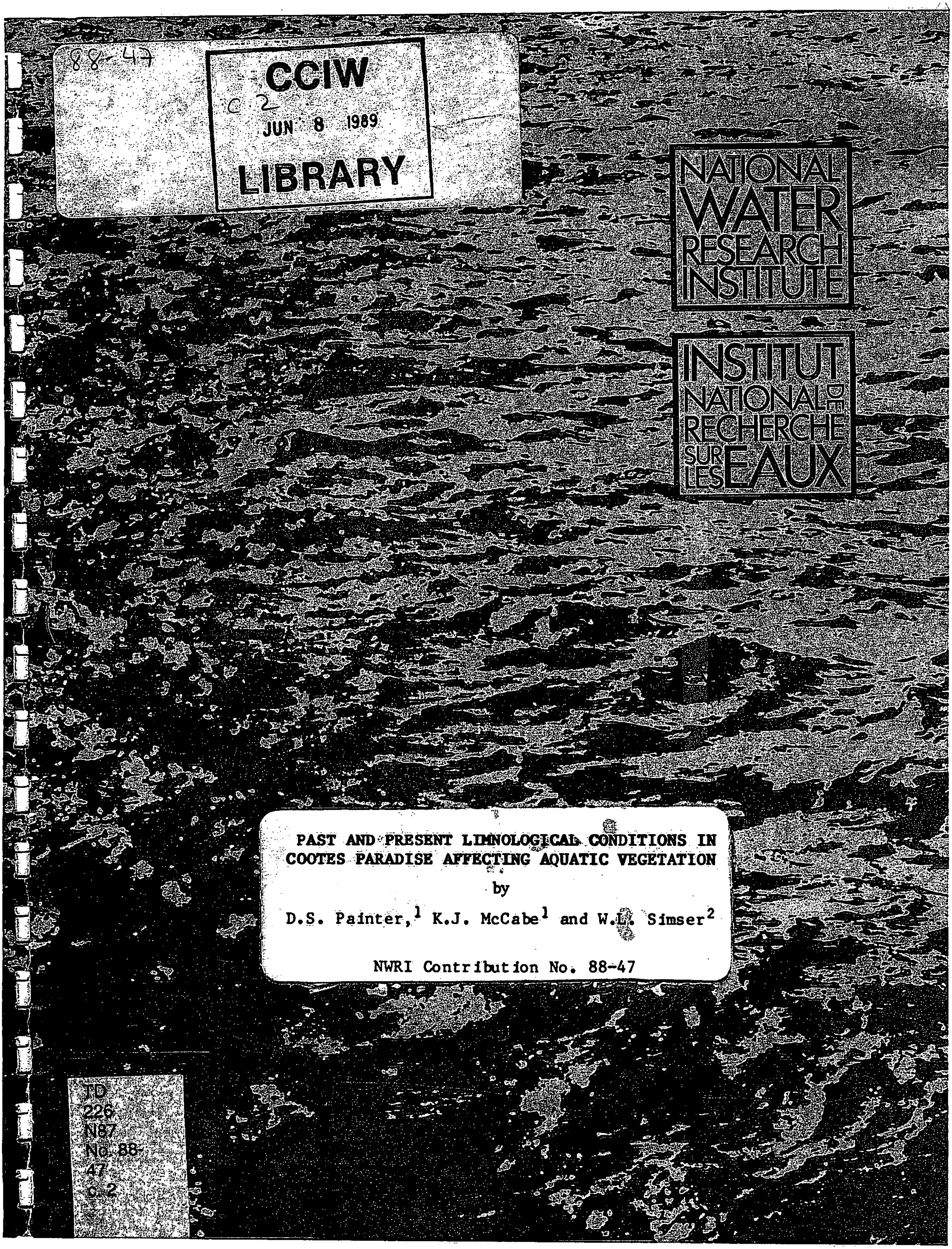

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PAST AND PRESENT LIMNOLOGICAL CONDITIONS IN COOTES PARADISE AFFECTING AQUATIC VEGETATION

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Executive Summary

Cootes Paradise, a wildlife sanctuary at the western end of Hamilton Harbour, has lost approximately 85% of its marsh habitat. Other Great Lakes coastal marshes have suffered similar losses. The latest Great Lakes Water Quality Agreement has recognized the need to preserve and restore wetlands threatened by urban and agricultural development and waste disposal activities (Annex 13). The recent Remedial Action Plan exercise has focused attention on the biological importance of Cootes Paradise. Loss of habitat for waterfowl in North America has resulted in the North American Waterfowl Management Plan, a binational agreement between Canada and the United States signed by the Minister of the Environment and the Secretary of the Interior. The Great Lakes-St Lawrence Lowland was identified in the Plan as an important area on the continent with specific goals for waterfowl habitat restoration.

This report examines and summarizes all historical data. A sampling program was designed based on the historical information to determine the current limnological conditions affecting marsh habitat (aquatic vegetation). An exhaustive review of the literature and an examination of the historical and present limnological conditions has provided a better understanding of the forces responsible for the loss of vegetation. Remedial measures to create vegetation can be recommended as requested in Annex 13 (3).

The present morphometry limits the potential for emergent plants to expand given the water level regime imposed on the marsh by Lake Ontario. Water clarity limits submergent plant growth and distribution. Reduction of sediment and nutrient loadings of 50-65% will be necessary but ineffective in improving water clarity if wind and wave resuspension of sediments and carp activity are allowed to continue. Direct destruction of submergent and emergent plants by carp and resuspension of sediments by carp and wind and waves within Cootes Paradise appear to be the most crucial forces to control for submergent plant recovery.

Résumé

Cootes Paradise, une réserve naturelle administrée par les Jardins botaniques royaux, est un plan d'eau de 250 hectares situé dans la partie ouest du port d'Hamilton. A partir de photographies aériennes, on se rend compte que la perte de végétation dans cette terre humide de classe I a commencé au début des années quarante et, en 1979, 75 % de cet habitat aquatique était disparu. Les présents stress environnementaux qui bloquent la croissance des macrophytes aquatiques sont les variations du niveau de l'eau, la turbidité et la présence des carpes. Pour l'instant, la turbidité passe pour être le facteur le plus critique pour la perte d'habitats. Les échantillons ont été prélevés en 18 emplacements afin d'identifier les sources qui contribuent au niveau élevé de seston et afin d'évaluer dans quelle mesure le limon et la chlorophylle sont responsables de la turbidité de l'eau. Les rapports entre les paramètres de qualité de l'eau et la façon dont ils varient saisonnièrement semblent indiquer que le limon constitue le principal facteur de l'extinction de la lumière dans l'eau. Bien que Spencer Creek constitue la source originelle du limon déversé dans Cootes Paradise, nous croyons que l'activité des carpes liée à l'alimentation et à la reproduction compte pour beaucoup dans la resuspension du limon. A deux flèches de sable, la resuspension du limon par le vent et les vagues ainsi

que par le déplacement de l'eau avec le courant et l'écoulement d'effluents d'égouts est également importante. Pour rétablir la végétation aquatique à Cootes Paradise, les mesures suivantes sont nécessaires :

les charges en seston et en phosphore du bassin hydrologique doivent être réduites de 50 % et 60 %, respectivement :

La resuspension des sédiments par le vent et les vagues doit être éliminée de façon à garder la concentration de seston dans Cootes Paradise entre 10 et 15 ug/L;

Il faut réduire la charge en phosphore provenant de la station d'épuration des eaux usées de Dundas et du port d'Hamilton ainsi que les CSO pour réduire la concentration en phosphore à 65 % de la concentration actuelle;

Le contrôle de la population des carpes sera nécessaire pour réduire l'effet destructeur qu'elles exercent directement sur la végétation et pour réduire leurs effets sur la turbidité.

ABSTRACT

Cootes Paradise, a wildlife sanctuary managed by the Royal Botanical Gardens, is a 250 hectare water body located at the western end of Hamilton Harbour. Based on aerial photographs, the loss of vegetation from this class 1 wetland began around the early 1940s and by 1979, 75% of its wetland habitat had disappeared. Current environmental stresses that are thwarting aquatic macrophyte growth are fluctuating water levels, water clarity and carp. At present, water clarity is perceived to be the most critical factor responsible for the habitat loss. Eighteen locations were sampled to identify the sources contributing to elevated seston and to assess the relative contributions of silt and chlorophyll to the water clarity problem. Relationships between water quality parameters and how they vary on a seasonal basis suggest that silt is the dominating factor responsible for limited light penetration. Although Spencer Creek is the ultimate source of silt to Cootes Paradise, we believe that the feeding and spawning activity of carp play a major role in resuspending silt. Resuspension of silt at two sandbar locations by wind and wave energy and water movement due to stream and sewage effluent flows is also important. To restore aquatic vegetation in Cootes Paradise the following actions will be necessary:

Loadings of seston and phosphorus from the watershed will have to be reduced by 50% and 60%, respectively;

Wind and wave resuspension of sediments will have to be eliminated so as to maintain seston concentrations in Cootes Paradise at 10-15 mg/l;

Reduction of phosphorus loading from the Dundas STP and Hamilton Harbour and CSOs sufficient to reduce phosphorus concentrations by 65%;

Carp control will be necessary to reduce their destructive influence of the vegetation directly and reduce their effects on water clarity.

Résumé

Cootes Paradise, une réserve naturelle située dans la partie ouest du port d'Hamilton, a perdu environ 85 % de son habitat de type marécageux. D'autres marécages côtiers des Grands lacs ont subi des pertes semblables. Le plus récent accord relatif à la qualité de l'eau dans les Grands lacs reconnaît la nécessité de conserver et de rétablir les terres humides menacées par l'urbanisation et l'exploitation agricole ainsi que par les activités liées à l'élimination des déchets (Annexe 13). Le récent plan de mesures correctives porte sur l'importance biologique de Cootes Paradise. La perte d'habitats a conduit à la mise en place du plan de gestion de la sauvagine d'Amérique du Nord signé par le ministre de l'Environnement du Canada et par le Secrétaire de l'Intérieur des États-Unis. Les plaines ~~des~~ Grands lacs et du Saint-Laurent sont identifiées dans le plan comme région continentale importante à laquelle sont rattachés des objectifs précis de rétablissement de l'habitat de la sauvagine.

Le présent rapport examine les données antérieures et en fait un résumé. Un programme d'échantillonnage a été préparé à partir des renseignements historiques; il vise à déterminer les présentes conditions limnologiques qui ont une action sur les habitats de marécages (végétation aquatique). Une revue complète de la

documentation ainsi que l'examen des conditions limnologiques passées et présentes nous ont aidés à mieux comprendre les facteurs responsables de la perte de végétation. Des mesures de correction pour établir une végétation peuvent être recommandées comme demandé dans l'annexe 13(3).

La présente morphométrie limite le potentiel d'expansion des plantes flottantes compte tenu du régime des niveaux d'eau imposé aux marécages par le lac Ontario. La turbidité limite la distribution et la croissance des plantes submergées. Une réduction des charges en sédiments et en matières nutritives de 50-65 % sera nécessaire, mais ne suffira pas à améliorer la limpidité de l'eau si la resuspension des sédiments par le vent et les vagues ainsi que l'activité des carpes se poursuit. La destruction directe de plantes submergées et flottantes par les carpes ainsi que la resuspension des sédiments par les carpes et le vent et les vagues à l'intérieur des limites de Cootes Paradise semblent être les facteurs critiques de rétablissement des plantes submergées.

Past Conditions

Cootes Paradise, a wildlife sanctuary managed by the Royal Botanical Gardens (RBG), is a 250 hectare Ontario Ministry of Natural Resources (OMNR) class one wetland located at the western end of Hamilton Harbour in Lake Ontario. Cootes Paradise is located in a strategic area for North American waterfowl. The western end of Lake Ontario from Burlington to Oshawa, which includes Cootes Paradise and Hamilton Harbour, was ranked by the Canadian Wildlife Service (CWS) as the second most important waterfowl staging area in Lake Ontario and the third most important area in the two lower Great Lakes (Dennis et al., 1984). The area also had the highest intensity of waterfowl usage per hectare of habitat in Lake Ontario (probably due to the lack of habitat relative to the numbers of waterfowl wishing to use the area). The North American Waterfowl Management Plan has identified the Great Lakes-St. Lawrence lowlands as a priority area requiring protection and restoration of 27,000 hectares of breeding and migration habitat for black ducks and other waterfowl. The Waterfowl Management Plan is a binational agreement in response to habitat loss throughout North America and declining waterfowl populations. The latest Great Lakes Water Quality Agreement between Canada and the United States has also affirmed the need to preserve and restore threatened wetlands in the Great Lakes basin (Annex 13, GLWQA). Like other wetlands in the Great Lakes, Cootes Paradise lost approximately 75% of its wetland habitat by 1979 (Whillans, 1982).

Historical topographical, hydrological and surveyors' maps suggest that Cootes Paradise remained almost completely vegetated with emergent plants from 1793 through to the early 1900s. From 1907 to 1938, 20% of the area was open water. Since 1946, the open water area of Cootes Paradise fluctuated between 55-92% of the total area. As a result of the loss of wetland vegetation in the 1940s, several scientific studies were attempted by McMaster University in the late 1940s and early 1950s to identify the causal factors (Kay, 1949; Turner, 1948; Sims, 1949; Warren; 1950).

Sims (1949) discussed the possibility that high suspended solids concentrations in the open water of Cootes Paradise were responsible for the loss of wetland vegetation. He also felt that high phytoplankton abundances in Chedoke Creek as a result of the Hamilton municipal garbage disposal site on the shores of Chedoke Creek may also play a part in the loss. Turner (1948) mentioned that high water levels and limited light penetration were probably affecting aquatic vegetation. Kay (1949) blamed carp for the loss of wild rice and increased turbidity. He considered carp control as necessary and suggested the construction of a dam at the high level bridge to control water level so that carp would be killed by drawdown during the carp fry period.

Lamoureux (1961) discussed the impact that carp had on aquatic vegetation in Cootes Paradise and the attempts from 1950 to 1960 to control carp. During a five year period, approximately 230,000 carp were removed from Cootes Paradise and Hamilton Harbour. Lamoureux observed uprooting, dislodging and destruction of aquatic vegetation by carp during the high water year of 1952 except in areas that had been fenced off to exclude carp. Even though high water persisted from 1951 to 1956, damage to aquatic vegetation by carp was greatly reduced due to the carp control program (Lamoureux, 1957). Lamoureux discussed the need for the program to continue to effectively control the carp population and restore the marsh, but it was unfortunately discontinued and the marsh proceeded to disappear.

This report summarizes the available past and present information on the physical and limnological and climatological conditions within Cootes Paradise which have affected the wetland vegetation. Explanations for the loss of vegetation will be provided and, based on a thorough understanding of the present stresses imposed on vegetation in Cootes Paradise, remedial measures to rehabilitate the area will be discussed.

Morphometry

Kay (1949) and Turner (1948) published water depth maps of Cootes Paradise based on a survey from June 20 to July 3, 1946. Figure 1 illustrates the water depths during 1946 based on their maps. Table 1 summarizes the daily water levels at the Port Dalhousie and Toronto gauges for the same period. The information in Table 1 is reproduced here in detail because the water level information in the earlier theses was incorrect.

Table 1 Daily Water Level

	Port Dalhousie		Toronto	
Date	Level (ft)	Level (m)	Level (ft)	Level (m)
June 20, 1946	246.10	75.00	246.08	75.00
21	246.04	74.99	246.06	74.99
22	246.00	74.98	246.03	74.99
23	245.99	74.97	246.03	74.99
24	245.98	74.97	246.01	74.98
25	246.01	74.98	246.03	74.99
26	246.00	74.98	246.01	74.98
27	245.99	74.97	245.99	74.97
28	245.96	74.96	246.00	74.98
29	245.98	74.97	246.01	74.98
30	245.94	74.96	246.00	74.98
July 1	245.96	74.96	245.97	74.97
2	245.96	74.96	245.99	74.96
3	245.97	74.97	245.99	74.97
Average	245.99	74.97	246.01	74.98

Fortunately, the water levels at both gauges were similar and reasonably constant over the period of their survey. The mean water level during the survey was 74.98 m with a maximum difference of only 5 cm. A similar survey was conducted on October 30, 1986 from 9:30 to 15:30 and the water level at the Burlington gauge was 75.07 m and varied by only 2 cm during that time interval. The water depths of Cootes Paradise during the 1986 survey are illustrated in Figure 2. The difference in mean water level between the two surveys was only 9 cm. Therefore, considering the accuracy of the water depth determinations, the two maps can be compared to one another without correction for water level changes.

The morphometry of Cootes Paradise in 1986 is uniform with the western end having a depth of 30-60 cm and gradually deepening to 120 cm in the eastern end. Between 1946 and 1986, the water depths in the western end of Cootes Paradise remained relatively constant, suggesting that no net deposition of sediment had occurred. In the eastern end of Cootes Paradise, however, the water depths decreased suggesting a net deposition of 15-60 cm of sediment had occurred over the forty year period. A comparison of water depths at several locations in the eastern end between 1946 and 1986 suggest that the deposition rate was approximately 1 cm/year.

The hypsometric curve for Cootes Paradise derived from the 1986 water depth information is presented in Figure 3. At the time of the survey, the mean depth of Cootes Paradise was 87 cm. Since the 1986 survey was conducted at a water level 17 cm above the normal June water level, the mean depth would normally be 70 cm in June. As illustrated in the hypsometric curve, the shoreline has a steep slope. In many areas, particularly along the south shore, the areas adjacent to the shore are deeper than the centre.

Lake Topography - Sedimentation and Resuspension

Hakanson and Jansson (1983) studied erosion and transportation of lake sediments with respect to lake topography. They derived the following equation to estimate the area of a lake involved in erosion and transportation of sediments:

$$\text{Area}_{E+T} = 25 * (\sqrt{A}/\text{Dmean}) * 41^{0.061 * \text{Dmean}/\sqrt{A}}$$

where: A = total lake area in km²;
Dmean = mean depth in meters.

For Cootes Paradise, with an area of 2.5 km² and a mean depth of 0.7 m, the area involved in erosion and transportation of sediments is 62.5%. With declining water levels through the summer, the mean water depth would be 0.6 m from May through September which means that 72% of the area could be involved in resuspension during this period. Hakanson and Jansson (1983) also discussed the significance of the ratio $A^{0.5}$/Dmean which would be 2.26 during June or 2.64 throughout the summer for Cootes Paradise. Based on the magnitude of the ratios, they would conclude that resuspension is important in Cootes Paradise, bottom dynamics govern the distribution patterns of pollutants and budget calculations could be inaccurate.

Lake Topography and Emergent Plants

Duarte et al. (1986) examined the extent of emergent vegetation in 60 lakes and reported a statistically significant (r^2 = 0.9) relationship between emergent vegetation area, total lake area and the ratio of area to mean depth. The equation derived from the data was:

$$\ln A_e = 0.72 * \ln A - 0.69 * \ln (\sqrt{A}/\text{Dmean}) + 0.72$$

where: A = lake area in hectares;
Dmean = mean depth in meters.

According to this equation, emergent vegetation in Cootes Paradise would only occupy 5% of the total area normally under water in June. Therefore, very little littoral habitat appears to be available in Cootes Paradise for emergent vegetation due to its topography at existing water levels.

Water Level Fluctuation

Seasonal Water Level Fluctuation and Submergent Plants

Lake Ontario water levels determine Cootes Paradise water levels. The annual cycle in Lake Ontario peaks in June (74.9 m) and troughs in December (74.4 m) with an annual fluctuation of 50 cm. Rorslett (1985) examined the effects of seasonal water level fluctuation on the depth of peak biomass of submerged macrophytes. The relationship he derived between the depth of peak biomass (D) and water level fluctuation is:

$$\log D = 0.27 + 0.12 * (\text{Mean annual water level range})$$

For Cootes Paradise, with an annual water level fluctuation of 50 cm, the predicted depth at which submerged macrophytes would perform best is 2.1 m. This depth does not exist in Cootes Paradise.

Rorslett's relationship takes into account ice scouring effects as well as water level fluctuations and describes an empirical response on the part of submerged macrophytes to annual water level changes. With a normal minimum water level of 74.4 m and an ice thickness of 0.5 m, submergent plants would be restricted to elevations less than 73.9 m or water depths greater than 100-120 cm during a normal June. This would restrict submergent plants to less than 12% of the total area of Cootes Paradise.

Seasonal Water Level Fluctuation and Emergent Plants

Emergent plants are also affected by water level fluctuations. Lyon et al. (1986) determined that Typha in the Great Lakes occupies depths that are flooded for 50-85% of the time from mid-June to mid-August and is excluded from depths that are flooded for longer periods. Since Typha is a dominant emergent plant in Cootes Paradise, their conclusions are pertinent to Cootes Paradise. Mid-July and July 31 represent 50 and 83% of the critical time period. Therefore, the average water level for July 15 (74.85 m) and July 31 (74.8 m) would limit emergent vegetation to elevations higher than 74.8 m. From the hypsometric curve, this elevation corresponds to approximately 0.5% and 1% (1.25 - 2.5 hectares) of the area of Cootes Paradise below the high water line. Glyceria, the other dominant emergent plant in Cootes Paradise occurs on drier hydrosoils than Typha, hence Typha is usually located at the water's edge if appropriate elevations are present. The steepness of the shoreline slope and the timing of the peak water level in Lake Ontario are important factors influencing the distribution and extent of emergent vegetation.

The timing of the peak water level also has an effect on spring spawners such as pike. Pike would have difficulty locating flooded terrestrial grasses for spawning in Cootes Paradise since the spring water level is normally 74.5 - 74.7 m and aquatic emergent plants and terrestrial grasses are limited to elevations higher than 74.8 and 74.9 m, respectively.

The peak water level in June also results in carp having access to and the potential to destroy flooded vegetation during their spawning period. The destruction of emergent plants by carp in June is evident throughout Cootes Paradise. Their spawning and feeding activities not only destroy the vegetation directly but also undercut the bank which eventually results in the loss of still more shallow habitat.

Annual Water Level Variations

Historical water level fluctuations in Lake Ontario from 1840 to 1986 are illustrated in Figure 4. Numerous publications have reflected on the impact of high and low water levels and suggest that high water is responsible for the loss of emergent plants and low water is necessary for their return. McDonald (1955) observed die-offs due to high water levels during winter, presumably due to submergence of dormant shoots. Although Busch and Lewis (1984) observed no relationship between a single year's water level and wetland vegetation, they did observe a response in wetland vegetation to the average water level in the preceding five years. McDonald (1955) also reported a compounding effect of multiple years of high water.

Multiple years of high water during summer and winter occurred during the 19th century in Lake Ontario. In particular, the periods between 1857-1865 and 1883-1887 experienced high water levels during the summer and winter which would have stressed the emergent vegetation. Sketches illustrating the extent of the marsh area are shown in Figure 5. From 1793 to 1856, historical maps indicate that the marsh occupied 100% of the available area. A map from 1862 of the Chedoke Creek area illustrates a significant loss of emergent vegetation. This loss could be due to the high summer and winter water levels during the preceding four to five years. From 1895 to 1907, low water persisted, providing ample time for vegetation to re-occupy Cootes Paradise. The 1907-09 topographical map shows 20% open water at the east end of Cootes Paradise. From 1907 to 1939, the marsh area remained at approximately 80% of the available area despite the long period of unusually low water between 1920 and 1942. For example, compare the water levels from 1920-1942 with the water levels prior to 1856 and then compare the 1935 map with the 1856 map. The marsh appears to have lost its ability re-colonize the east end of Cootes Paradise.

Cairns and coworkers (COA, 1988) examined aerial photographs of Cootes Paradise from 1928 to 1985. They determined that over 200 hectares of Cootes Paradise was an emergent marsh between 1928 and 1939 (Figure 6). They also observed a dramatic reduction in emergent vegetation between 1946 and 1953; a small return from 1954 to 1959; a gradual decrease from 1959 to 1972; a major loss from 1972-1974 and a small comeback from 1974 to 1985. Multiple years of low water levels existed from 1957 to 1971 and normal water levels have existed from 1979 to 1985. The emergent vegetation should have increased in area from 1957 to 1971 but instead it exhibited a gradual decline from 40% to 28% of the total area of Cootes Paradise. The normal water levels from 1979 to 1985 should have provided sufficient time for the emergent vegetation to equilibrate to the water level regime and yet in 1985, only 16% of Cootes Paradise supported emergent vegetation. The present emergent vegetation consists of manna grass (Glyceria maxima) and cattails (Typha sp.) above the high water line. As discussed earlier, the emergent vegetation has difficulty expanding below the high water line due to a) the steepness of the slope of the shore, b) high water stress during the growing season and c) the effects of carp.

Reznicek and Keddy (1985) indicate that if the slope angle of the wetland sediment is known, the response in wetland area to changing water levels can be calculated. From the hypsometric curve, 94.1% of Cootes Paradise has a linear slope of -108.62 (st. error = 5.24, r^2 = .988). Figure 7 represents the area of emergent vegetation from the aerial photographs interpreted by

Cairns and coworkers plotted against the five year annual average water level. The graph of percent marsh area plotted against the five year annual average water level has a slope of -89.3 (st. error = 16.2). The regression coefficient (r) is 0.825 indicating the five year annual average water level accounts for 68% of the variation in marsh area. The slope of the regression and the slope of the hypsometric curve are not statistically different, supporting Reznicek and Keddy's comment concerning the relationship between wetland area, water level and sediment slope. Using a mean slope of -100, a drop in water level of 10 cm would increase the marsh area by 10%. Currently, under normal Lake Ontario water levels, the marsh area is approximately 15% of the total area. The relationship between water level and recent marsh acreage would suggest that the current emergent plant area in Cootes Paradise is what would be expected under normal Lake Ontario water levels. For the emergent vegetation to return to 85% of the available area, the average water level of Lake Ontario would have to drop 70 cm. Such a large permanent drop is unlikely to occur given the water level control capabilities for Lake Ontario.

Water Clarity

Historical trends

George North, a local Hamilton naturalist, commented that the water clarity was such that one could see fish and the bottom in the eastern end of Cootes Paradise during the 1920s. The water depths in the eastern end of Cootes Paradise were 135-180 cm (Figure 1). Discussions we have had with other local individuals have confirmed that the bottom was visible in 1 meter of water during the 1930s. Turner (1948) attributed the lack of submergent vegetation below 1 meter during the 1940s to high water turbidity. The average Secchi disc transparency, an expression of water clarity, was 38 cm in the open water area during 1948 (Kay, 1949). Water clarity was measured by Bacchus (1974) in 1973/74 and by the Ministry of Environment (MOE,1977) in 1975 and by the Royal Botanical Gardens from 1977 to 1987. The Secchi disc transparencies in the main body of Cootes Paradise varied from 10-47 cm during the 1970s and from 7 to 32 cm during the 80s (Figure 8). Secchi was also very poor in West Pond (6-25 cm) with a few readings of up to 39 cm (Figure 9). Based on the available information, water clarity dropped dramatically from the 1920s to the 1940s and less dramatically from the 1940s to the present.

Spatial trends

Numerous studies have sampled various stations within the marsh to illustrate spatial patterns in water clarity. Figure 10 depicts station locations referred to in the text. Bacchus (1974) measured Secchi disc transparency and turbidity (FTU) at 13 stations (Figures 11 and 12). Incoming water clarity was better than the water clarity in West Pond and the open water stations. Water clarity in the Westdale cut, an area well protected from wind and waves, was better than adjacent open water stations. In 1975, the Ministry of Environment measured turbidity at 8 stations within the marsh (Figure 13). Turbidity was lowest at the incoming stations and at West Pond, increased dramatically at the end of the Willow line, and then decreased through the open water area. The data collected by the RBG from 1977 to 1987 indicated that Stations CP 1 and 2 generally had lower Secchi disc transparencies than the two inflows (CP 4 and CP 6, Figure 14). In other words, water clarity was reduced in Cootes Paradise compared to the inflows. Water clarity in West Pond (CP 5) was also reduced relative to its inflow (CP 6) (Figure 15). Kay (1949) also observed, in 1948, water clarity (Secchi disc transparency) decrease from the inflows into Cootes Paradise. CP 3 had the best water clarity (50 cm); CP 2 had the poorest water clarity (35 cm); and CP 1 showed some improvement (42 cm) compared to CP 2, probably due to sedimentation of seston in the eastern end of Cootes Paradise (see morphometry section).

What is the source of the reduced Secchi disc transparencies and high turbidities in the open water area of Cootes Paradise? Traditionally, water clarity in lakes is related to algal abundance as expressed by chlorophyll$_a$ concentration. However in streams, water clarity is a function of suspended silt because algal growth in negligible. Since Cootes Paradise shares characteristics of both rivers and lakes, suspended solids (seston) could be comprised of suspended silt and algae.

Spatial Seston and Chlorophyll trends

Spatial patterns of seston for 1975 (Figure 16) confirm the 1973/75 trends in Secchi disc transparency and turbidity (Figures 11-13). The highest seston concentrations were measured at the end of the Willow Line during 1975. The spatial patterns of chlorophyll in 1973 (Figure 17) and 1975 (Figure 18) do not follow the same pattern as Secchi disc transparency or turbidity. The average seston concentrations from May to October for 1975, 79, 80, 86 and 87 increased from the inflows (CP 4B and CP 6) through the Willow Line (CP 3) towards the main body of Cootes Paradise (CP 1+2) (Figure 19). Geometric means for station CP 4B were calculated to dampen the influence of extreme seston concentrations as a result of storm events as illustrated in Figure 20.

Historical Seston trends

Seston concentrations have not changed significantly from 1973 to 1987. Figures 21 and 22 illustrate the historical trend in seston at stations CP 1+2 and CP 5. Seston concentrations at CP 1+2 ranged between 25 and 150 mg/l and between 10 and 300 mg/l at CP 5 with one isolated storm event in July of 1979 that caused seston concentrations to dramatically increase at all stations that were sampled.

Interrelationships between water clarity parameters

Chlorophyll and Secchi disc transparencies from the 1973/74 data collected by Bacchus (1974) are plotted against one another in Figure 23. At low chlorophyll concentrations (<25 µg/l), Secchi disc transparencies ranged from 5 to 95 cm. At high chlorophyll concentrations (200 to 1000 µg/l), Secchi disc transparencies ranged from 17 to 40 cm. Despite these extremely high chlorophyll concentrations, Secchi disc transparencies did not drop below 17 cm. Statistically, there was no relationship between Secchi and chlorophyll (r^2=0.06).

A turbidity versus chlorophyll plot of Bacchus' data is provided in Figure 24. No significant relationship was observed between these two parameters (r^2=0.03). A significant relationship was observed between turbidity and Secchi (r^2=0.51, Figure 25). The turbidity method chosen by Bacchus (Formazin turbidity) measures the light scattering due to particles in the water sample and should be related to Secchi disc transparency. The lack of a relationship between chlorophyll and turbidity or Secchi suggests that algal cells do not dominate the particulates.

A plot of Secchi disc transparency versus chlorophyll using the RBG's data from 1977 to 1986 is provided in Figure 26. At low chlorophyll concentrations (<25 µg/l), Secchi disc transparencies ranged from 4 to 78 cm while at high chlorophyll concentrations (>200 µg/l), Secchi disc transparencies ranged from 8 to 43 cm. No relationship was observed, again suggesting that the algae were not a major contributor to the poor water clarity. Attempts to relate Secchi disc transparency and chlorophyll$_a$ concentrations in Lake Ontario have also failed (Kwiatkowski and El-Shaarawi, 1977), because the particulate material even in Lake Ontario is 50% detritus or heterotrophic organisms (Stadelmann and Munawar, 1975).

The classical approach to lake management is the control of phosphorus loading to reduce algal growth and improve water clarity. No relationship was found between total phosphorus and chlorophyll or total phosphorus and Secchi disc transparency using 9 years of RBG data (Figures 27 and 28).

Sediment Resuspension

Historical sediment loadings from the Spencer Creek watershed as well as the Dundas STP are the ultimate sources of suspended silt in the water column of Cootes Paradise. Spencer Creek (the main inflow) has low seston concentrations (5-30 mg/l) from May to October and the Dundas STP effluent averages only 5.5

mg seston/litre. Therefore, the higher seston concentrations and reduced Secchi disc transparencies in the open water area of Cootes Paradise must be due to other processes occurring within the marsh before it reaches the open water or some other attribute of the discharge. One possibility is that the water velocity of Spencer Creek and the Dundas STP discharge is great enough to result in the scouring or resuspension of surficial sediment. Scouring of surficial sediment was observed when the water level dropped in the fall of 1987. In one month's time, channels were created that were approximately 30 cm deep in areas that were previously flat.

Wind and wave resuspension must also be important in Cootes Paradise due to its shallow nature and orientation to the predominate wind directions. Figure 29 illustrates the wind roses for Cootes Paradise for the months of April to November. The prevailing wind directions are from the south-west and the north-east (50-60% of the time) which is also the main axis of the water body. Mean wind speed is similar throughout the period (approx. 12 km/hr) and rarely is Cootes Paradise calm.

The surficial sediment of Cootes Paradise is comprised of 25.5% sand, 46% silt and 28.5% clay (Mudroch, 1981). The threshold velocity necessary to resuspend similar sediment is only 2-3 cm/sec (Lam and Jaquet, 1976). Water velocity measurements at the sediment-water interface were made on several occasions and the empirical relationships between wind speed and water velocity reported by Witting (1909) ($v = 0.48 * \sqrt{W}$) and Van Dorn (1953) ($v = 0.033 * W$) were found to be appropriate. With a mean wind speed of 12 km/hr, the water velocity at the sediment-water interface would be approximately 9-11 cm/sec. Therefore, water velocities are adequate to result in the resuspension of surficial sediment. As mentioned previously, 60-70% of Cootes Paradise could be involved in erosion and transportation of sediments (Hakanson and Jansson, 1983). A seston increase of 20 mg/l would require the resuspension of only the top 12 microns of the sediment surface from this area. Wind and wave energy could be very important in resuspending sediments and maintaining the suspended sediments in the water column.

Winter sampling by Bacchus (1974) and the Ministry of Environment (MOE,1986) has provided water clarity data under ice cover. Water turbidity, expressed as FTUs, in the main body of Cootes Paradise during ice cover was lower when compared to the ice-free season data. Figure 30 illustrates the variation in water turbidity (FTU) from June 1973 to May 1974 (Bacchus, 1974) as well as the daily discharge of Spencer Creek (CMS= m^3/s) during the same period. Water turbidity does not appear to be a function of discharge since discharge during the winter is high compared to the summer months. The water turbidities observed by Bacchus during the winter (FTU ~ 10) suggest that Secchi disc transparencies could have been between 40 and 95 cm. Wind and wave resuspension of sediments could be a significant factor in the water turbidity problem in Cootes Paradise. However, wind and wave energy are not the only factors affecting resuspension that are missing during the winter period. Carp are also absent. The influence of carp on water clarity by physical resuspension of sediments must also not be ignored and is discussed later. The only definite conclusion from the winter data is that water velocities generated by the Spencer Creek and Dundas STP inflows are insufficient to scour the sediment surface and result in turbid water.

Bacchus (1974) also sampled a very sheltered area in Cootes Paradise (Westdale Cut). The Westdale Cut is an inlet approximately 1 kilometre deep and 100 meters wide with steep banks on either side rising to a height of 20-30 meters. Figure 31 illustrates the seasonal Secchi disc readings from the Westdale Cut and the main body of Cootes Paradise. Secchi readings during the summer from the inlet averaged 29 cm compared to the open water area average of 23 cm. Even though the Westdale Cut is very sheltered, the Secchi disc readings were only 6 cm different. The shallow nature of Cootes Paradise, the nature of the sediments, and its orientation to the perennial wind direction will make control of wind and wave resuspension very difficult if not impossible. The information from the Westdale Cut also suggests that reduction of wind and wave resuspension of sediments would not achieve a significantly improved water clarity.

Submergent Plants and Water Clarity

Submergent plant growth is stressed in Cootes Paradise by the effects of water level fluctuation and ice scouring as discussed earlier. Most submergent plants are restricted to water depths greater than 1 metre, making light penetration in the water column of paramount importance. Chambers and Kalff (1985) examined the depth distribution of submergent plants in 90 lakes and determined that angiosperms were limited to water depths which received greater than 21% of the incident photosynthetically available light. In Cootes Paradise, with a mean daily irradiance of 1300 $\mu E/m^2/s$ and yearly mean Secchi disc transparencies of 20-30 cm (extinction coefficients of 5-7 m^{-1}), submergent plants would be restricted to water depths less than 20-29 cm. Emergent plants colonize these depths in Cootes Paradise, thereby excluding submergent plants.

Chambers and Kalff (1985) also observed statistically significant relationships between Secchi disc transparency, the maximum depth of colonization and the depth of maximum plant biomass. The maximum depth of colonization (Z_c) was correlated to Secchi disc transparency (D) ($r=0.76$, $\sqrt{Z_c} = 1.33 * \log D + 1.40$). The depth of maximum biomass (Z_b) was correlated to Secchi disc transparency ($r = 0.63$, $Z_b = 0.54 * \log D + 1.15$).

Canfield et al. (1985) also determined a relationship between Secchi disc transparency and maximum depth of colonization for 108 lakes ($r = 0.7$, $\log Z_c = 0.61 * \log D + 0.26$). Table 2 provides the solutions to the above equations for a few Secchi disc transparencies.

Table 2
Depth of maximum biomass and maximum depth of colonization

Secchi m	Z_b m	Z_c (Chambers and Kalff) m	Z_c (Canfield et al.) m
0.25	0.8	0.35	0.8
0.50	1.0	1.00	0.9
0.75	1.1	1.50	1.4
1.00	1.15	2.00	1.8
1.50	1.25	2.65	2.7
2.00	1.30	3.30	3.65

Given the stresses imposed by water level fluctuation, significant submergent plant growth will not occur in Cootes Paradise unless the Secchi disc transparency increases to approximately 75 cm.

