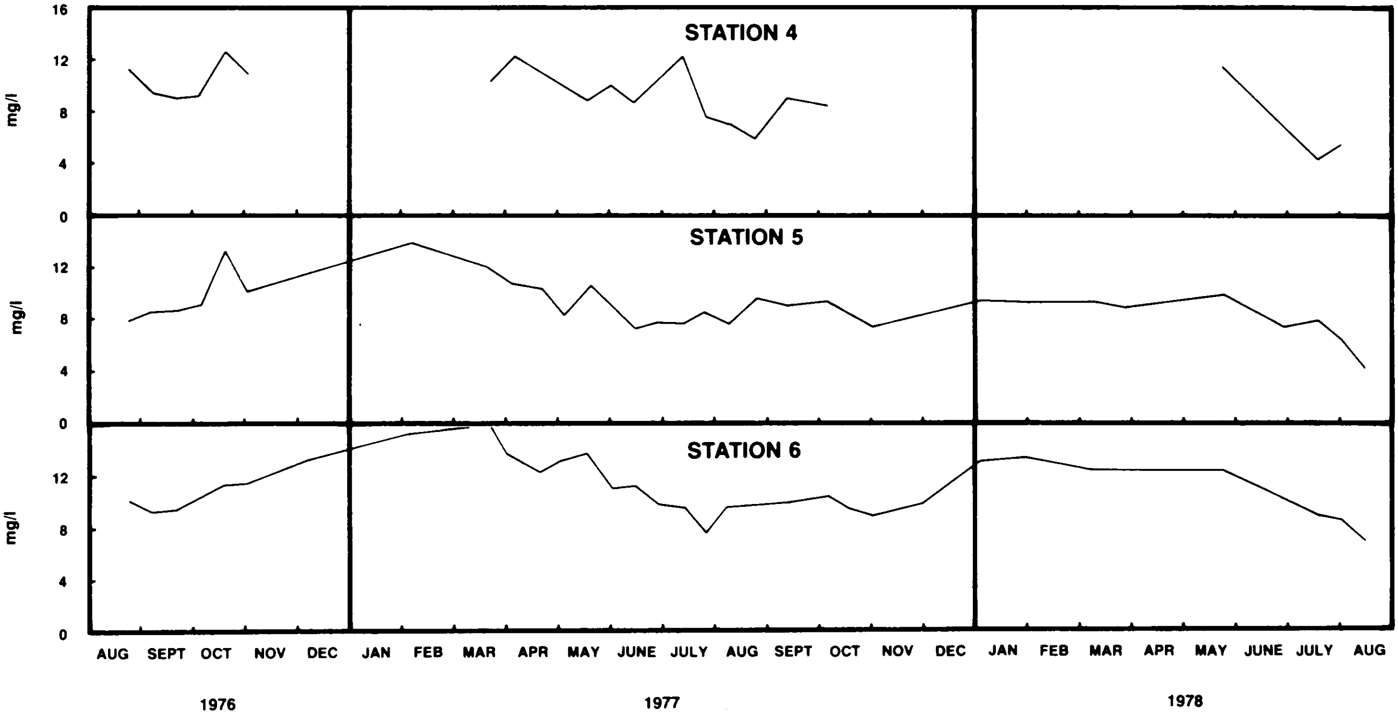

Figure 3. Continued. Dissolved oxygen (mg/l) levels at stations 4, 5 and 6.

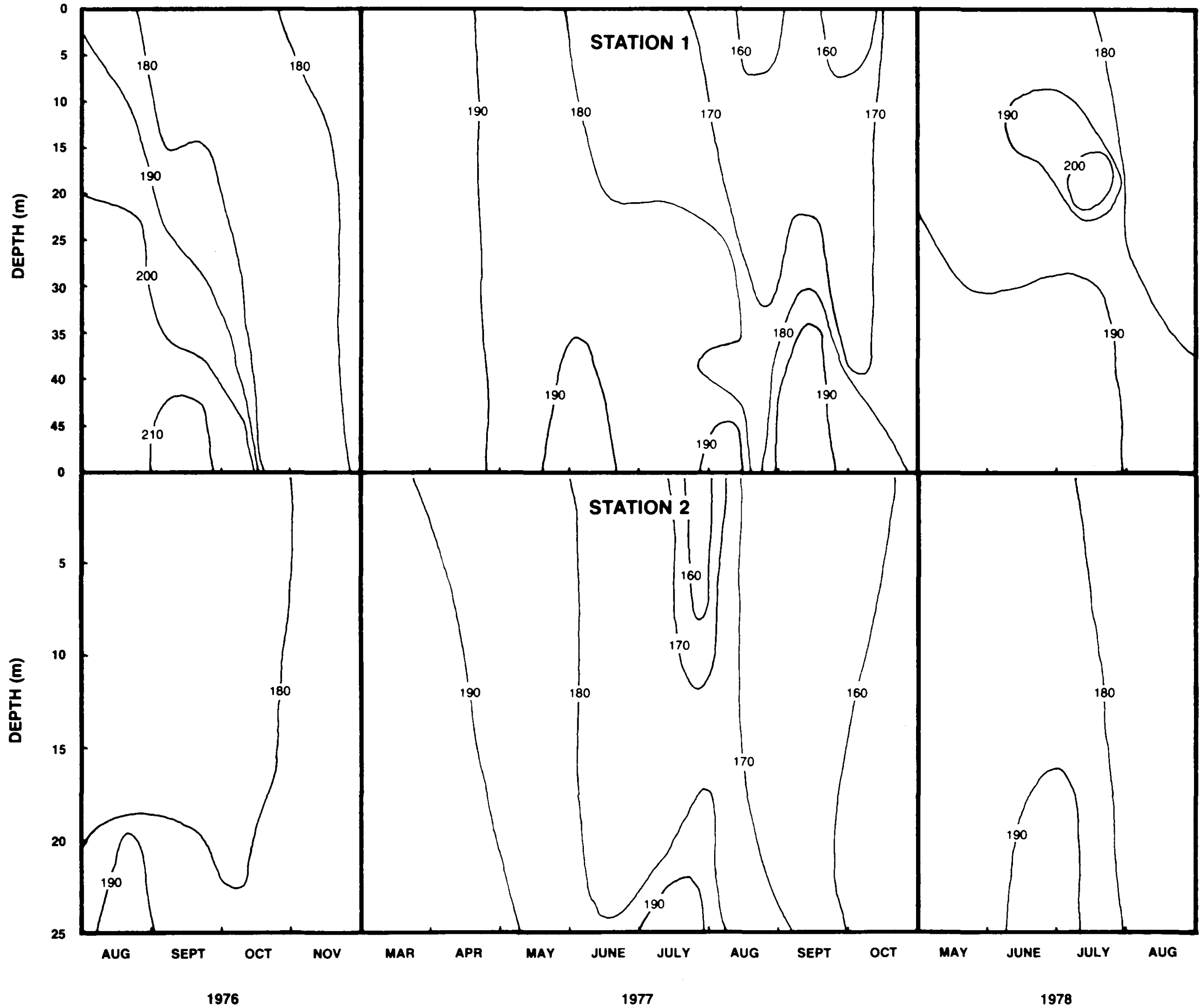

Figure 4. Total alkalinity (mg/l) profile at stations 1 and 2.

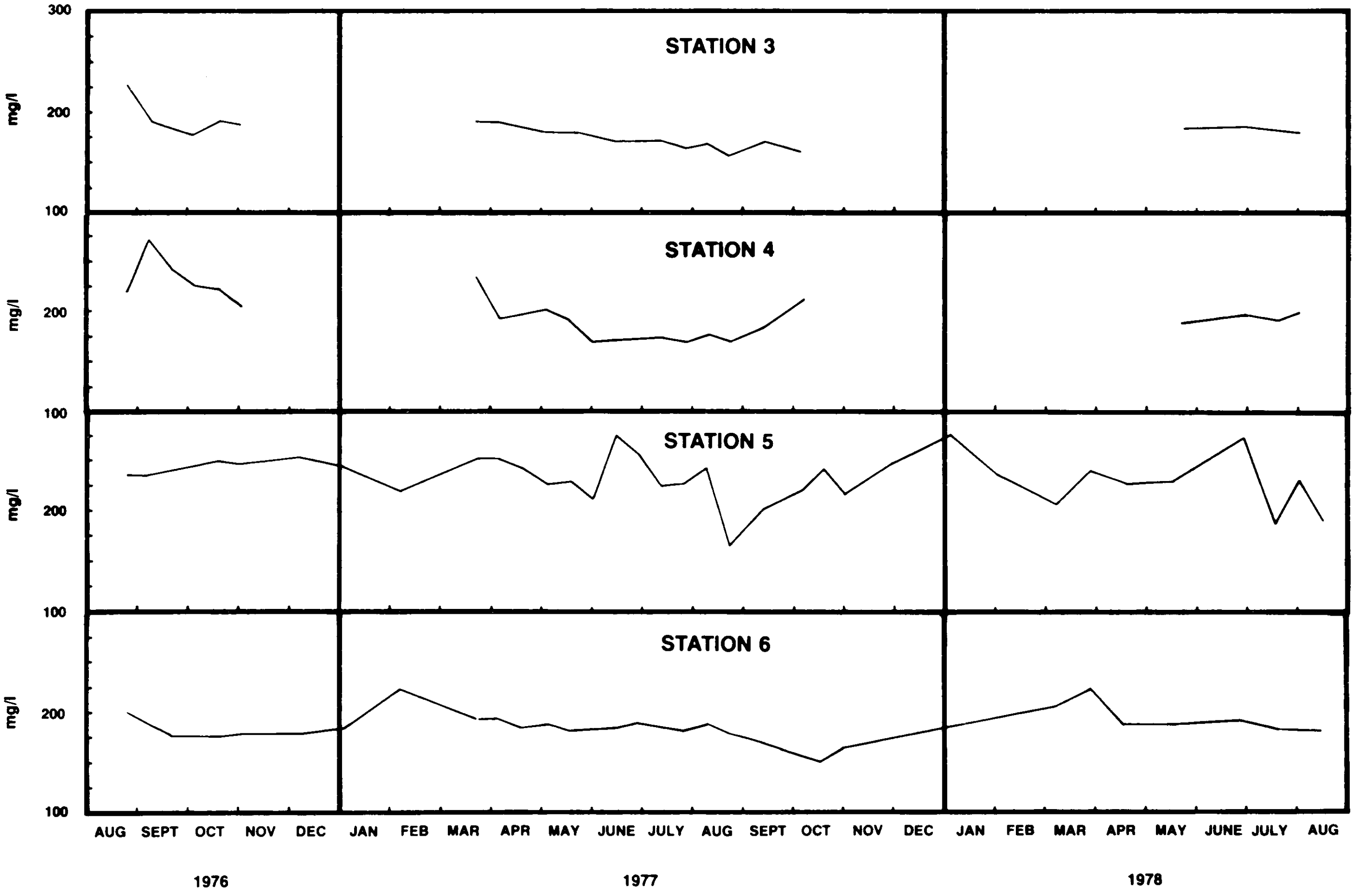

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Figure 4. Continued. Total alkalinity (mg/l) level at stations 3, 4, 5 and 6.

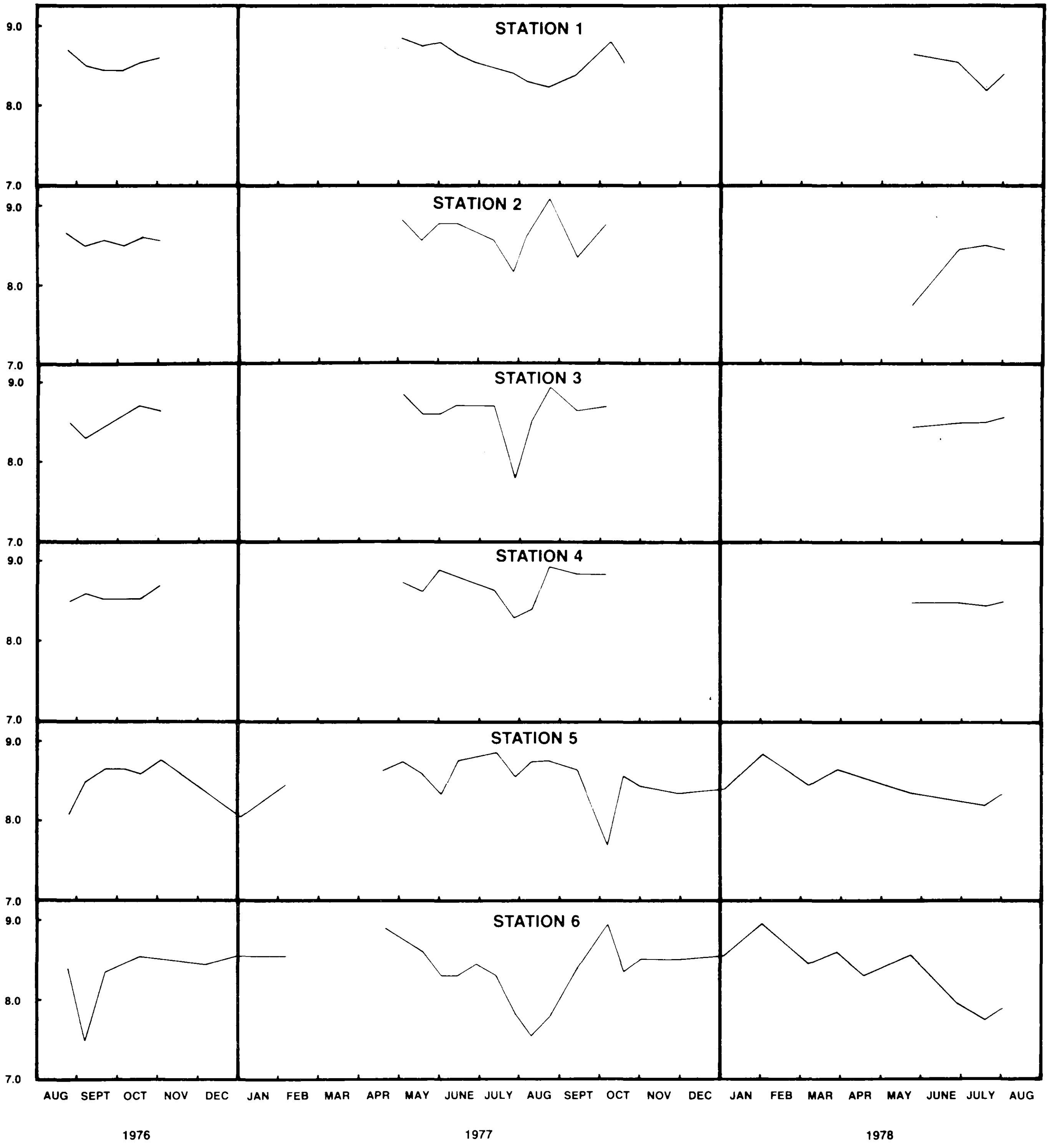

Figure 5. Hydrogen ion concentration (pH) at stations 1, 2, 3, 4, 5 and 6.

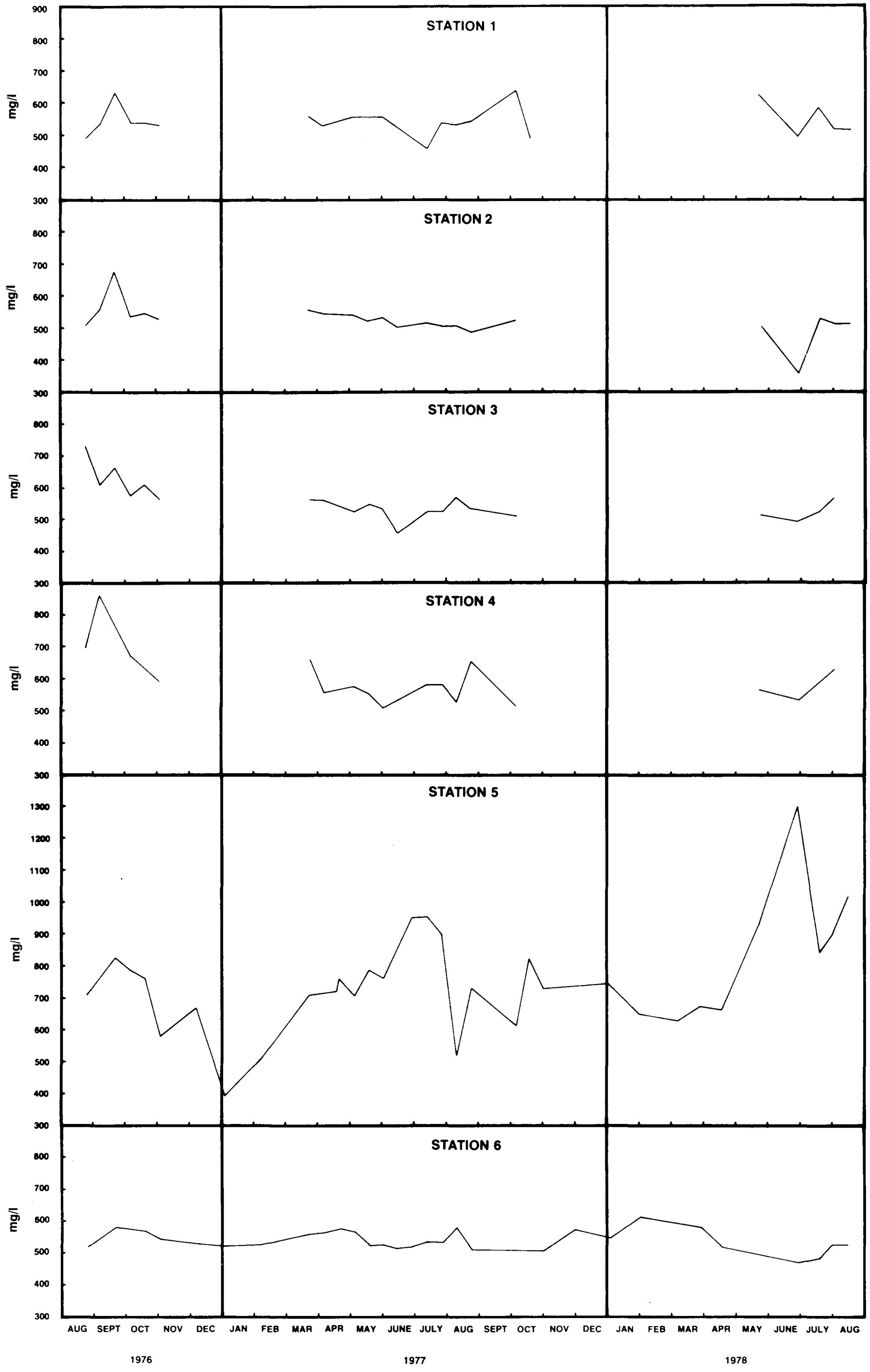

Figure 6. Total solids (mg/l) at stations 1, 2, 3, 4, 5 and 6.

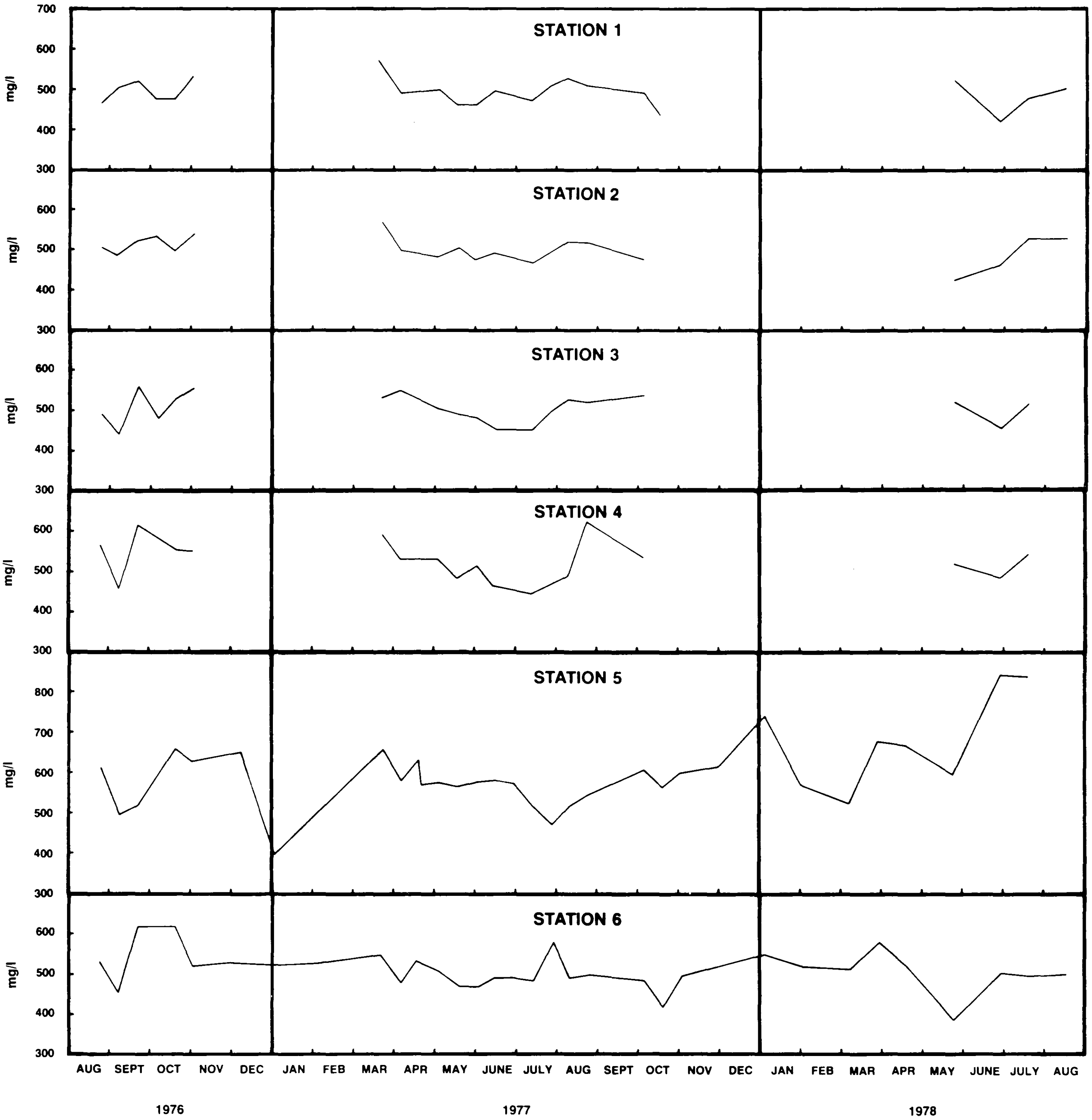

Figure 7. Total dissolved solids (mg/l) at stations 1, 2, 3, 4, 5 and 6.