Duarte et al. (1986) reported a relationship between area of submergent plant growth (A_m), the total lake area (A) and the light intensity at the mean depth of the lake (I_z) ($n = 51$, $r^2 = 0.89$, $\ln A_m = 0.94 * \ln A + 0.87 * \ln I_z - 0.37$). For Cootes Paradise, with a mean depth of 70 cm and Secchi disc transparency of 20-30 cm, the light intensity at the mean depth is almost negligible and submergent plants would only occupy 2.5% of the total area. Again, given the stresses imposed by the water level fluctuation and the presence of emergent rather than submergent plants at the depths where sufficient light is available, submergent vegetation is virtually excluded from Cootes Paradise. During the 1987 field season, submergent plants were rare in Cootes Paradise. For example, Lemna minor, water lilies, 40-50 small clumps of Potamogeton pectinatus and only 1 plant of P.crispus were observed. In 1946-48, 24 species of submergent and floating-leaved macrophytes were recorded and in 1968/72 only 11 species remained (Simser, 1982).

Water Chemistry

Both ammonia and nitrate concentrations in 1948 in the open water of Cootes Paradise were approximately 0.75 mg/l. Raw water chemistry data from 1973 to 1987 for the open water stations CP 1+2 and West Pond (CP 5) are shown in Figures 32-43. Reductions in ammonia and increases in nitrate occurred from 1973 to 1978 due to improvements at the Dundas STP. Major changes in ammonia and nitrate concentrations have not occurred since 1978 in the open water area. West Pond had higher concentrations than the open water. Boar and Crook (1985) observed a link between the regression of reedswamp with high nitrate-nitrogen additions. When nitrate-nitrogen concentrations were greater than 3 mg/l, floating mats of reedswamp grew more luxuriously above water than below causing the floating root and rhizome mat to lose stability and be susceptible to erosion. If floating vegetation in Cootes Paradise once existed, high levels of nitrogen originating from the Dundas STP could have been responsible for its loss.

In another study, Balls et al. (1985) speculated that a loss of submergent aquatic plants may be associated with ecosystems where total phosphorus concentrations exceed 100 µg/l. They discovered that submergent vegetation could flourish in phosphorus-rich environments but that the fish community structure was the determining factor in the elimination of submergent plants. An unsuitable fish community, comprised of an abundance of planktivorous fish would selectively graze on the larger zooplankters. The lack of zooplankters such as Daphnia allow the phytoplankton to proliferate and water clarity to decrease, thereby affecting submergent plants. A shift in the zooplankton community structure between 1949 and 1979 has been documented by Simser (1982). He found that populations of the Cladoceran Bosmina longirostris and Rotifers, particularly of the genus Brachionus, more than doubled whereas Copepods and Cladocerans of the genus Daphnia decreased significantly over the time period. Zooplankton grazing by pelagic forage fish (alewife, gizzard shad and young of the year carp to name a few) probably caused this change in the zooplankton community structure.

In Cootes Paradise, the total phosphorus concentration has always exceeded 100 µg/l. Even though the total phosphorus concentration has remained high, a marked reduction in both total phosphorus and soluble reactive phosphorus occurred after 1975. This trend was most evident at station CP 5 which is closer to the Dundas STP than CP 1+2 and is a result of improved water treatment procedures.

Chlorophyll concentrations at the open water stations (CP 1+2) have fluctuated greatly, not only within a season but from year to year with less fluctuations between 1984 and 1987 (Figure 44). Chlorophyll concentrations in West Pond (CP 5) have declined from 1973 to present with reductions occurring between 1975 and 1977 (Figure 45). The chlorophyll reductions coincided with reductions in phosphorus. Average chlorophyll concentrations at CP 5 in 1973 and 75 were 700 and 400 µg/l while phosphorus concentrations averaged 10 and 4 mg/l. After improvements at the Dundas STP, phosphorus concentrations averaged 100-500 µg/l and chlorophyll concentrations averaged 100-225 µg/l.

Effect of carp on aquatic vegetation and water clarity

Evidence to suggest that carp were numerous enough in Cootes Paradise to have a detrimental effect on the survival of rooted aquatic plants is outlined in the Royal Botanical Gardens Technical Bulletin entitled "Changes in the Aquatic Biota of Cootes Paradise Marsh" (Simser, 1982). Results of a carp control program conducted by the RBG from 1952 to 1956 yielded a total of 93,000 carp. This abundance of fish most certainly had an impact on the aquatic biota and the water quality of Cootes Paradise by agitating the bottom sediments and making the water turbid.

Cahn (1929) studied the effect of introducing carp to an artificial lake. The introduction resulted in the total destruction of aquatic vegetation which in turn, eliminated the native game fish which had been successfully breeding in the lake for eight years. In Cahn's report he described "a very peculiar pitted condition on the muddy bottom. Everywhere were moon shaped or semi-round depressions about a quarter of an inch deep. These covered the entire exposed bottom so thickly as to overlap in many places. It was not until they began seining that they realized that the depressions were the work of carp - the impressions of the mouth where the fish had sucked the soft muck in search of food. This carp 'mumbling', then, satisfactorily accounted for the total absence of aquatic vegetation. The fish had rooted out every plant in the lake and rendered the water almost opaque".

There are many reports in the literature which blame carp for adversely affecting growth of aquatic vegetation and increasing water turbidity through their movements which in turn reduce light penetration. Robel (1961) discovered a highly significant negative linear relationship between the amount of vegetation present and carp population levels. When carp density was in excess of 200 lbs/acre, the amount of vegetation was greatly reduced. At carp densities of 400 lbs/acre or greater, vegetation was destroyed. Robel also performed carp exclosure experiments to investigate how carp density affects water clarity by comparing water turbidity inside the carp exclosures to the surrounding area. He determined that 2000 lbs/acre of carp was required to radically increase water turbidity. This density may be considered higher than usual since the sandy clay soil type in their study area was fairly resistant to becoming suspended in the water.

In Threinen and Helm's (1954) carp exclosure study, the fencing served to improve water clarity as well as increase vegetation abundance. Six days after the construction of the exclosure, a difference in water clarity was observed. Water clarity, as measured by Secchi disc transparency, was twice as much inside the fenced area (26 inches) as outside the fenced area (13 inches). After one month there was no sign of turbidity

inside the fenced area with clear visibility
feet) while the Secchi depth outside the fen
poor (15 inches). After 6 weeks, the fence wa
carp access to the luxuriant stands of vegetati
in the thinning of vegetation and muddy water.

In a carp elimination experiment, King and
a significant effect on the total subm
abundance. Because the soil was coarse, lin
very rapidly following a disturbance, there was
water clarity. The study area was a 45 acre
with an average water depth of 8 to 10 i
submergent vegetation was Chara which was spar
area. Eight weeks after most of the carp wer
lbs/acre), the Chara increased 3000 percent. T
percent more vegetation inside the fenced ar
variety of species. Intensive early spri
activity and feeding were the primary reasons f
growth while uprooting of vegetation during fe
the most important influence on the leafy pondw

Tyron's (1954) carp exclosure experiment a
lack of submergent vegetation to the mechan
carp's rooting and splashing habits. Turbid
within the quadrats as outside and no differen
open and closed quadrats. The total weigh
material was compared at two stations during a
Total production for the screened quadrat at st
deep) was 1300 g/m² and the unscreened qua
g/m². The screened quadrats at station 2 (1-2
598 g/m² and the unscreened produced only
turbidity may be responsible for the general
submergent vegetation in the lake, the ca
responsible for differences in production.

Macrae (1979) observed that enclosures
exhibited consistent and severe losses in p
carp densities used in his experiments were
Losses in some plant species were as hig
biomass was reduced 67.2%. The total plant
gastro-intestinal tract contents never exceeded
vegetation was merely incidental to the ing
macro-invertebrates.

Carp can significantly impact abund
composition of aquatic vegetation and dependin
type, carp can also affect water clarity. Ro
shown that carp populations greater than
adversely affect aquatic vegetation. If the
carp at spawning age is between 5 and 10 lbs,
of carp required to adversely affect the aquati
range between 12,350 and 24,700 for an area t

Paradise. At carp densities greater than 400 lbs/acre (24,700 to 49,400 carp), aquatic vegetation would be totally destroyed. Lamoureux (1961) reported the removal of 50,000 and 70,000 carp from Cootes Paradise in 1955 and 1956 using seine nets. If this is an indication of the number of carp present in Cootes Paradise now, and there is no reason to assume otherwise, aquatic vegetation will not return at the existing carp density.

All of the carp experiments reported in the literature have involved the addition of carp to vegetated areas or the total exclusion of carp from a poorly vegetated area. No experience has been reported on the effect of carp density on the return of plants to non-vegetated areas such as Cootes Paradise. A density of 20 carp per hectare may affect aquatic plant abundance in an existing weed bed but a much smaller density of carp may be required to permit aquatic vegetation to return to a non-vegetated area. The degree of carp control in Cootes Paradise to ensure the return of submergent vegetation is unknown.

Present Condition of Cootes Paradise

Based on the analysis of the historical information, the current environmental stresses that are thwarting submerged macrophyte growth are water clarity and carp. Submergent plant growth is also restricted to those species capable of withstanding fluctuating water levels. At present, the water clarity is perceived to be the most critical factor responsible for the lack of submergent vegetation. Therefore, in 1987 we initiated a sampling program to identify the sources contributing to elevated seston concentrations and the relative contributions of silt and chlorophyll$_a$ to the water clarity problem. We also examined the relationship between water quality parameters such as seston, suspended mineral, suspended organics, dissolved organic carbon, absorbance of the filtered water, chlorophyll$_a$, Secchi disc transparency and light extinction coefficients and how they vary on a seasonal basis. When the sources of silt and the relationships over time of various water clarity parameters have been identified, we would have sufficient information to make recommendations for remedial action to restore the submergent vegetation in Cootes Paradise.

The sampling locations were chosen to elucidate the processes responsible for the high seston concentrations in Cootes Paradise. Spencer Creek, Borer's Creek, Chedoke Creek and the outflow from the Dundas STP represent the inflows to Cootes Paradise. Sampling stations located along Spencer Creek as it flows into Cootes Paradise and combines with other inflows were sampled to determine if resuspension of silt along the creek channel was occurring. Sampling stations within Cootes Paradise were located to determine the importance of wind induced resuspension and sedimentation.

Due to declining water depths as the season progressed, the data were separated into two groups. From April 8 to September 8 the inflow of West Pond (receiving body for the Dundas STP effluent), Borer's Creek and a portion of Spencer Creek flowed along the north shore while the remainder of Spencer Creek flowed along the Willow Line. During this time, stations CP 5C, 5D and 3A were sampled. After September 8 and continuing until November 3, the water level had dropped sufficiently to cause the north shore area to become exposed and force the water of West Pond, Borer's Creek and Spencer Creek to flow into Cootes Paradise via the Willow Line. Stations CP 5C, 5D and 3A were therefore not sampled during this time period. As the sand bar at the end of the Willow Line became exposed, Spencer Creek was forced to flow south before turning east to continue into Cootes Paradise. Station CP 3B changed location to reflect the water quality of Spencer Creek entering Cootes Paradise after it had flowed over the sand bar. Therefore, the effect of the sand bar was determined by comparing stations CP 3 and 3B.

Water Clarity

For both time periods, the Secchi disc transparency became increasingly poorer downstream from the Dundas STP and Spencer Creek (Figures 46 and 47). The change in Secchi depth transparency can be explained by the notable increase of seston along these stretches of water (Figures 48 and 49). These figures also illustrate that the sandbar situated at the outlet of Spencer Creek into Cootes Paradise was a major contributor to the elevated seston at stations CP 3B, 2 and 1. However, between April 8 and September 8 the total seston did begin to settle out as the water reached the open water stations. It is interesting to note that when the water flowed over the sandbar from CP 3 to CP 3B, the increase in seston was primarily mineral in content (Figures 50 and 51). The spatial pattern in chlorophyll$_a$ (Figure 52-53) does not follow the spatial pattern in Secchi disc transparency. The Secchi depth improves from 21 to 24 cm from station CP 3B to CP 1 and the seston concentration drops from 99 to 78 mg/l but the chlorophyll$_a$ concentration increases from 38 to 67 µg/l.

Even though the sandbar was a major contributor to the large seston concentrations in Cootes Paradise, water clarity insufficient for plant growth had been created further upstream within the Willow Line. During the April to September period, Secchi disc transparencies decreased from 68 cm to 42 cm in the very short distance from CP 4B to CP 4A. There are no external sources of sediment between these stations and yet the mean seston concentration increased from 20 to 28 mg/l. The decrease in water clarity is not due to instream bank erosion since the time period involved is during low flow. One possible factor for the decreased water clarity is the presence of thousands of carp which inhabit Cootes Paradise. We believe that carp activity in that short section of Spencer Creek could be the cause of the reduced water clarity. Elevated seston concentrations between stations with no external silt sources were also observed at other locations (5A-5B, 5C-5D, 4-3).

At the stations near the outlet of the sewage treatment plant (CP 6), the mineral content of the total seston was lower than the Spencer Creek water (CP 4B). This trend was measured consistently over the entire sampling season as shown in Figures 54 - 58 which illustrate the seasonal trend in total seston and mineral at stations CP 6, 5, 4B, 3B and 1. On average, the total seston at station CP 4B was quite low, but in the event of a rain storm, a short lived yet drastic influx of seston to the creek resulted. For example, the heavy rainfall on June 21st and 22nd (Julian day 172 and 173) was responsible for elevating the seston concentration to 2300 mg/l but two days later the seston concentration was only 123 mg/l (Figure 59).

At stations CP 1, 3B, 4B, 5 and 6, the chlorophyll$_a$

concentration (Figures 60-64) seemed to peak on several occasions during our sampling season but not necessarily at the same time at all stations. Station CP 5 had by far the highest levels of chlorophyll throughout the season in Cootes Paradise.

Interrelationships between water clarity parameters

The relative contributions of seston and chlorophyll to water clarity were examined using data collected over the season from all the stations. We were not surprised to find a poor relationship between chlorophyll and extinction coefficient (Figure 65, $r^2 = 0.303$) and an even poorer relationship between chlorophyll and the inverse of Secchi disc transparency (1/Secchi) (Figure 66, $r^2 = 0.18$).

A good relationship between extinction coefficient and Secchi disc transparency was observed (Figure 67). Extinction coefficient data plotted against 1/Secchi (Figure 68) provided a linear relationship with an r^2 of 0.741. Since these water clarity parameters are related, we chose to compare the rest of our data with 1/Secchi since we measured it more often than extinction coefficient.

A strong relationship was found between seston and 1/Secchi (Figure 69, $r^2 = 0.763$) although an even stronger correlation was found between mineral and 1/Secchi (Figure 70, $r^2 = 0.76$). This was not surprising since the majority of the seston was mineral in content and seston and mineral concentrations were strongly correlated ($r^2 = 0.957$). When the effect of chlorophyll on the water clarity in Cootes Paradise was also included in the regression analysis, we found a slight yet significant improvement of the regression equation giving an r^2 of 0.80.

When station CP 5 was examined separately, we found a strong relationship to predict 1/Secchi using mineral and chlorophyll with an r^2 of 0.95. This was only a slight improvement over the prediction of 1/Secchi using mineral alone ($r^2 = 0.92$). Chlorophyll was a significant factor in the water clarity at CP 5 only ($r^2 = 0.45$).

We measured dissolved organic carbon and the absorbance of the filtrate at 440 nm as well as total seston, mineral and chlorophyll at CP 1. The suspended mineral concentration was the most significant factor determining water clarity at CP 1 ($r^2=0.76$). The absorbance of the filtrate was also statistically significant (abs. only $r^2=0.51$; mineral + abs. $r^2=0.79$). The addition of chlorophyll ($r^2=0.01$) or dissolved organic carbon did not improve the multiple regression (mineral + abs + chlorophyll $r^2=0.8$). The absorbance of the filtrate was also related to the concentration of mineral in the seston ($r^2=.44$), which is understandable because the absorbance of the filtrate is most probably due to soil humics.

The lack of a strong relationship between chlorophyll (r^2 = 0.18) or suspended organics (r^2 = 0.305) with Secchi disc transparency or light extinction coefficient leads us to believe that the water clarity problem in Cootes Paradise is not caused by biological production of algae (except at CP 5) nor is it caused by daily discharges of seston from the sewage treatment plant or Spencer Creek. The data indicates that the mineral portion of the suspended seston plays a paramount role in the reduction of water clarity in Cootes Paradise. The water clarity problem appears to be associated with the resuspension of silt as the Spencer Creek flows along the Willow Line and over the sandbar situated at the outlet of the creek.

Table 3 illustrates the relative importance of mineral, absorbance of the filtrate and chlorophyll in determining Secchi disc transparencies at the open water station (CP1). Even though chlorophyll was not statistically significant, chlorophyll was included in the table to illustrate the lack of sensitivity in water clarity to changes in chlorophyll. Mineral concentrations were determined from a relationship derived between total seston and % mineral (r^2=58%, col. 6 derived from col. 1). The absorbance of the filtrate was determined from the concentration of mineral (r^2=52%, col. 7 derived from 6; 4 derived from 3). The relationship between absorbance and mineral was improved over the one derived for CP 1 only (r^2=44%) by including the Hamilton Harbour data to cover a broader range of mineral and absorbance values. The form of the equations relating % mineral with seston and absorbance with mineral were consistent with chemical equilibria reactions. The last column (8) in the Table is the most probable Secchi disc transparency derived from the equation

$$\text{Secchi} = \frac{-\ln 0.2}{(0.067 * \text{min.}) + (4.74 * \text{Abs.}) + (0.010 * \text{chla})}$$

where Secchi is in meters
min. is the mineral concentration in g/m^3
Abs. is the absorbance of the filtrate through a 1 meter path length
and chla is the chlorophyll$_a$ concentration in mg/m^3.

The form of the equation was chosen to be consistent with light attenuation theory (Lorenzen, 1980) and is indicative of water bodies with high non-algal light absorption.

The Secchi depth (col. 8) was determined from the mineral and absorbance in columns 6 and 7 and the chlorophyll in column 2. The middle column (5) provides a predicted Secchi depth using the mineral and absorbance and chlorophyll in columns 2-4 to illustrate the relative sensitivity of Secchi depth to changes in mineral and absorbance.

Typical seston concentrations at CP1 would be 75 mg/l of total seston of which 85-90% would be mineral. Chlorophyll concentrations varied from 10 to 150 µg/l at CP 1. Seston concentrations were varied from slightly above what was observed at CP 1 in 1987 to values low enough to result in water clarities that would support submergent plant growth in Cootes Paradise (Secchi >75 cm). Seston concentrations would have to decrease to concentrations below 15 mg/l to achieve sufficient water clarity for submergent plant growth. At seston concentrations below 15 mg/l, a five fold variation in the chlorophyll concentration affects the Secchi depth transparency but only by as much as the change in Secchi due to a 20% change in the mineral composition of the seston and the resulting increase in background absorption of the filtrate.

At seston concentrations ranging from 15 to 25 mg/l and chlorophyll$_a$ concentrations ranging from 10 to 25 µg/l, the predicted Secchi depth in Cootes Paradise would be between 78 and 49 cm. Only when seston concentrations are reduced to 10 mg/l and chlorophyll$_a$ concentrations are reduced to 10-25 µg/l will water clarity in Cootes Paradise be adequate for aquatic plant growth with an allowance for seasonal variability.

The incoming seston concentration on Spencer Creek was 20 mg/l. Hence, any increase in seston and reduction in water clarity as the water enters Cootes Paradise would be unwanted. The resuspension of sediment by carp, waves, and water currents and nutrient enrichment by the Dundas Sewage Treatment Plant and the subsequent growth of algae would thwart the attainment of seston concentrations 10 mg/l and chlorophyll$_a$ concentrations below 10-25 µg/l.

Table 3
Predicted Secchi disc transparencies

Seston g/m^3	Chloro. mg/m^3	Mineral g/m^3	Absorb. m^{-1}	Secchi cm	Mineral g/m^3	Absorb. m^{-1}	Secchi cm
5	10	1	0.08	291	2	0.12	196
5	20	1	0.08	247	2	0.12	175
5	30	1	0.08	214	2	0.12	158
5	40	1	0.08	189	2	0.12	144
5	50	1	0.08	170	2	0.12	132
10	10	4	0.16	141	6	0.20	110
10	20	4	0.16	130	6	0.20	103
10	30	4	0.16	120	6	0.20	97
10	40	4	0.16	112	6	0.20	91
10	50	4	0.16	105	6	0.20	86
15	10	9	0.25	86	11	0.27	78
15	25	9	0.25	80	11	0.27	73
15	50	9	0.25	71	11	0.27	65
15	75	9	0.25	64	11	0.27	59
15	100	9	0.25	58	11	0.27	55
25	10	17.5	0.34	56	20	0.37	51
25	25	17.5	0.34	53	20	0.37	49
25	50	17.5	0.34	49	20	0.37	45
25	75	17.5	0.34	46	20	0.37	42
25	100	17.5	0.34	43	20	0.37	40
50	10	37.5	0.50	32	44	0.55	29
50	25	37.5	0.50	31	44	0.55	28
50	50	37.5	0.50	30	44	0.55	27
50	75	37.5	0.50	29	44	0.55	26
50	100	37.5	0.50	27	44	0.55	25
75	10	60	0.63	23	69	0.68	20
75	25	60	0.63	22	69	0.68	20
75	50	60	0.63	21	69	0.68	19
75	75	60	0.63	21	69	0.68	19
75	100	60	0.63	20	69	0.68	18
100	10	85	0.75	17	94	0.79	16
100	25	85	0.75	17	94	0.79	16
100	50	85	0.75	17	94	0.79	15
100	75	85	0.75	16	94	0.79	15
100	100	85	0.75	16	94	0.79	15

Water Chemistry

The effluent from the Dundas sewage treatment plant results in nutrient enrichment in the west end of Cootes Paradise. Figures 71 to 77 illustrate the spatial pattern of seasonal mean concentrations of ammonia, nitrate, nitrite, total Kjeldahl nitrogen (TKN), total phosphorus, soluble phosphorus and total dissolved solids. Ammonia, nitrate and nitrite concentrations decreased significantly before entering the main body of Cootes Paradise presumably due to assimilation and dilution by Borer's and Spencer Creek. Although TKN concentrations also dropped significantly between CP 6 and CP 3B, it was evident that the inputs of Chedoke Creek and Hamilton Harbour contributed to the loading.

The Dundas sewage treatment plant is also a source of phosphorus to Cootes Paradise. Phosphorus concentrations also decrease significantly before entering the main body through processes of dilution, sedimentation and assimilation. Chedoke Creek enters Cootes Paradise at concentrations 2 to 3 times greater than the open water. Spencer Creek mean total and soluble phosphorus concentrations were 100 and 30 µg/l, respectively.

The Future

Submergent and emergent plants are affected by water level fluctuations, both seasonally and annually and by carp. Submergent plants are affected by water clarity. Water clarity is a function of suspended sediments and the background absorbance of the water caused by soil humics. Algal abundance (chlorophyll) affects water clarity in West Pond but is an insignificant factor in the main body of Cootes Paradise due to the high seston concentrations.

Emergent Plants

The extent and species composition of emergent vegetation in Cootes Paradise depends on the availability of substrate at depths with seasonal water level fluctuations which are not stressful. Emergent vegetation is limited in Cootes Paradise by the current morphometry of the shore at the normal water level regime of Lake Ontario. Currently, 15% of the total area in Cootes Paradise is occupied by emergent vegetation, comprised mainly of Glyceria (manna grass) above the high water line. Estimates discussed at the beginning of this report would suggest that 1-5% of Cootes Paradise below the high water line could support emergent vegetation given the water level regulation of Lake Ontario and consequently Cootes Paradise. Return of emergent vegetation similar to what was present prior to 1934 would require a permanent water level drop of 70 cm. This will not occur.

The plant community in Cootes Paradise prior to 1934 was distinctly different from the present community. The plant community in the past was dominated by wild rice. One of the early surveyors commented that Cootes Paradise should be developed as a wild rice farm because he had never seen wild rice as extensive as he had encountered it in Cootes Paradise. Descriptions of the marsh in the 1920s also suggest that wild rice was an important plant species (Wragg, 1949). Wild rice is susceptible to siltation, wave action, carp and pests but less affected by water level. It prefers alluvial deposits in approximately 1 meter of water and therefore Cootes Paradise would have been perfect habitat for it. The RBG began studies in the 1940s to determine the factors responsible for the loss of aquatic plants and the effect of carp on wild rice in Cootes Paradise was mentioned. The loss of wild rice should not be underestimated since its return will be highly unlikely. Siltation, wave action and carp remain as major impediments to its return.

The two emergent plants that dominate Cootes Paradise are Glyceria and Typha. Both plants are aggressive and exclude other emergent species, and therefore reduce diversity and resiliency. Both plants are also of limited wildlife value. But due to their aggressive nature, any improvement in conditions for emergent plant growth, in general, would likely promote these two plants.

The Dundas sewage treatment plant effluent results in high nitrogen concentrations in the West Pond area. Floating emergent beds could have been excluded from West Pond by the high nitrogen levels if Boar and Crook's hypothesis is correct; however, the loss of marsh vegetation occurred from the east to the west. The plant community in the past was dominated by wild rice which is not a floating plant species, therefore the significance of high nitrogen loading to the emergent vegetation is unknown. A sewage treatment plant discharged into Chedoke Creek during the 1930-40s and may have been a factor in the loss of floating vegetation (if it existed) in the east end of Cootes Paradise. At present, emergent vegetation in Cootes Paradise would be unaffected by high nutrient loading.

Very little expansion of emergent plants from their present areas is to be expected due to water levels and shoreline morphometry. Carp may still further reduce the areal extent of emergent plants by damaging and uprooting the existing plants during high water years and undermining the banks and slowly reducing the extent of the areas with suitable water depths. The two areas particularly vulnerable are the cattail marshes at Bulls Point and south of the Willow Line.

Submergent Plants

Submergent plants are restricted to water depths greater than 100 cm due to seasonal water level fluctuations. For submergent plants to grow in such water depths, Secchi disc transparencies would have to increase from approximately 20 cm to greater than 75 cm. Our best estimate would be that suspended sediment concentrations would have to decrease from 75 mg/l to 10-15 mg/l to achieve suitable water clarity. At this seston concentration, chlorophyll would also have to be drastically reduced from its present levels. The incoming concentrations of seston in Spencer Creek are slightly higher than what would be necessary for suitable water clarity. The summer average water clarity in Spencer Creek was 68 cm. A recent non-point source loading study concluded that only a 10-15% reduction in sediment loading to Cootes Paradise could be expected due to urbanization and adoption of no-till agricultural practices in the watershed (Ecologistics, 1988). Loadings of sediment due to stormwater discharges from the new urban areas were not included in the estimates so future loadings of sediment will probably not be significantly different from today.

Carp activity and wind and wave resuspension of sediments appear to be the predominate forces responsible for the elevated seston. Limited data would suggest that control of wind and wave resuspension could reduce seston concentrations to a small extent but even in the Westdale Cut, with very sheltered conditions and no upstream source of sediments, submergent plants are absent and water clarity is poor. Settling experiments performed with Cootes Paradise water in the laboratory indicate that 3 days would be required to settle out sufficient silt to achieve the desired water clarity. Obviously, the laboratory conditions are totally unrealistic but the message here is that once the material is resuspended into the water column, it will remain suspended for some time. Settling of seston in the east end of Cootes Paradise was observed during the summer of 1987 but not during the fall. The difference between summer and fall could be due to the shallower depth in Cootes Paradise during the fall increasing wind and wave resuspension and restricting carp activity to the east end. Wind and wave resuspension of sediments certainly can occur in the western two-thirds of Cootes Paradise due to its shallow nature. Any process that elevates the seston concentration above the incoming concentration will have to be minimized.

The problem facing us is to determine the relative importance of carp or wind and wave energy in the resuspension of sediments in Cootes Paradise. The problem may however be an academic one. The high density of carp will destroy any aquatic vegetation even if adequate water clarity could be achieved and adequate water clarity can't be achieved due to the carp even if wind and wave energy could be reduced.

The control of carp therefore becomes a critical requirement for the return of submergent as well as emergent plants. The Royal Botanical Gardens staff are well acquainted with carp control. For a decade, the RBG controlled carp in Cootes Paradise, with positive results. But the long-term commitment, cost and labour involved in carp removal and exclusion techniques ultimately ended the exercise. Recently, the RBG has experimented with water level control as a carp control measure in Mercer's Glen. In the 2.2 hectare pond, approximately, 150 carp were killed during a winter drawdown. A four fold increase in submergent plant distribution was observed the following summer. Water clarity was also much improved. Attempts were made in West Pond to construct a carp exclosure fence. The carp gained access to the area despite our best efforts to exclude them. The exclosure of carp using fences would at best be a temporary measure, limited to small areas, aesthetically unpleasant and therefore of limited value.

Biocontrol

Water clarity in nutrient-enriched marshes may not necessarily be poor. The zooplankton species composition will influence the algal abundance and therefore the algal contribution to water turbidity. The zooplankton species composition is affected by the fish species composition.

Recently, biocontrol of water clarity has been demonstrated by stocking lakes with predator fish which prey upon forage fish (Shapiro et al. 1982). The forage fish selectively graze upon the large zooplankters such as Daphnia. The numbers of forage fish could be reduced by stocking predators, thereby increasing the abundance of zooplankton and decreasing the abundance of algae and ultimately increasing the water clarity. In lakes where biocontrol has been attempted, the numbers of predators has been high relative to their prey. Examples from the literature are: a stocking ratio of 1 predator for every 2.2 prey (Shapiro and Wright, 1984);

3000 largemouth bass per hectare (Spencer and King, 1984);

117 kg/hectare (2160 trout per hectare) (Benndorf et al. 1984);

150 largemouth bass per hectare (Hrbacek et al. 1961);

80,000 walleye fry per hectare (Lynch, 1979).

The composition of fish in Cootes Paradise is dominated by planktivorous fish with very few predators (see Simser, 1982) and the zooplankton composition is consistent with the theory upon which biocontrol is based. Can the introduction of large numbers of predators affect the water clarity in Cootes Paradise? Because the water clarity in Cootes Paradise is not affected significantly by algal (chlorophyll) abundance, introductions of predators would not likely affect water clarity.

Recently, pike have been introduced to promote the abundance of sport fish in Hamilton Harbour. Could the introductions of pike affect forage fish abundance in Cootes Paradise? Snow (1978) followed the population dynamics of pike and their prey in a Wisconsin reservoir for 15 years and observed that even at a population level of 148 pike per hectare, pike did not affect the abundance of their prey (bluegills). Beyerle (1970) also reported that northern pike have little effect on bluegill sunfish. Pike have a food conversion efficiency of 7.5 to 1 and the average weight gain for pike is approximately 400 grams per year (Ciepielewski, 1973). Therefore, the average pike would consume 3000 grams of forage fish per year. Pike also have a size preference and species preference feeding behaviour (Lawler, 1965). The majority of their prey is less than 9 cm (Lawler, 1965; Snow, 1978). Assuming an average weight of 60 grams per fish for the two most abundant fish in Cootes Paradise (alewife and white perch, COA, 1988), a single pike would consume only 50 fish per year. Therefore, the introduction of pike in Hamilton Harbour would not likely affect water clarity in Cootes Paradise given the high numbers of forage fish available in Hamilton Harbour and Cootes Paradise and the virtually unlimited supply provided by Lake Ontario.

Summary

Cootes Paradise is a wildlife sanctuary managed by the Royal Botanical Gardens. Like other marshes around the Great Lakes, much of Cootes Paradise has disappeared. Loss of habitat for waterfowl in North America has resulted in the North American Waterfowl Management Plan. The Great Lakes-St Lawrence Lowland was identified as an important area on the continent with specific goals for waterfowl habitat restoration. The latest Great Lakes Water Quality Agreement has also recognized the need to preserve and restore threatened wetlands. The recent Remedial Action Plan exercise has focused attention on the biological importance of Cootes Paradise.

As little as 50 years ago, Cootes Paradise was more than 85% marsh. The abundance of waterfowl as a result of the extensive marsh in a strategically important area of the continent was the basis for the marsh's name. The present 250 hectares of very turbid water dominated by carp is hardly deserving of its name. The time has come to restore the area to its past glory and biological potential.

The present morphometry limits the potential for emergent plants to expand given the water level regime imposed on the marsh by Lake Ontario. The current densities of carp also limit the potential of emergent vegetation to expand due to their destructive activities on the marsh fringe.

Poor water clarity, carp, and water level fluctuation limit submergent plants. Carp control alone may no longer be effective. The large expanses of unprotected sediment susceptible to wind and wave resuspension could maintain poor water clarity. The incoming water clarity in Spencer Creek is currently insufficient for submergent plant growth. Relatively minor increases in the total seston concentration have dramatic effects on the water turbidity of the inflowing water (a 26 cm decrease in Secchi depth caused by a 8 mg/l increase in seston).

At the required seston concentration of the Spencer Creek inflow, mean chlorophyll concentrations would also have to decrease to 10 µg/l for adequate water clarity. Chapra and Dobson (1981) developed a relationship between total phosphorus and chlorophyll$_a$. Total phosphorus would have to be approximately 40 µg/l to produce an algal population with a chlorophyll$_a$ concentration of 10 µg/l. Algal blooms during the year would result in chlorophyll$_a$ concentrations roughly 3 times the mean or 30 µg/l. The response in algal abundance to reduced phosphorus loading in Cootes Paradise is difficult to predict given the lack of a relationship between chlorophyll and total phosphorus in Cootes Paradise and uncertainties regarding the phosphorus loading reductions require to achieve a particular phosphorus concentration.

The Remedial Action Plan Goals Problems and Options Discussion Document for Hamilton Harbour has stated that 1) chemical precipitation of the Dundas sewage, 2) 50% reduction in phosphorus loading from Spencer Creek, 3) elimination of CSO's entering Chedoke Creek, and 4) 65% loading reduction of phosphorus into Hamilton Harbour could reduce the total phosphorus concentration in Cootes Paradise from 100 to 38 µg/l (COA, 1988). The incoming Spencer Creek mean total and soluble phosphorus concentrations during 1987 were 100 and 30 µg/l, respectively. A 50% reduction in Spencer Creek phosphorus loading may be insufficient to achieve the 40 µg/l total phosphorus concentration. A 60% reduction may be necessary.

To achieve the desired water clarity (>75 cm Secchi depth) to promote submergent plant growth in Cootes Paradise, all the following actions would be necessary:

the incoming seston in Spencer Creek would have to be reduced from 20 to probably 10 mg/l;

phosphorus loading within Spencer Creek would have to be reduced by 60% so that phosphorus concentrations entering Cootes Paradise would be less than 40 µg/l total phosphorus;

wind and wave resuspension of sediments would have to be minimized so as to maintain the seston concentration at 10-15 mg/l in the open water area of Cootes Paradise;

the chemical precipitation of the Dundas sewage to reduce phosphorus loading to Cootes Paradise, the CSO entering Chedoke Creek will have to be diverted, and a 65% reduction of phosphorus loading to Hamilton Harbour will have to be implemented;

carp would have to be controlled to reduce their destructive influence on the vegetation directly and their effects on water clarity.

The recent study on soil erosion predicted that rural soil erosion and phosphorus loading on the Spencer Creek watershed will decrease by 15% during the next 20 years with the conversion of rural land to urban land and with a 45% adoption of no-till agricultural practices. The study did not include the particulate and phosphorus loading from the new urban areas in their estimate of particulate loadings from the Spencer Creek watershed to Cootes Paradise. Achievement of a 60% loading reduction of both soil and phosphorus would appear unlikely during the next 20 years.

The RBG in cooperation with Ducks Unlimited is investigating the possibility of engineering diked cells in the shallower areas of Cootes Paradise. If the project is approved, wind and wave resuspension of sediments from the open area of Cootes Paradise will be virtually eliminated. The growth of emergent and submergent vegetation inside the diked cells will be guaranteed because all factors affecting aquatic plant growth identified in this report will be controlled. The open face of the sloping berm wall will also provide new area for emergent plants. The lack of appropriate area was identified as limiting the expansion of emergent plants in Cootes Paradise. If the project is not approved, other engineering solutions will have to be investigated to minimize wind and wave resuspension of sediments.

The Dundas Sewage Treatment Plant was recently upgraded by the costly construction of sand filters. Chemical precipitation of the sewage could be implemented. In the future, the plant will reach its present capacity. One of the options would be to divert the sewage to the Hamilton treatment plant at that time. If the watershed reductions in phosphorus loading will only be approximately 15% then diversion of the Dundas sewage, CSO control and the Hamilton Harbour loading reduction of 65% would achieve the necessary loading reduction to theoretically achieve a total phosphorus concentration of 40 µg/l.

Carp control will be necessary to result in the return of submergent vegetation in the open water areas of Cootes Paradise. The level of control is unknown but certainly fewer than 20 carp per hectare will be necessary. The method of control depends of the resources available. Control of carp will have to be exercised indefinitely.

Submergent plants will not return to Cootes Paradise on the short-term. Long-term reductions in soil and phosphorus loadings on the Spencer Creek watershed and the diversion of the Dundas sewage effluent will probably not be sufficient to improve water clarity. Wind and wave resuspension will have to be minimized and carp will have to be controlled. The long-term scenario for aquatic plants in Cootes Paradise is not optimistic.