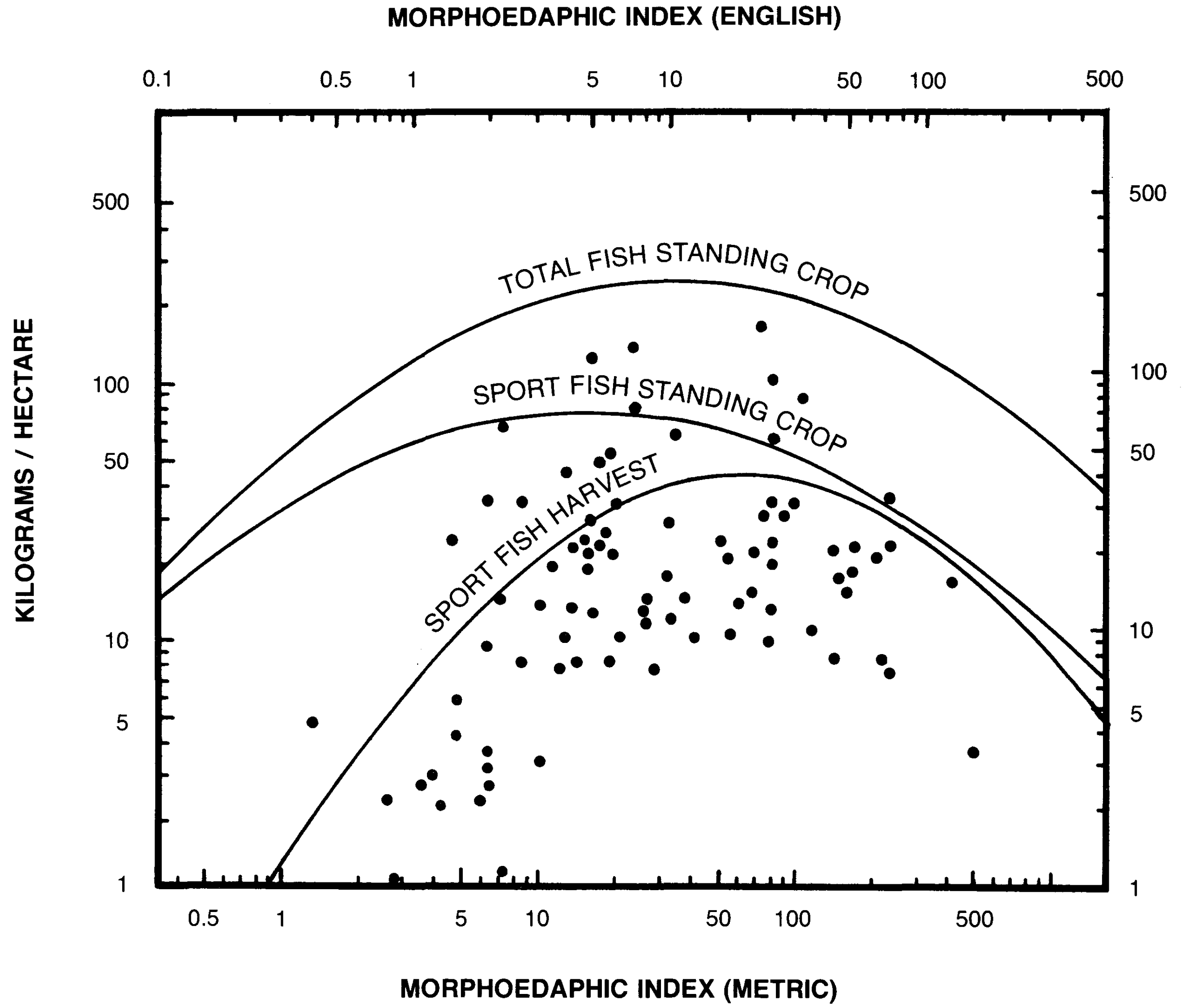

Figure 8. Curvilinear regressions of reservoir total and sport fish standing crop on morphoedaphic index (total dissolved solids in ppm divided by mean depth in meters) and sport fish harvest on the morphoedaphic index — total dissolved solids divided by mean depth or depth of top of thermocline where a stable thermocline is formed (Jenkins and Morais 1971).

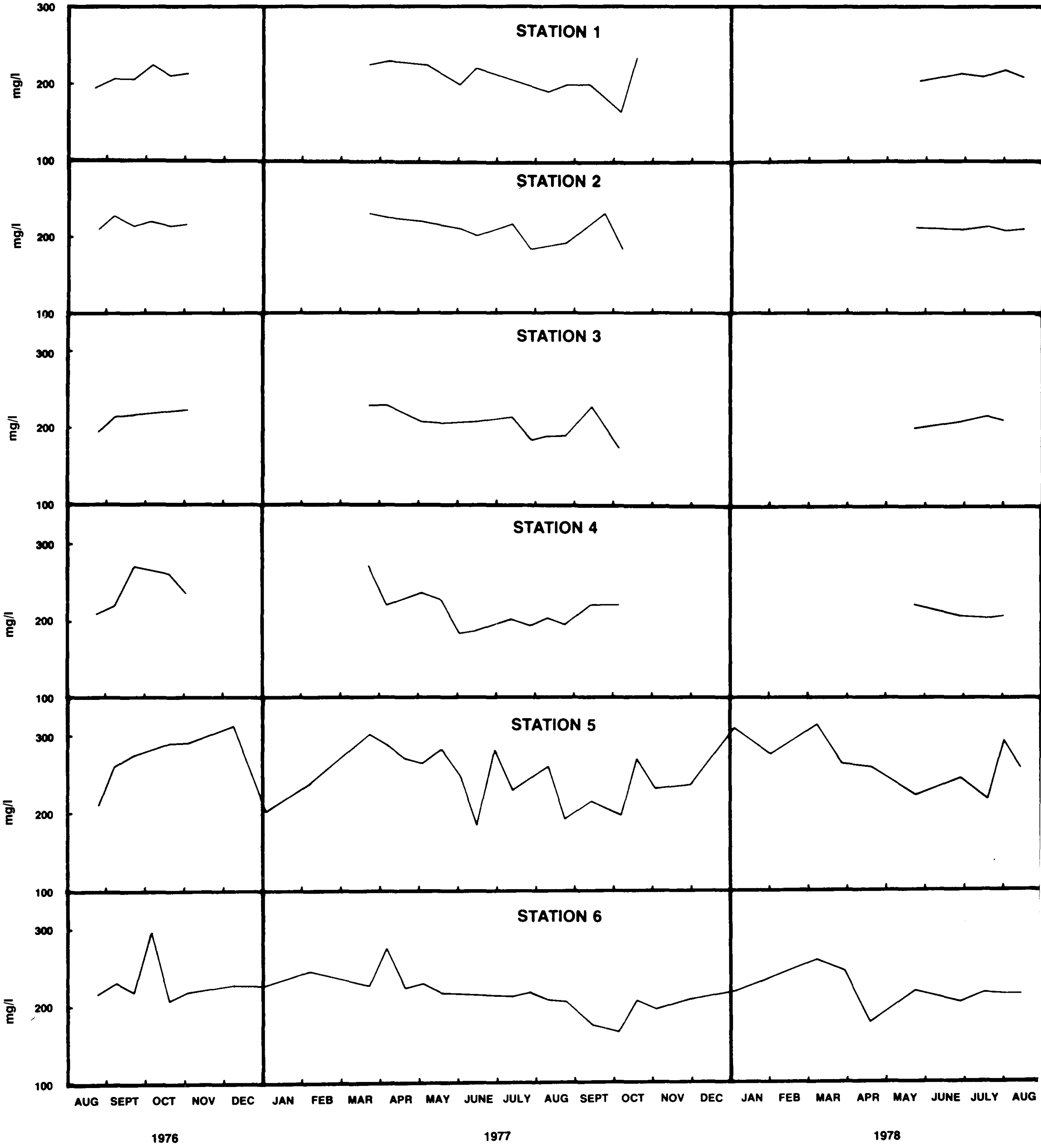

Figure 9. Total hardness (mg/l) levels at stations 1, 2, 3, 4, 5 and 6.

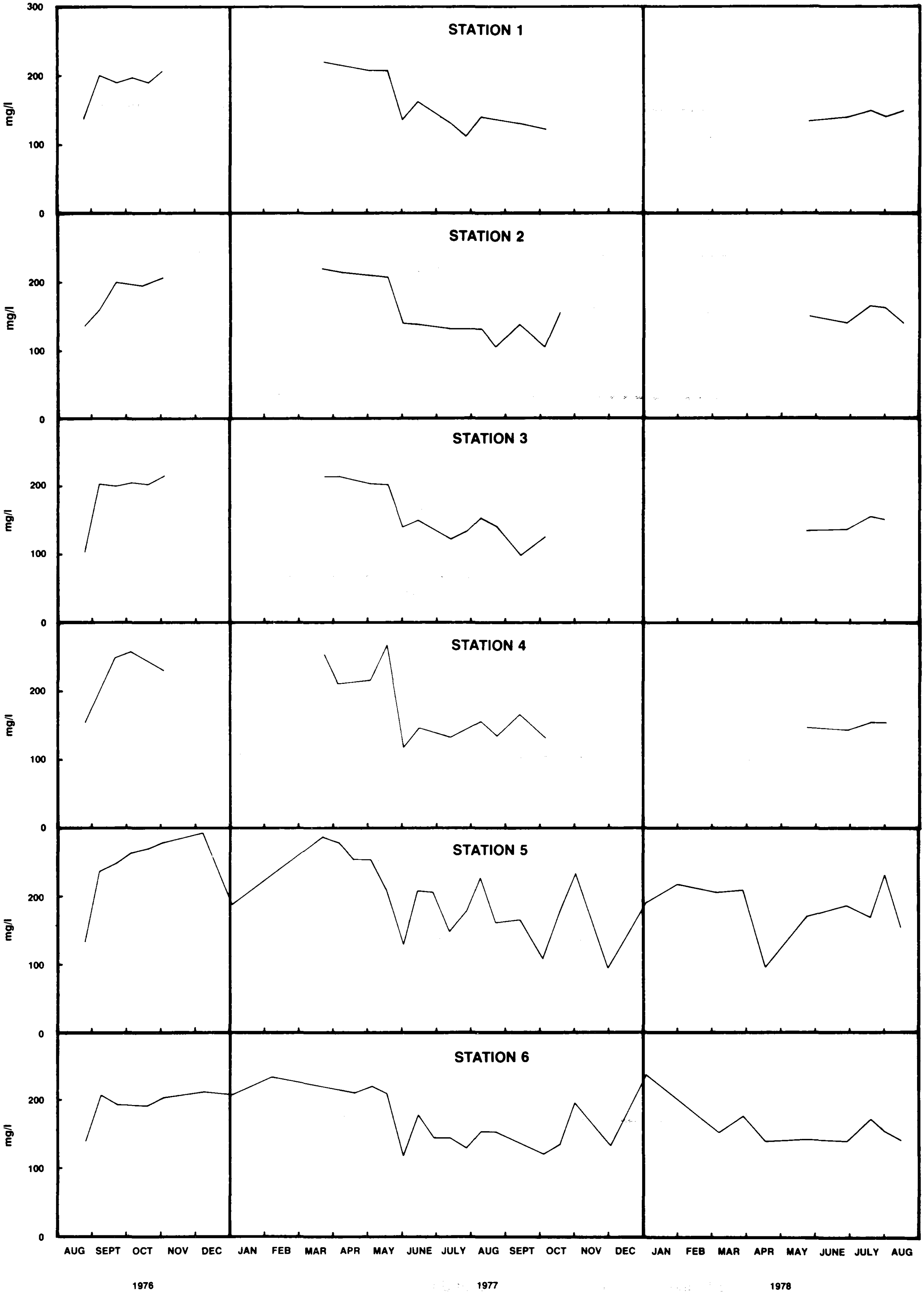

Figure 10. Calcium hardness (mg/l) levels at stations 1, 2, 3, 4, 5 and 6.

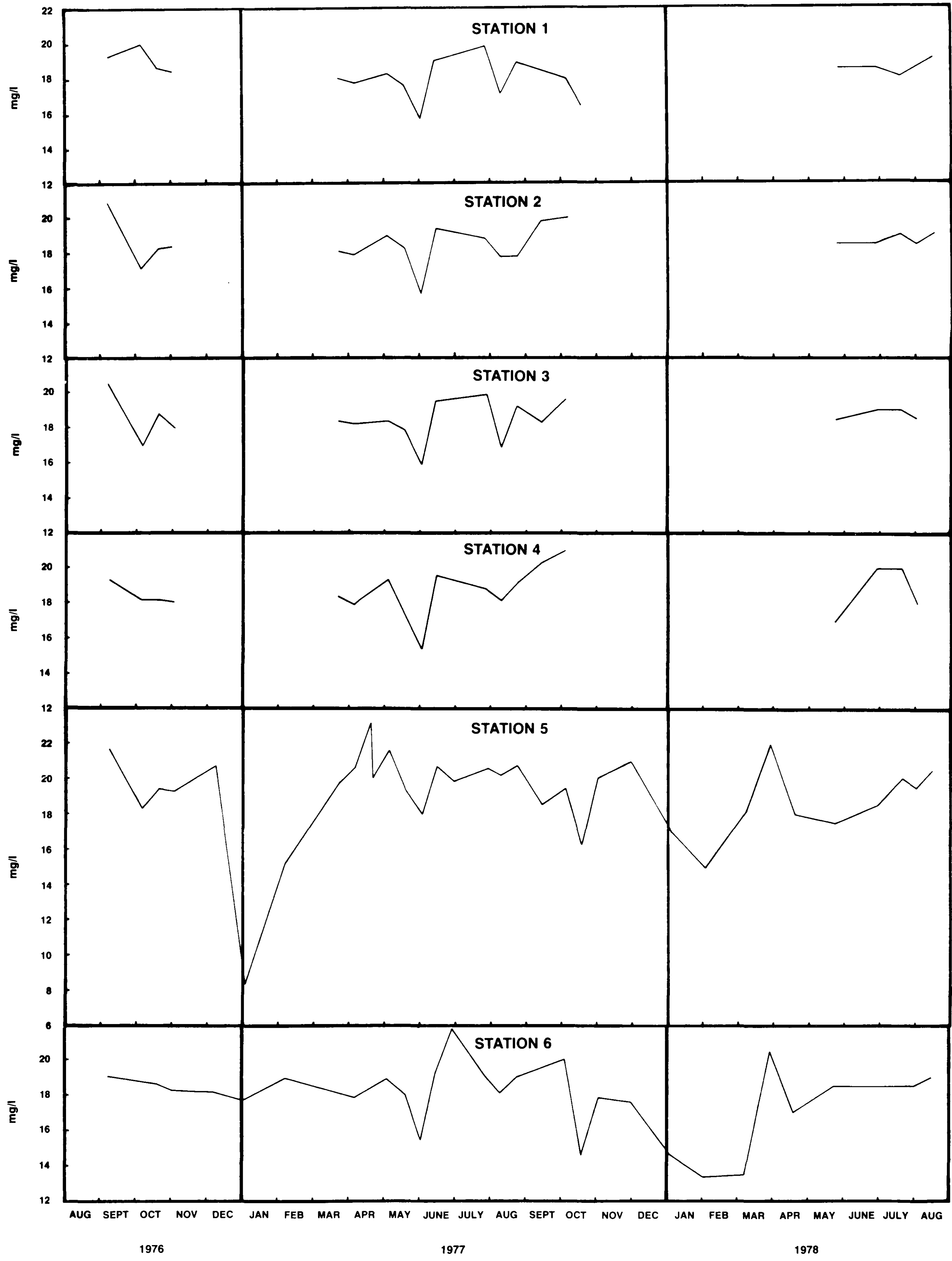

Figure 11. Chloride (mg/l) levels at stations 1, 2, 3, 4, 5 and 6.

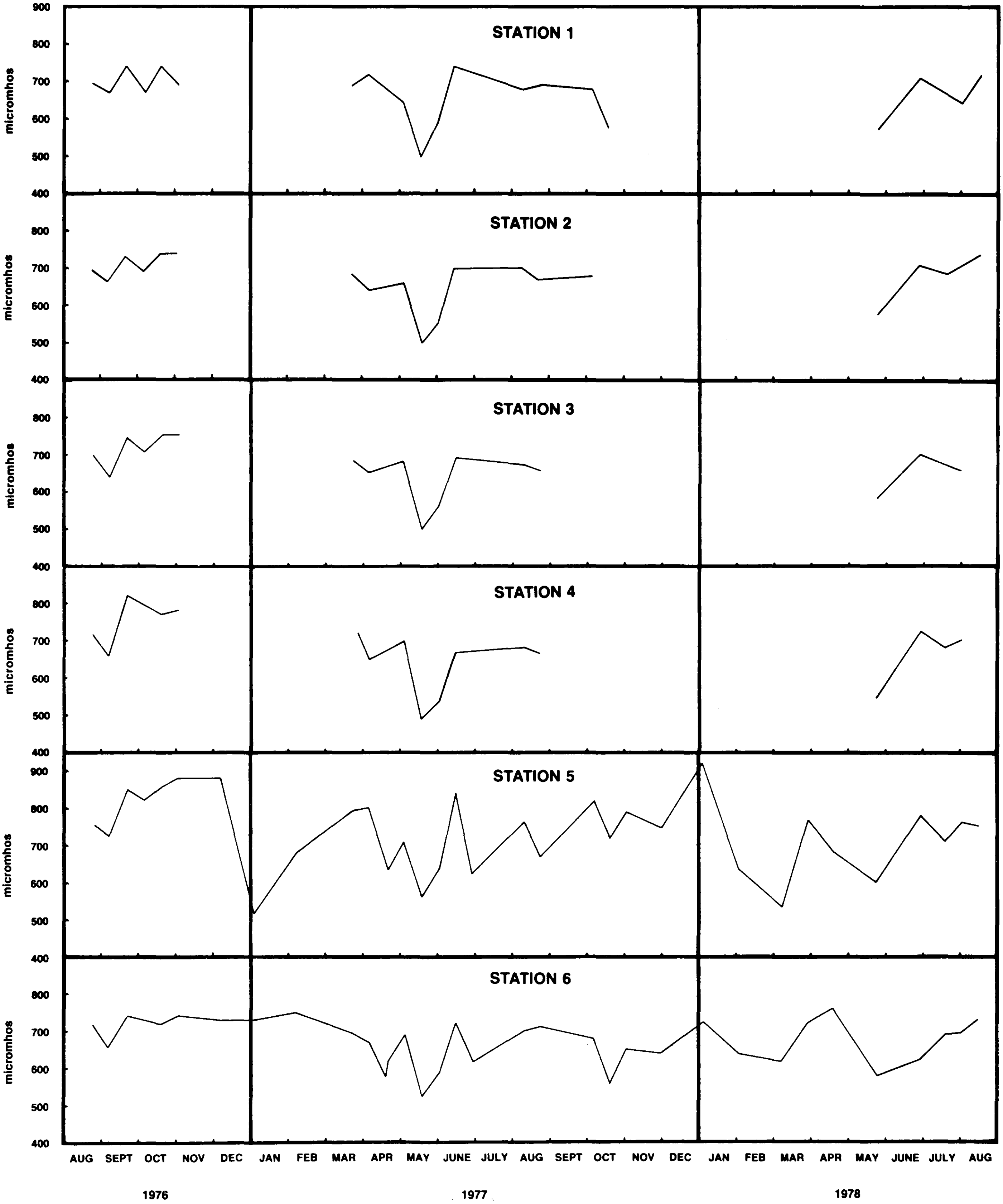

Figure 12. Specific conductance (μmhos) at stations 1, 2, 3, 4, 5 and 6.

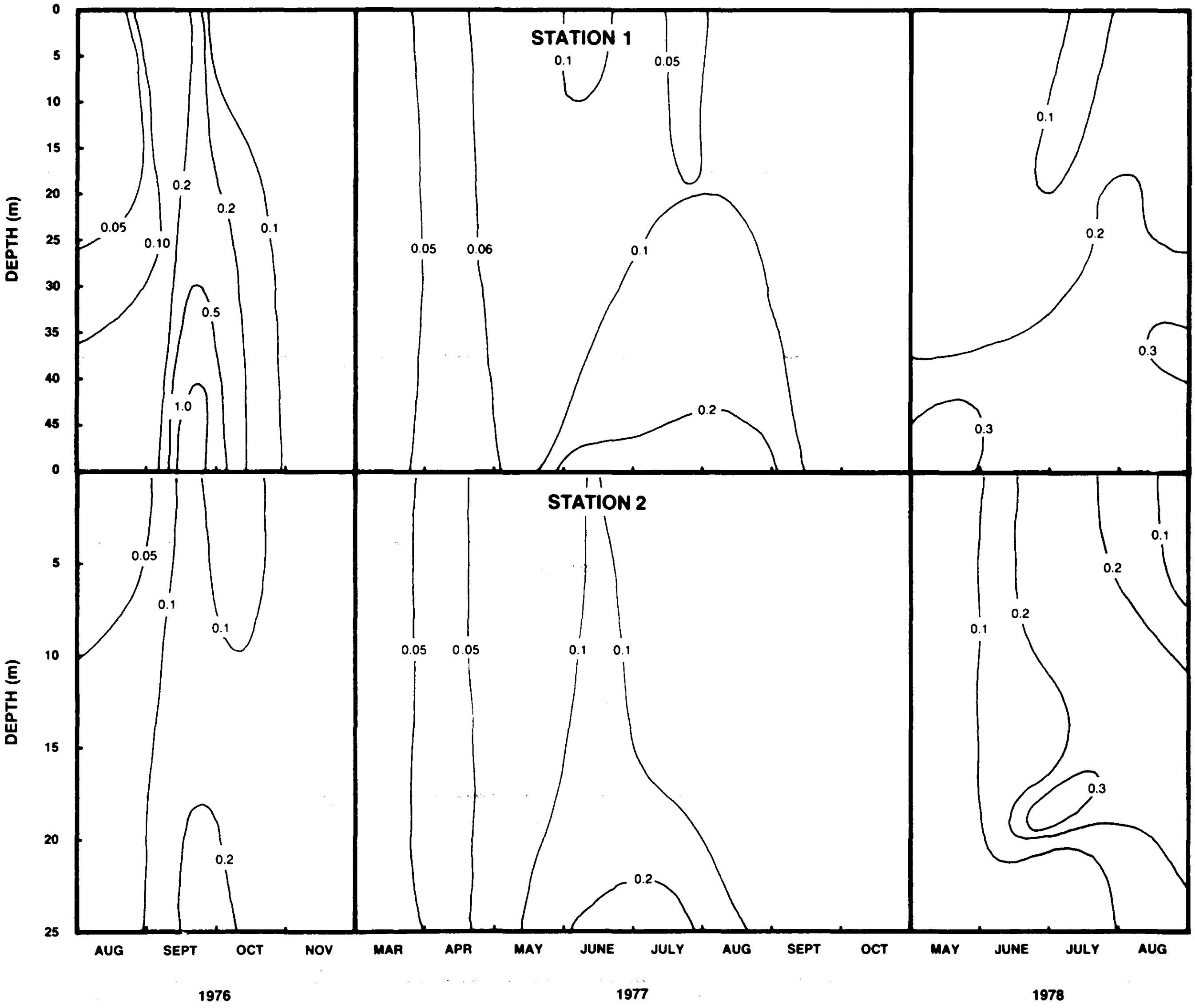

Figure 13. Total phosphate (mg/l) profile at stations 1 and 2.

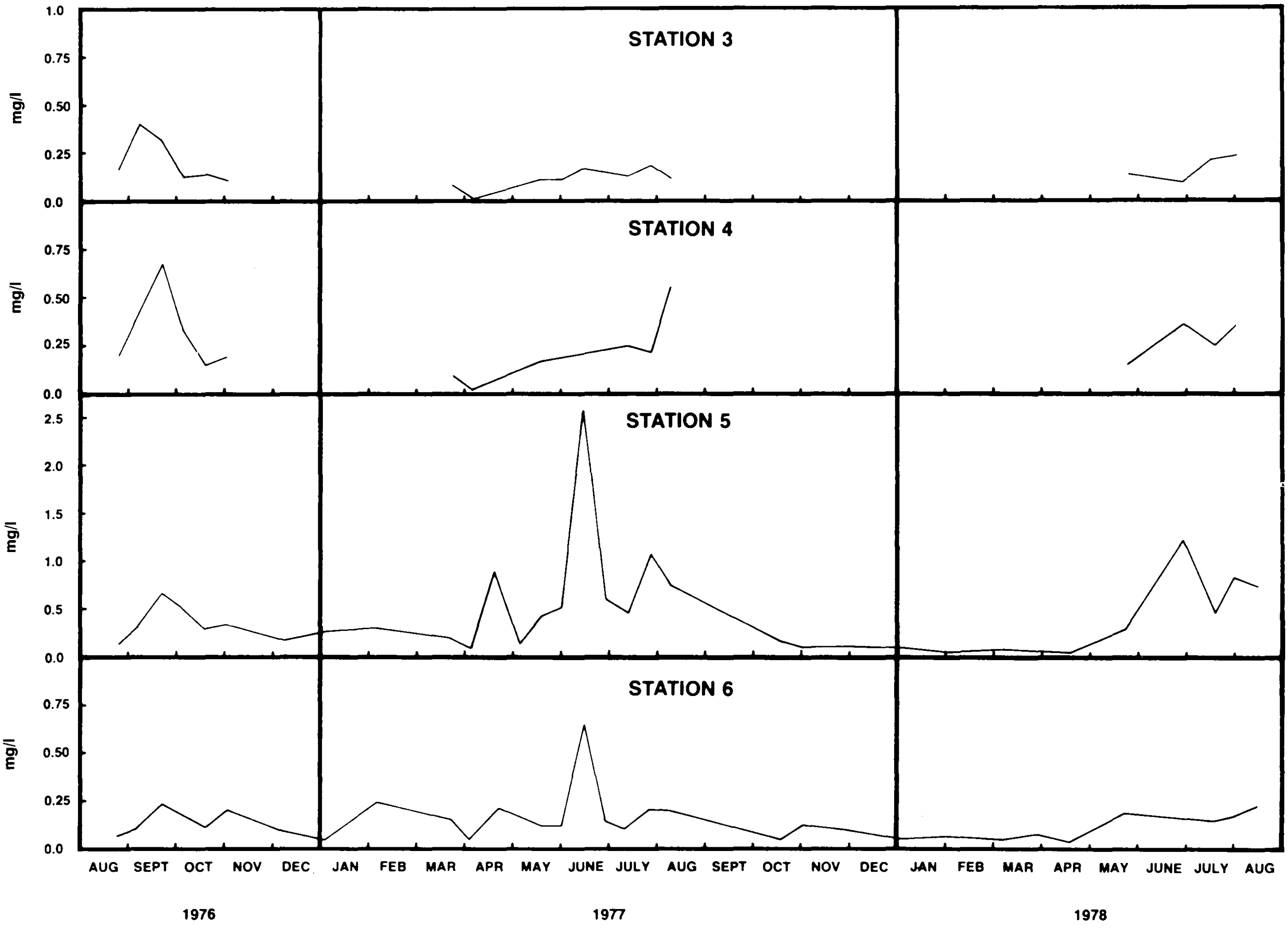

Figure 13. Continued. Total phosphate (mg/l) levels at stations 3, 4, 5 and 6.