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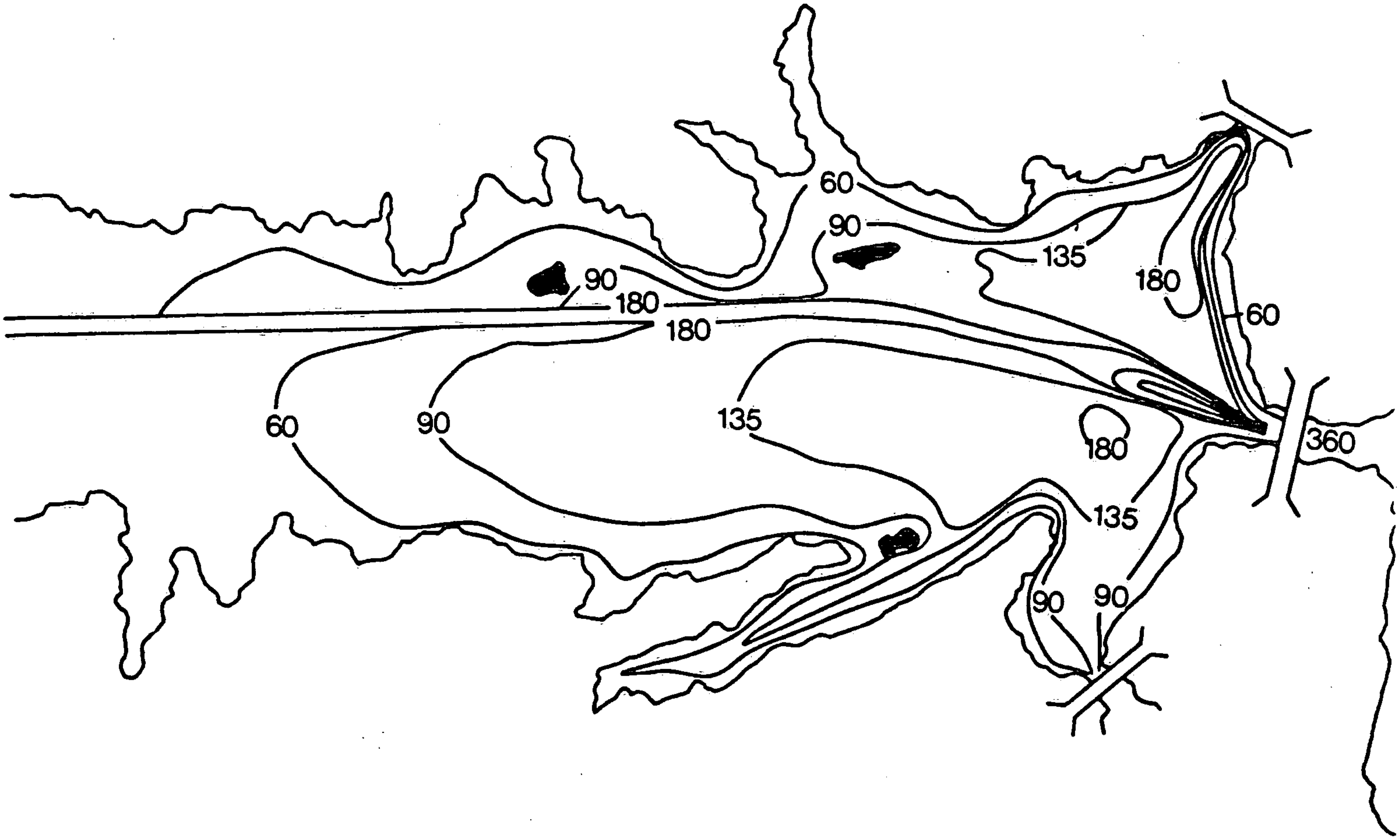
Figure 1

Water Level was 74.98 m
Great Lakes Datum (1955)



COOTES PARADISE
WATER DEPTHS (cm)
1946

COOTES PARADISE 1986

DEPTHS IN cm

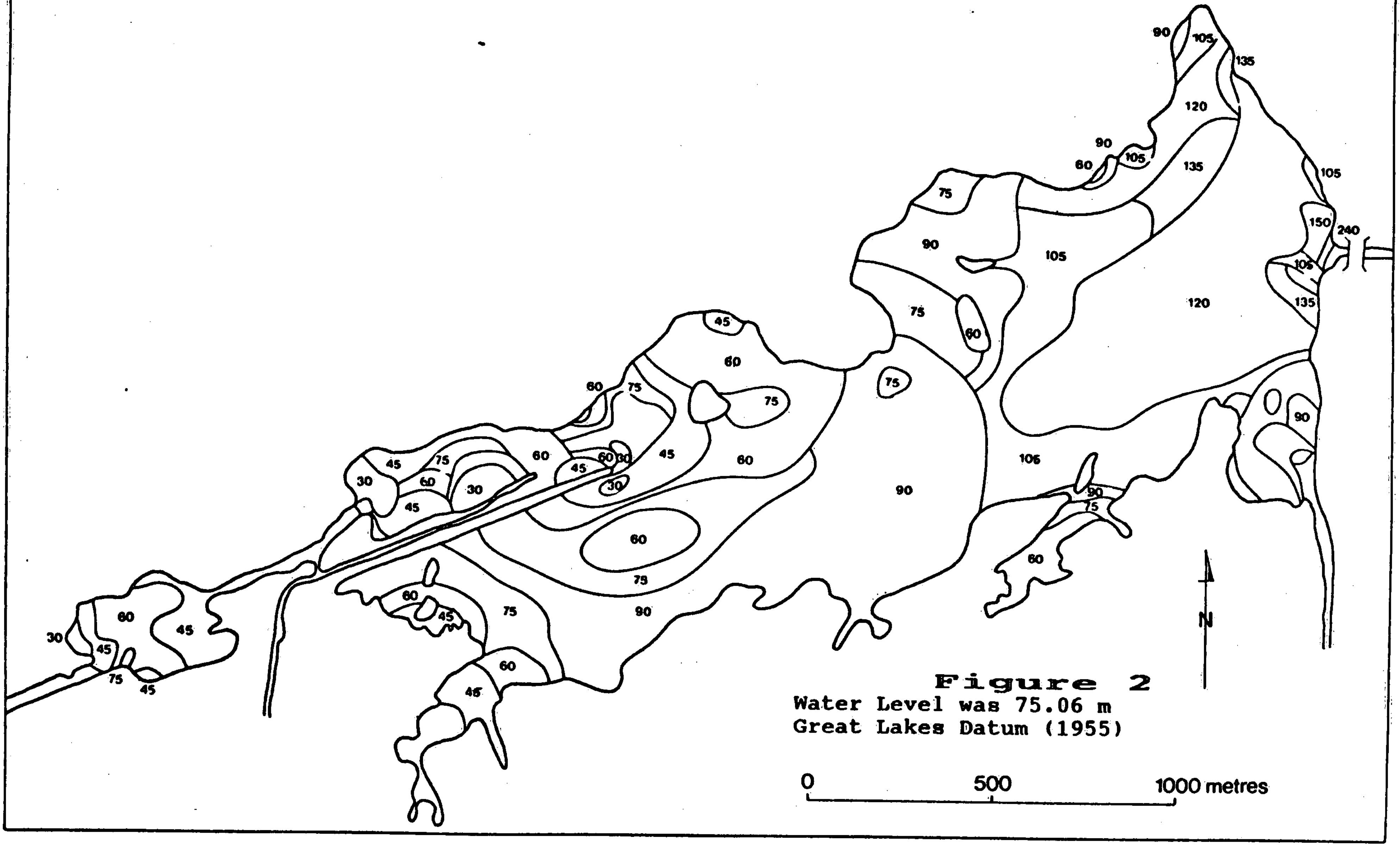


Figure 2

Water Level was 75.06 m
Great Lakes Datum (1955)

Figure 3

HYPSOMETRIC CURVE COOTES PARADISE

1986

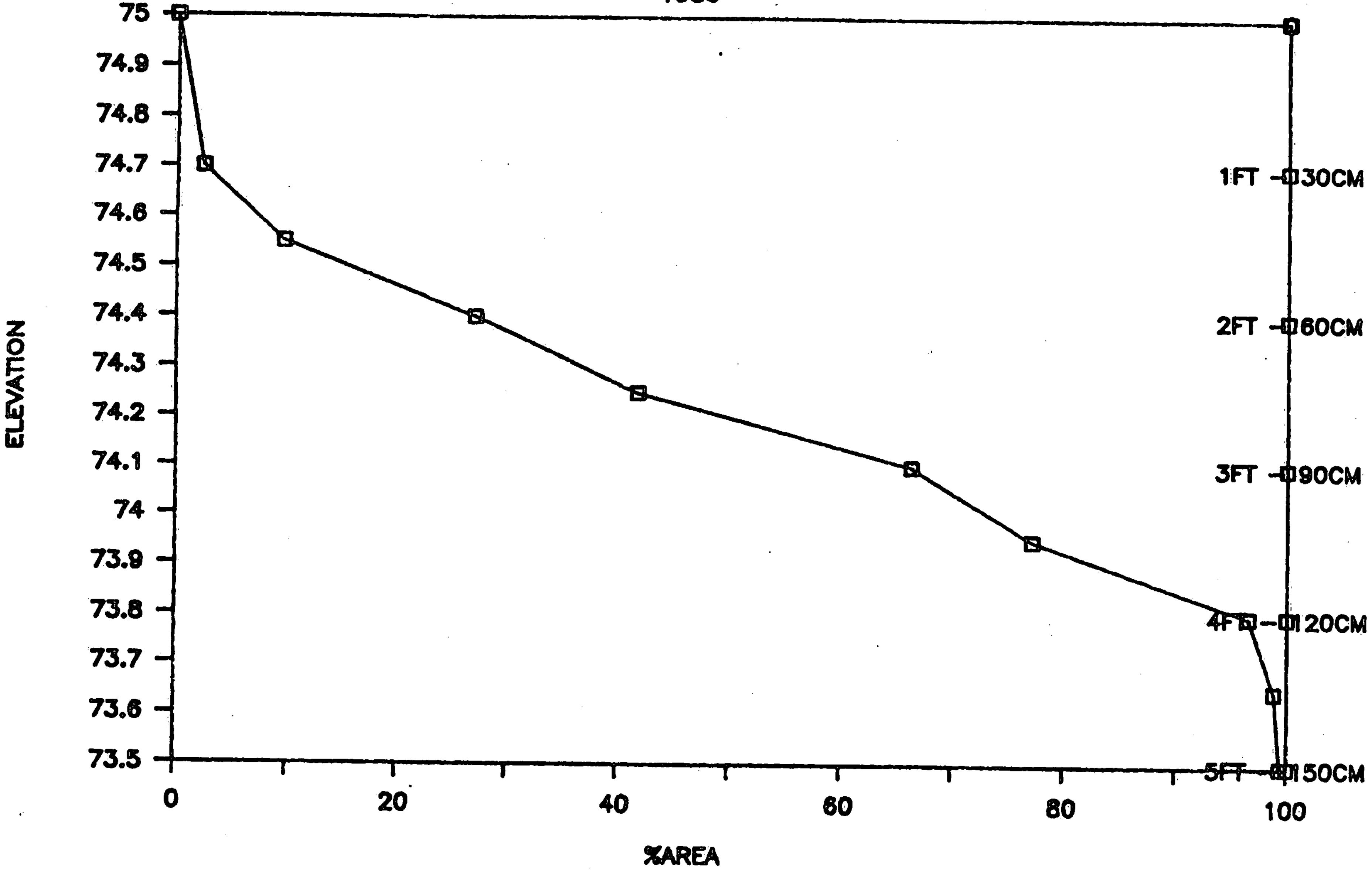
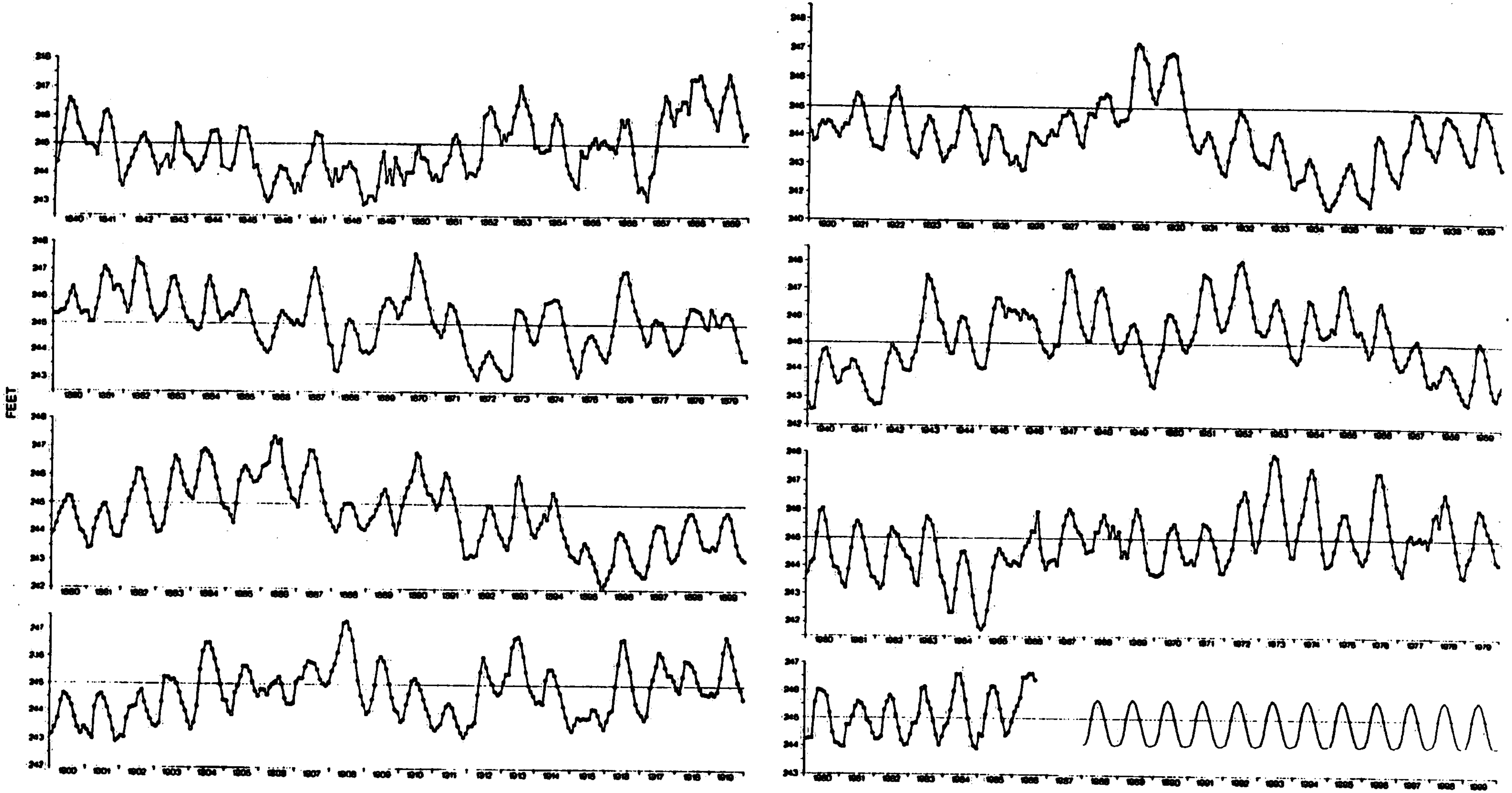


Figure 4



Lake Ontario Historical water levels

Figure 5

Extent of marsh vegetation in Cootes Paradise from 1793 to 1935 based on historical maps.

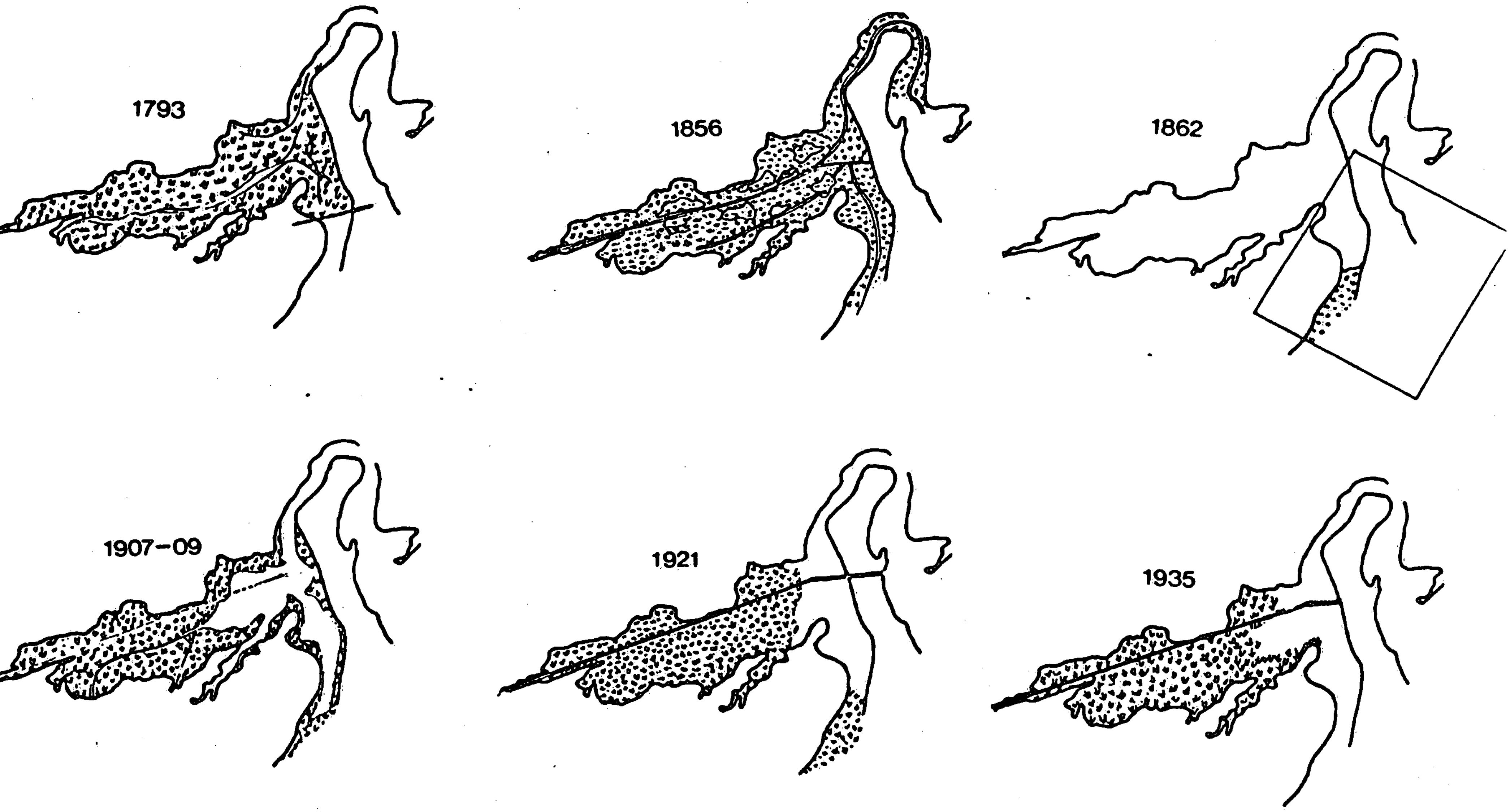


Figure 6

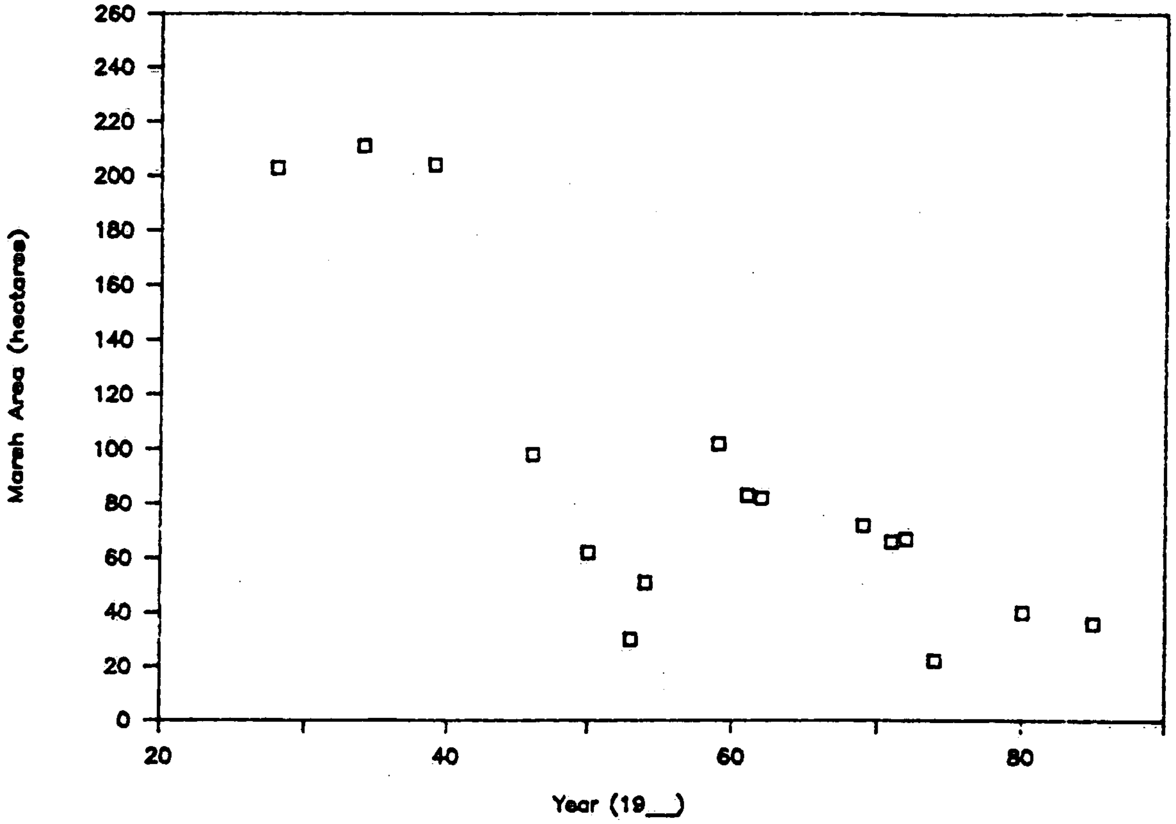


Figure 7

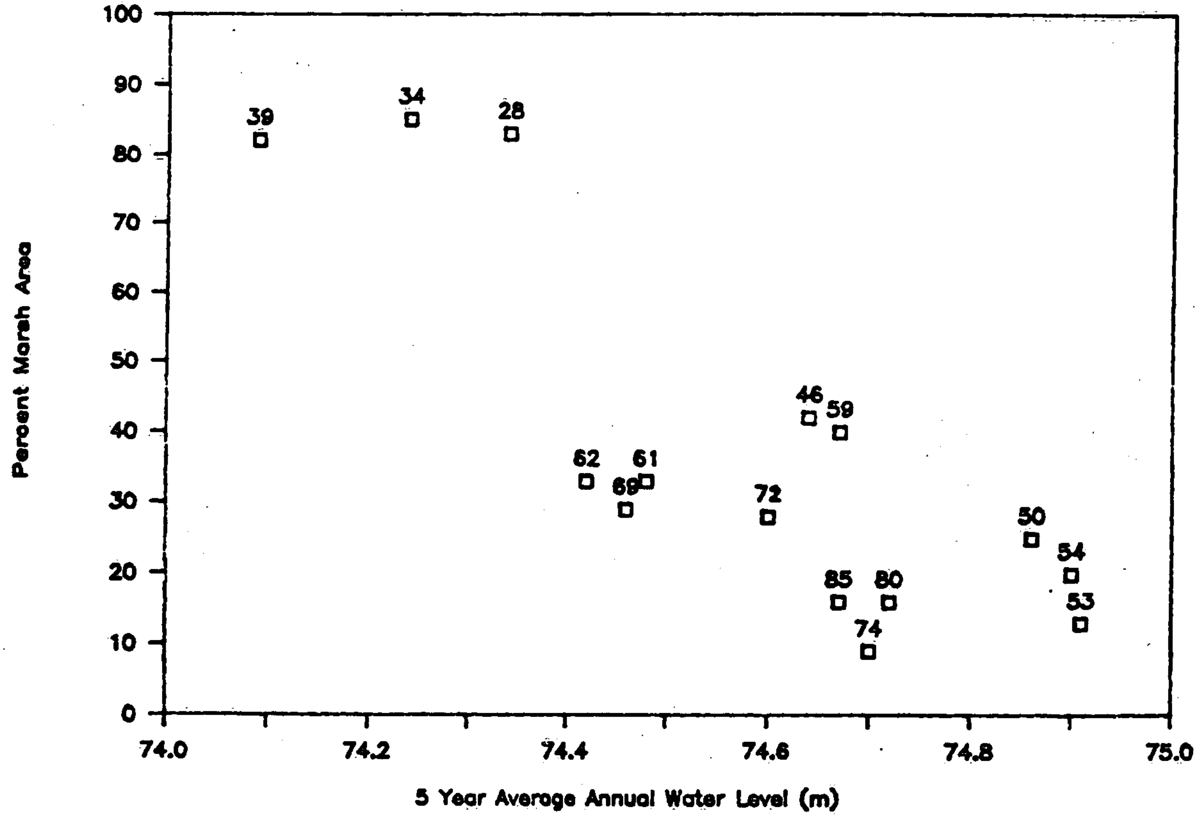


Figure 8

Historical Summer Secchi

Open Water – CP 1+2

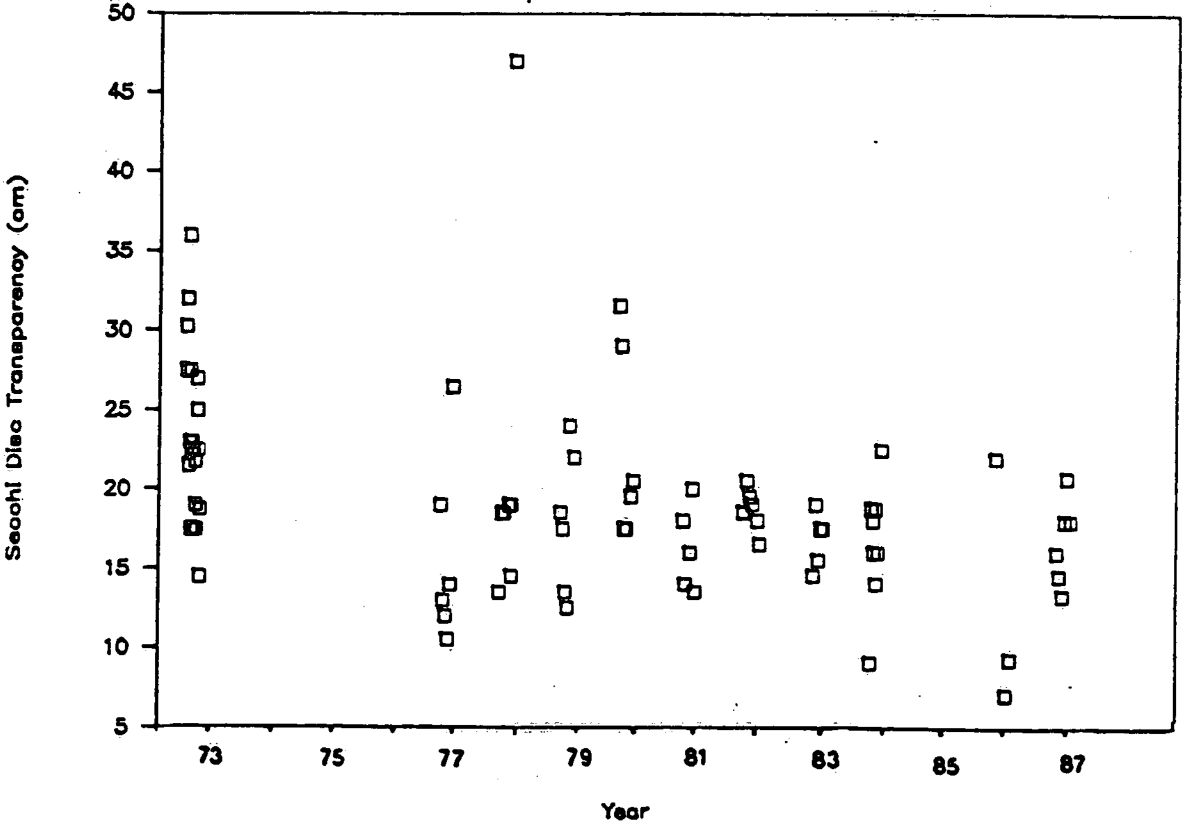


Figure 9

Historical Summer Secchi

West Pond – CP 5

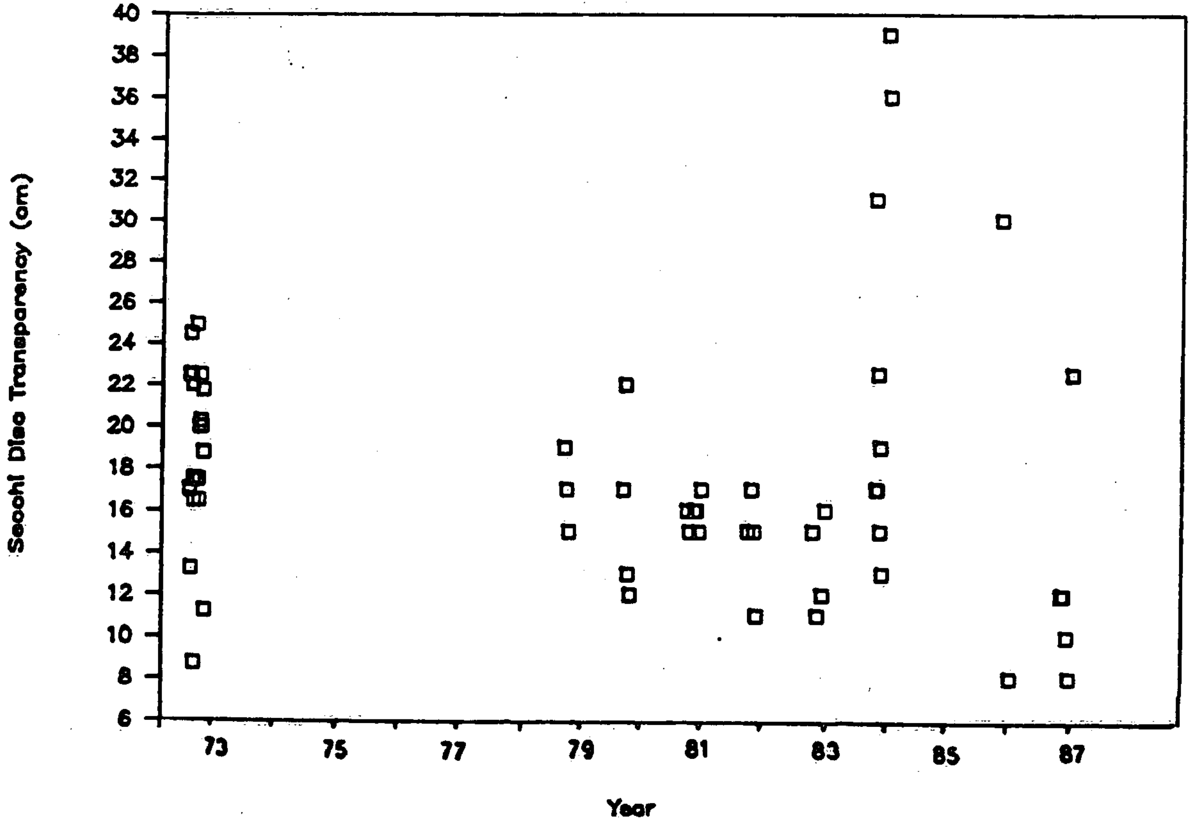
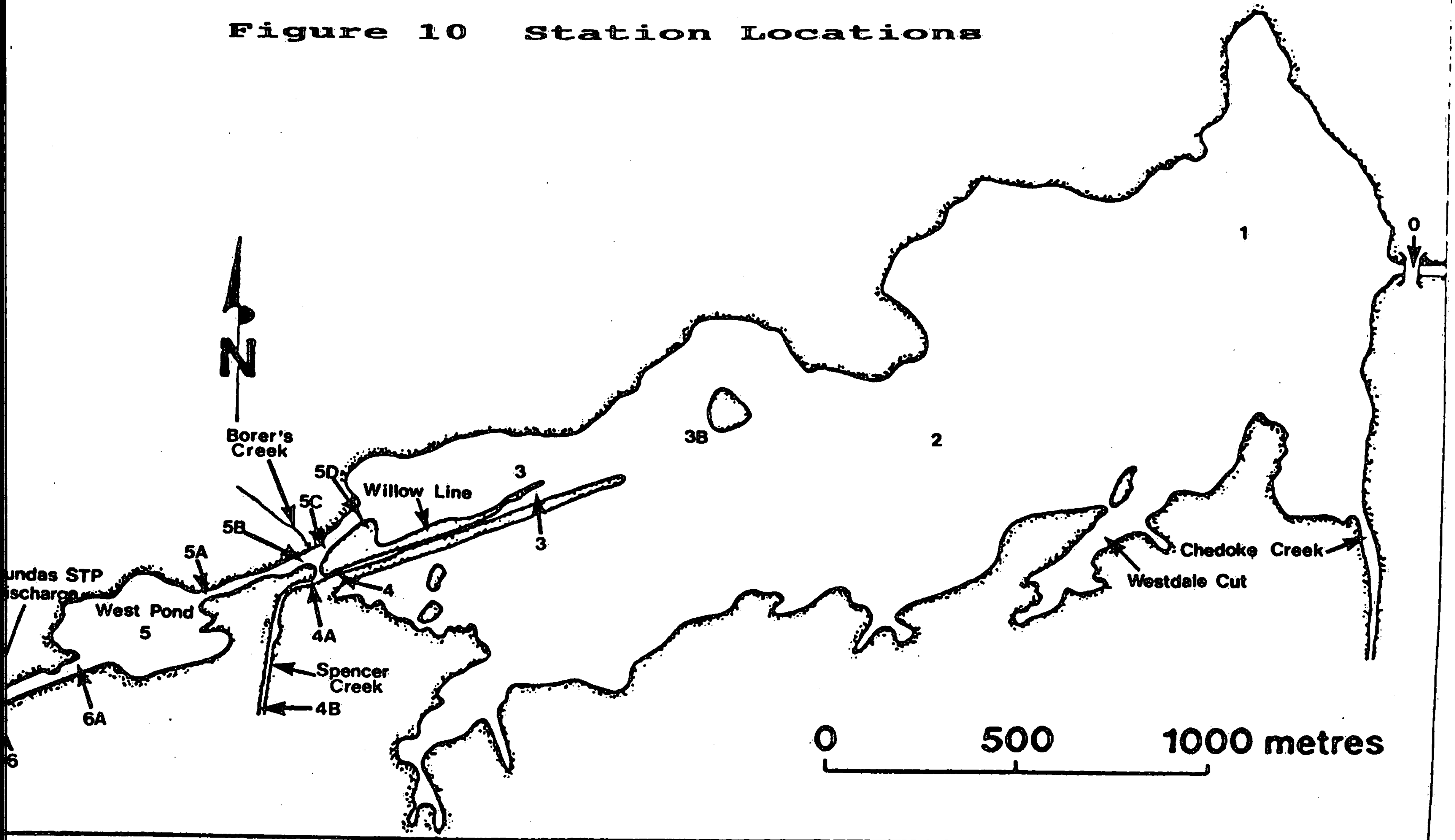
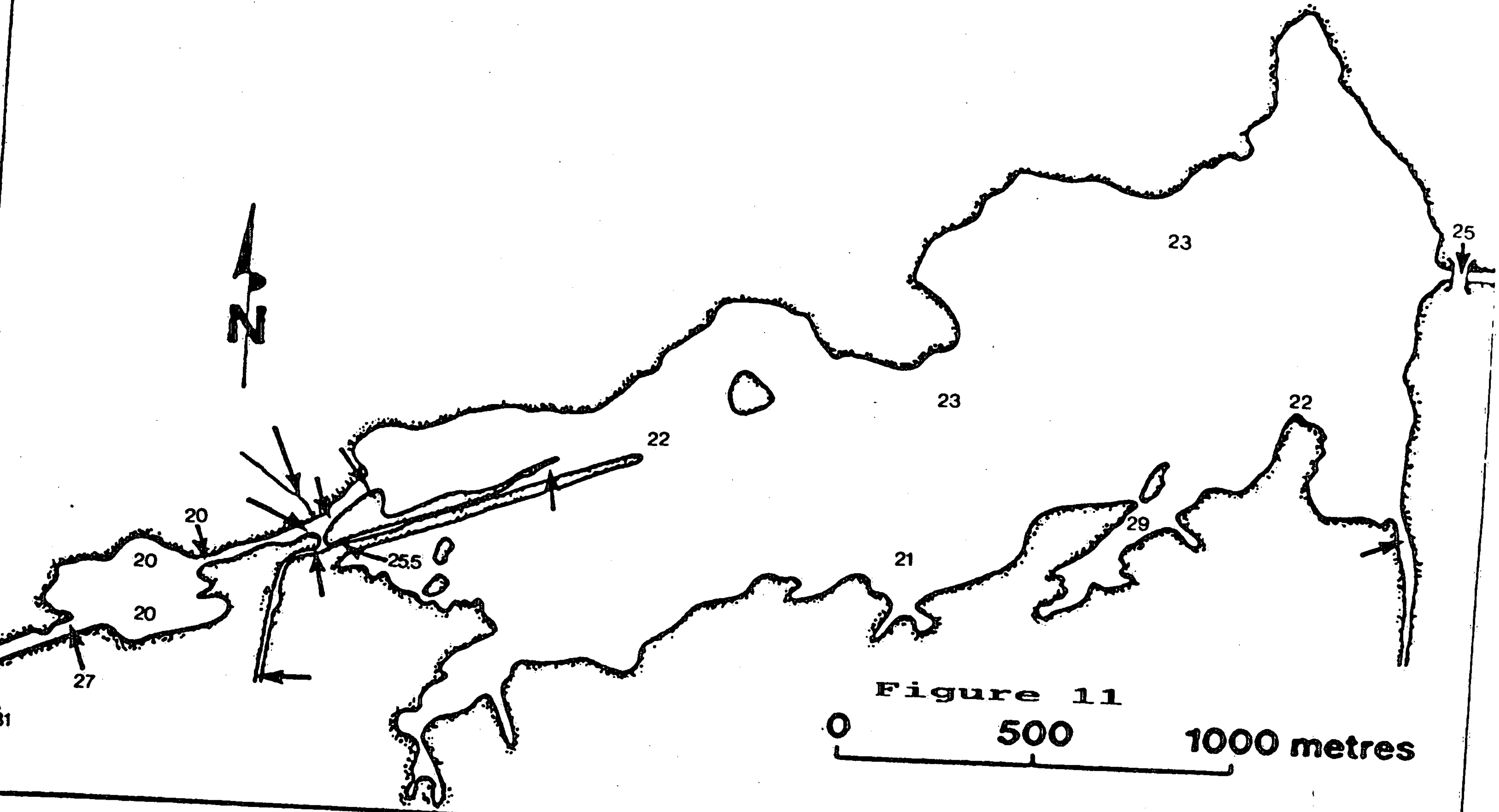