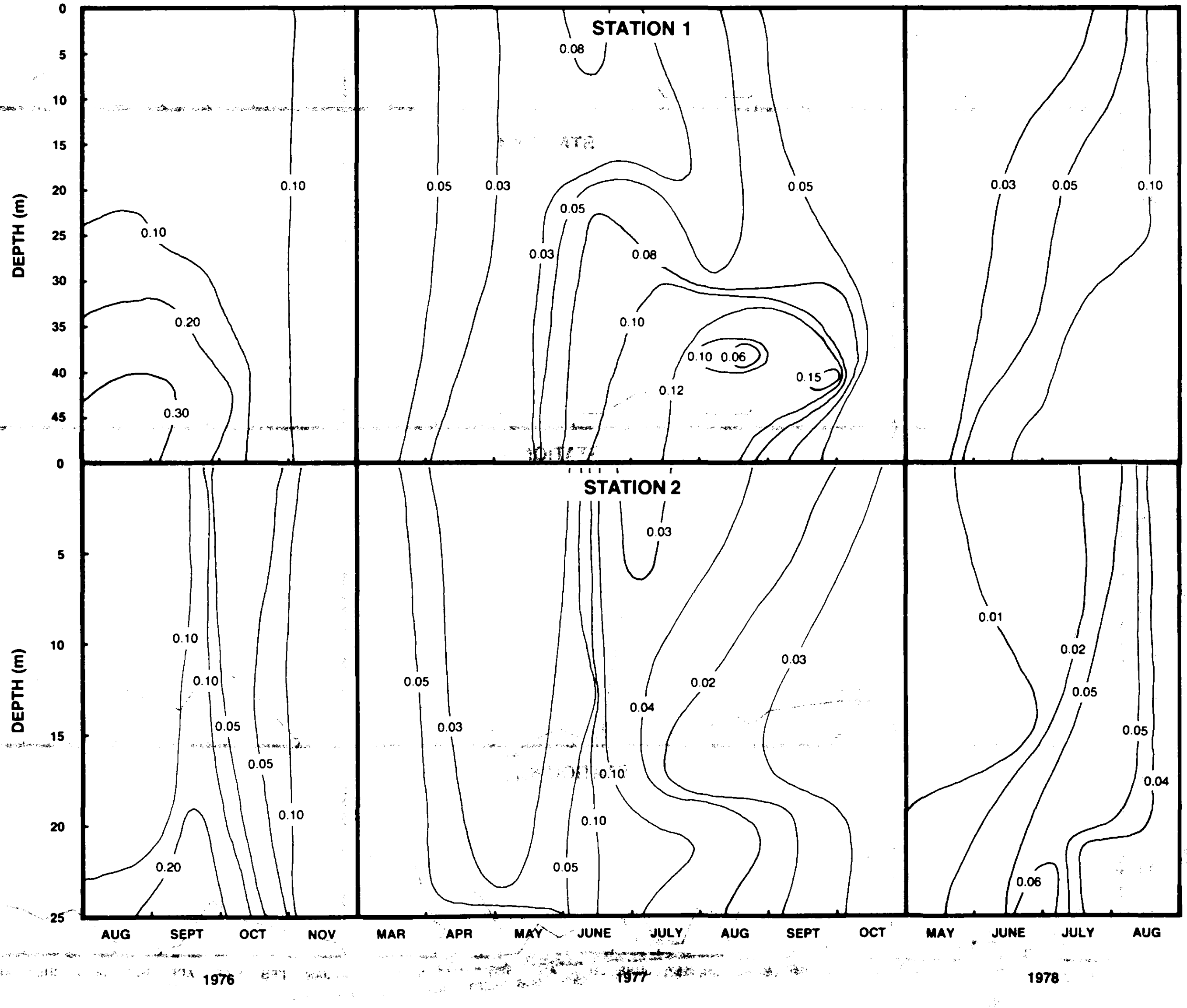

Figure 14. Orthophosphate (mg/l) profiles at stations 1 and 2.

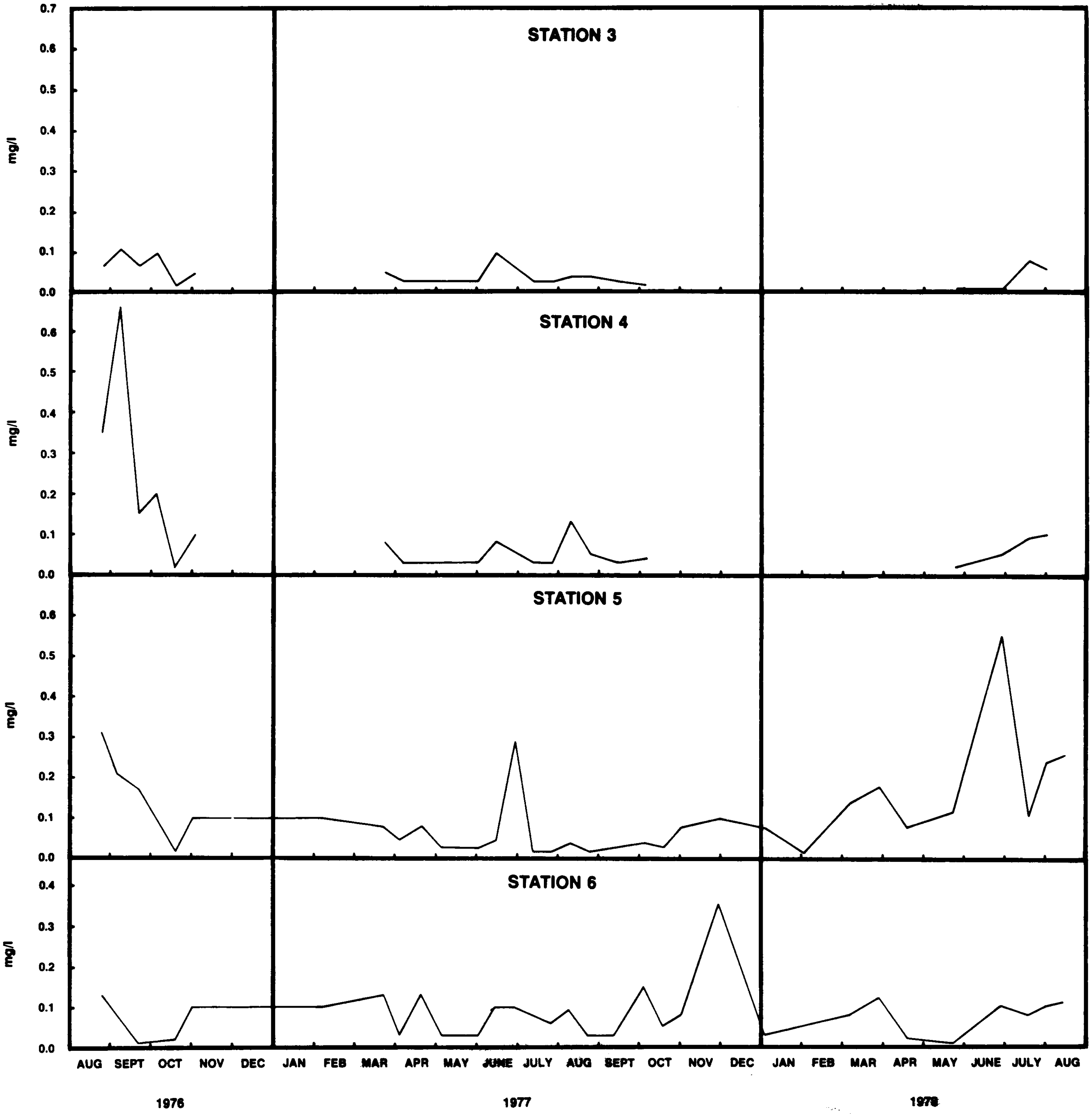

Figure 14. Continued. Orthophosphate (mg/l) levels at stations 3, 4, 5 and 6.

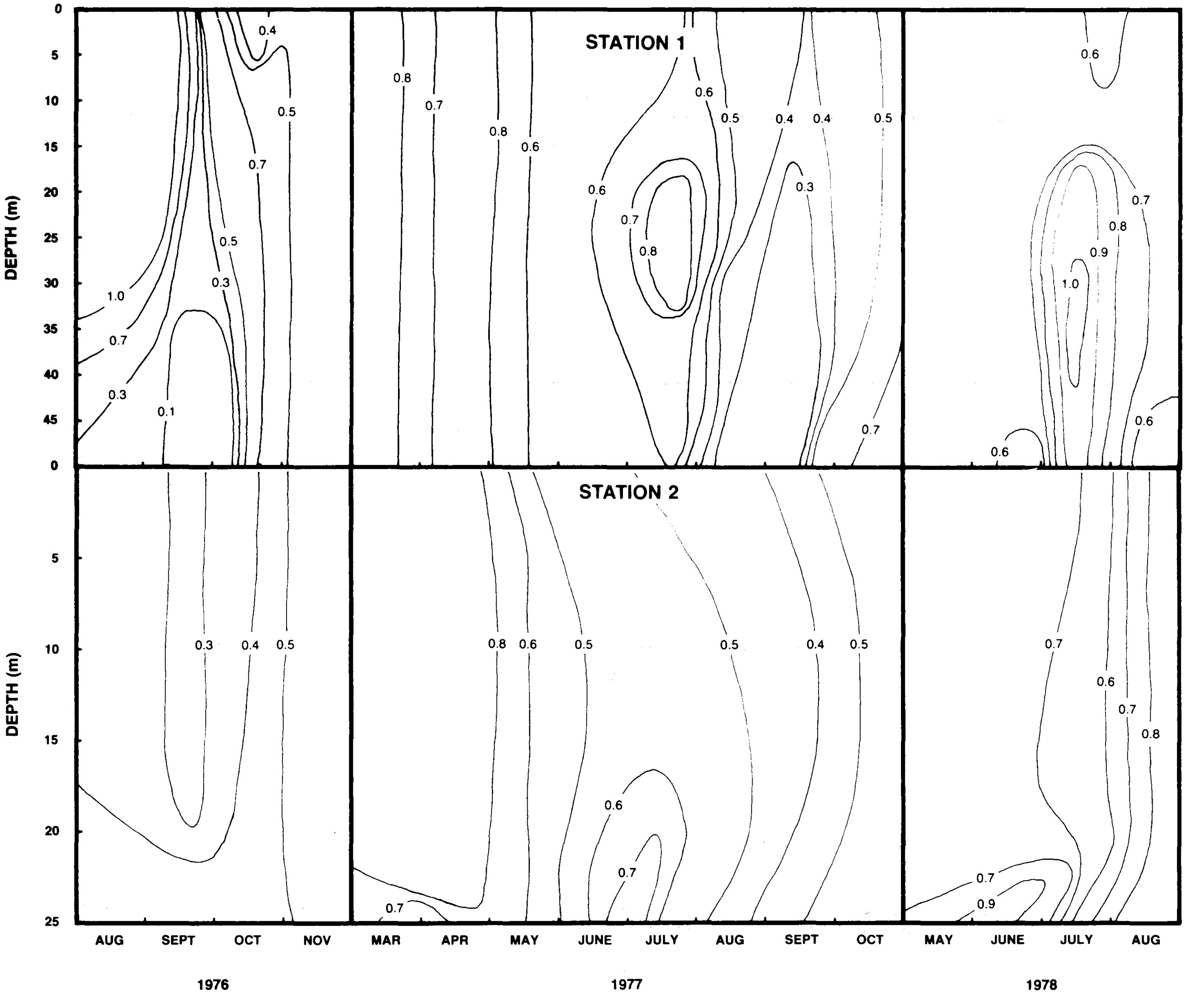

Figure 15. Nitrate nitrogen (mg/l) profiles at stations 1 and 2.

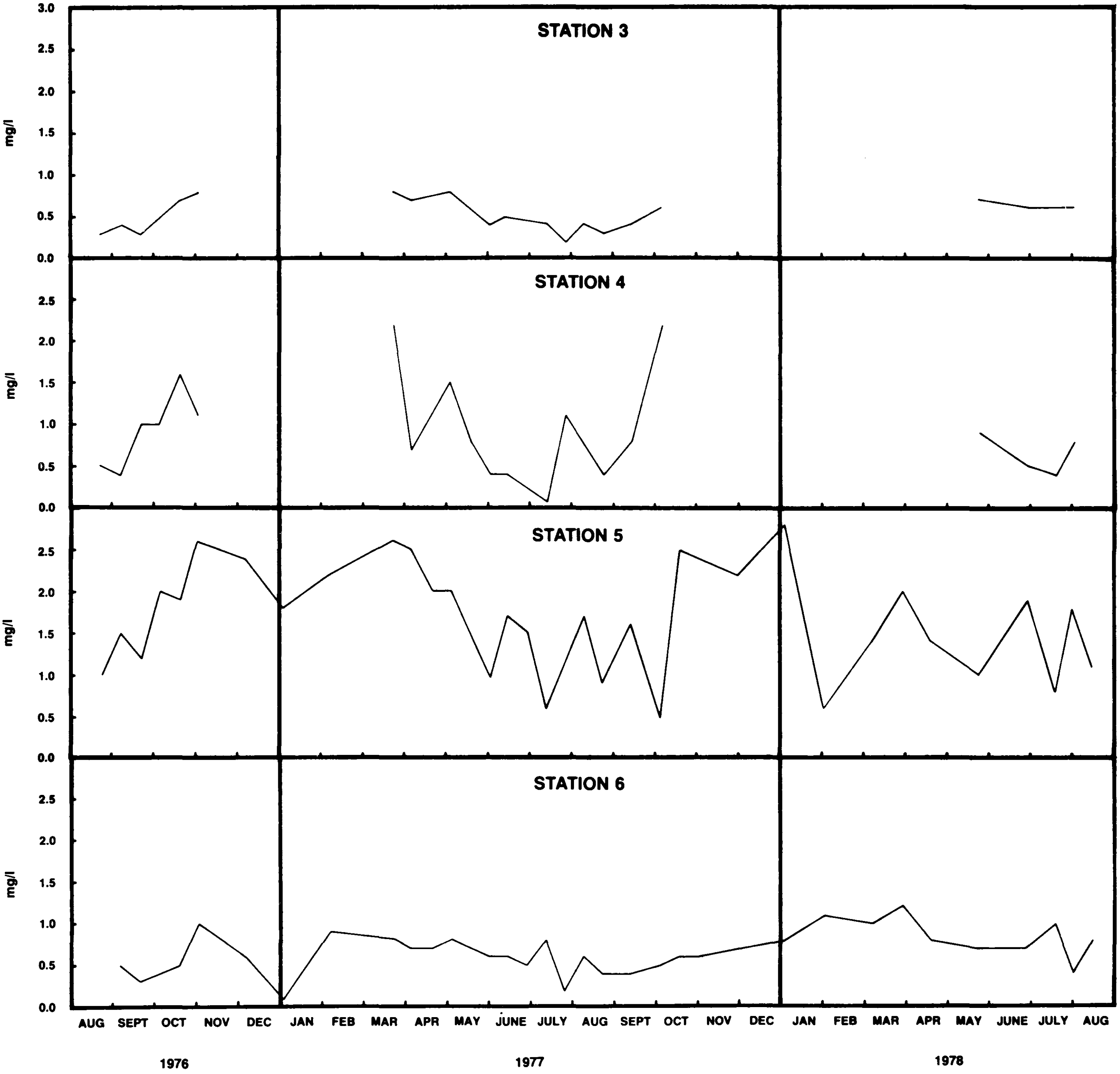

Figure 15. Continued. Nitrate nitrogen (mg/l) levels at stations 3, 4, 5 and 6.

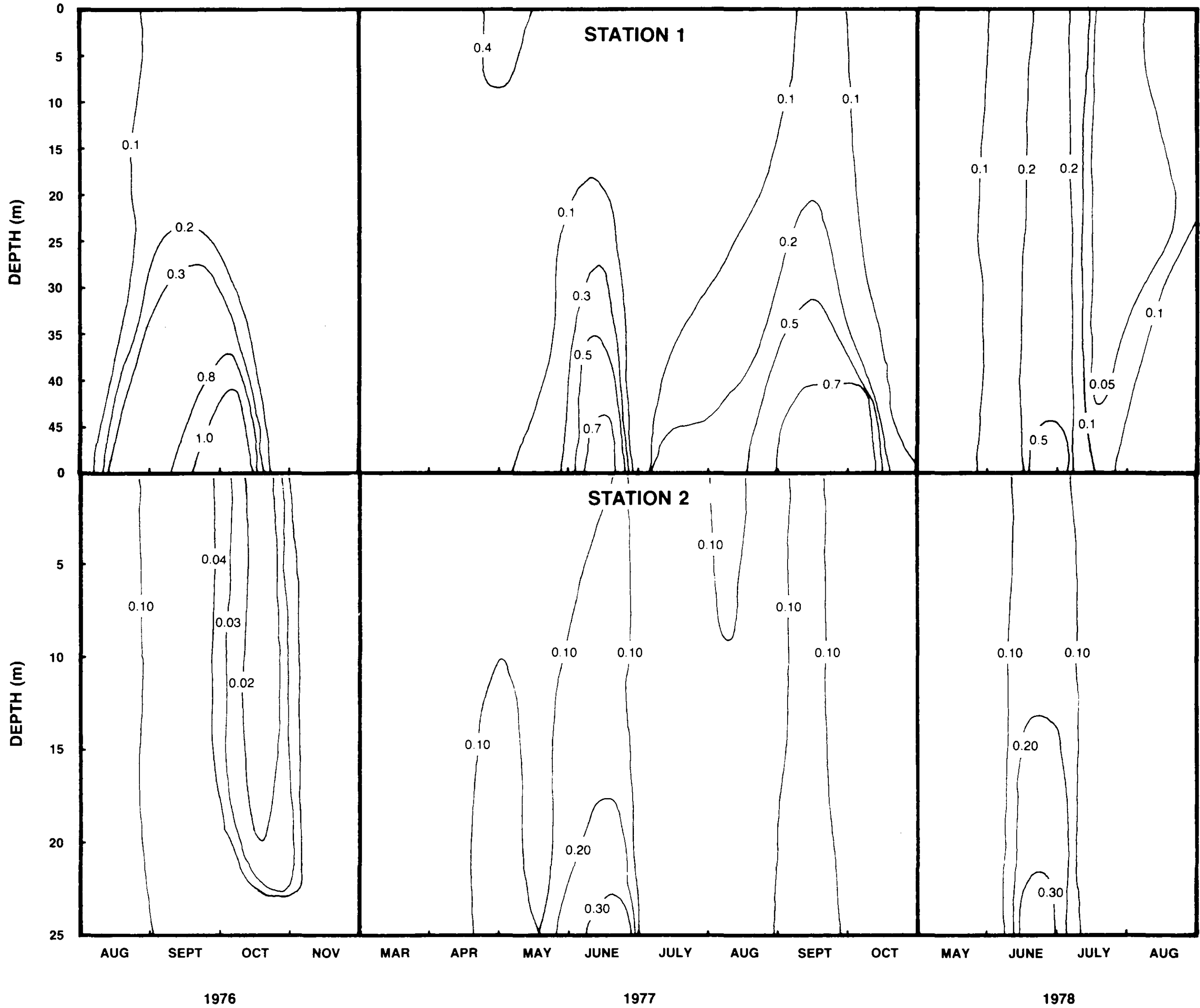

Figure 16. Ammonia nitrogen (mg/l) profiles at stations 1 and 2.

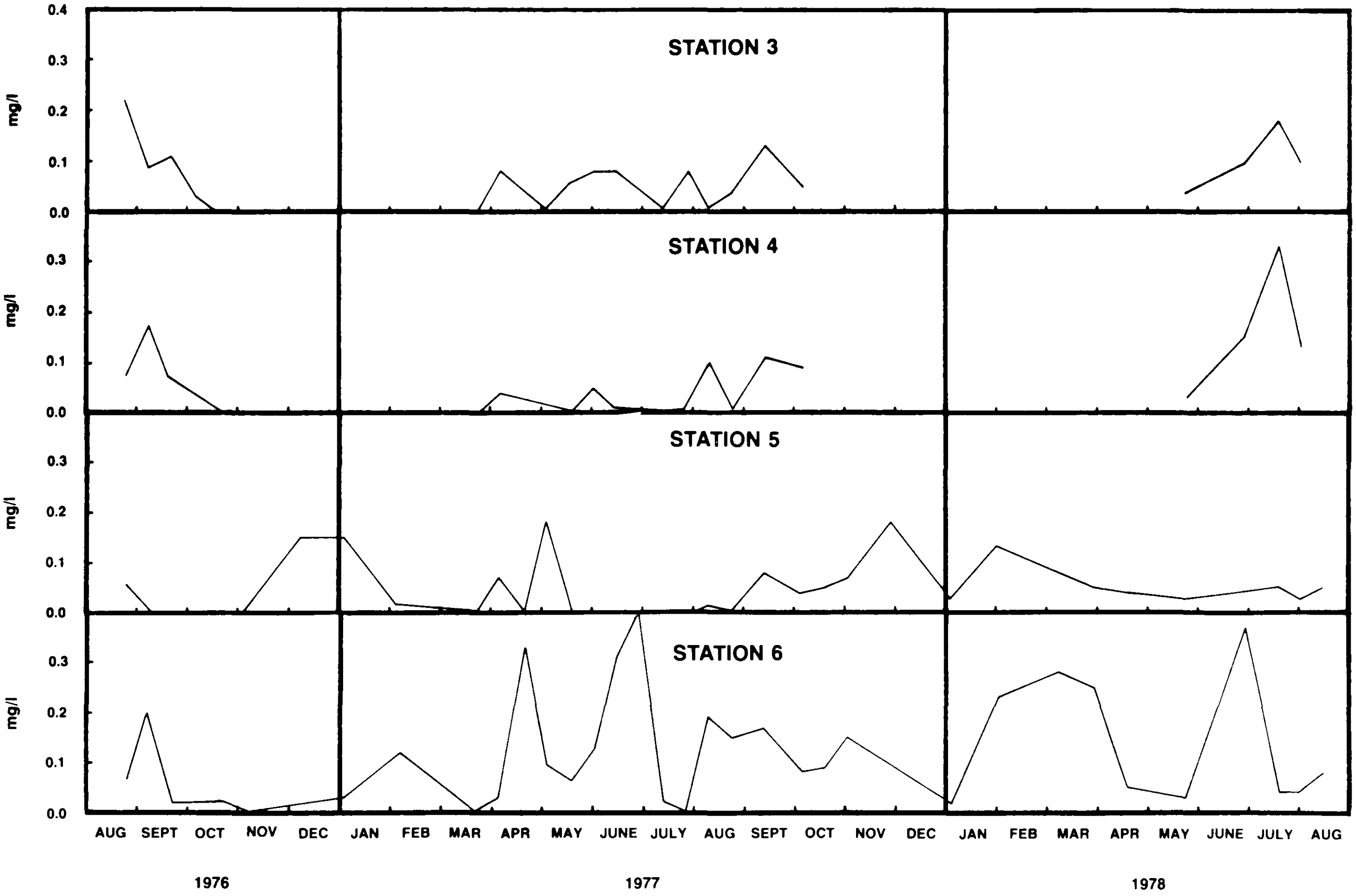

Figure 16. Continued. Ammonia nitrogen (mg/l) levels at stations 3, 4, 5 and 6.