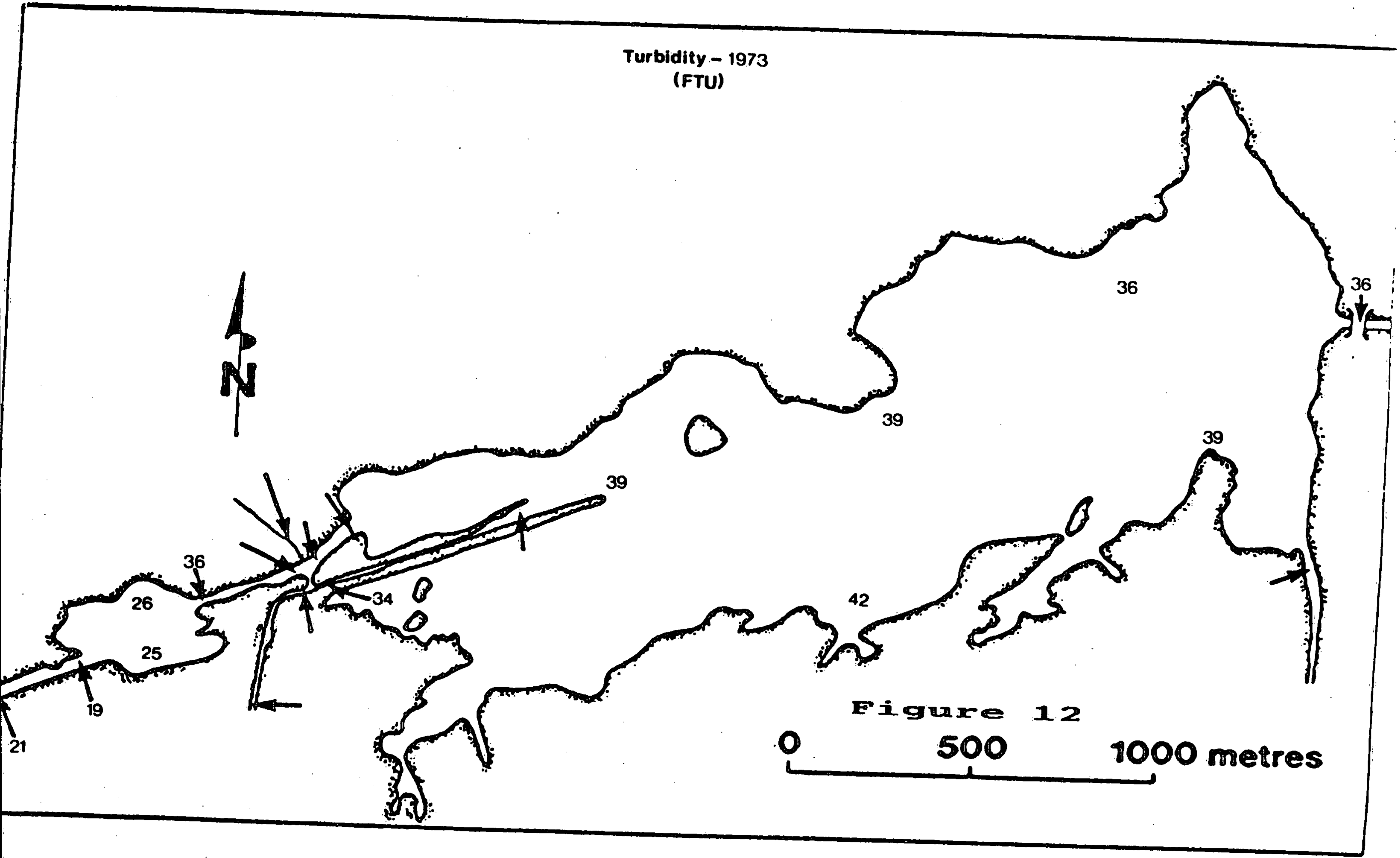
Figure 10 Station Locations





Secchi - 1973

Figure 11



Turbidity - 1973
(FTU)

Figure 12

Turbidity - 1975
(FTU)

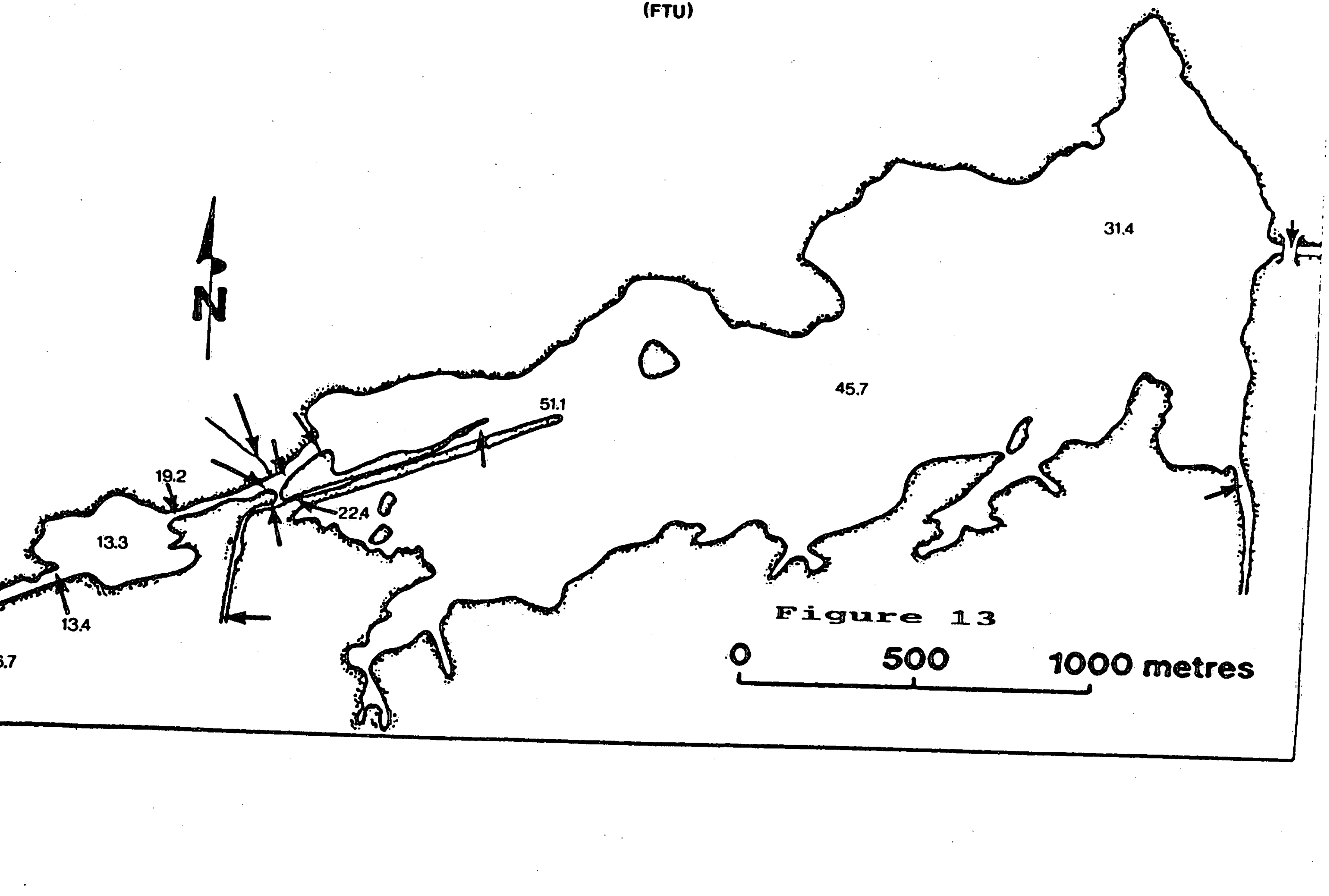


Figure 13

Figure 14

Historical Secchi

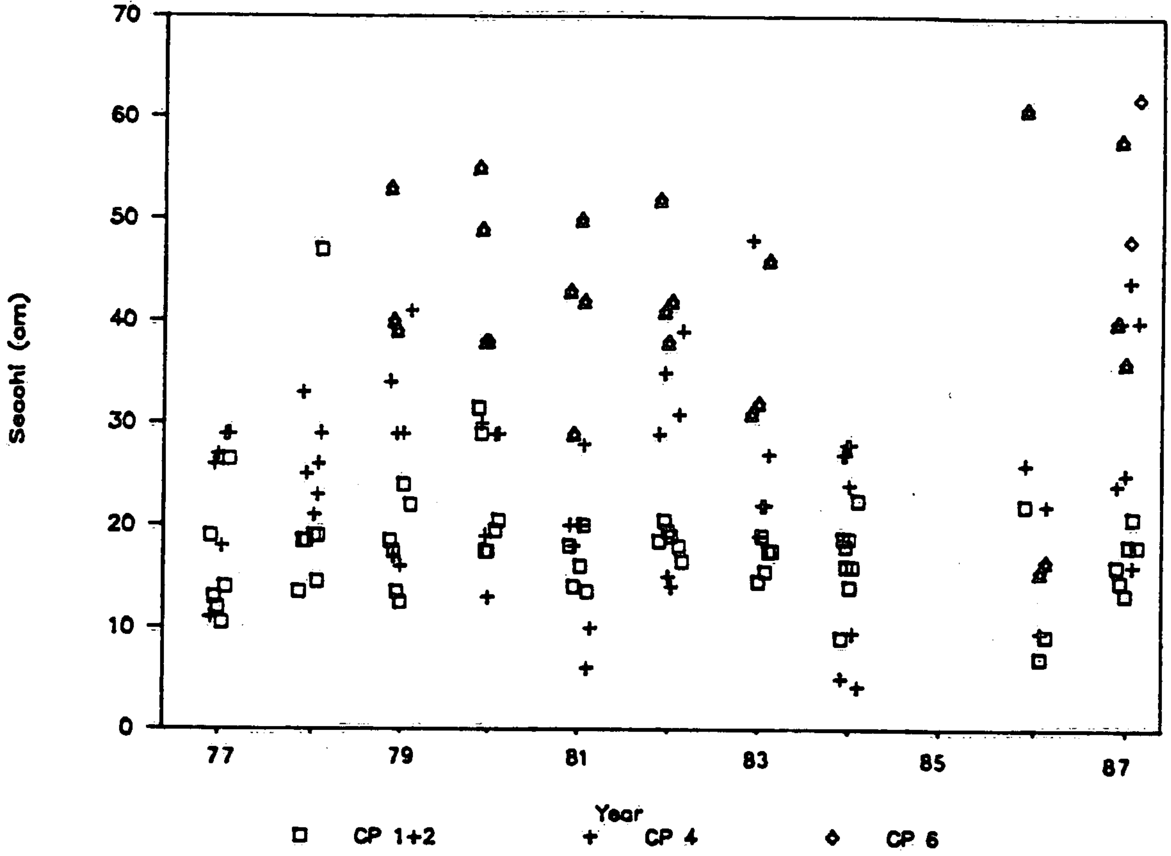
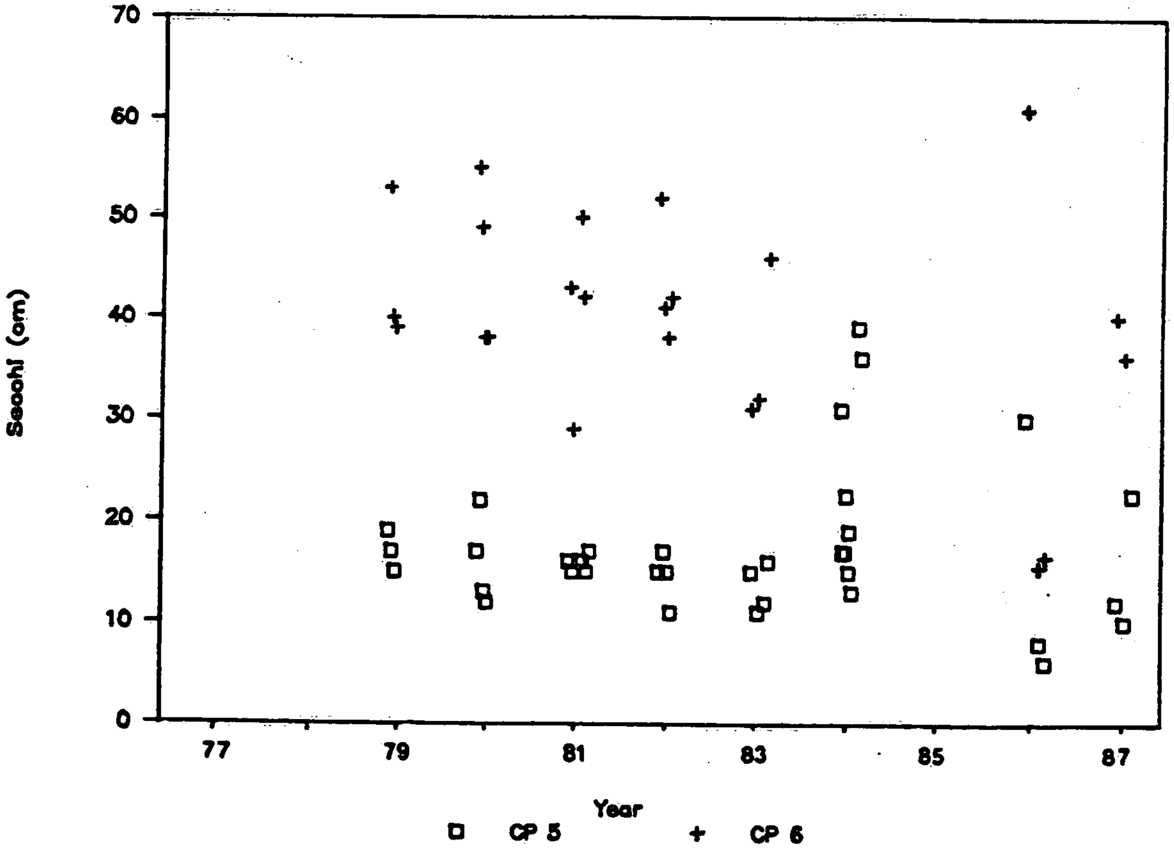


Figure 15

Secchi Disc Transparency



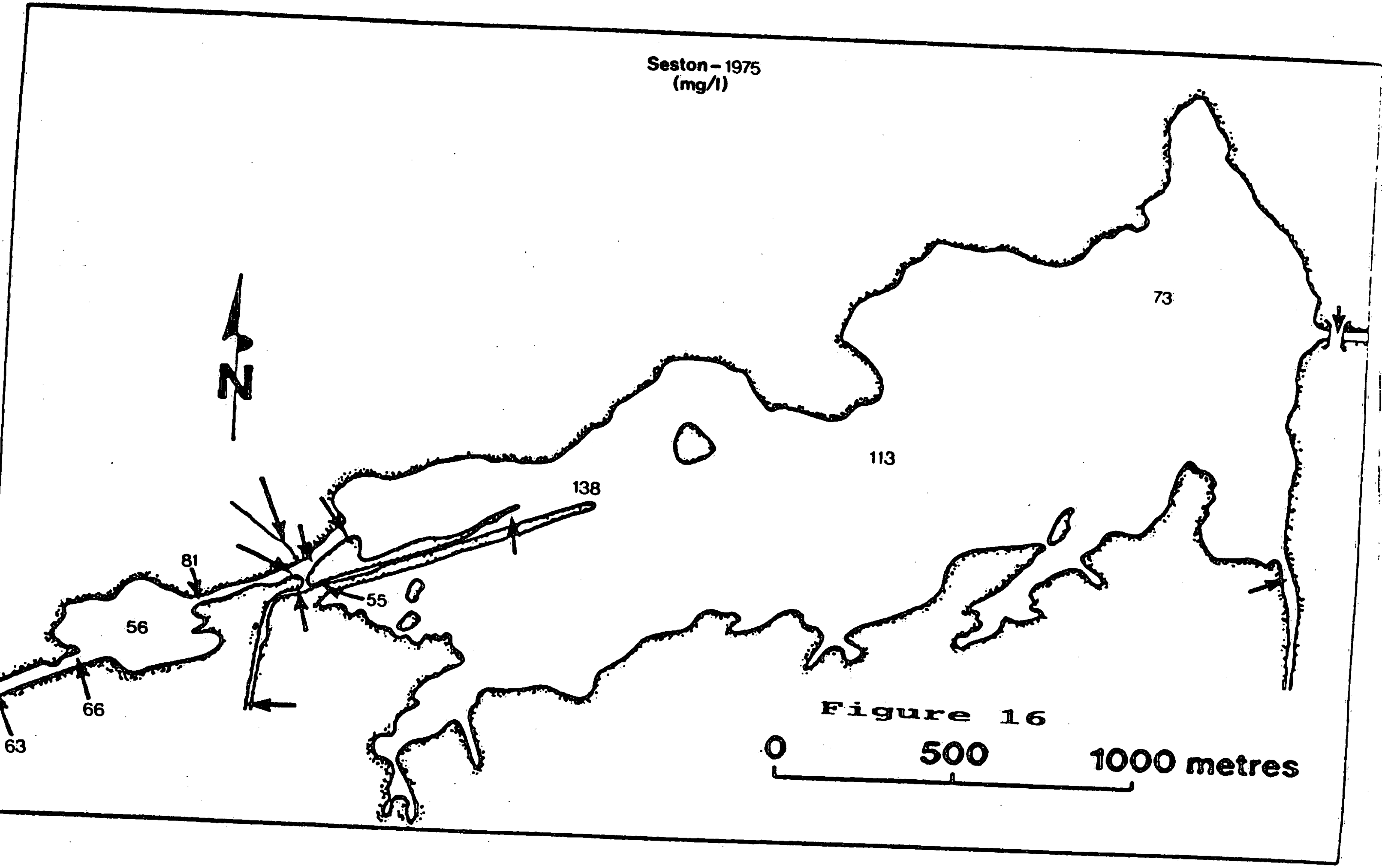
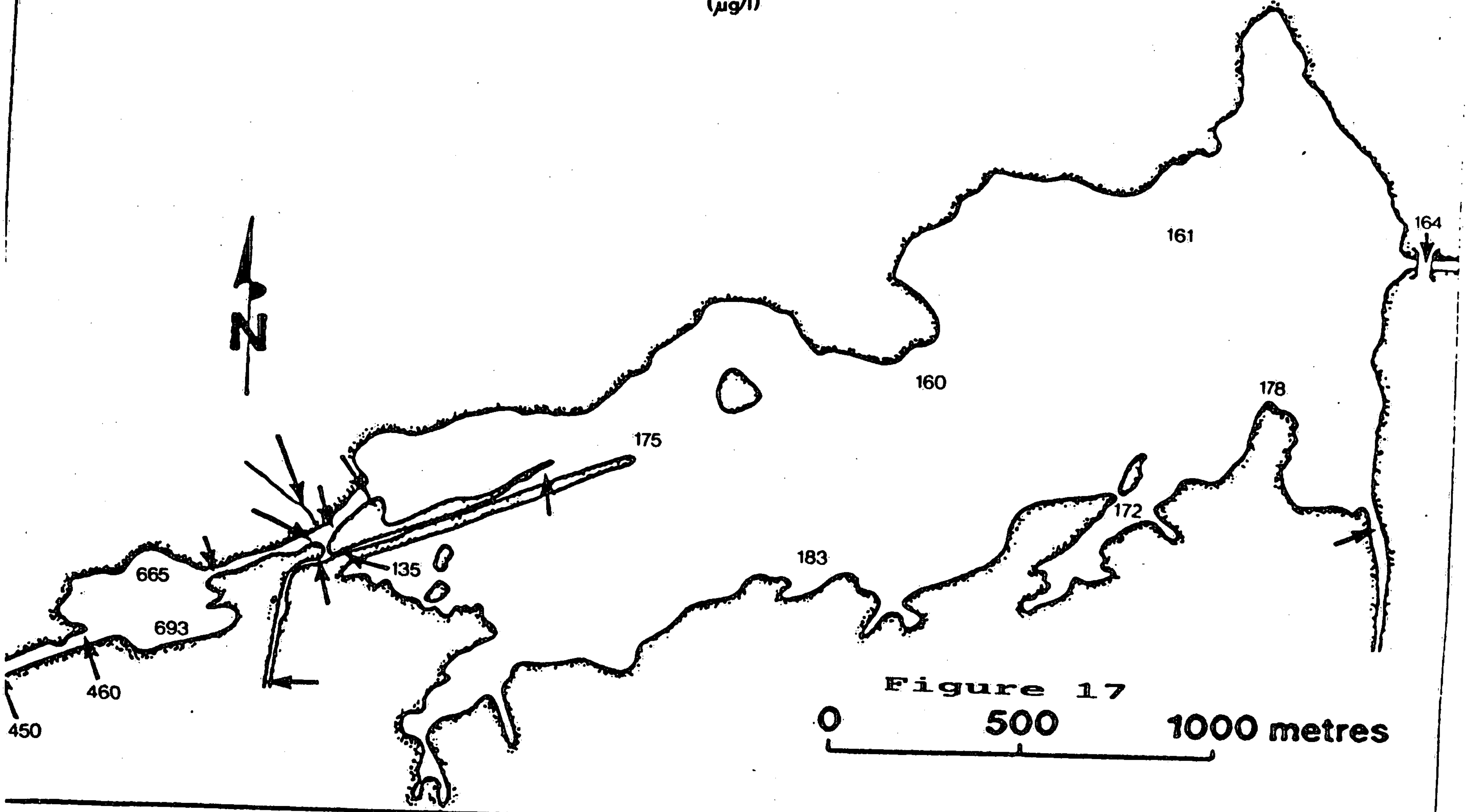


Figure 16



Chlorophyll – 1973
(μg/l)