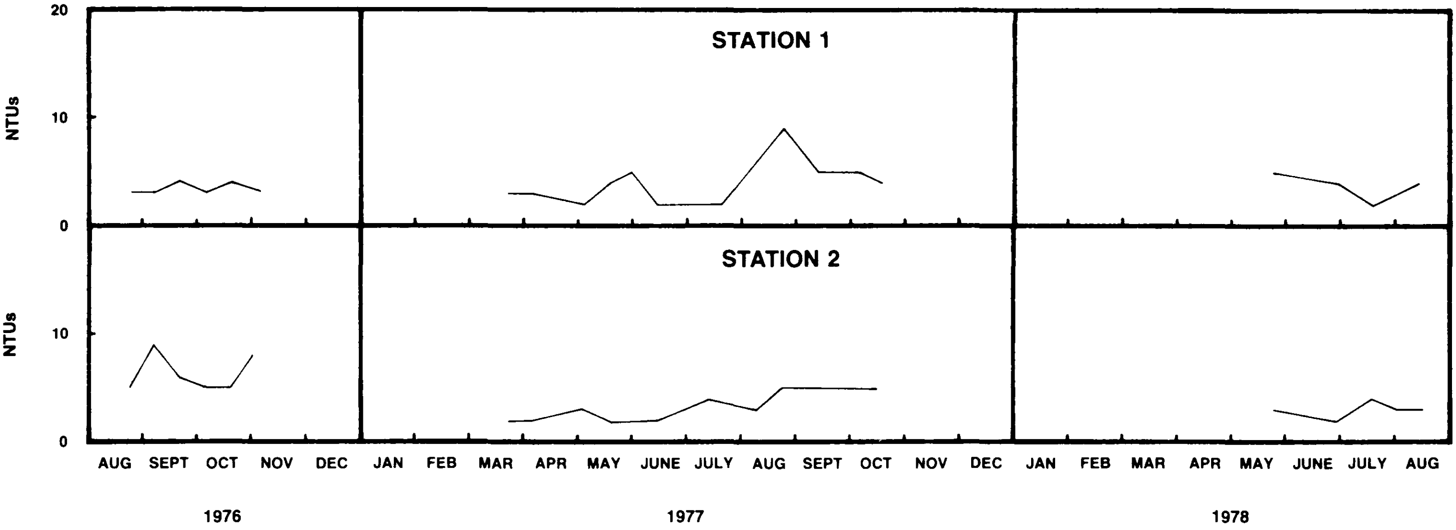

Figure 17. Turbidity (NTU) levels at stations 1 and 2.

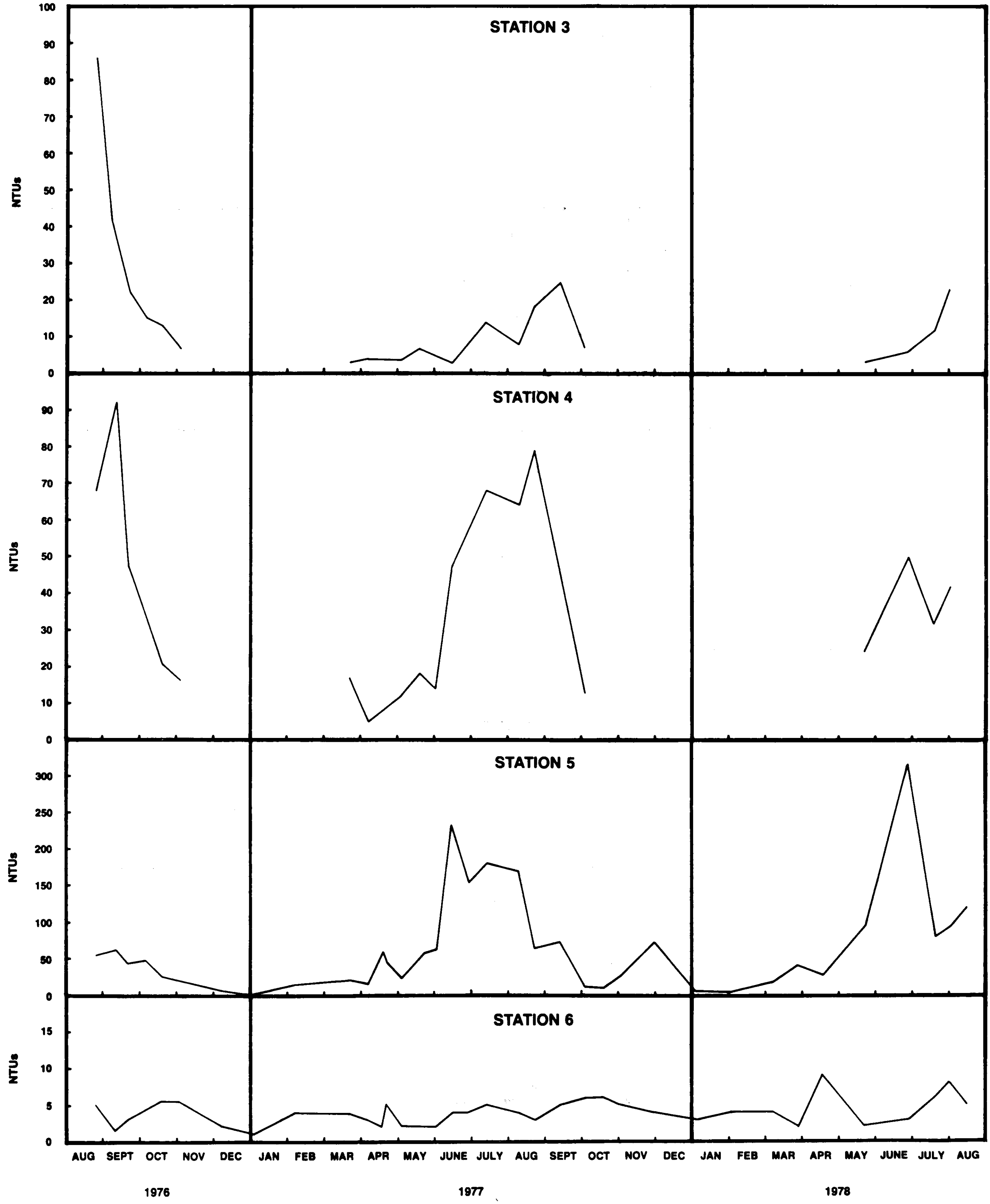

Figure 17. Continued. Turbidity (NTU) levels at stations 3, 4, 5 and 6.

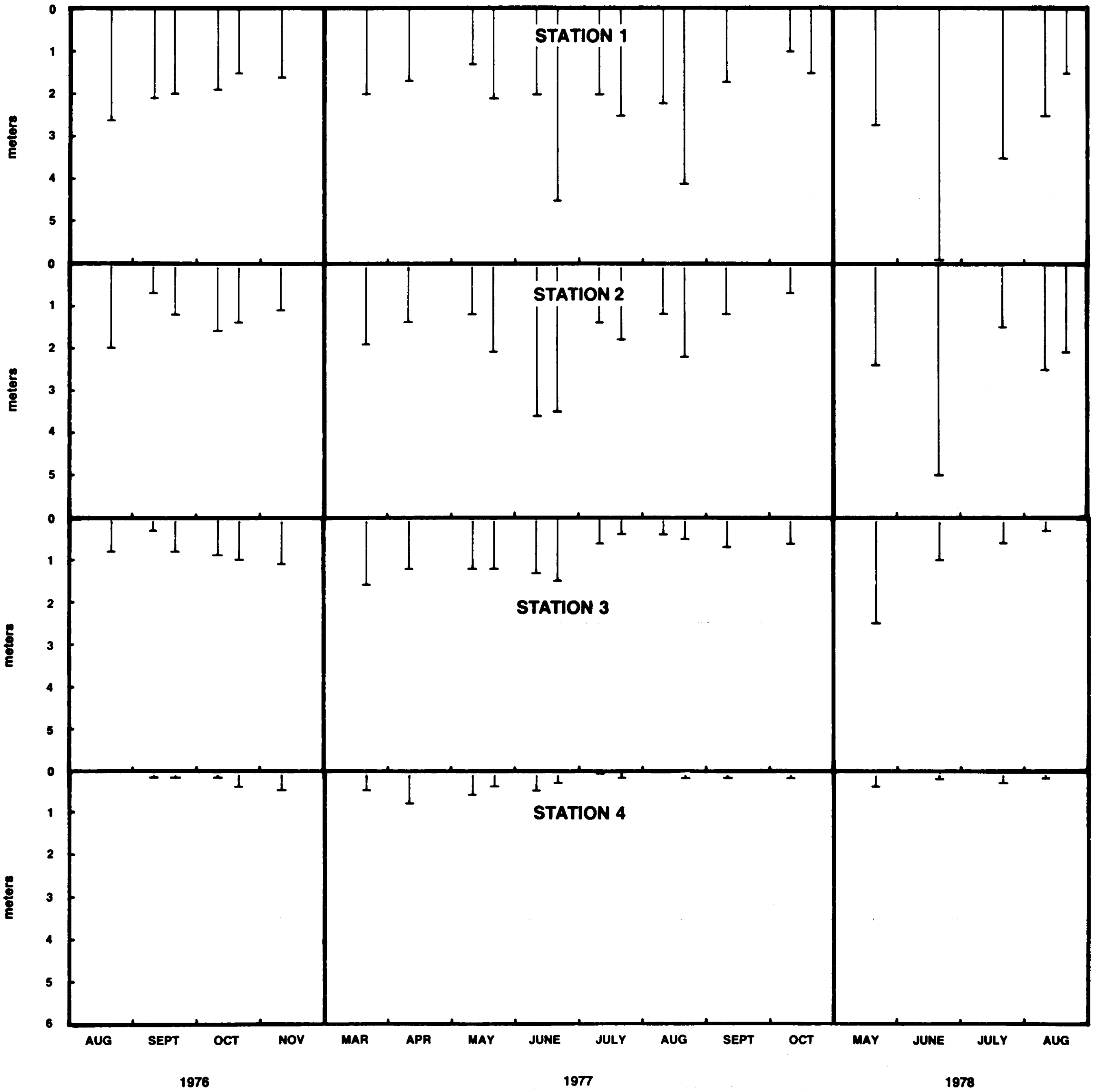

Figure 18. Secchi disk (m) readings at stations 1, 2, 3 and 4.

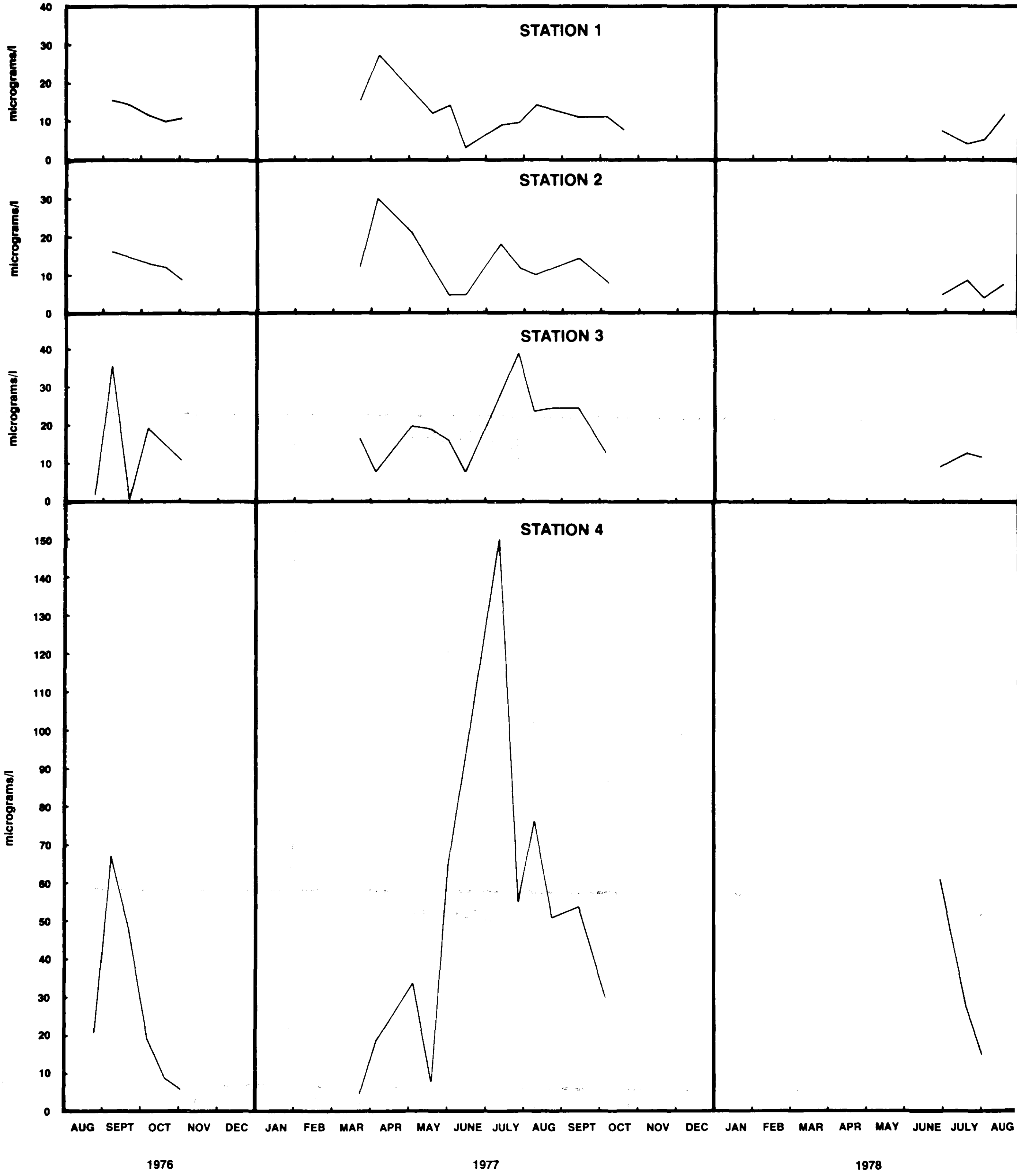

Figure 19. Chlorophyll a concentrations at stations 1, 2, 3 and 4.