Figure 17

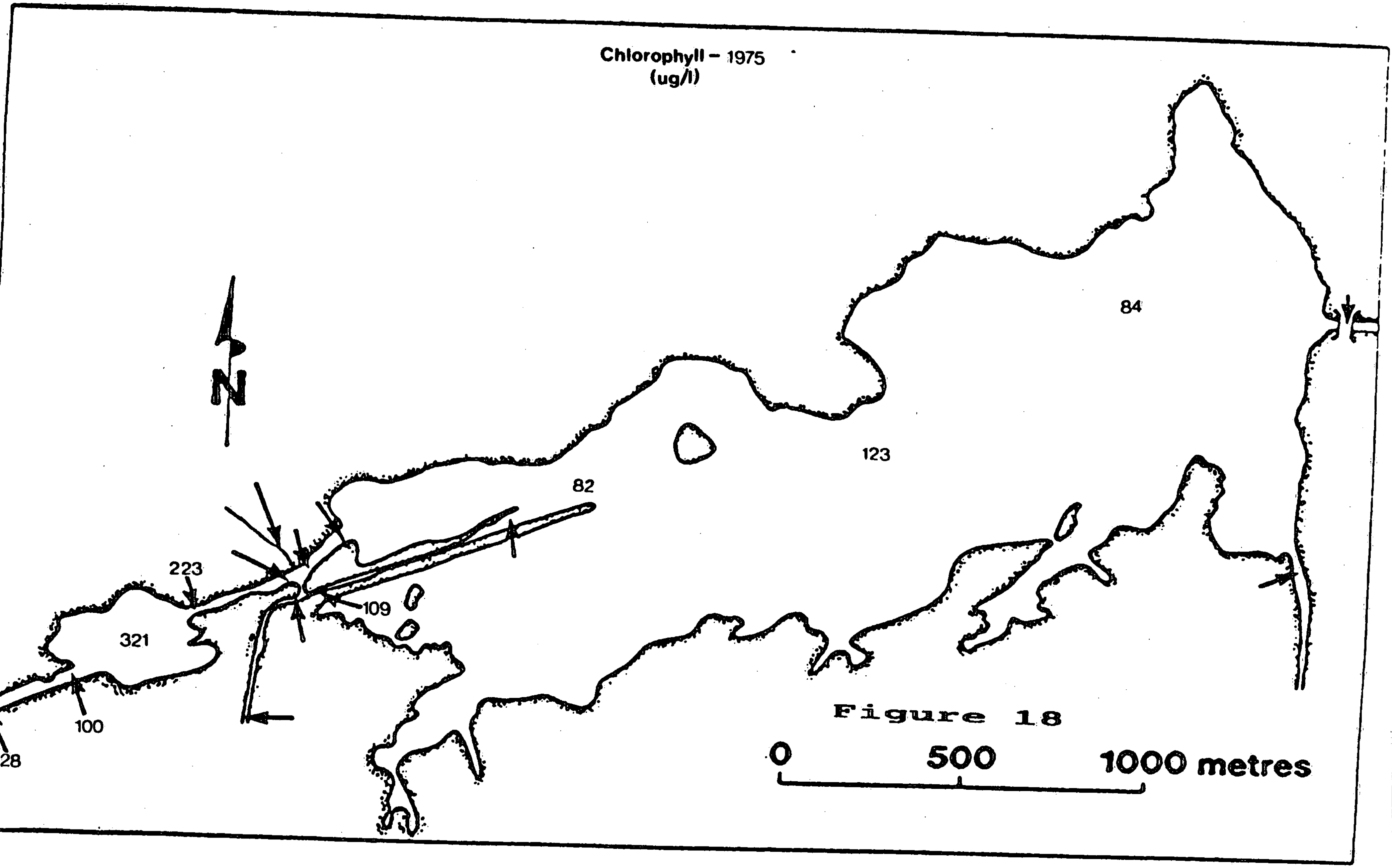


Figure 18

Chlorophyll – 1975
(ug/l)
N
84
123
82
223
109
321
100
28
0
500
1000 metres

Figure 19

Seston

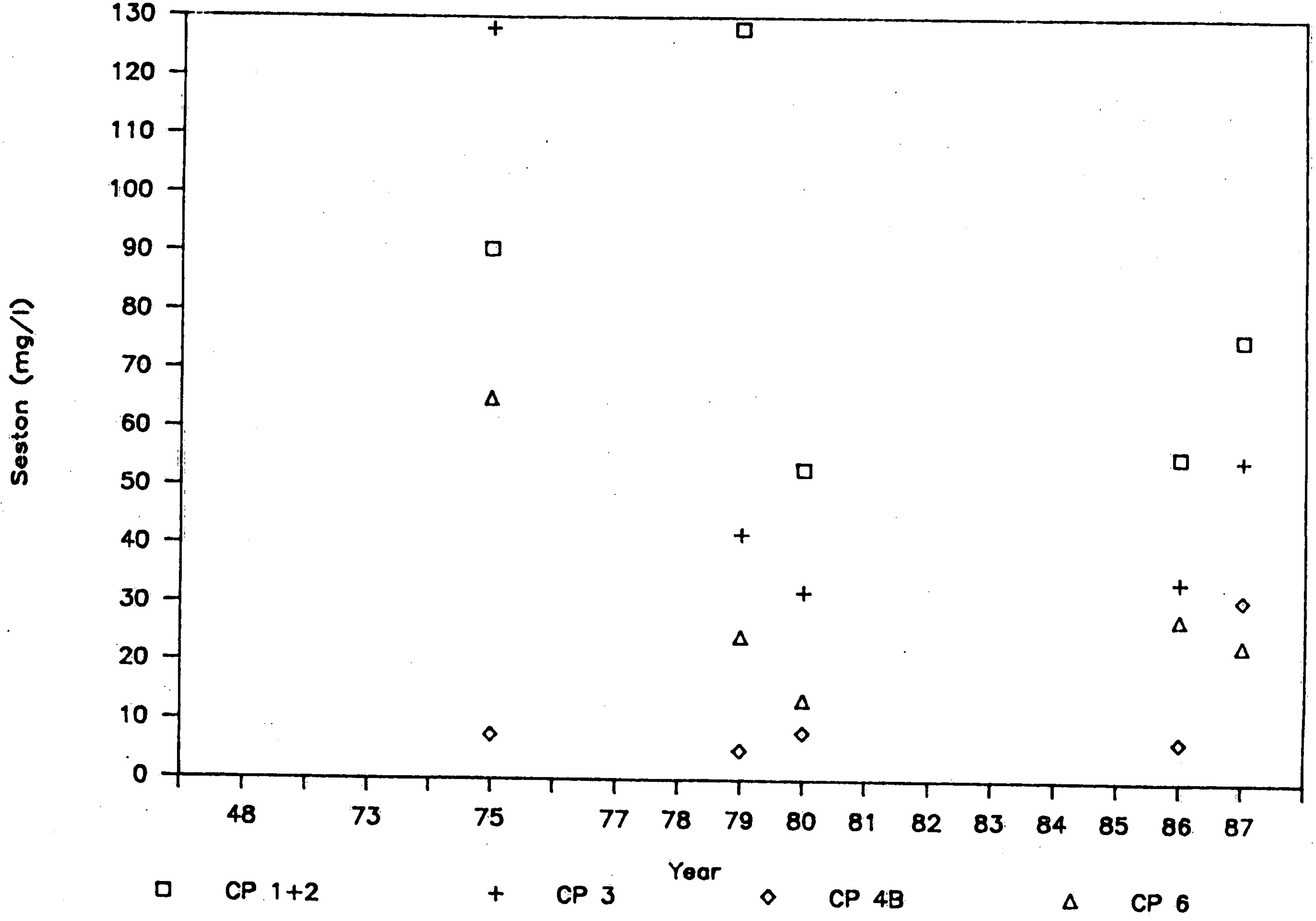


Figure 20

Seston – 1986

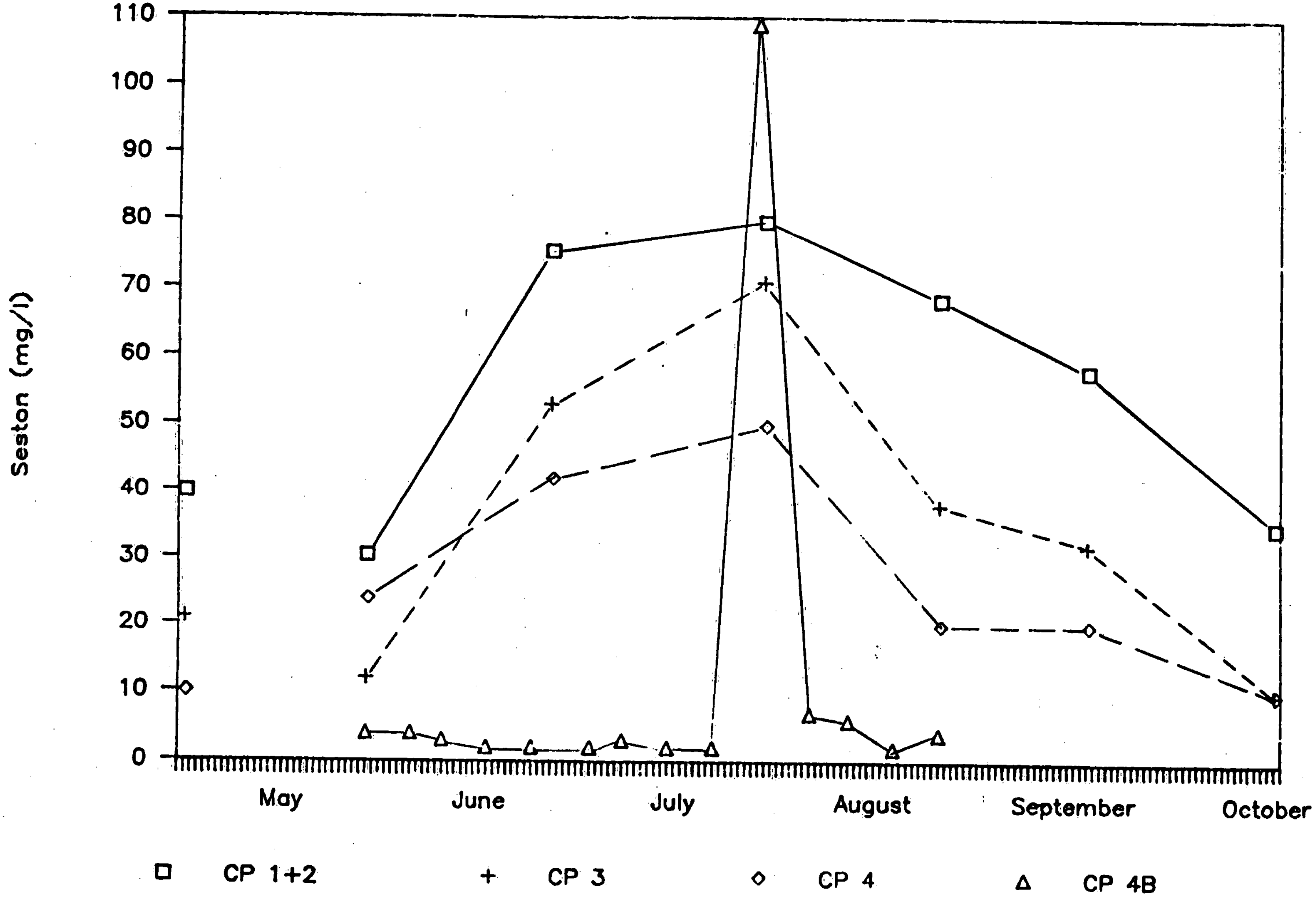


Figure 21

Historical Summer Seston

Open Water – CP 1+2

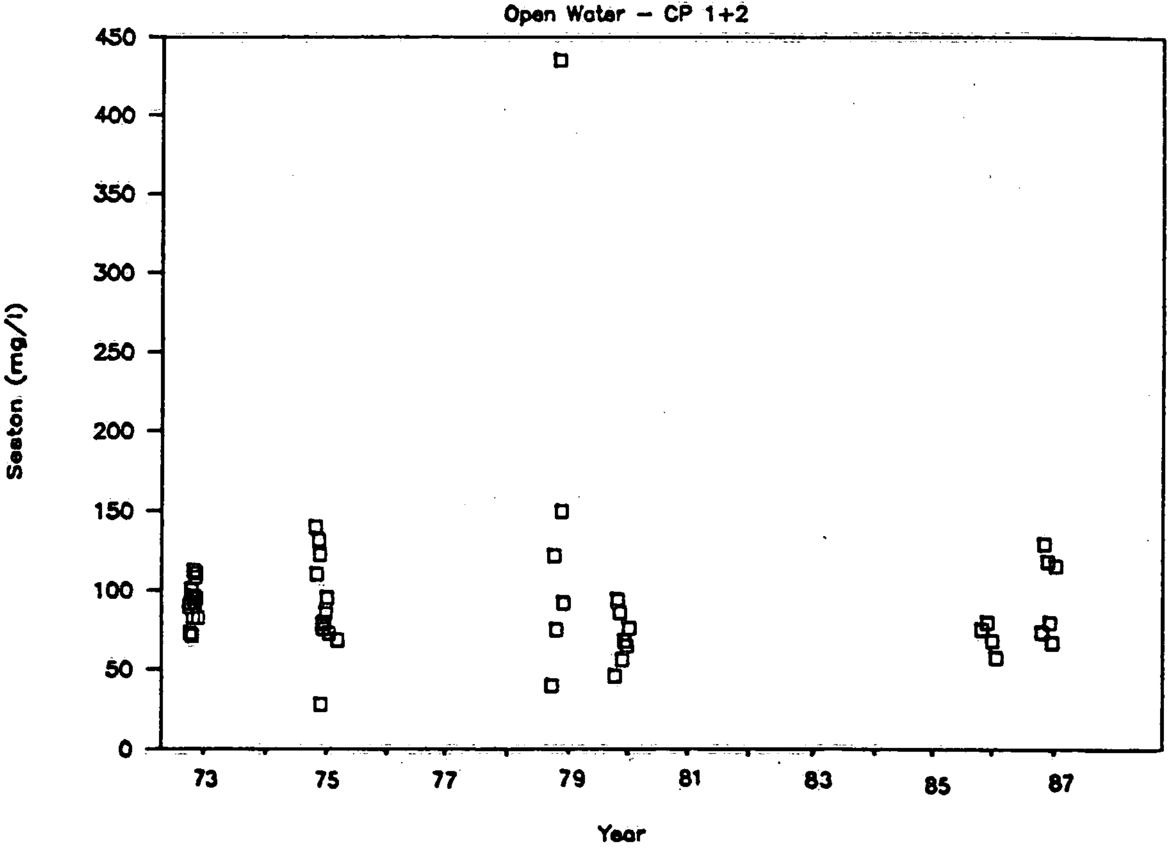


Figure 22

Historical Summer Seston

West Pond – CP 5

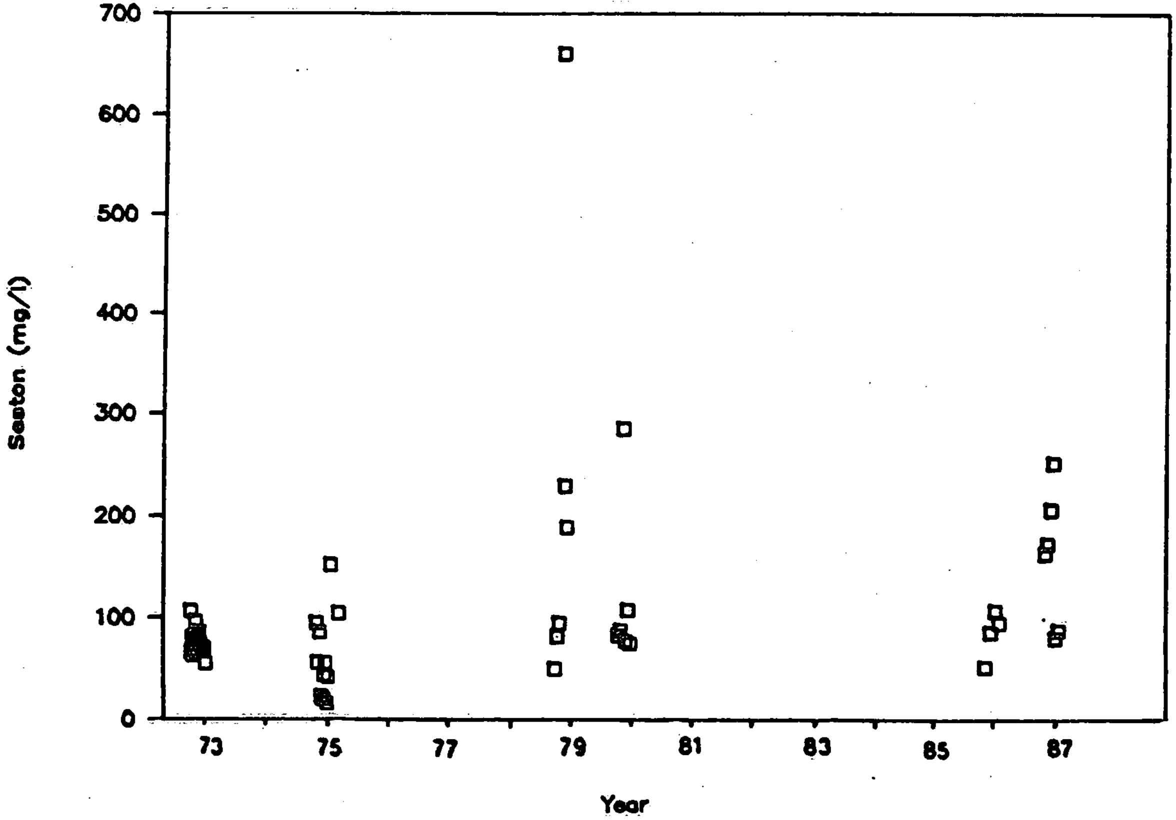


Figure 23

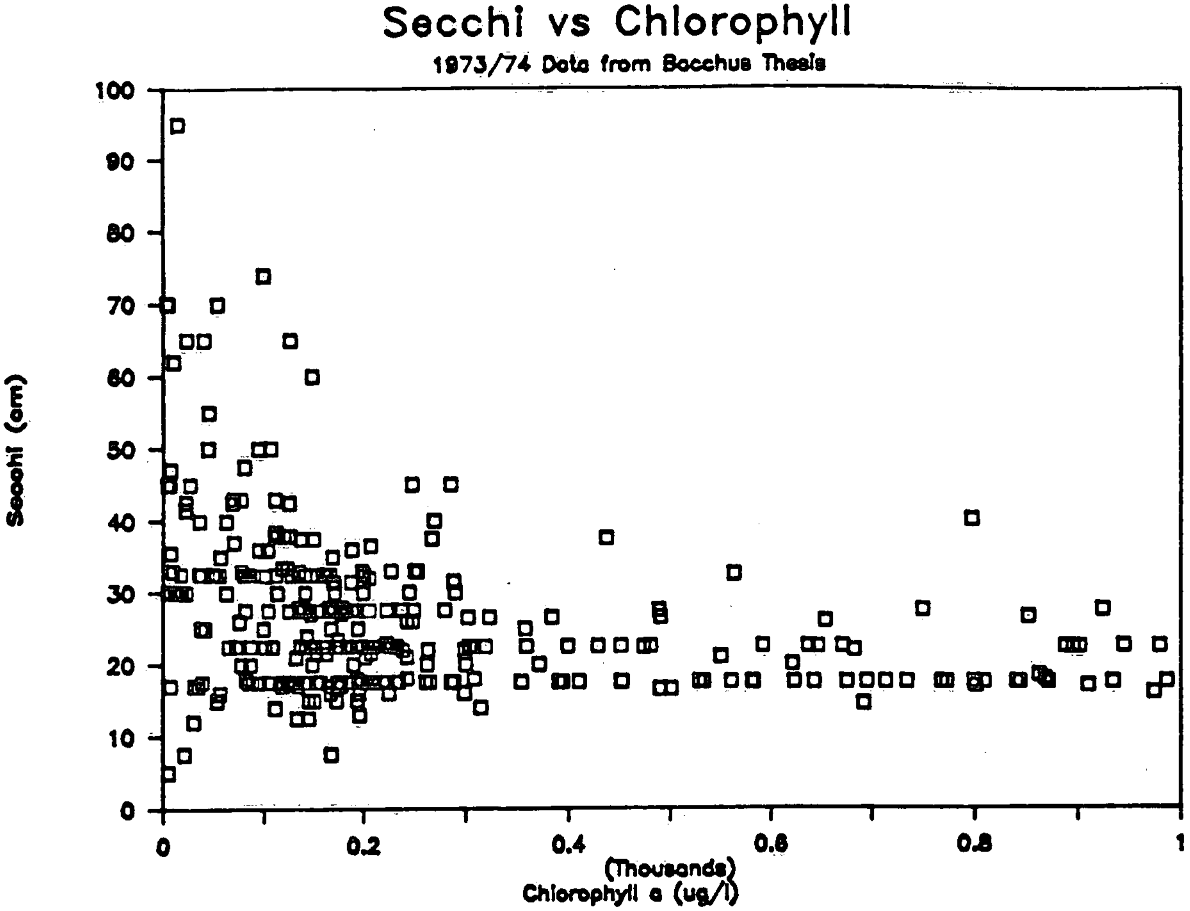


Figure 24

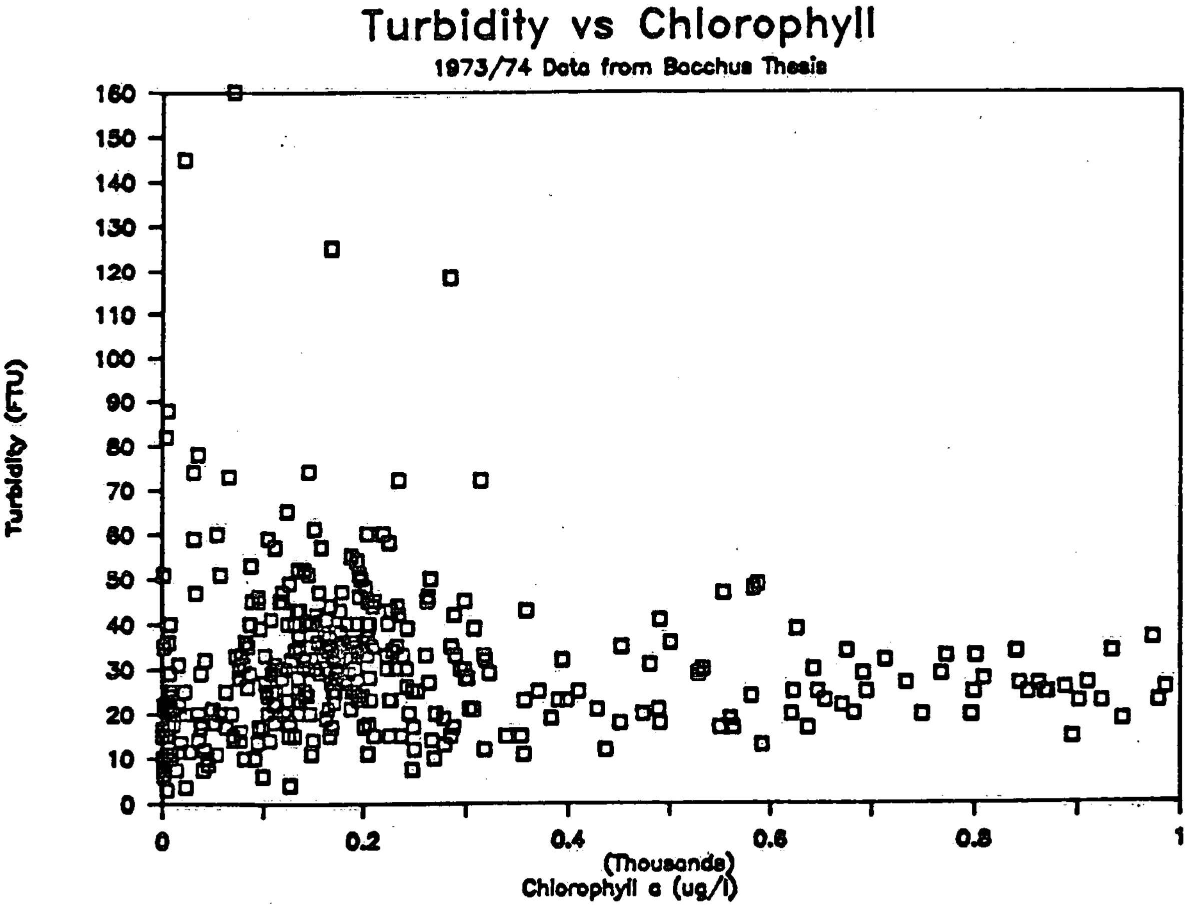


Figure 25

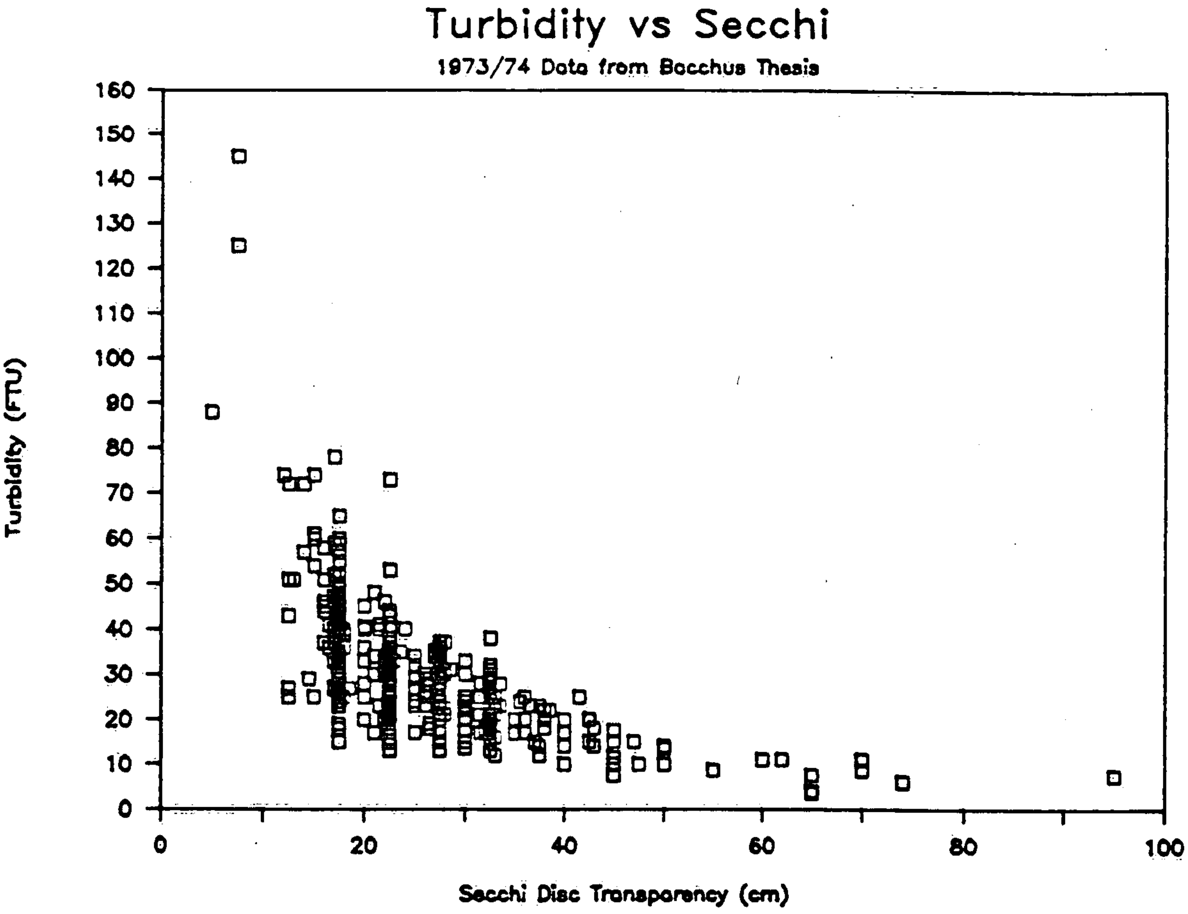


Figure 26

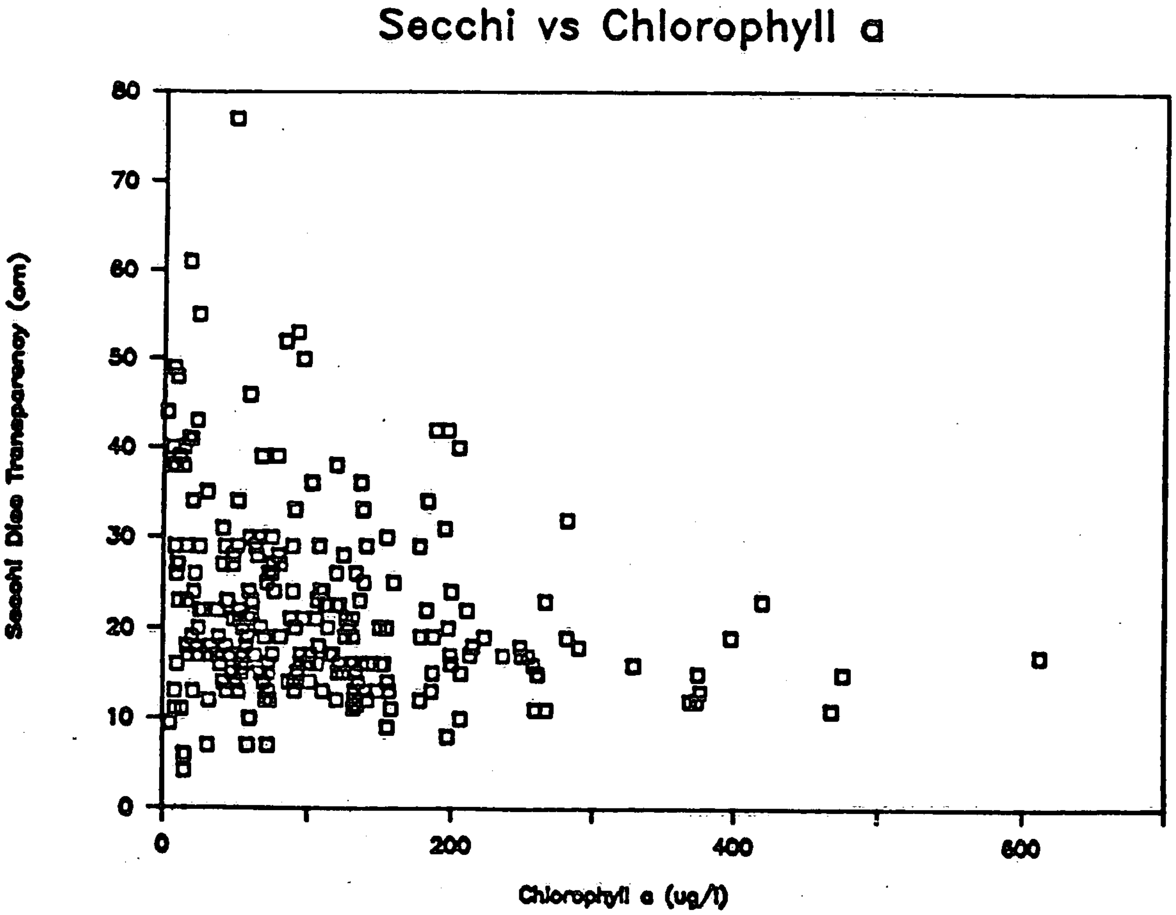


Figure 27

Chlorophyll a vs Total Phosphorus

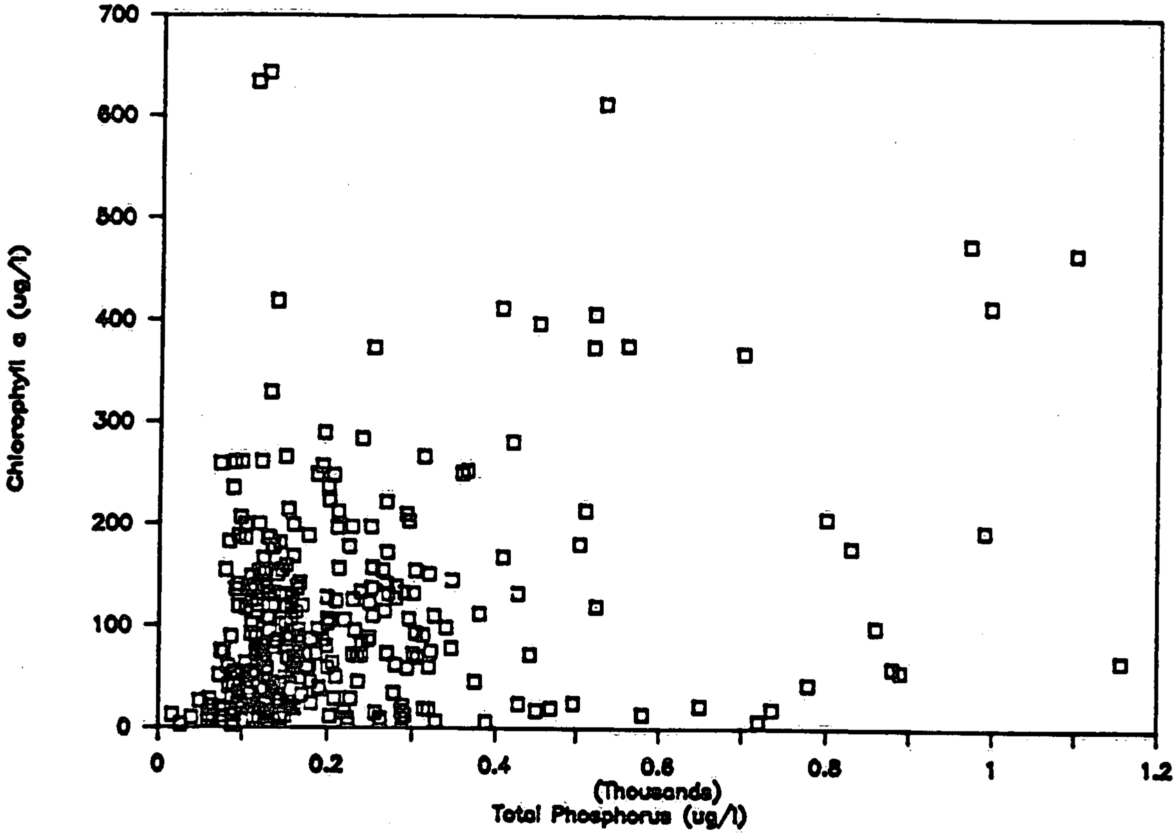
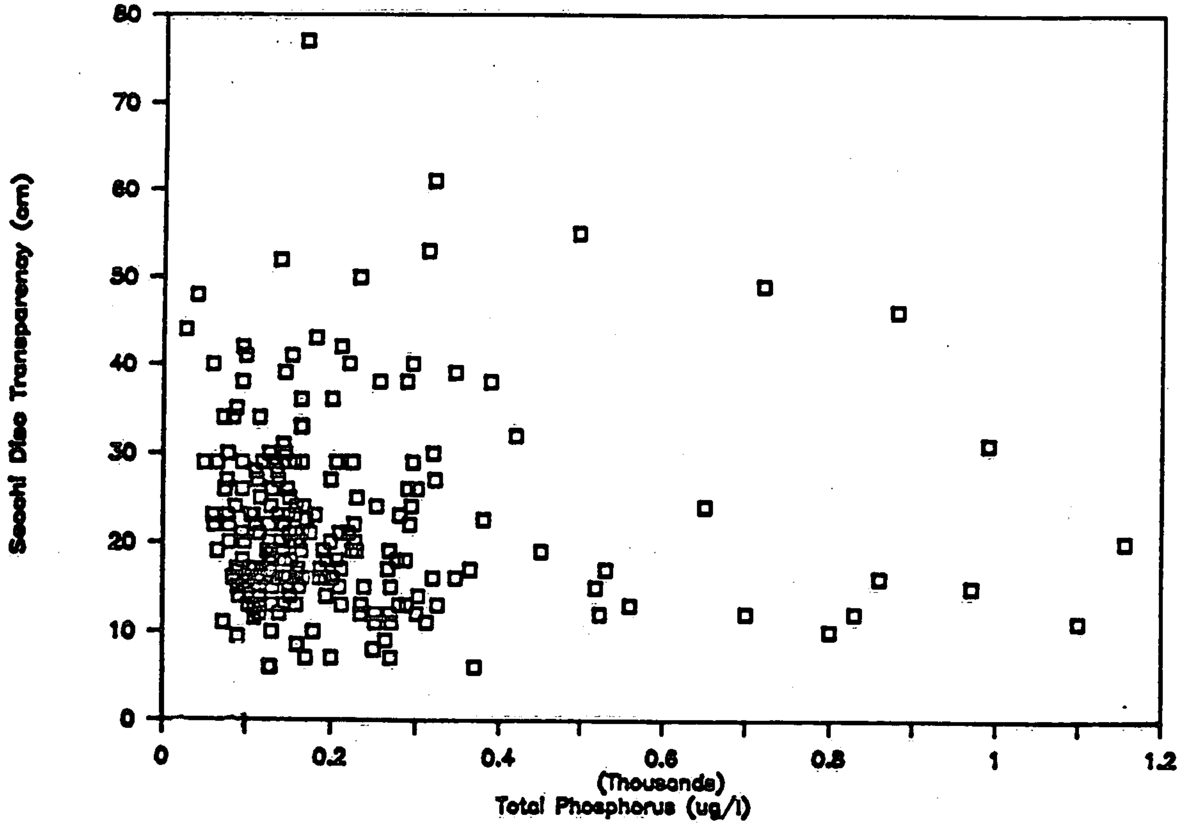


Figure 28

Secchi vs Total Phosphorus



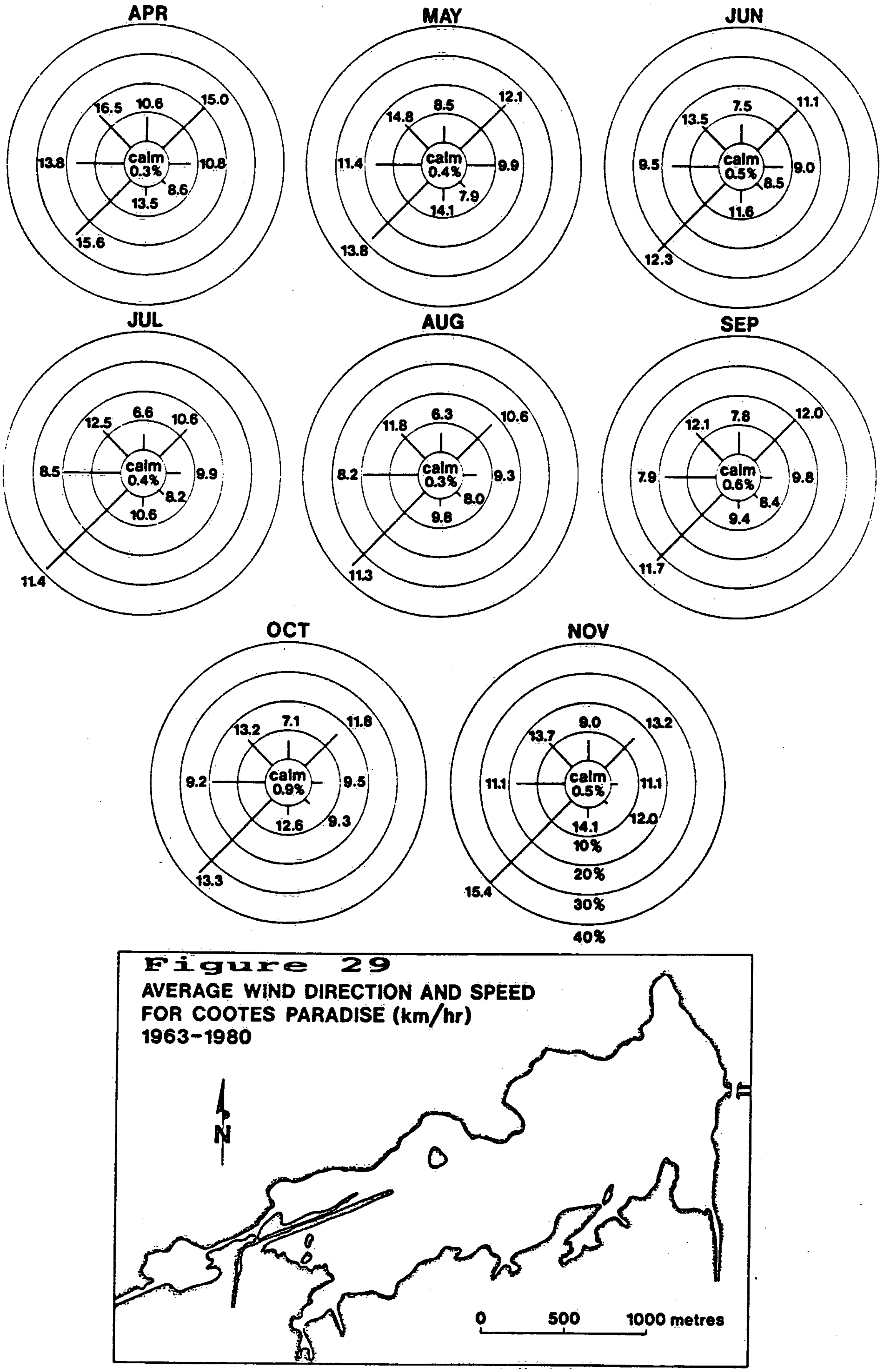


Figure 29

AVERAGE WIND DIRECTION AND SPEED FOR COOTES PARADISE (km/hr) 1963-1980

Figure 30

Creek Discharge & Open Water Turbidity

1973 – 1974

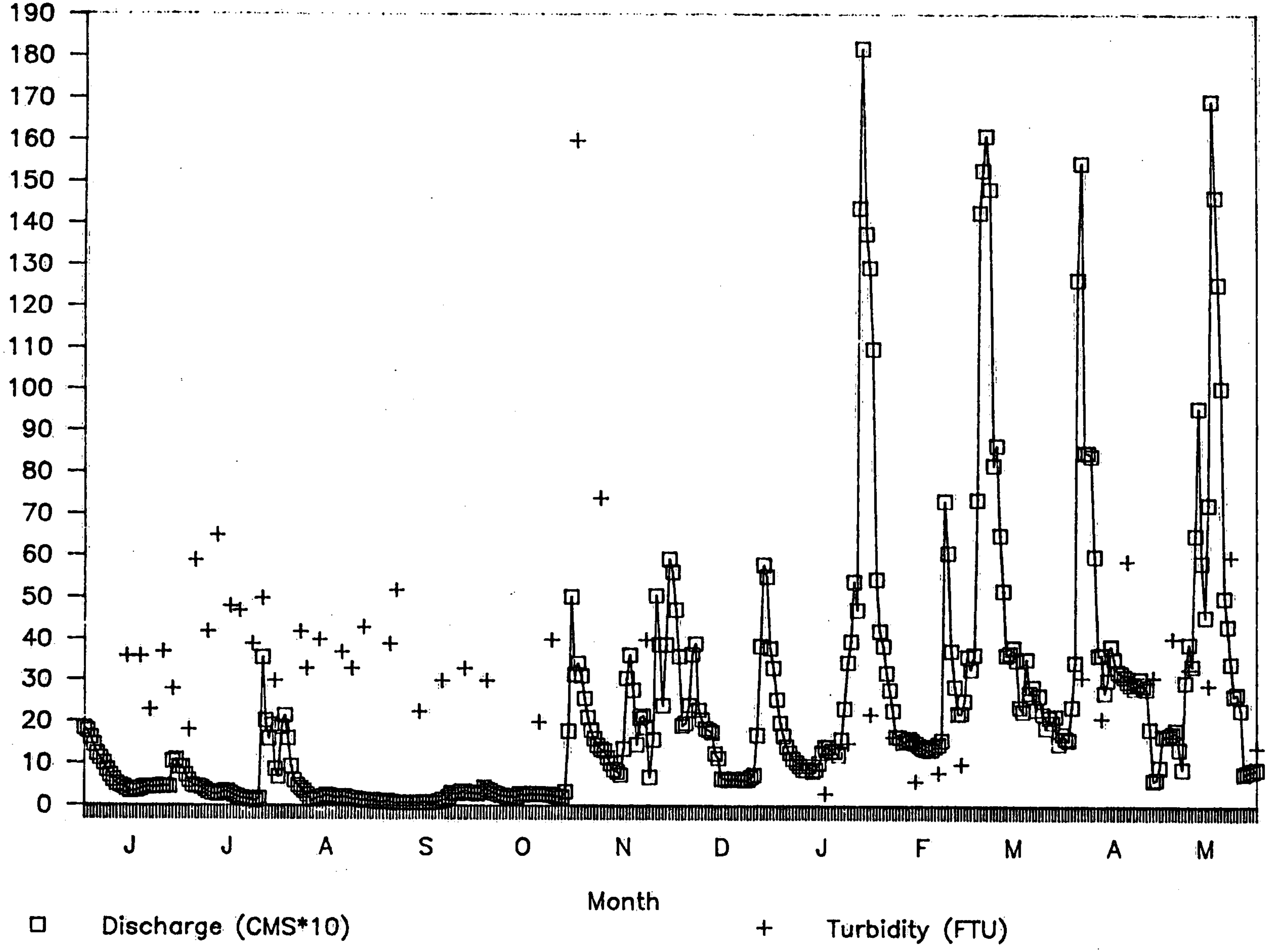


Figure 31

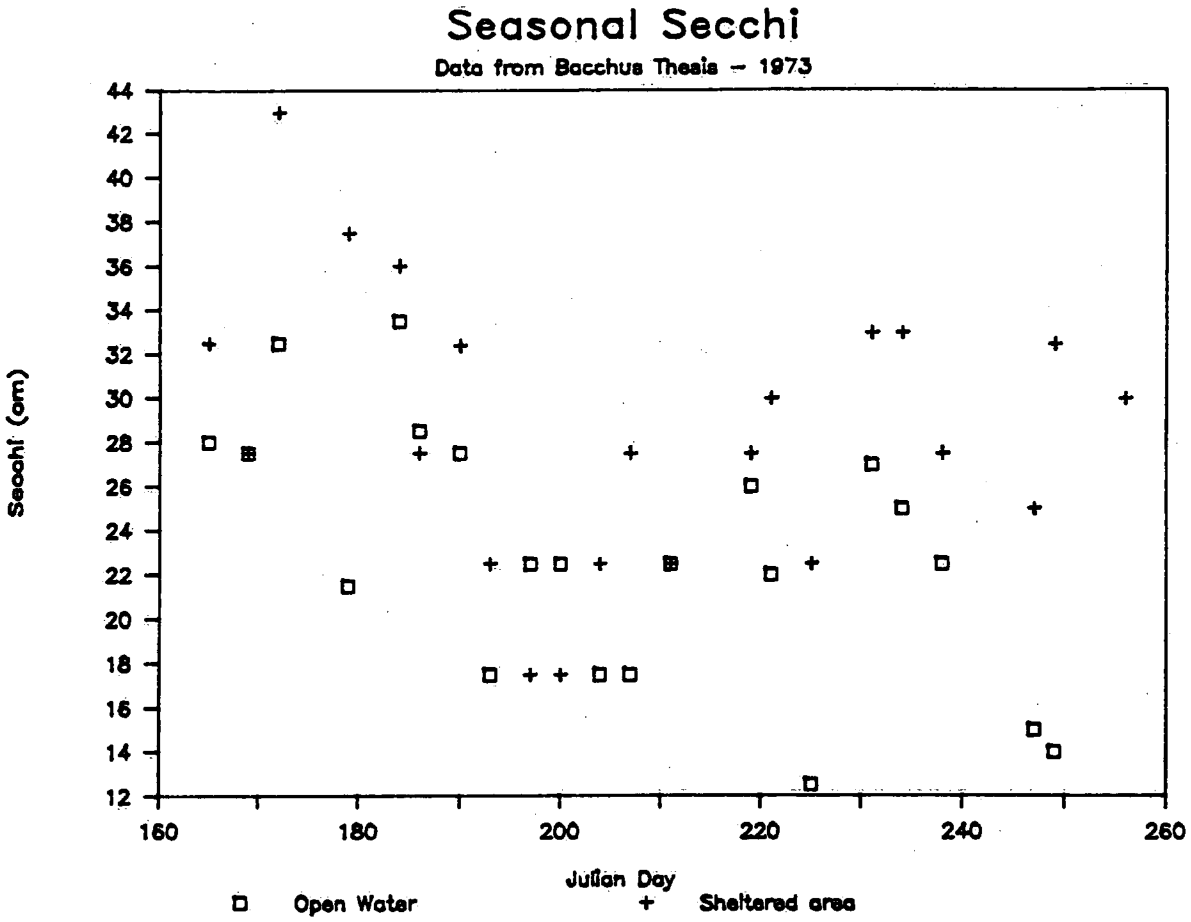

Seasonal Secchi
Data from Bacchus Thesis - 1973
Secchi (cm)
44
42
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
160
180
200
220
240
260
Julian Day
□ Open Water
+ Sheltered area

Figure 32

Historical Summer Ammonia

Open Water – CP 1+2

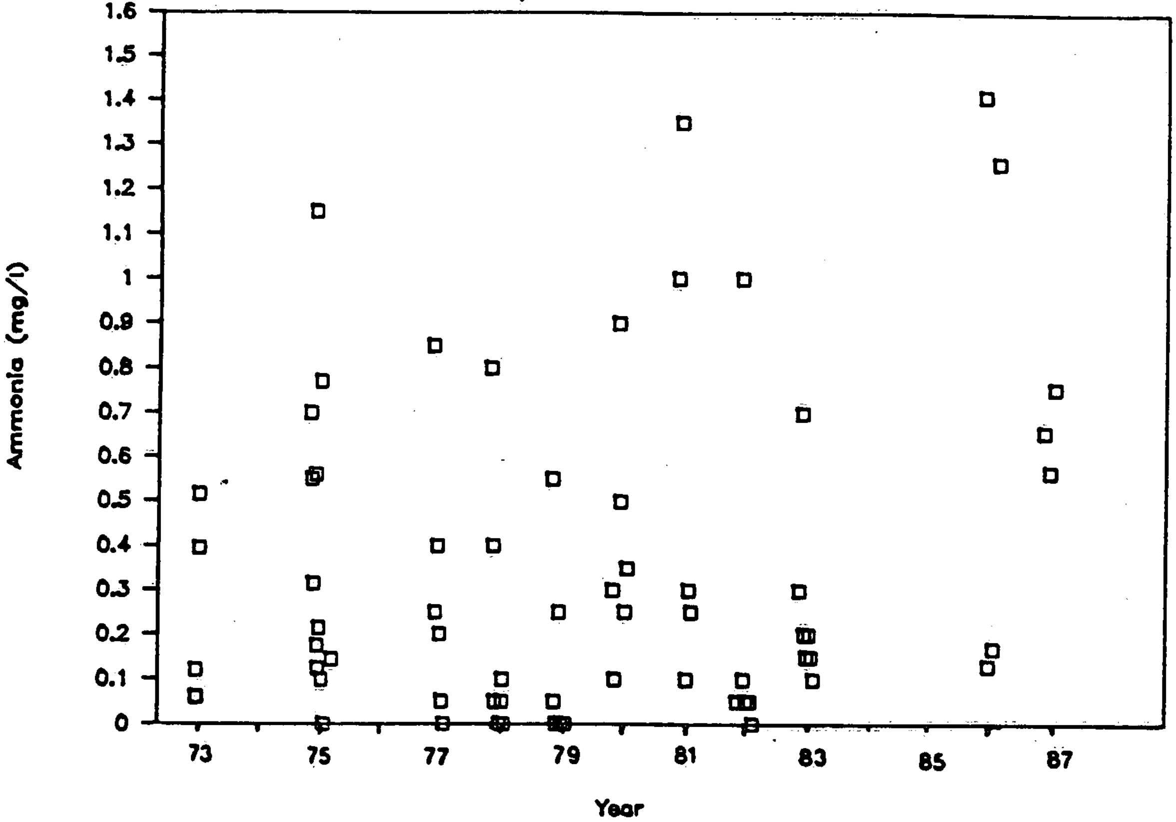


Figure 33

Historical Summer Ammonia

West Pond – CP 5

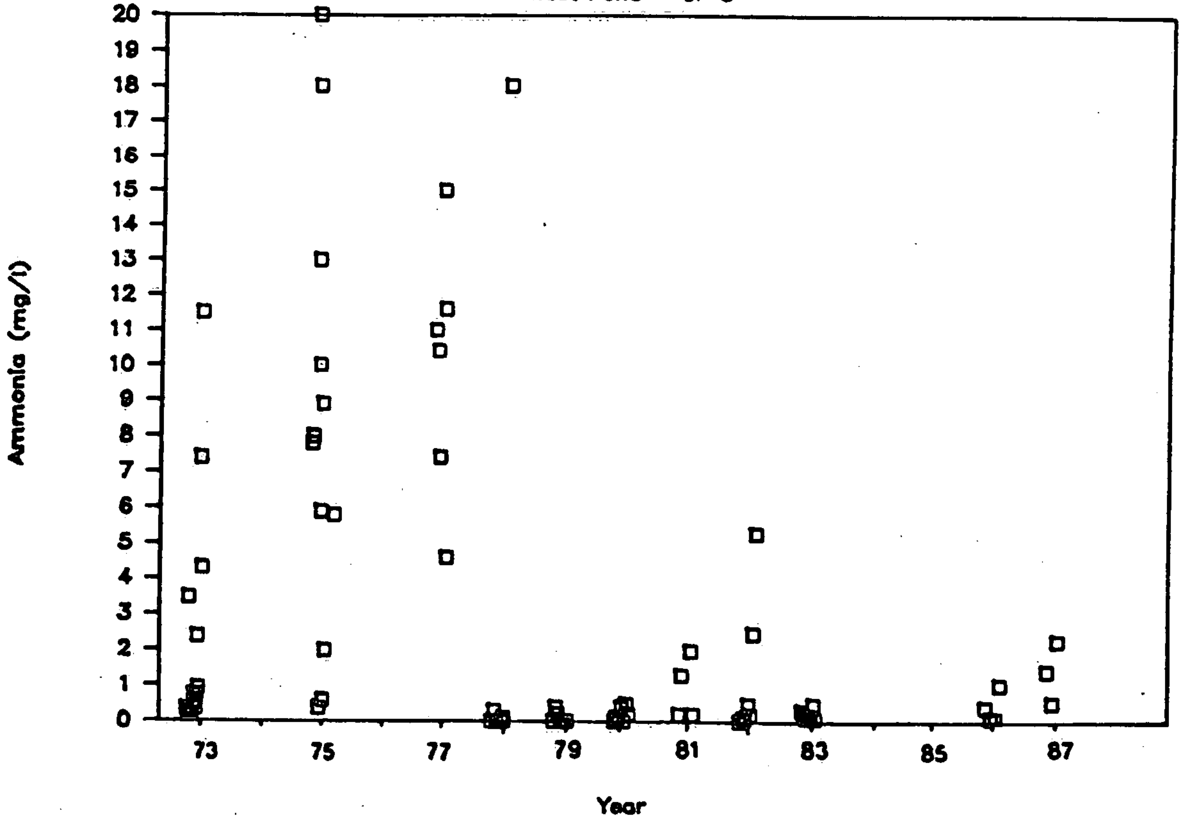


Figure 34

Historical Summer Nitrate

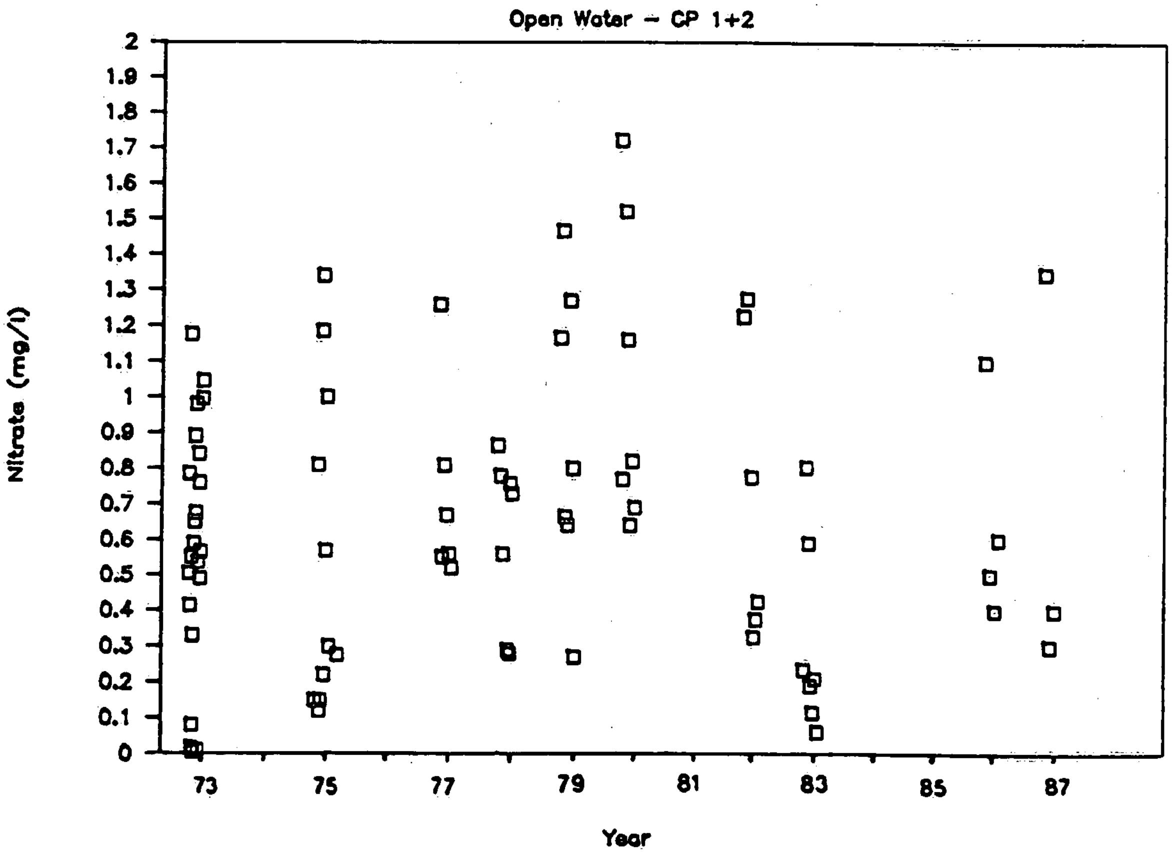


Figure 35

Historical Summer Nitrate

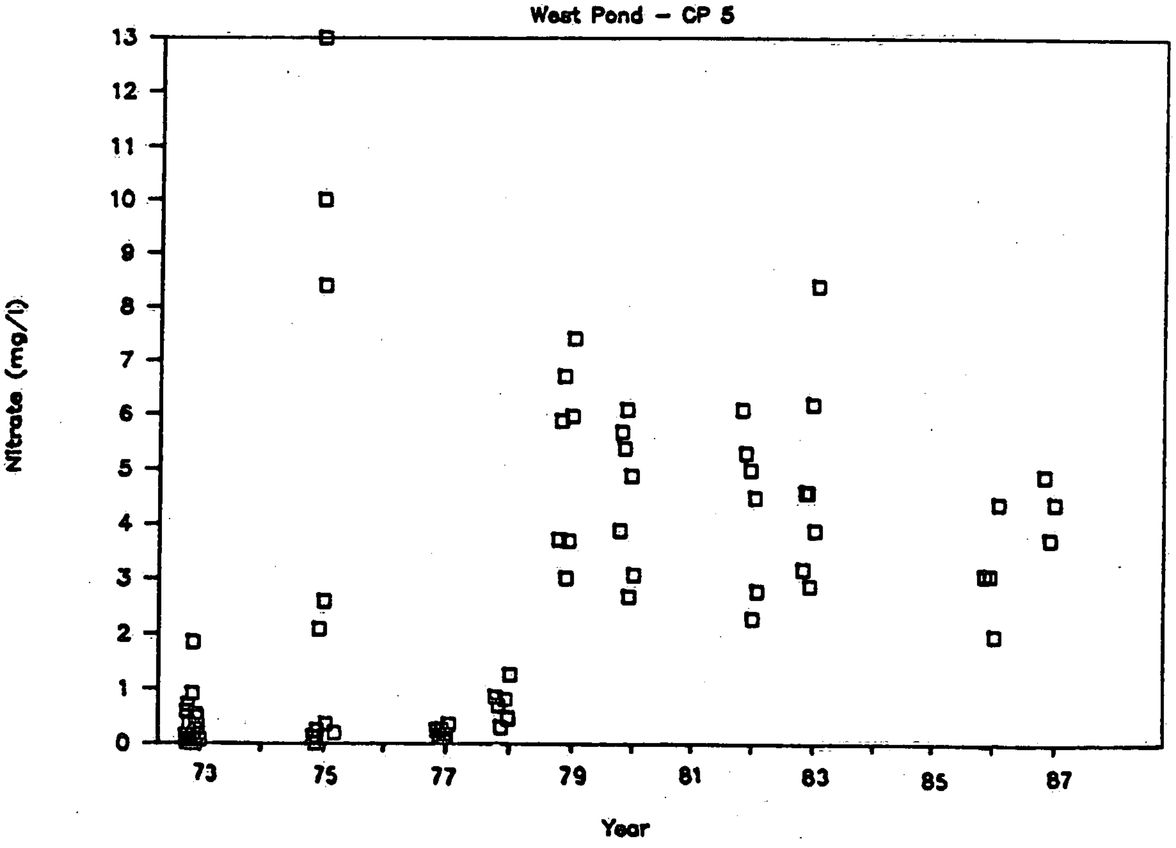


Figure 36

Historical Summer Total Phosphorus

Open Water – CP 1+2

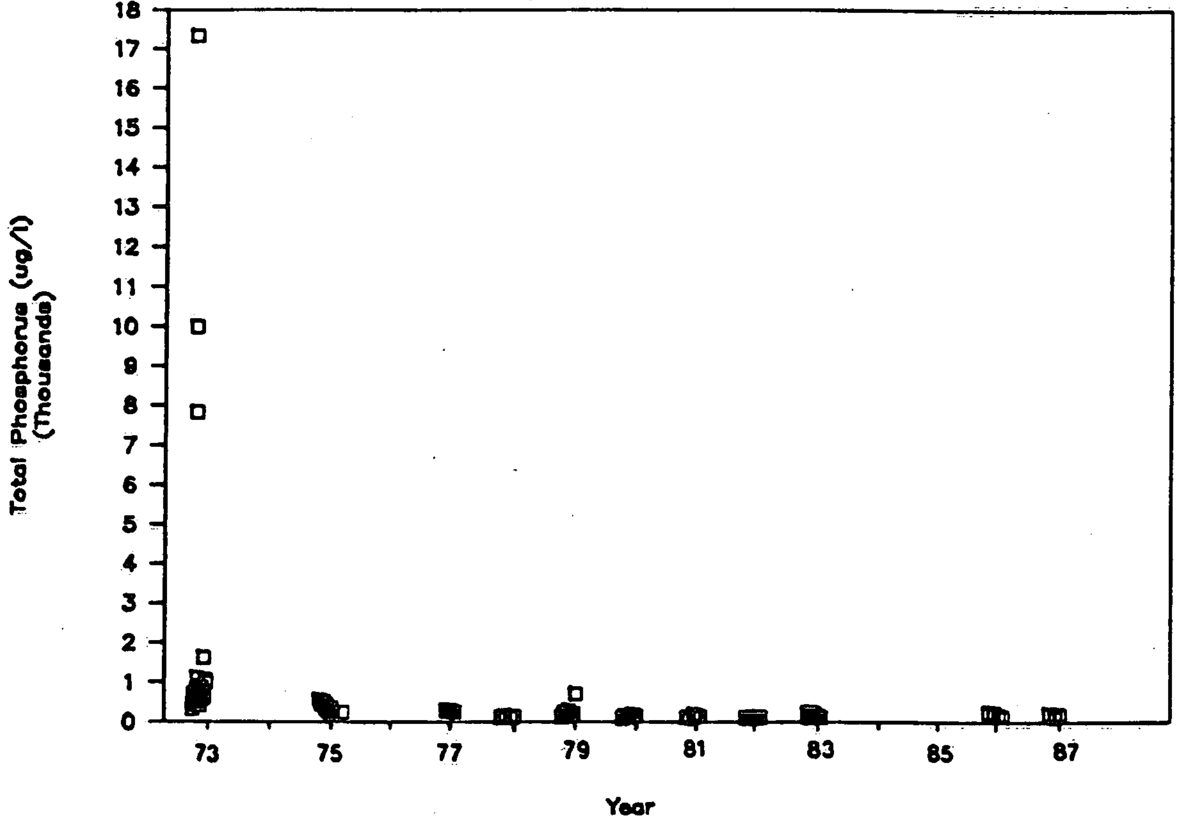


Figure 37 Expanded Scale

Historical Summer Total Phosphorus

Open Water – CP 1+2

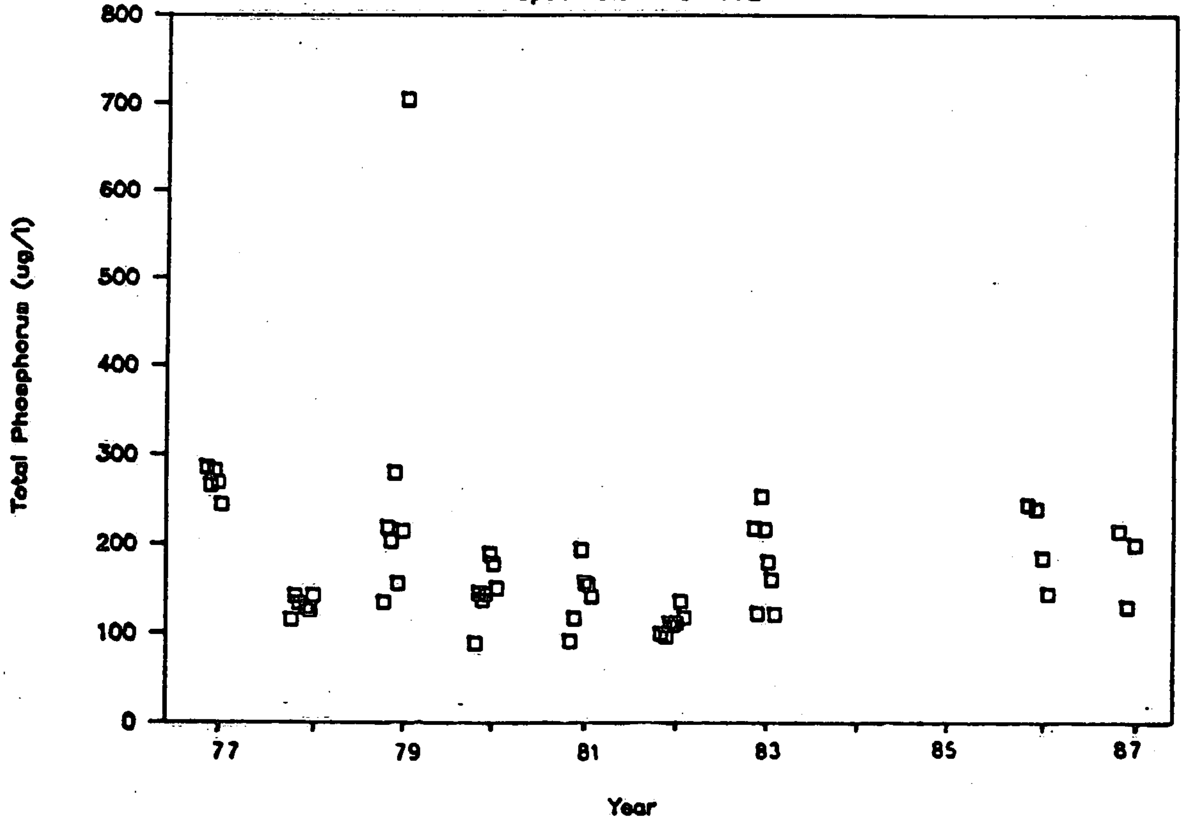


Figure 38

Historical Summer Total Phosphorus

West Pond – CP 5

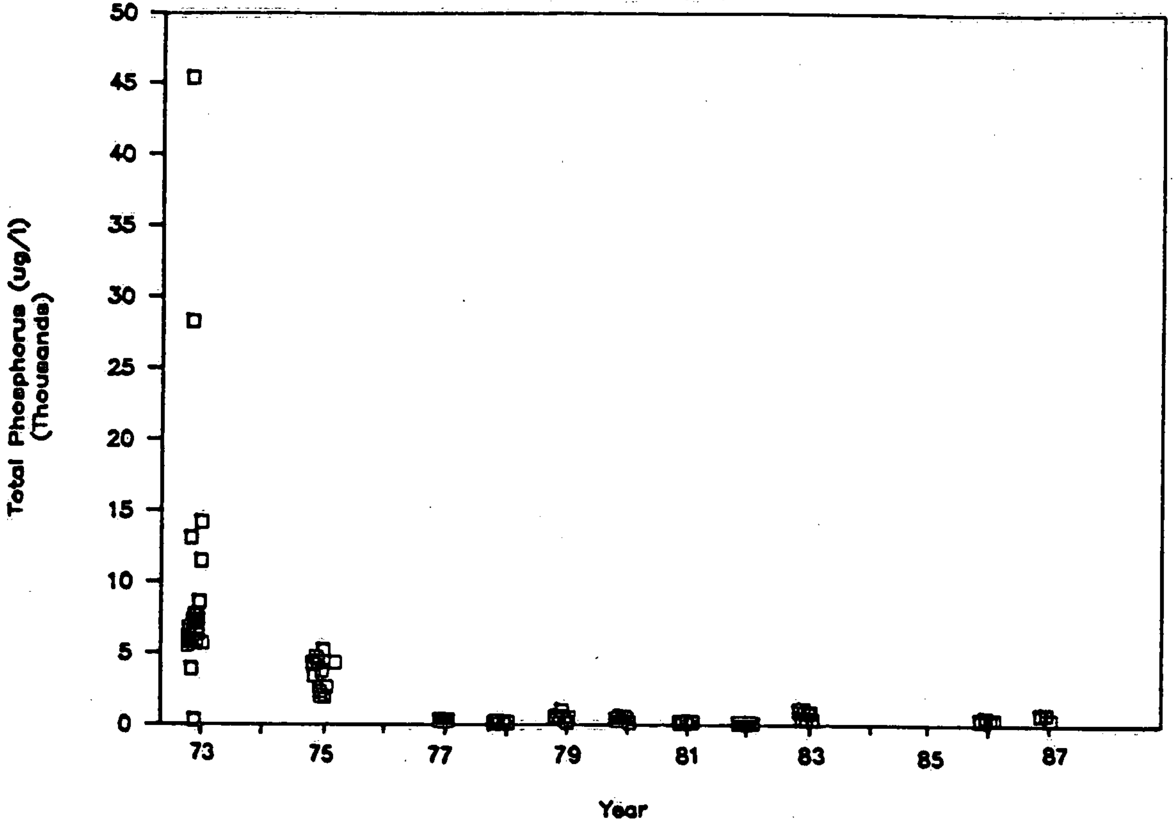


Figure 39 Expanded Scale

Historical Summer Total Phosphorus

West Pond – CP 5

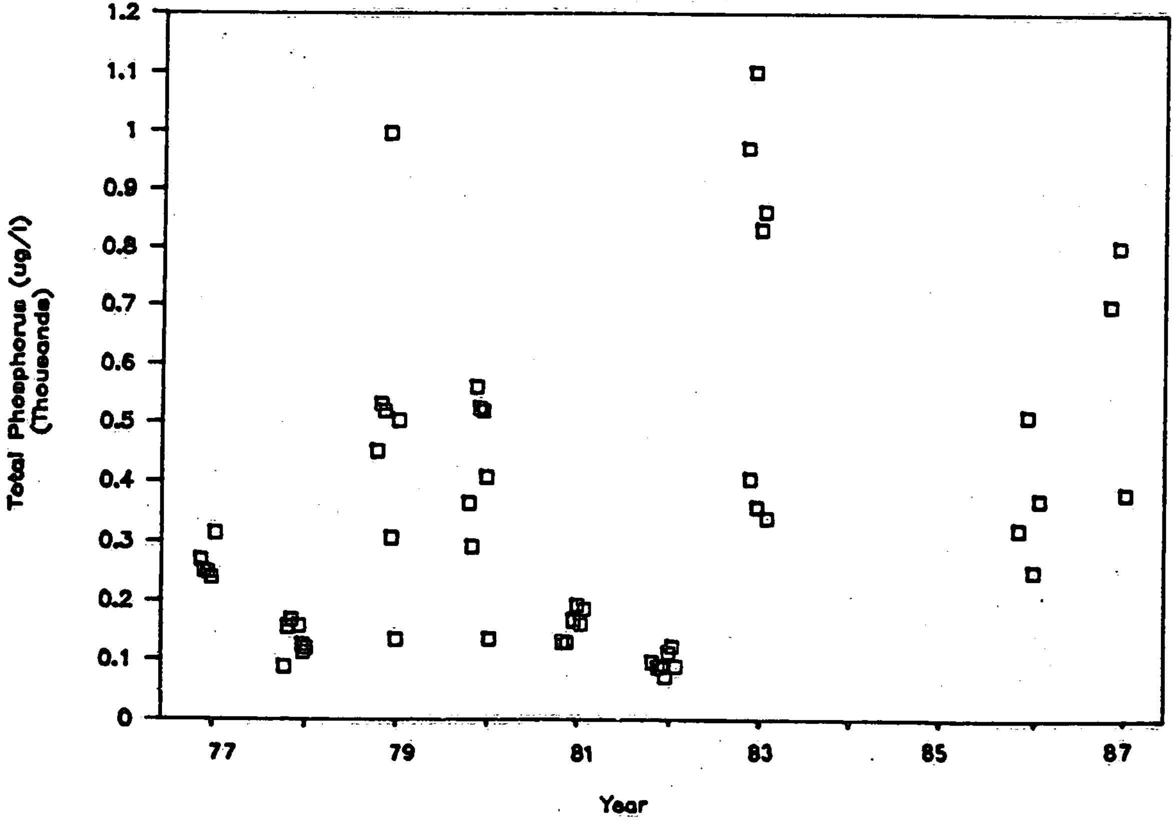


Figure 40

Historical Summer SRP

Open Water – CP 1+2

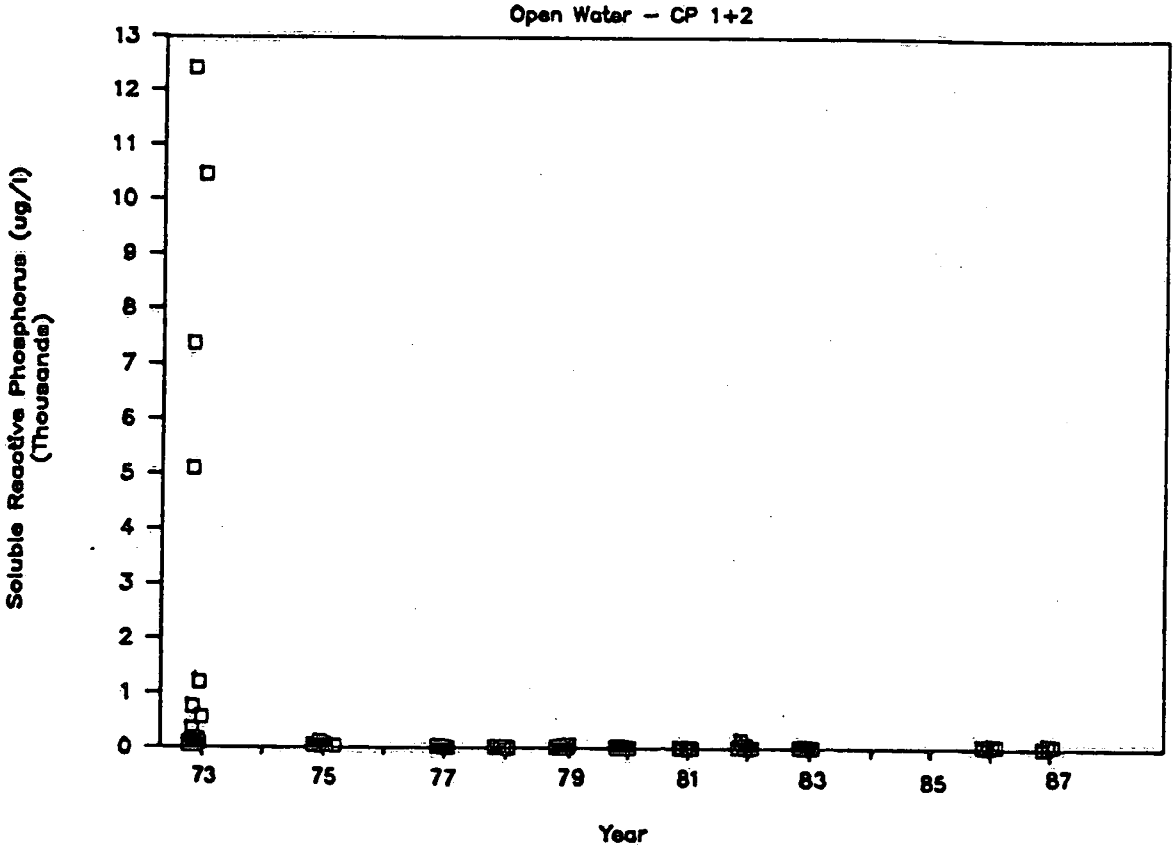


Figure 41 Expanded Scale

Historical Summer SRP

Open Water – CP 1+2

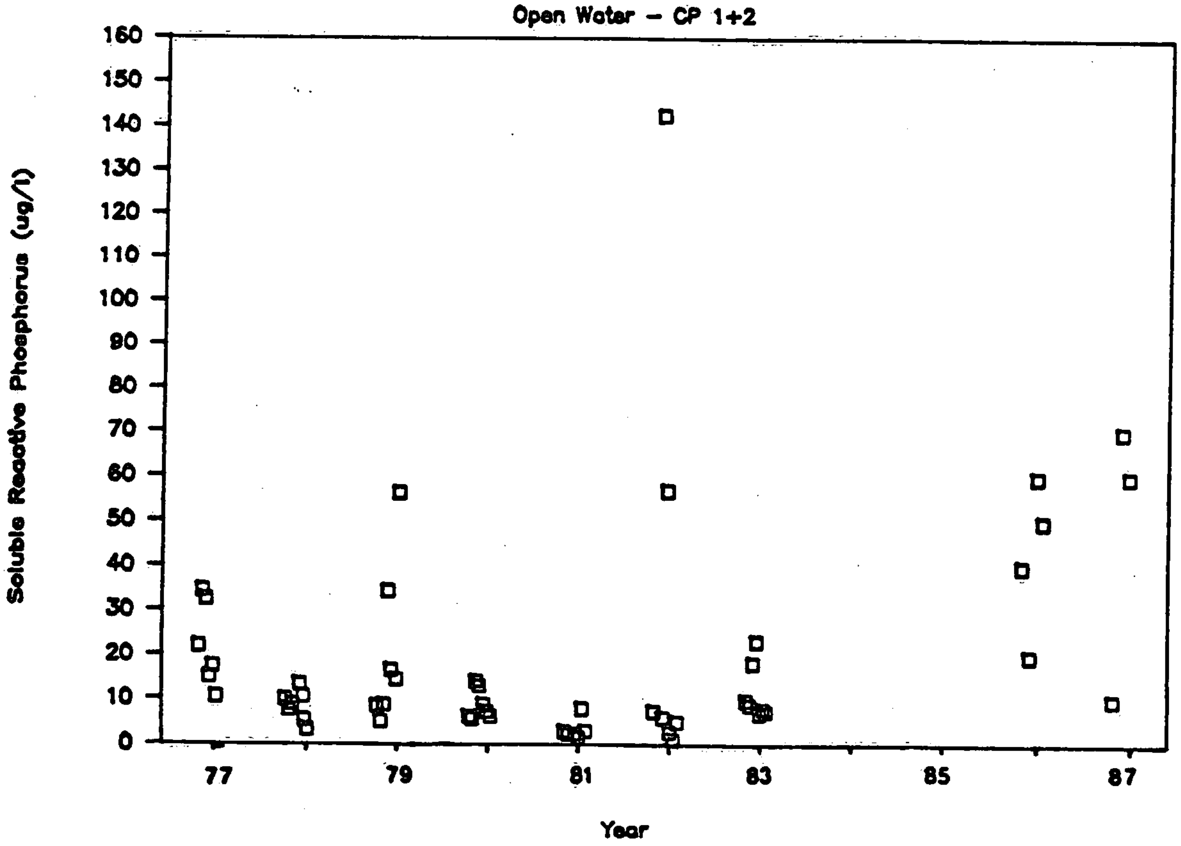


Figure 42

Historical Summer SRP

West Pond – CP 5

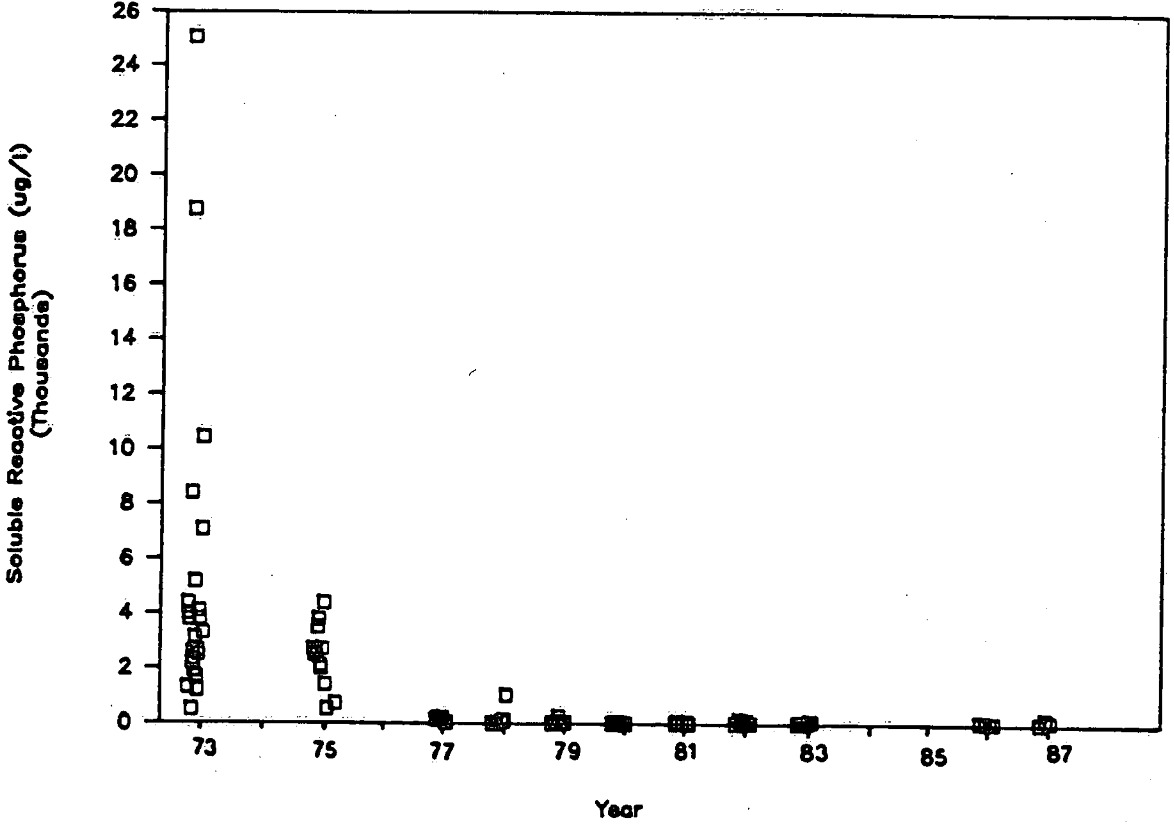


Figure 43 Expanded Scale

Historical Summer SRP

West Pond – CP 5

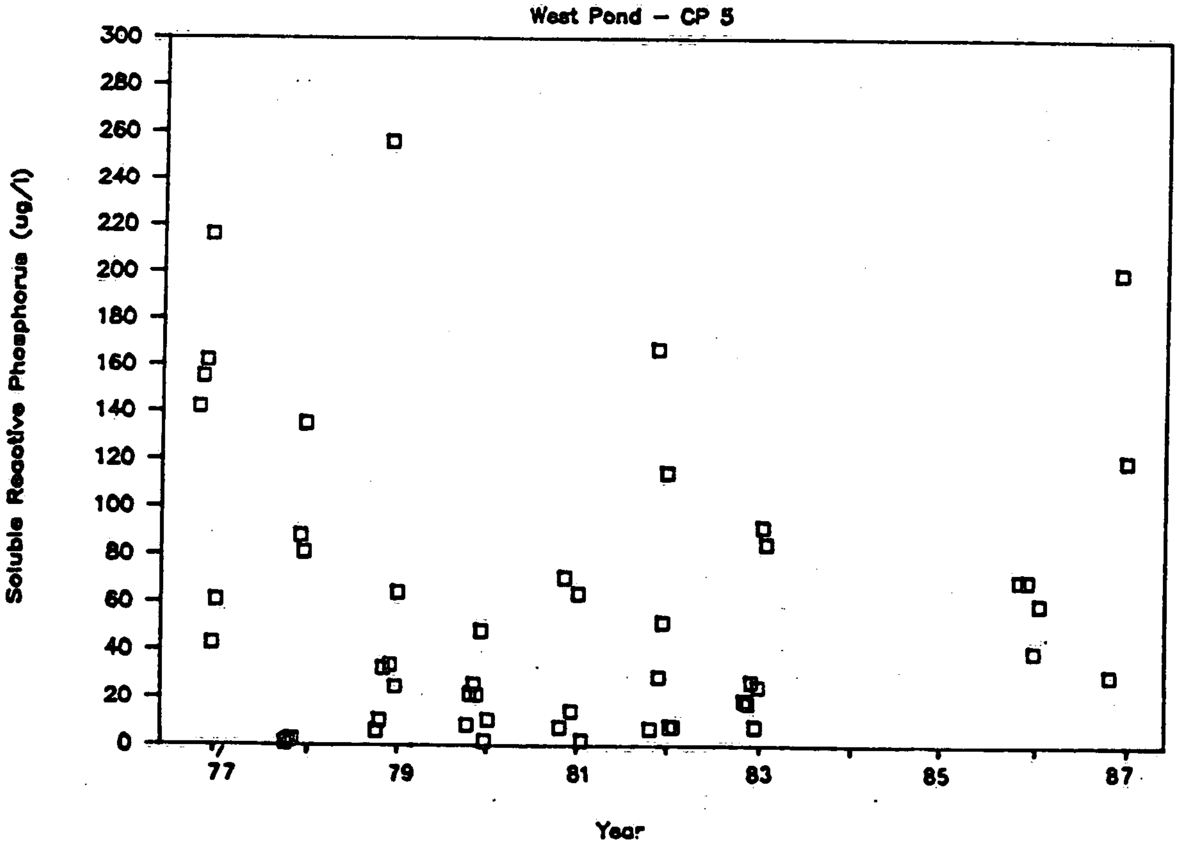


Figure 44

Historical Summer Chlorophyll

Open Water – CP 1+2

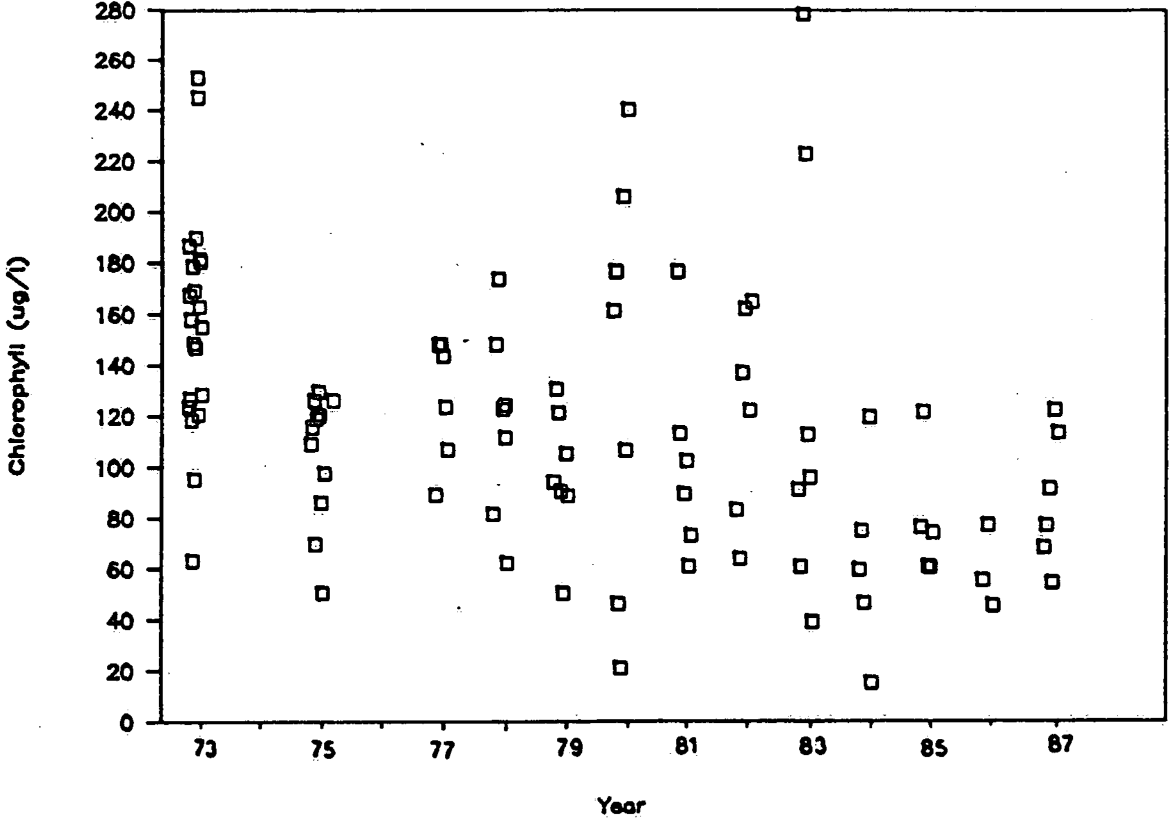
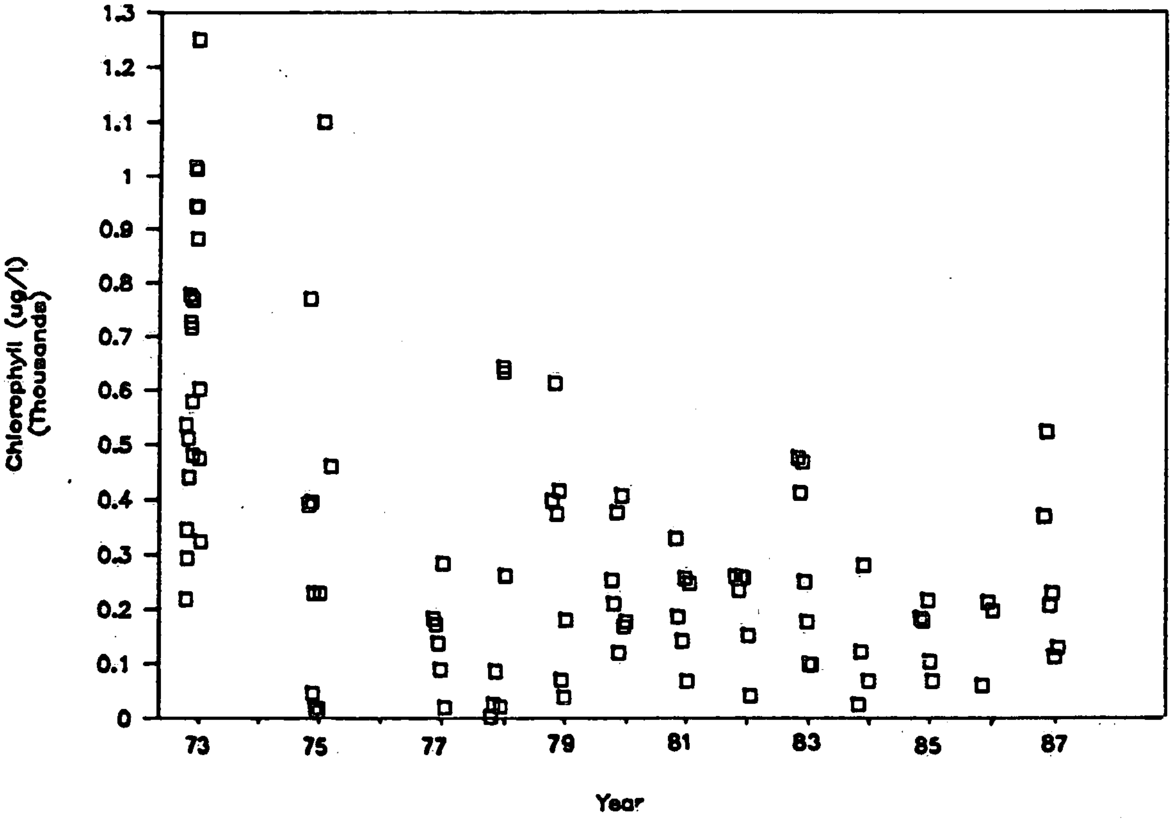