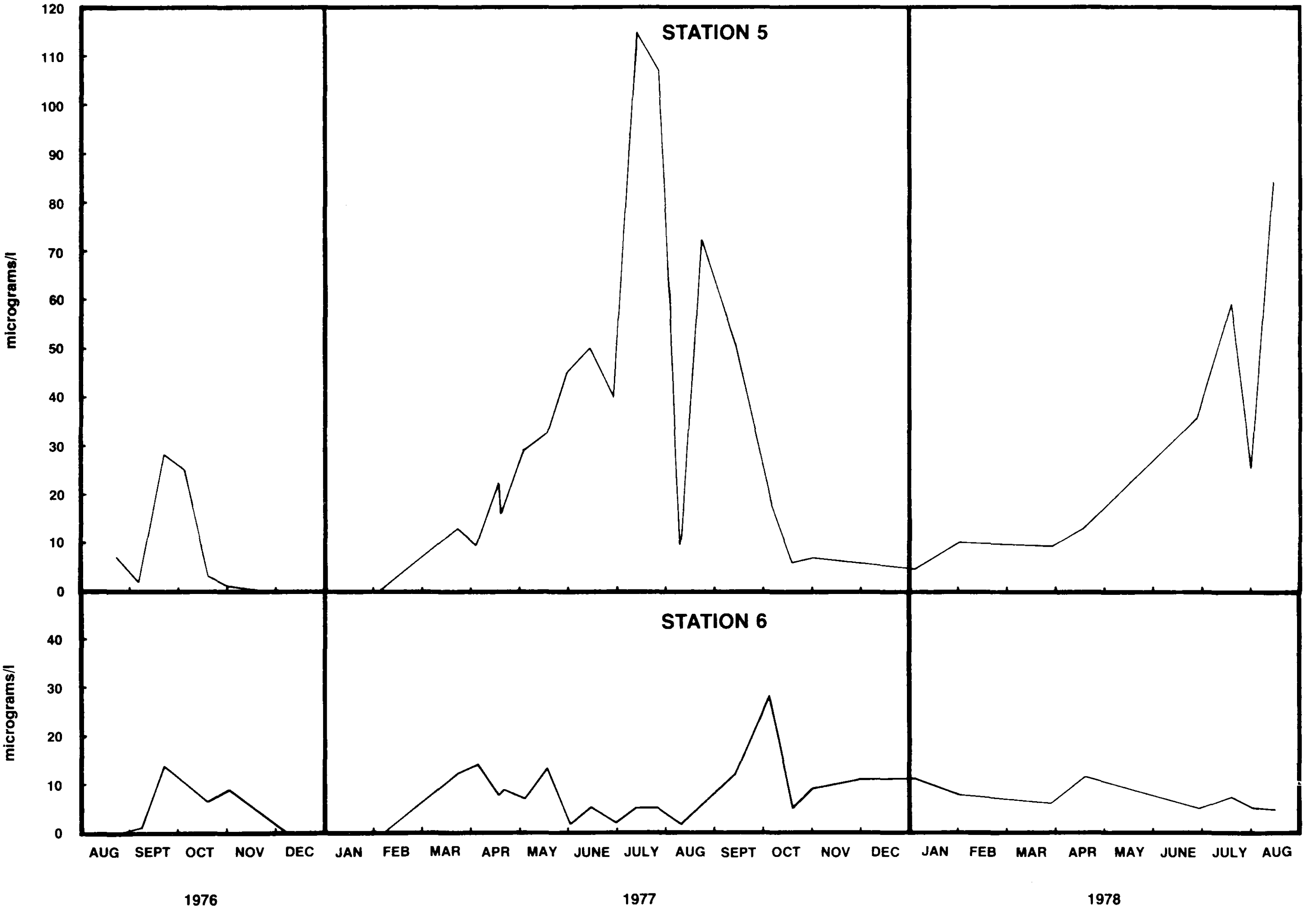

Figure 19. Continued. Chlorophyll a concentrations at stations 5 and 6.

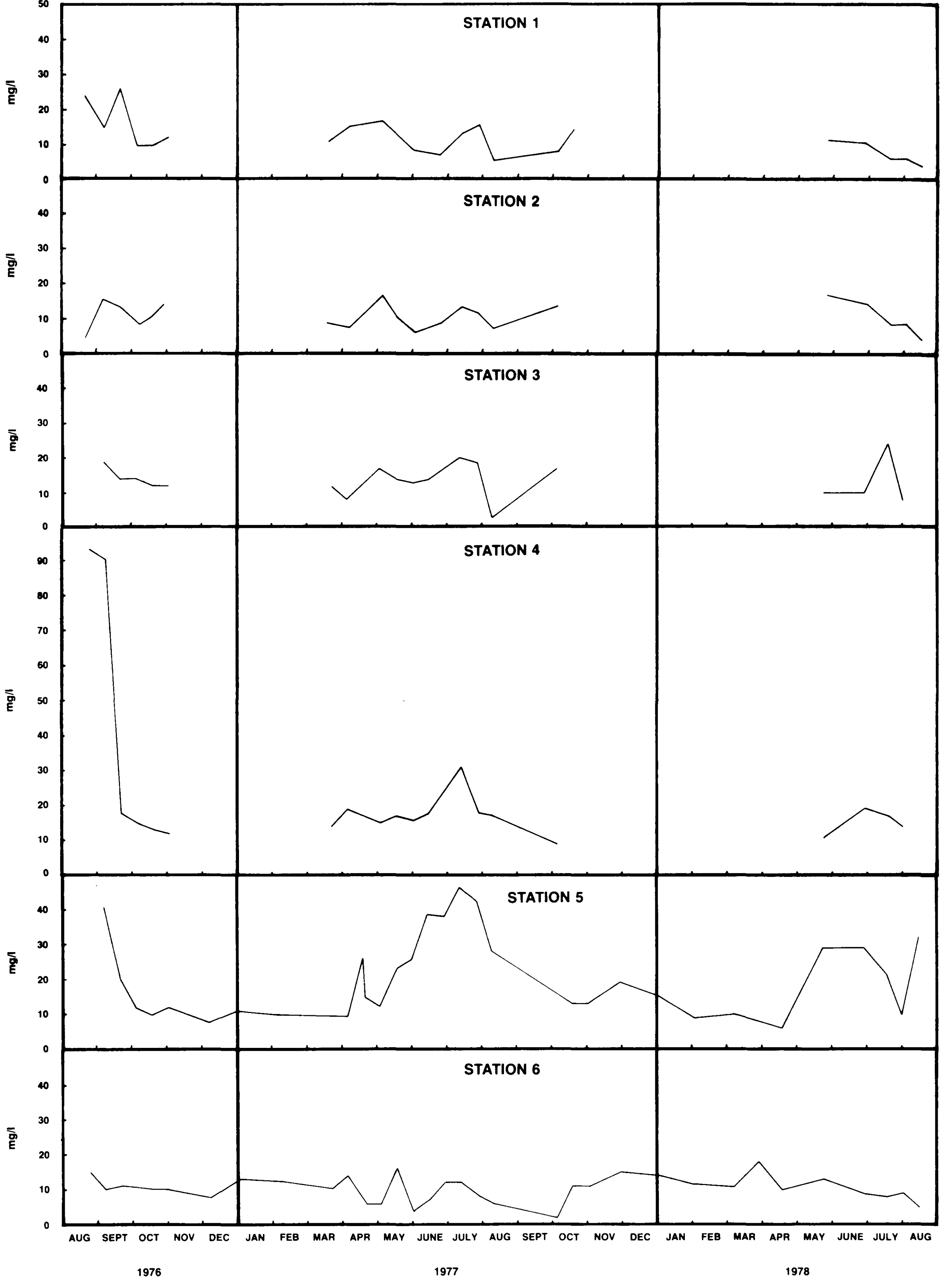

Figure 20. Chemical oxygen demand (mg/l) values at stations 1, 2, 3, 4, 5 and 6.

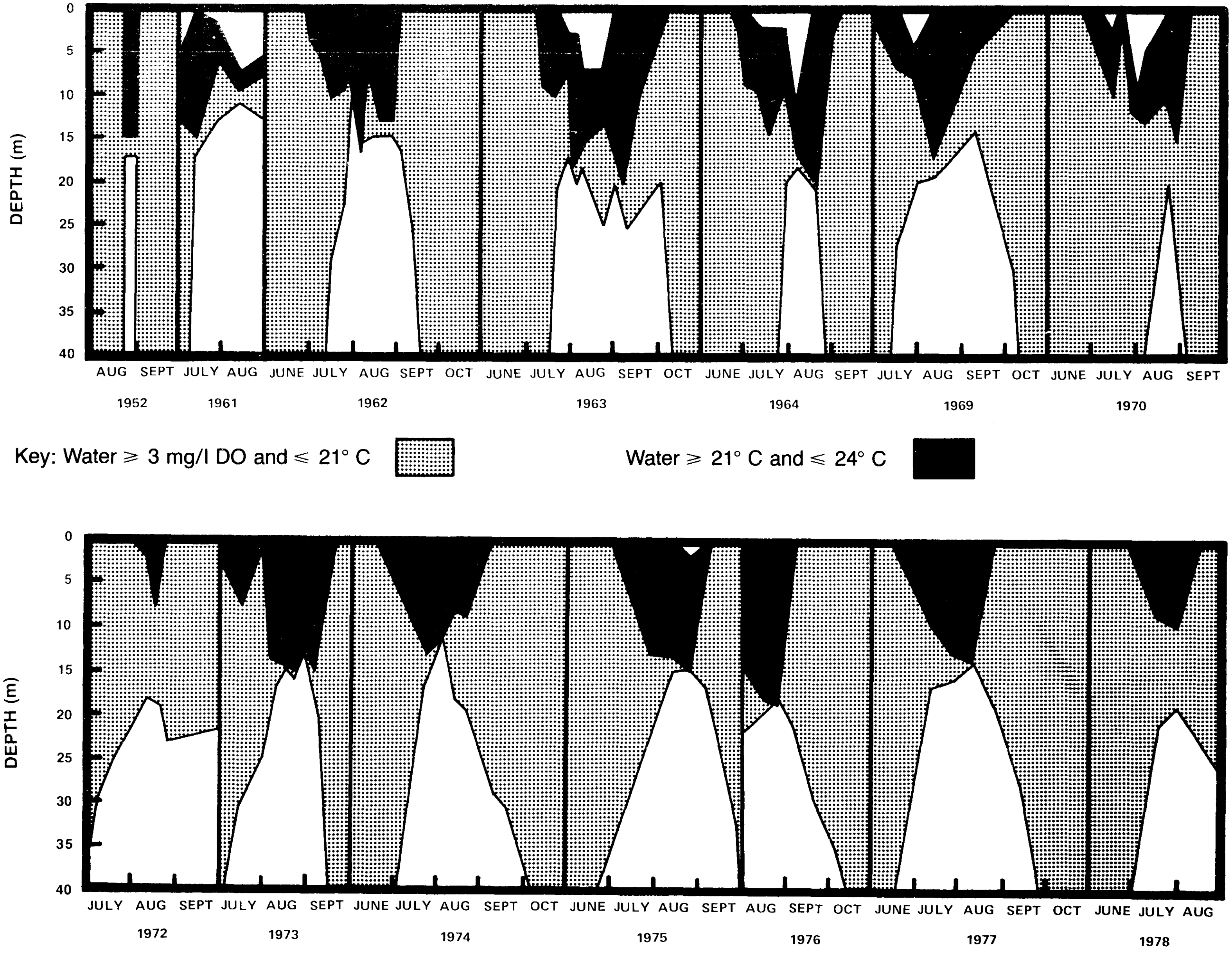

Figure 21. Lake McConaughy trout habitat available at 21° C (3mg/l DO) and at 24° C (3 mg/l DO).