Figure 45

Historical Summer Chlorophyll

West Pond – CP 5



Secchi - (April 8-Sept 2/87)
(cm)

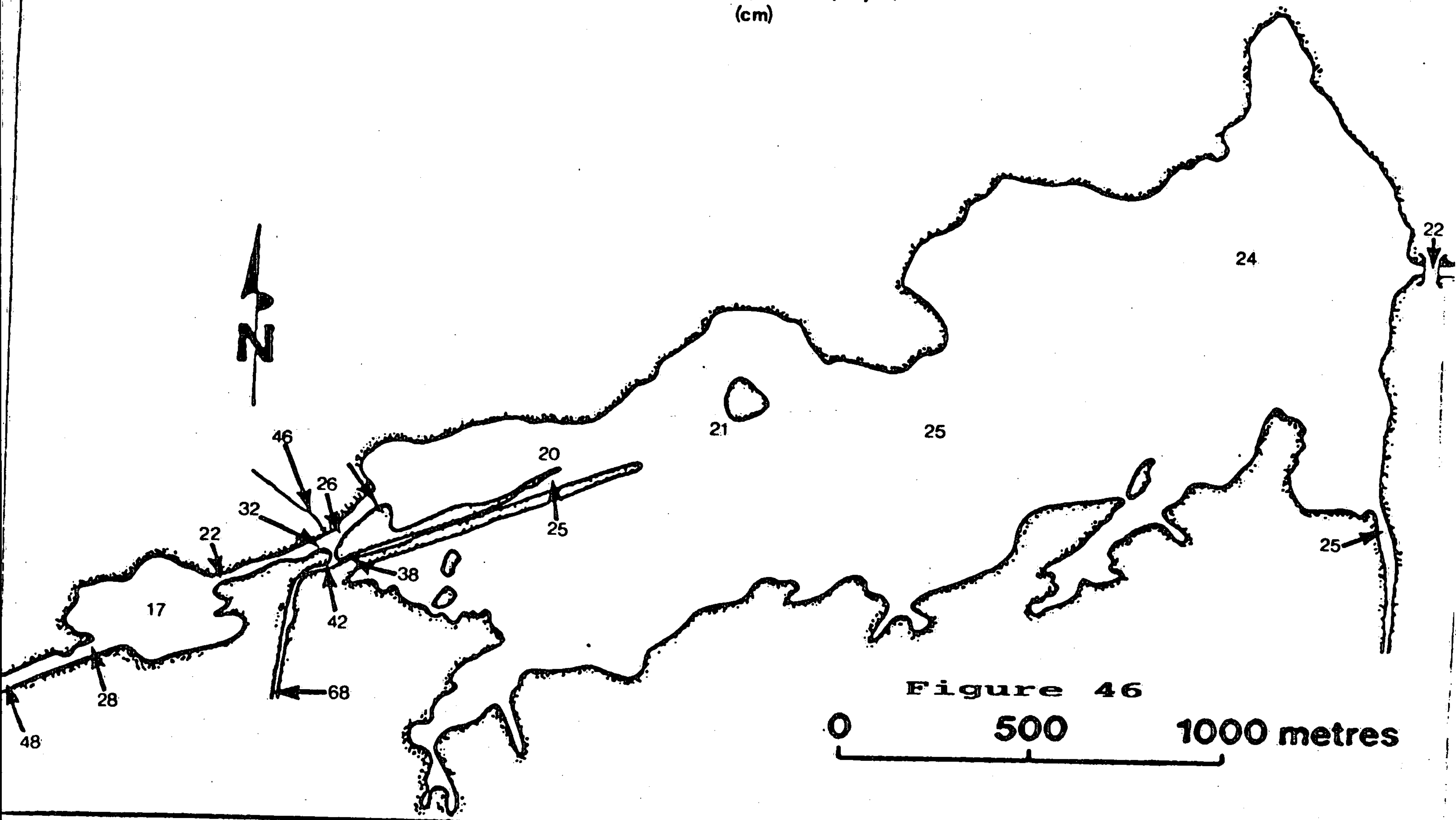


Figure 46

Secchi – (Sept 14 – Nov 3/87)
(cm)

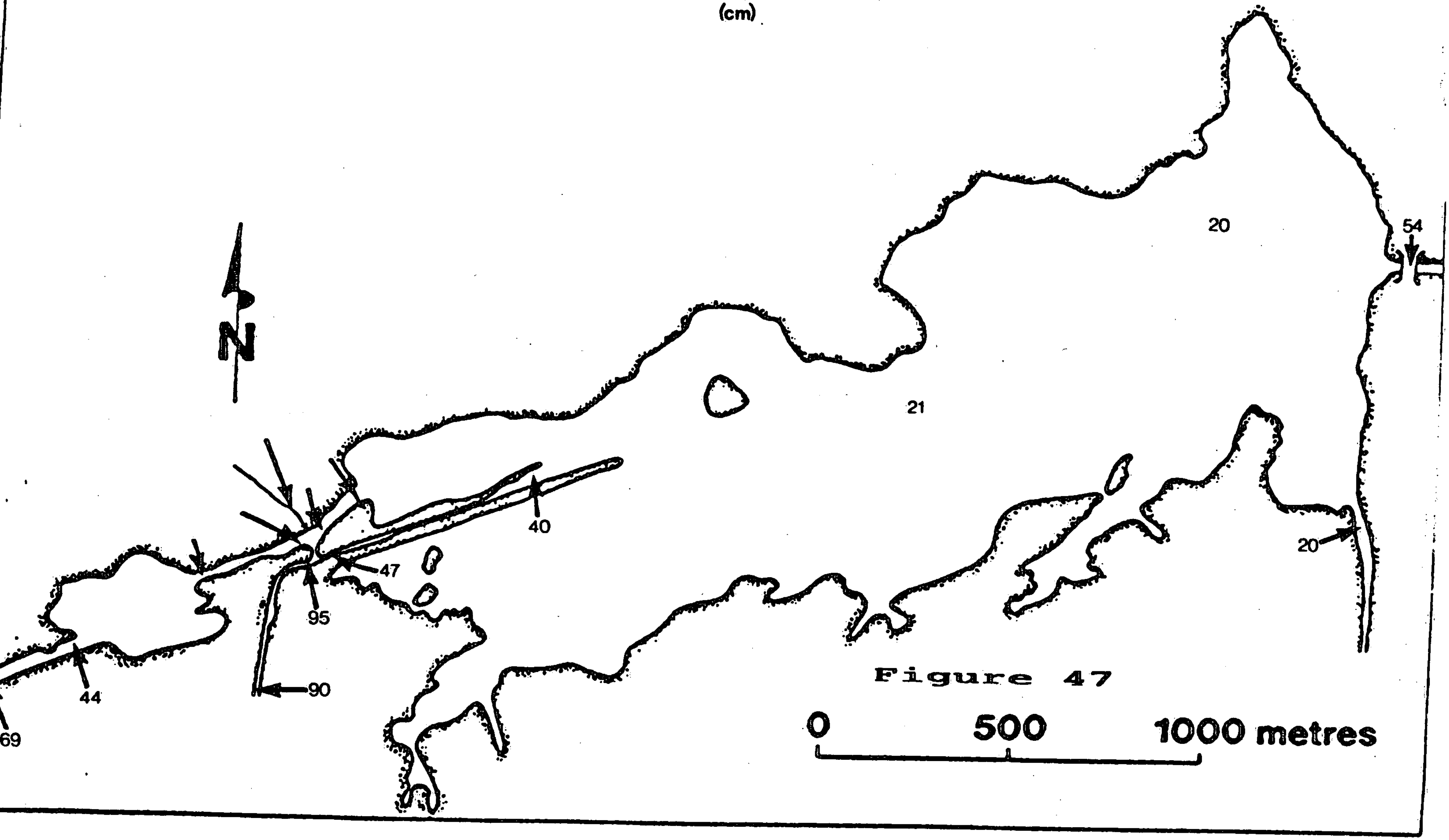


Figure 47

Seston - (April 8 - Sept 8/87)
(mg/l)

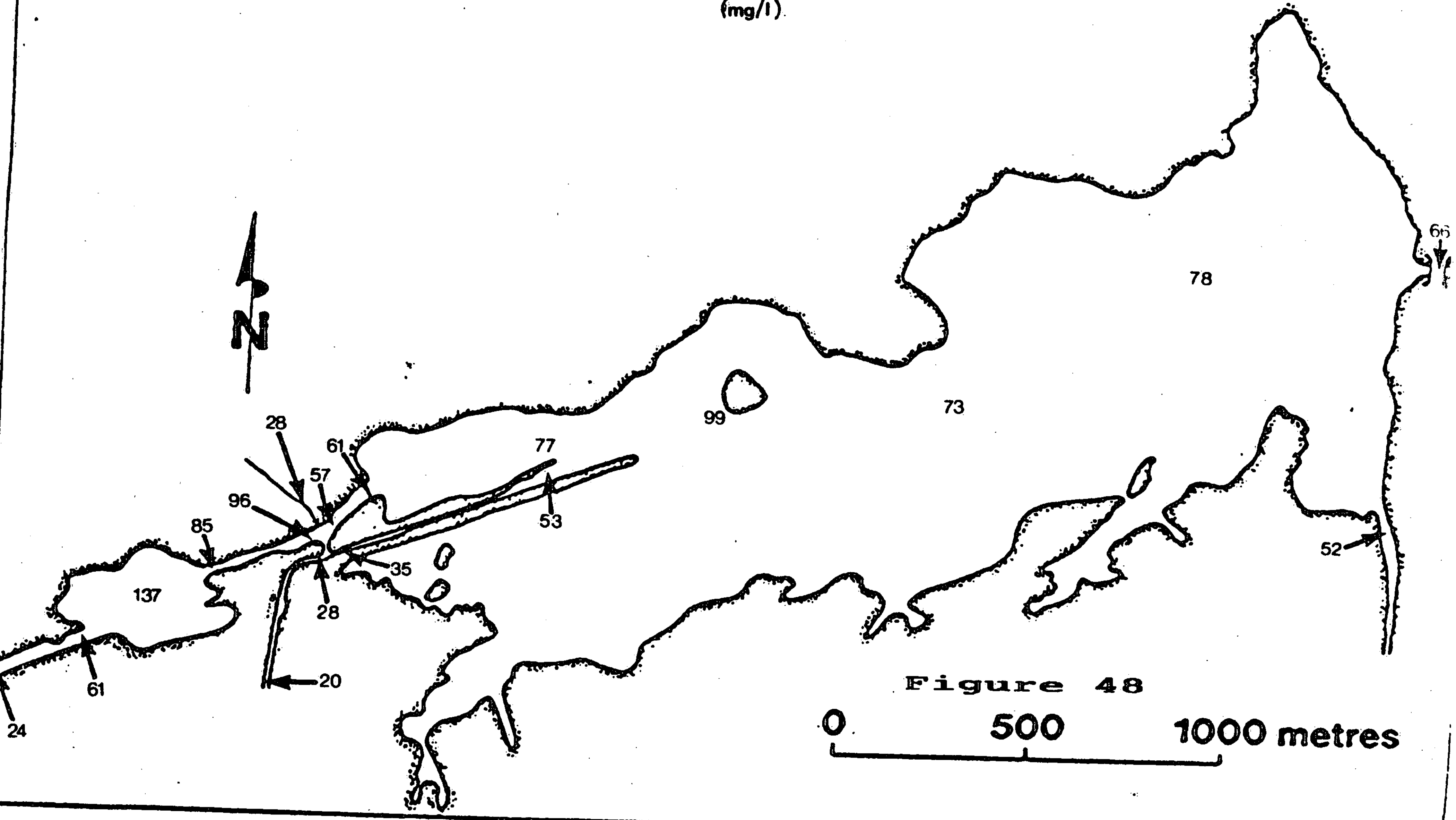


Figure 48

Seston–(Sept 14–Nov 3/87)
(mg/l)

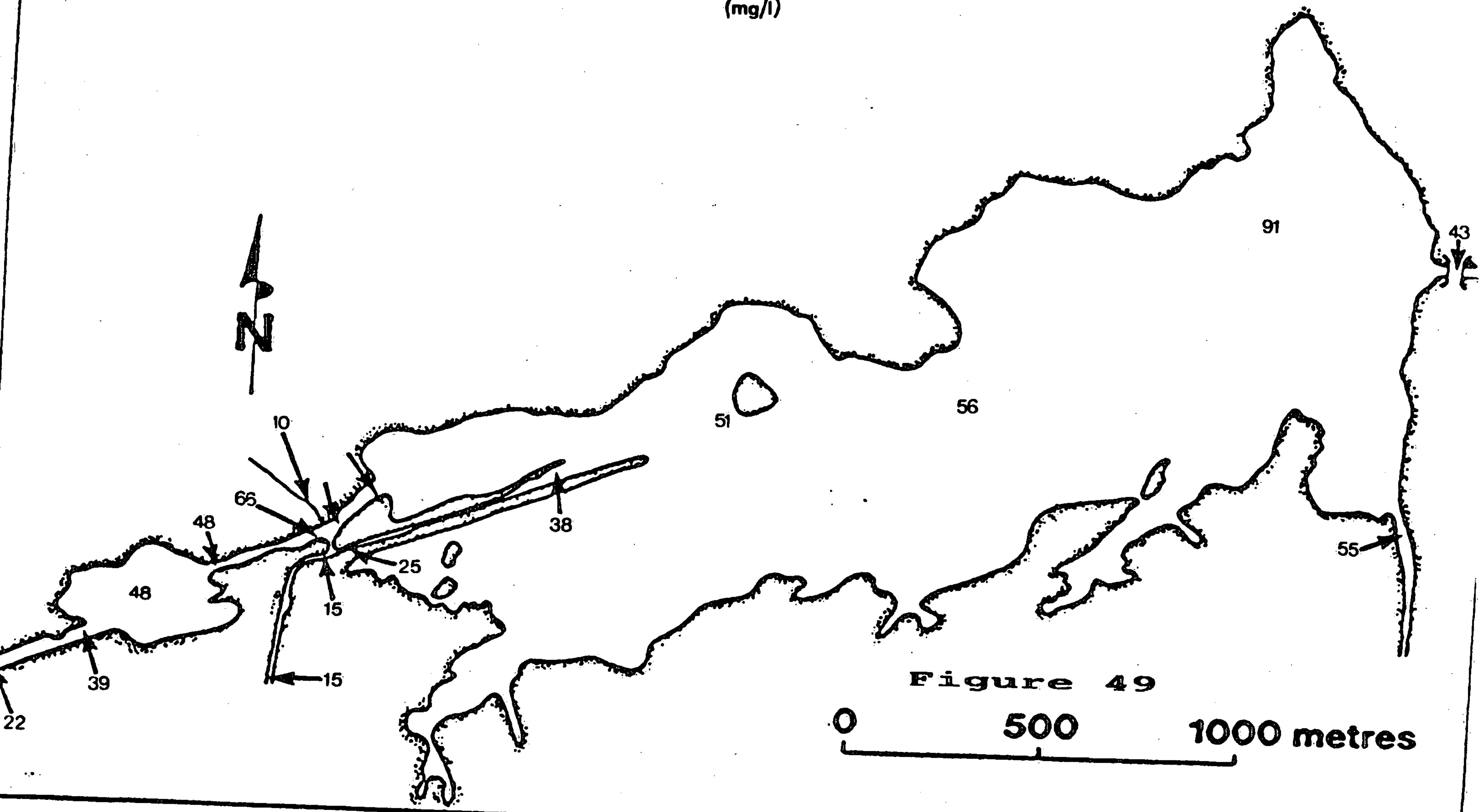


Figure 49

Percent Mineral - (April 8-Sept 8/87)

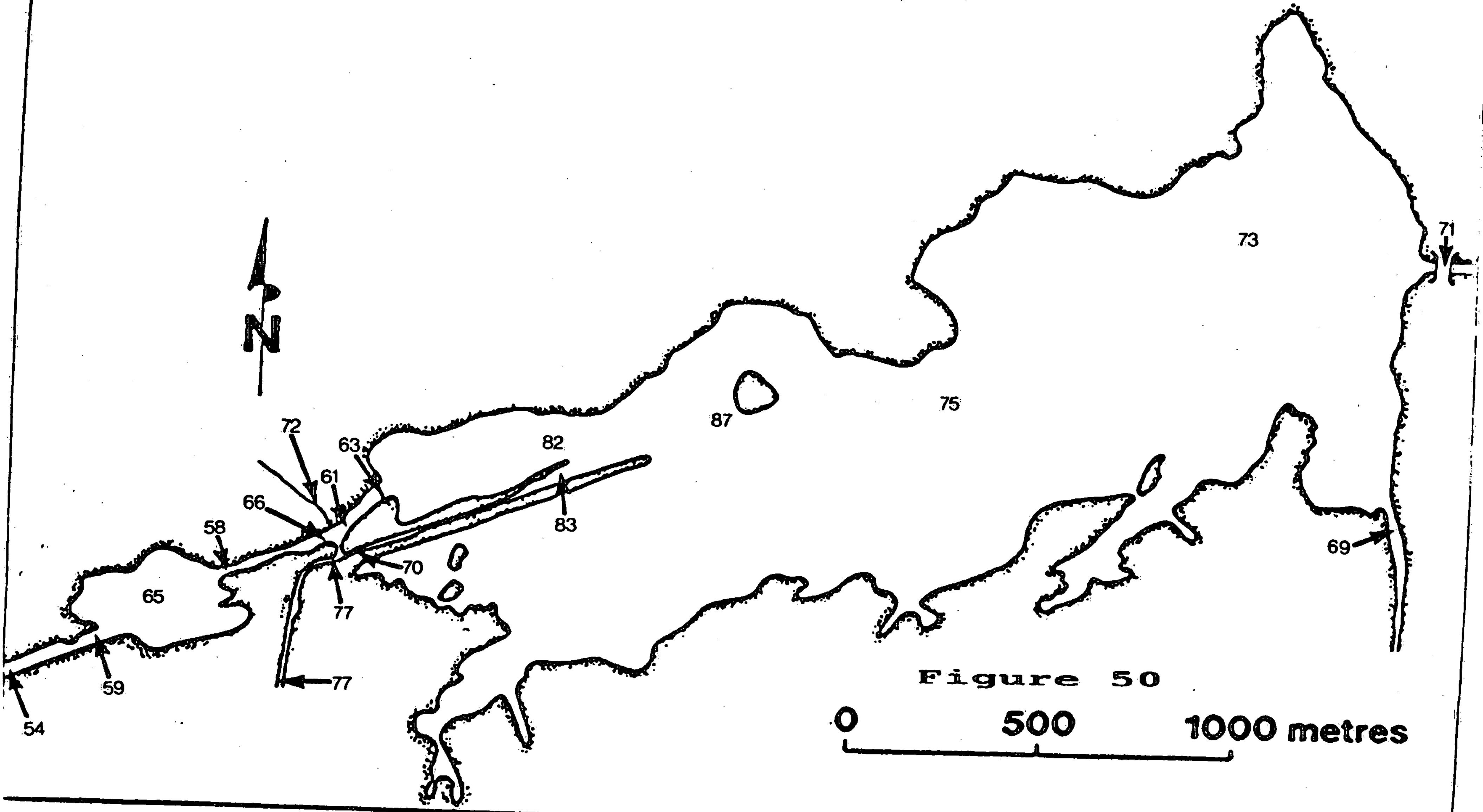


Figure 50

Percent Mineral - (Sept 14 - Nov 3/87)

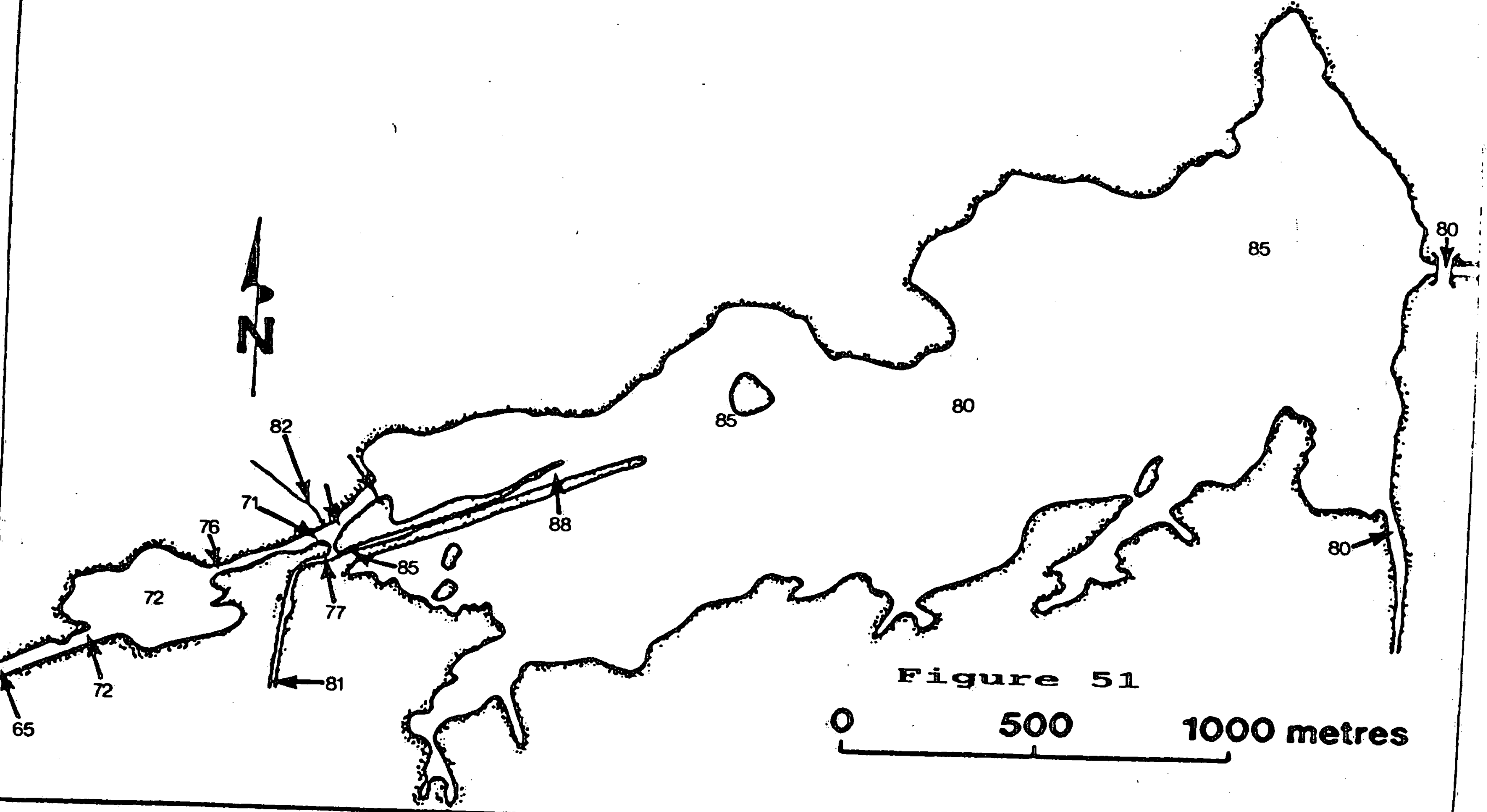


Figure 51

Chlorophyll - (April 8 - Sept 8/87)
(µg/l)

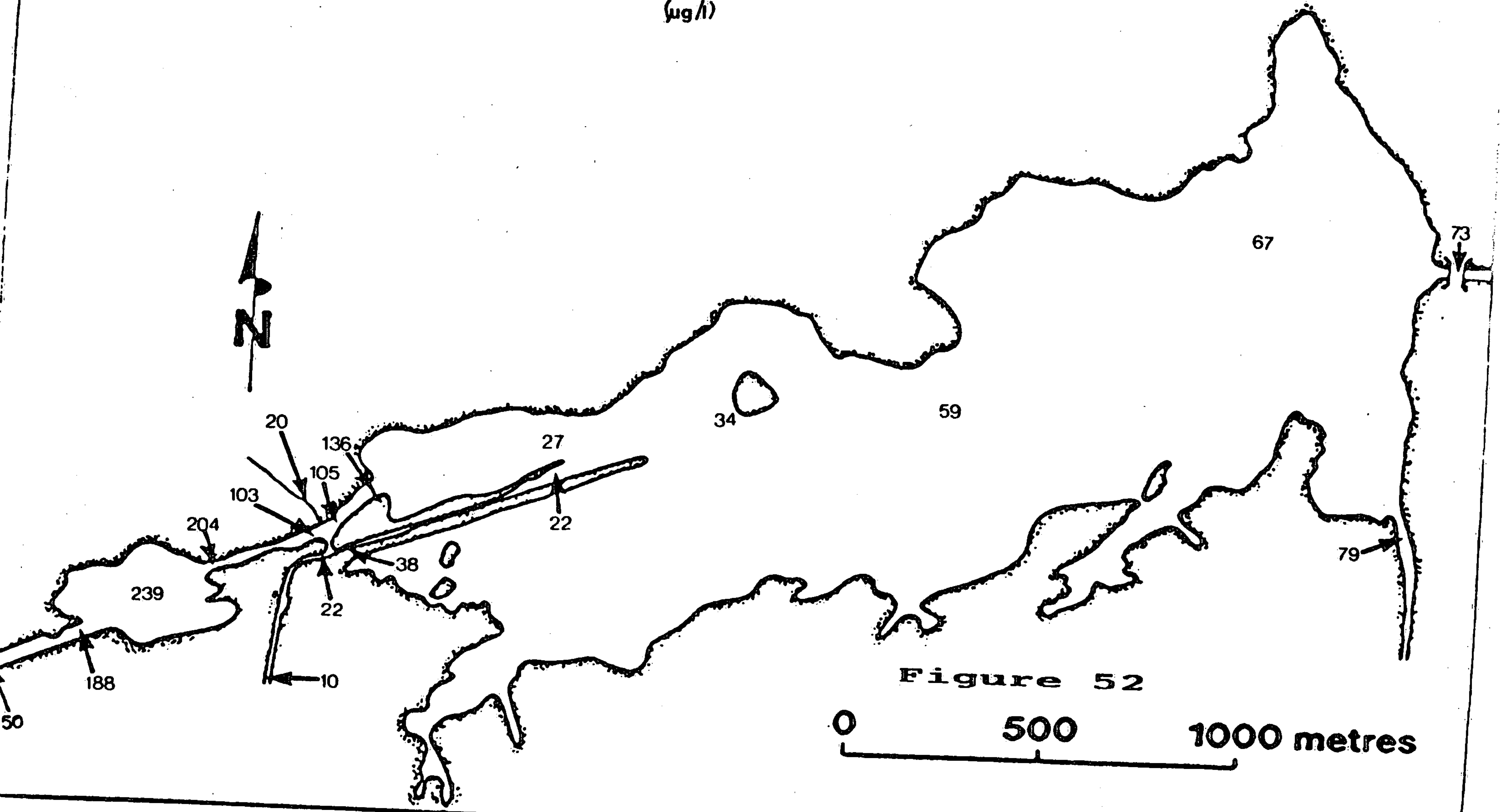


Figure 52

Chlorophyll - (Sept 14-Nov 3/87)
(µg/l)

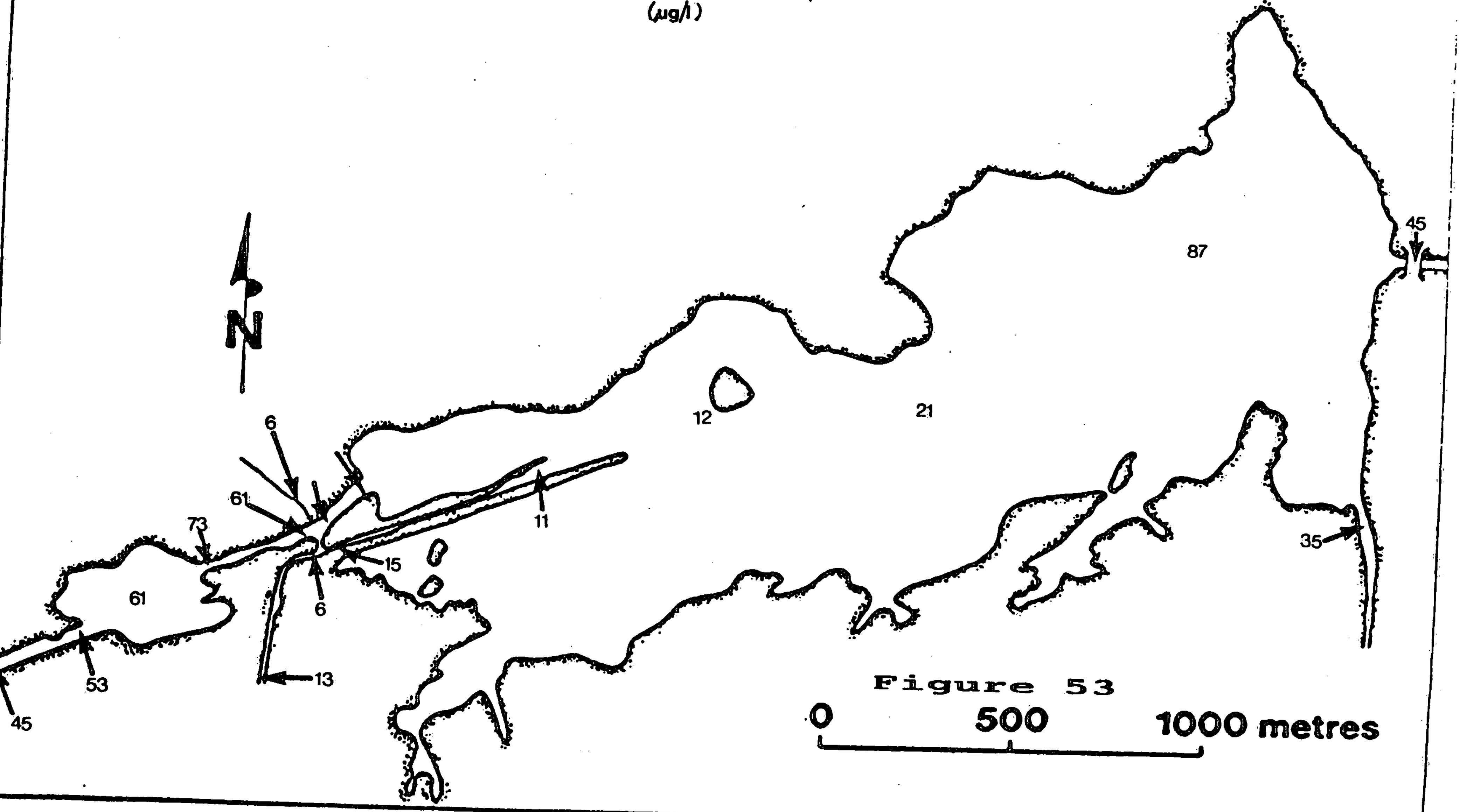


Figure 53

Figure 54

Seasonal Suspended Material

Cootes Paradise – CP 6

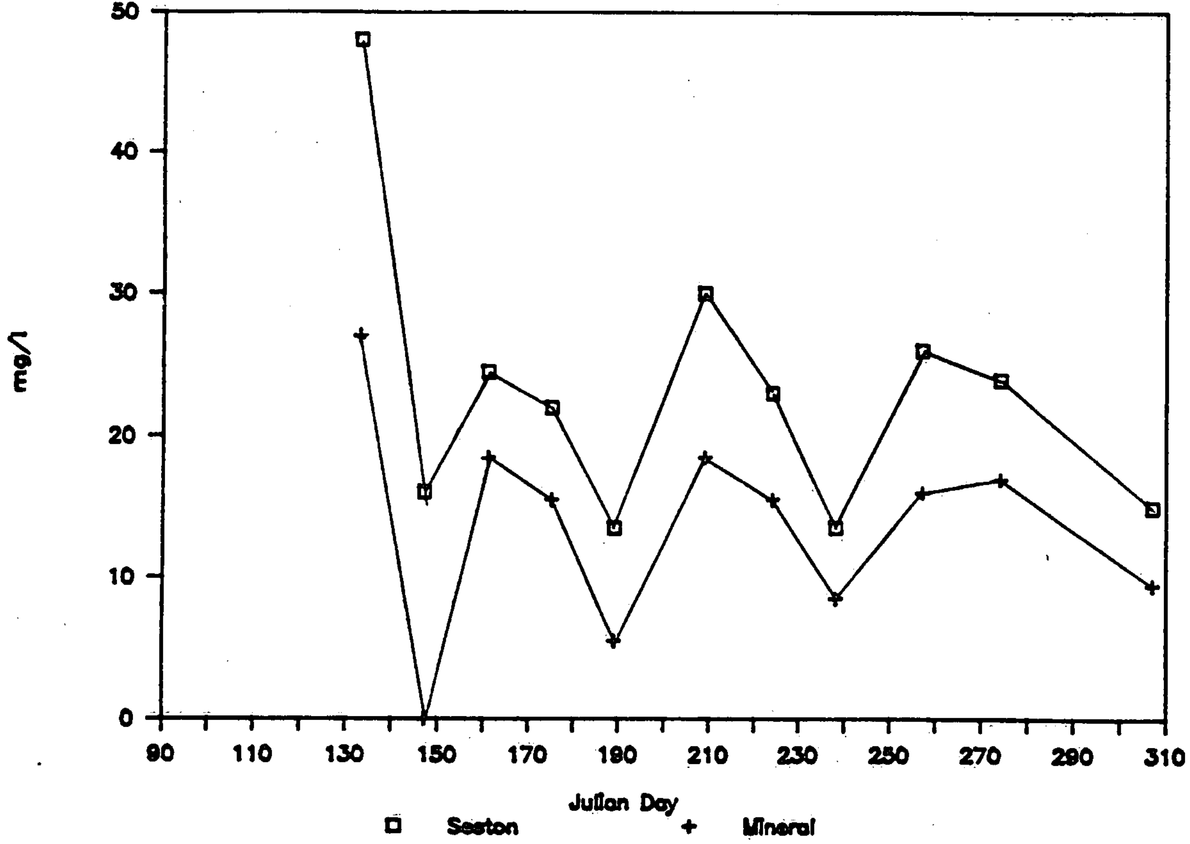


Figure 55

Seasonal Suspended Material

Cootes Paradise – CP 5

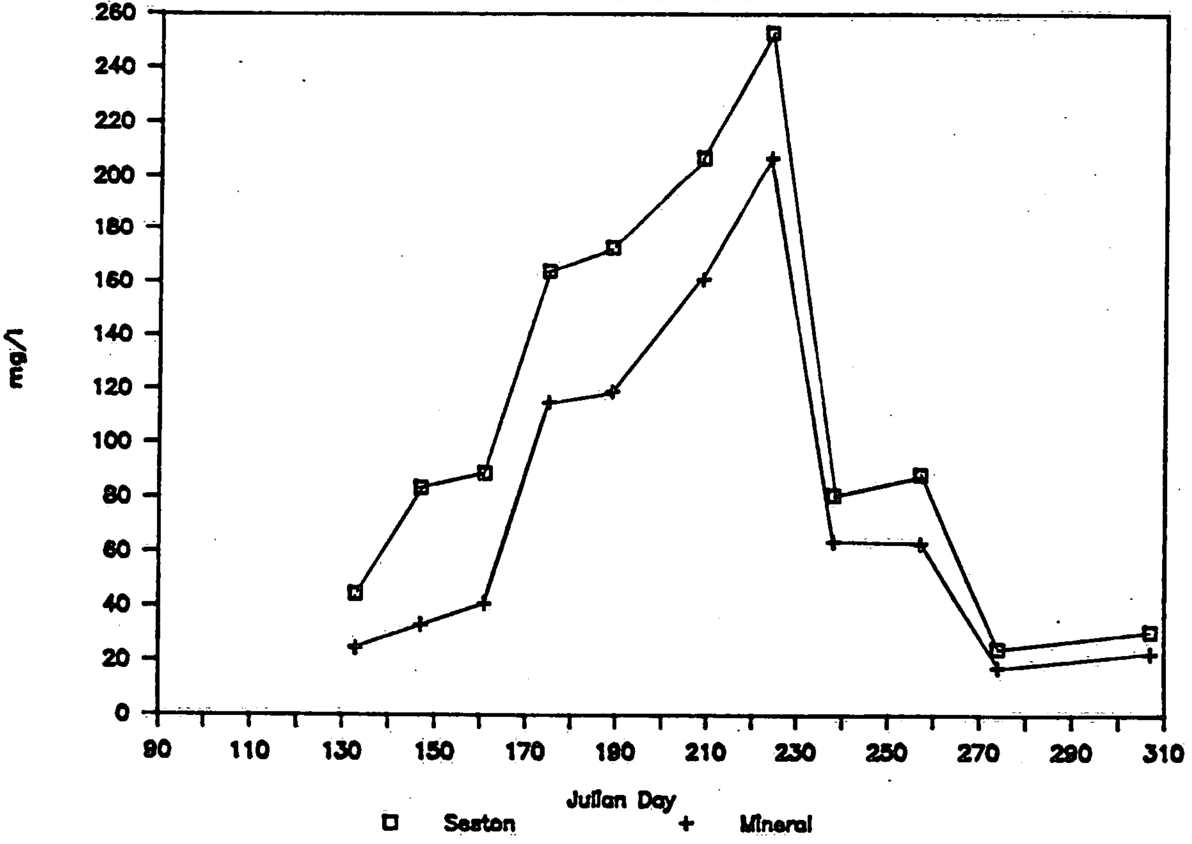


Figure 56

Seasonal Suspended Material

Cootes Paradise - CP 4B

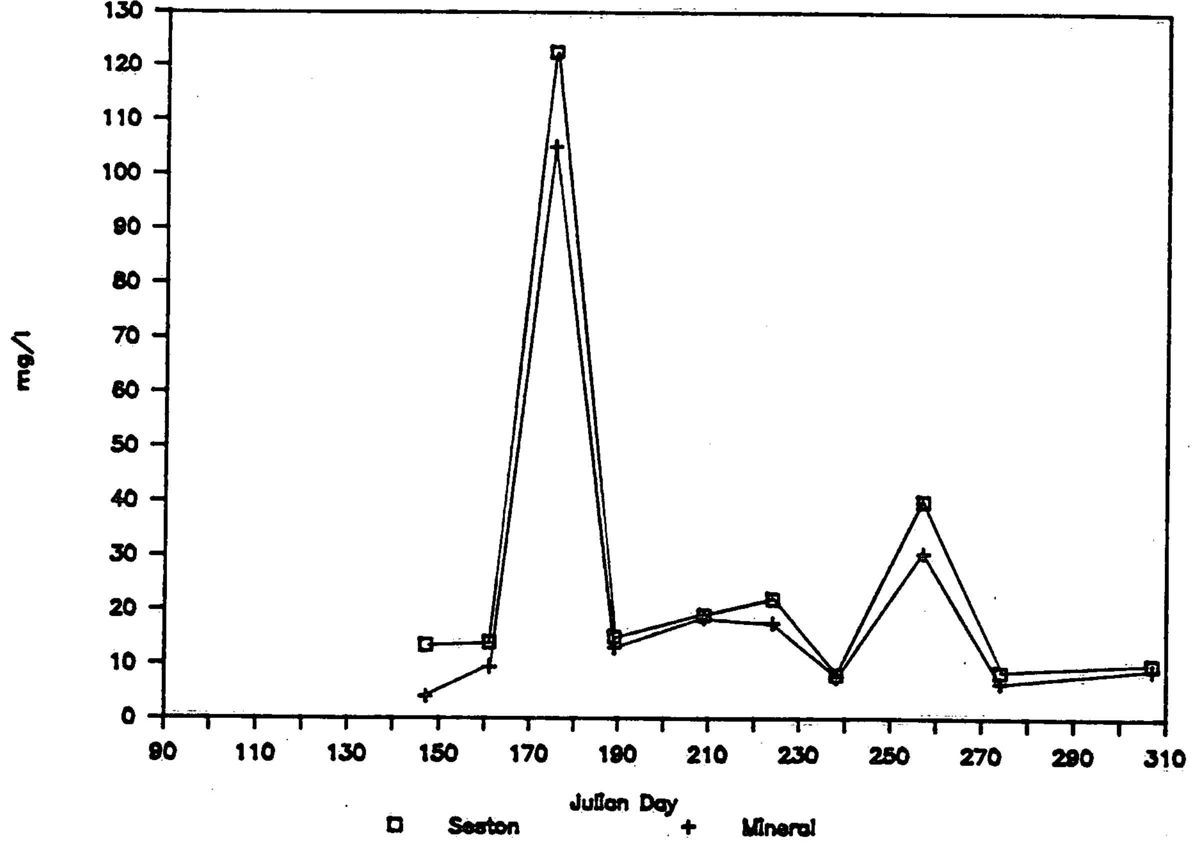


Figure 57

Seasonal Suspended Material

Cootes Paradise - CP 3B

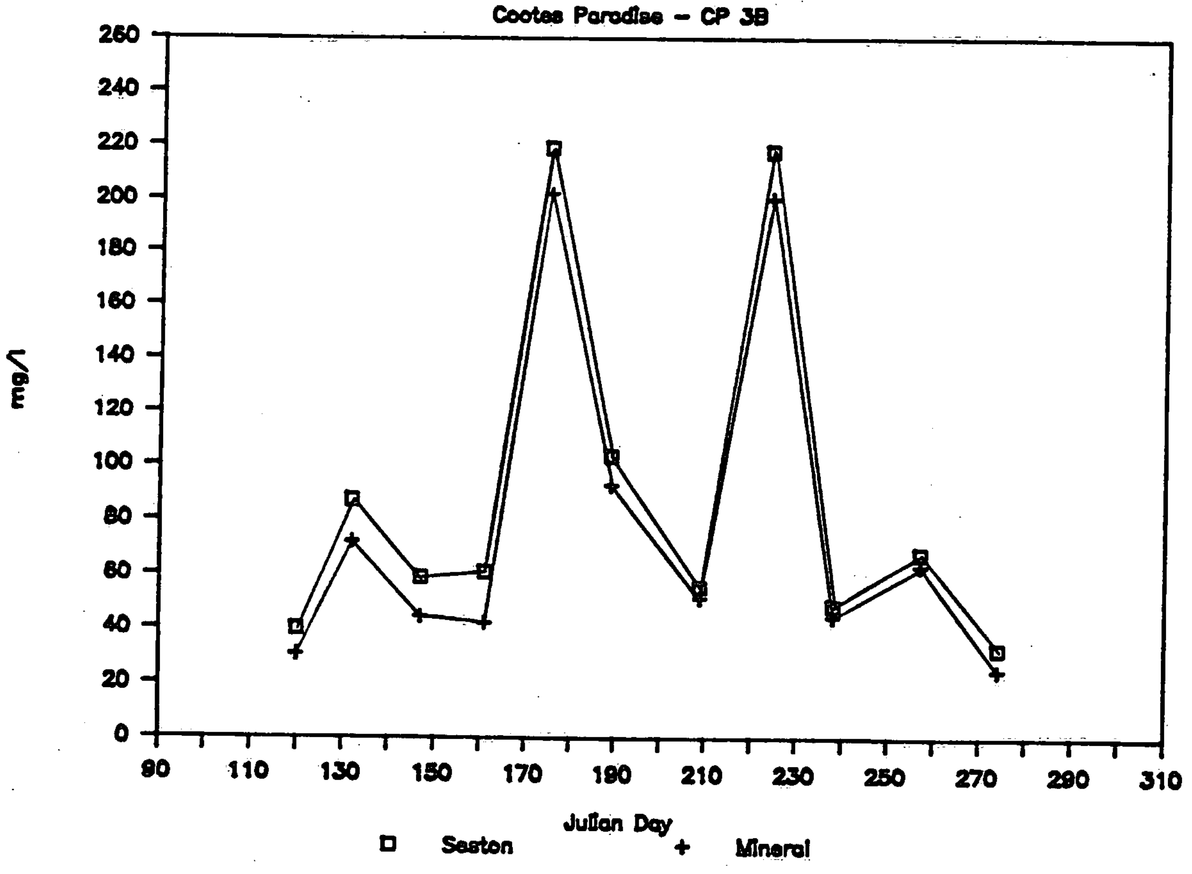


Figure 58

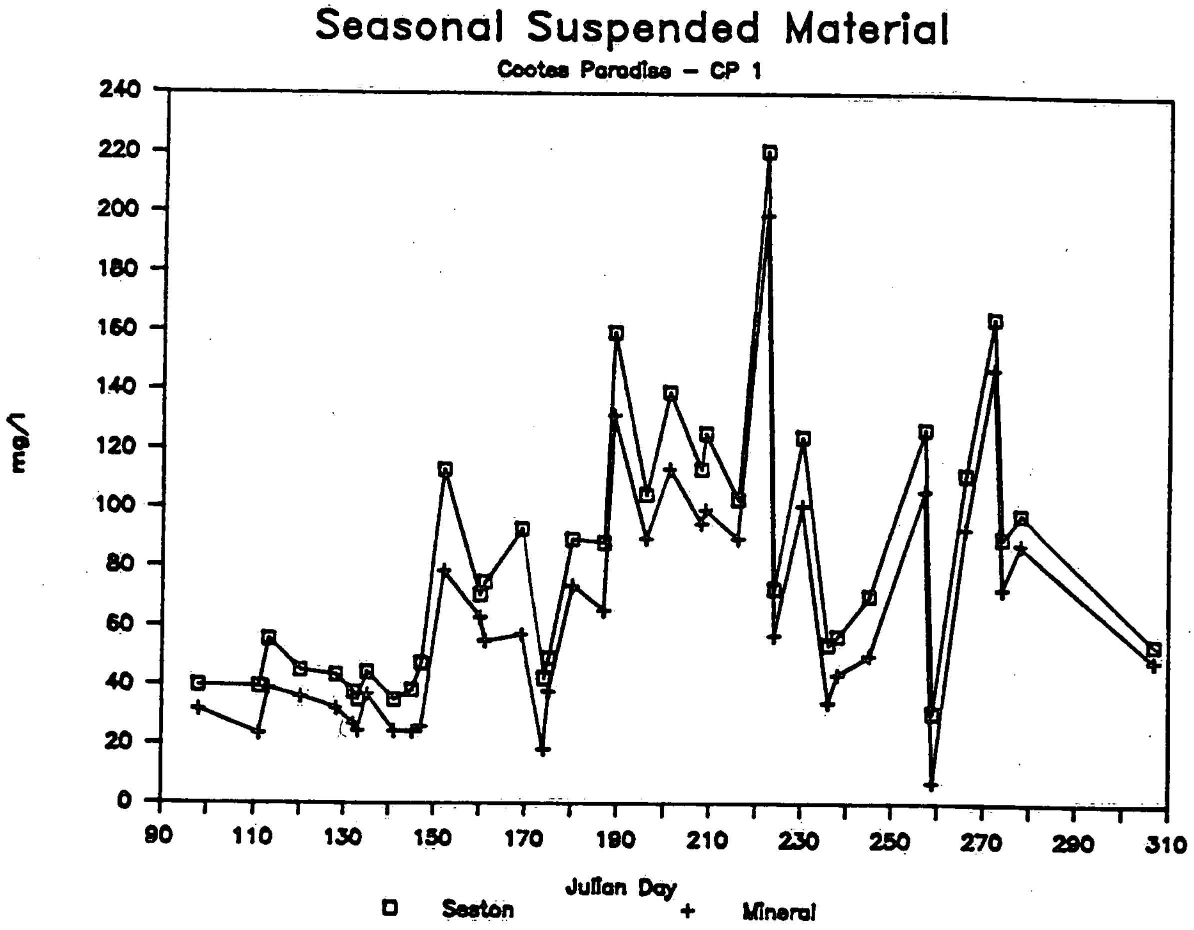
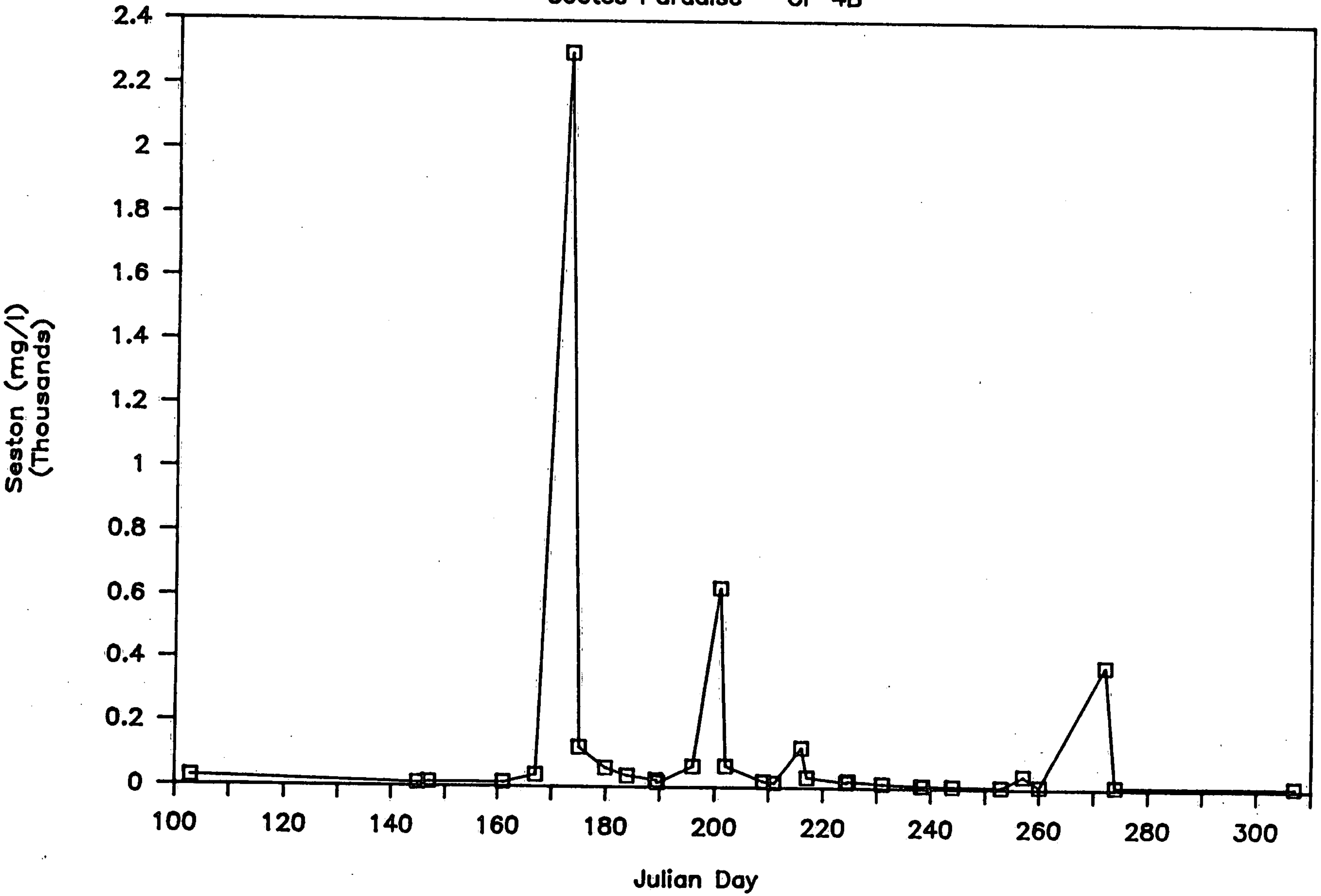

Seasonal Suspended Material
Cootes Paradise - CP 1
mg/l
240
220
200
180
160
140
120
100
80
60
40
20
0
90
110
130
150
170
190
210
230
250
270
290
310
Julian Day
□ Seston
+ Mineral

Figure 59



Seasonal Seston

Cootes Paradise – CP 4B

Figure 60

Seasonal Chlor a & Secchi

Cootes Paradise - CP 6

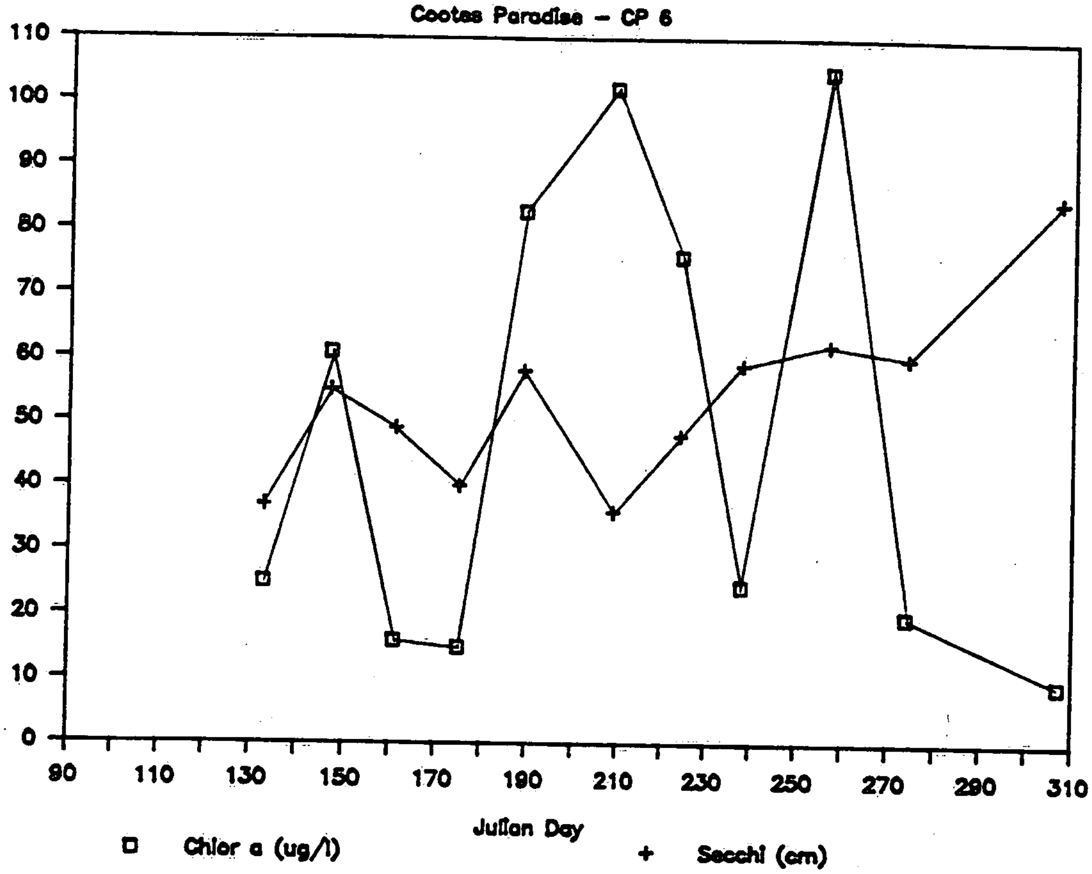


Figure 61

Seasonal Chlor a & Secchi

Cootes Paradise - CP 5

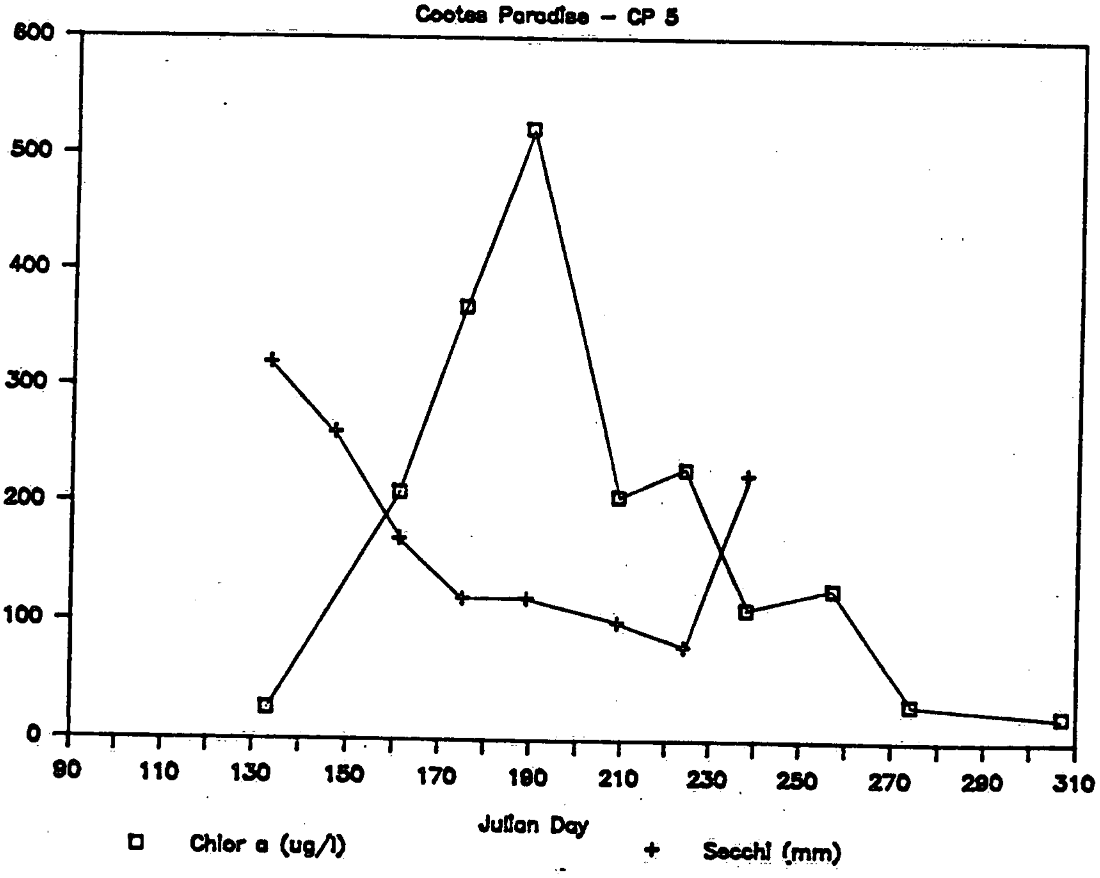
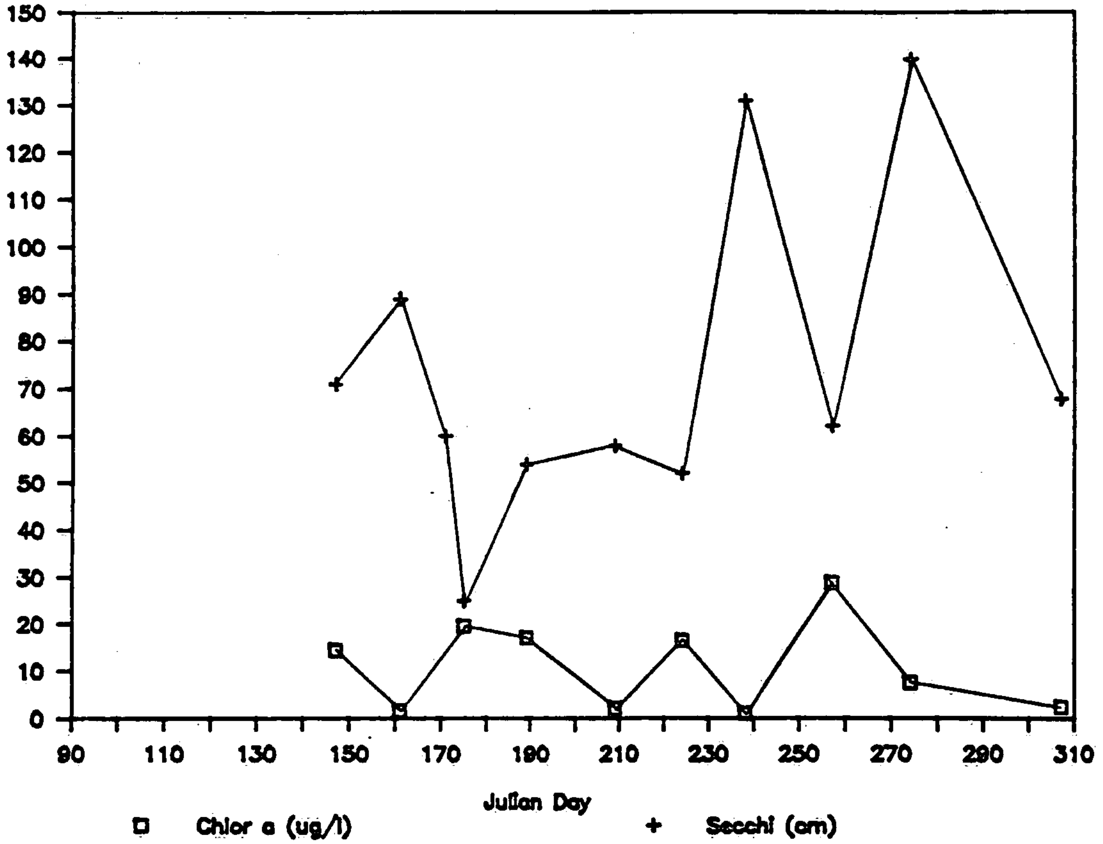


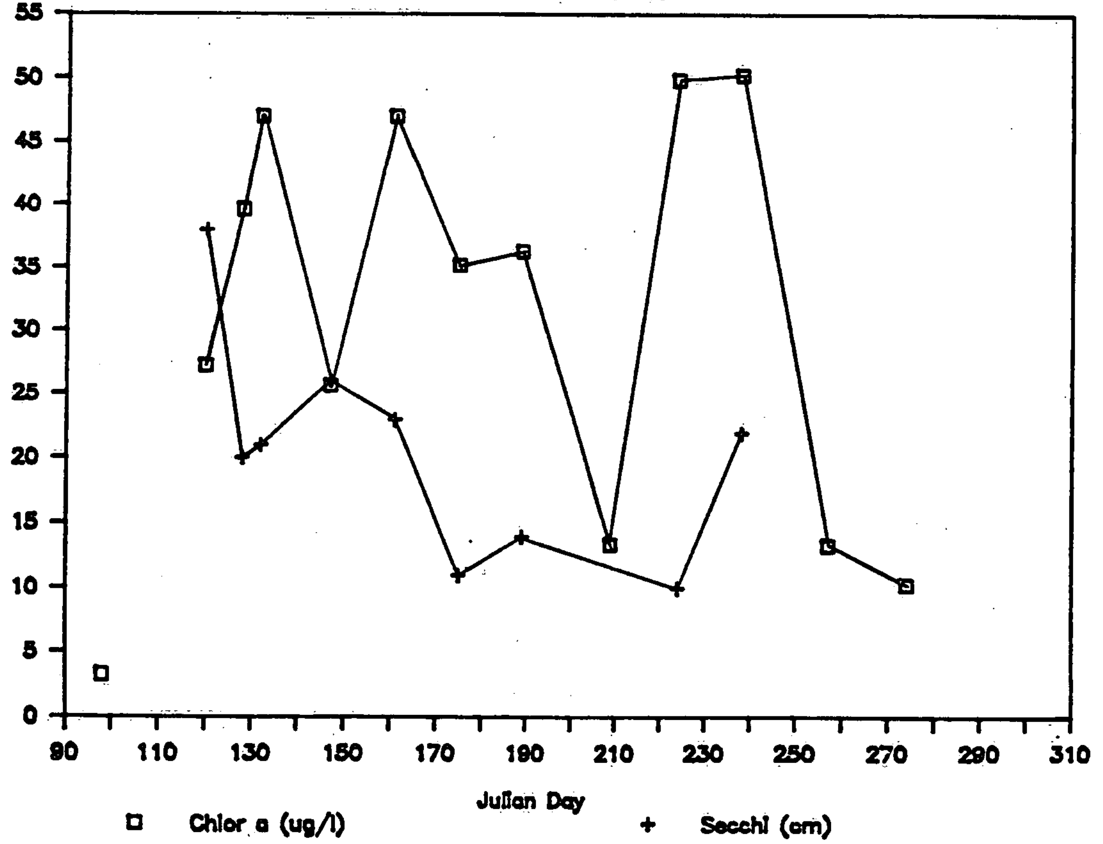
Figure 62



Seasonal Chlor a & Secchi

Cootes Paradise – CP 4B

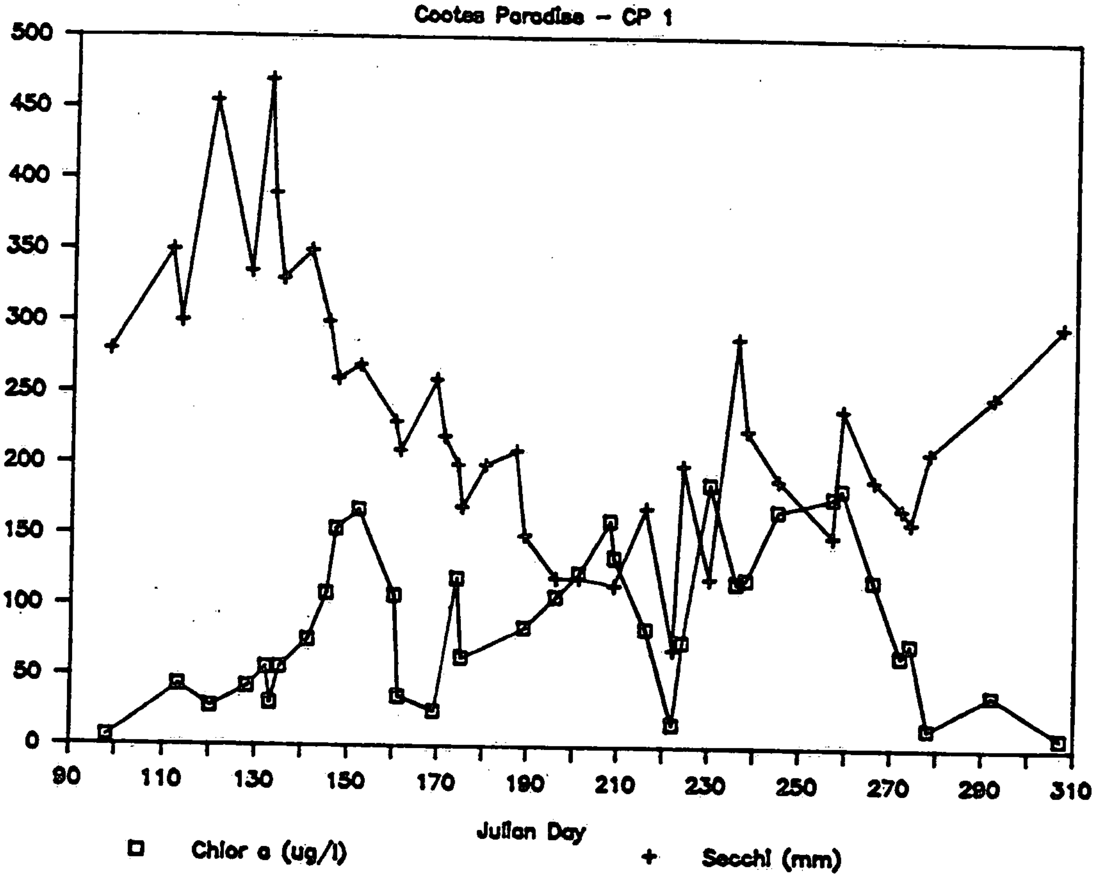
Figure 63



Seasonal Chlor a & Secchi

Cootes Paradise – CP 3B

Figure 64



Seasonal Chlor a & Secchi

Cootes Paradise – CP 1

Figure 65

Chlorophyll a vs Extinction Coefficient

Cootes Paradise 1987

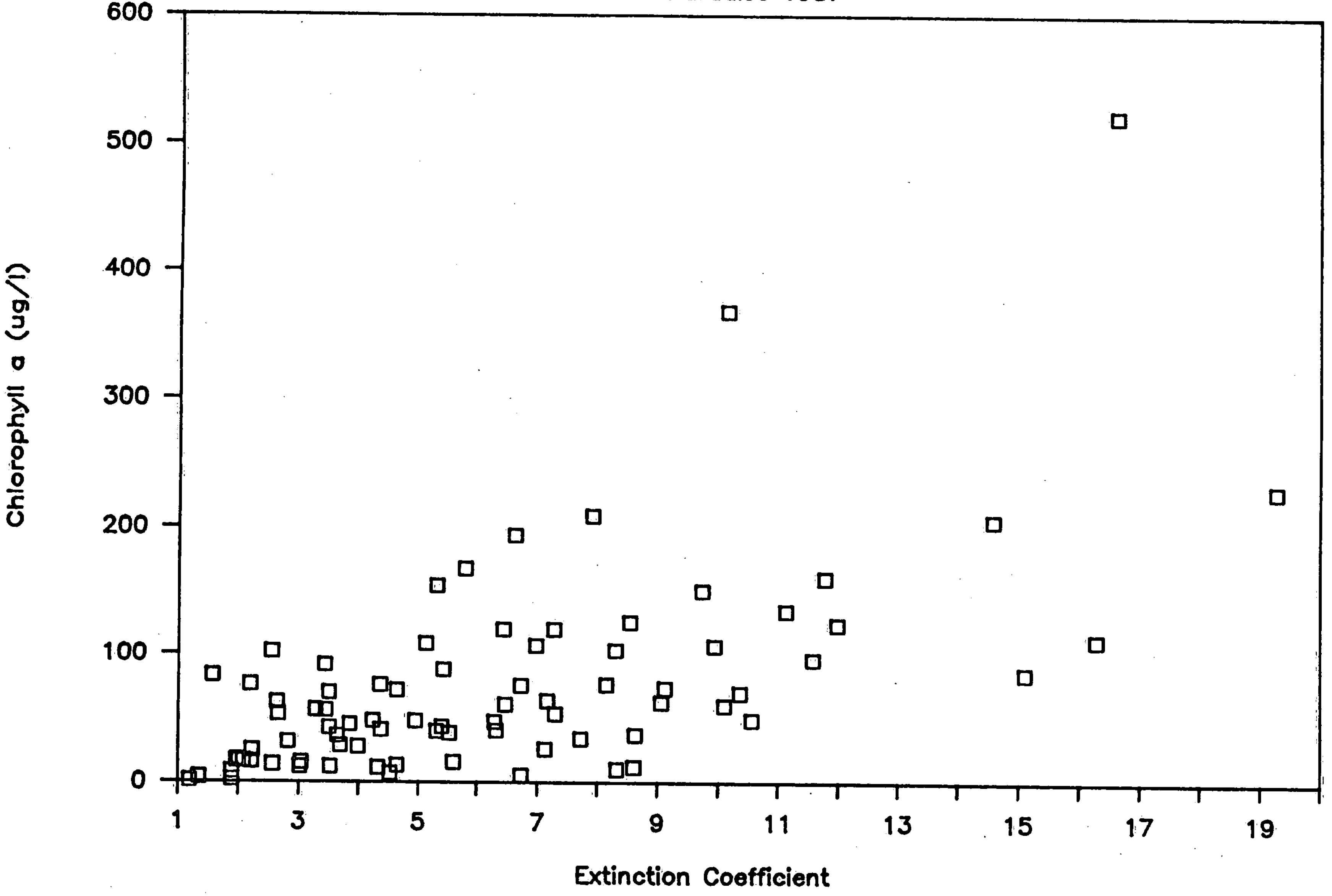


Figure 66

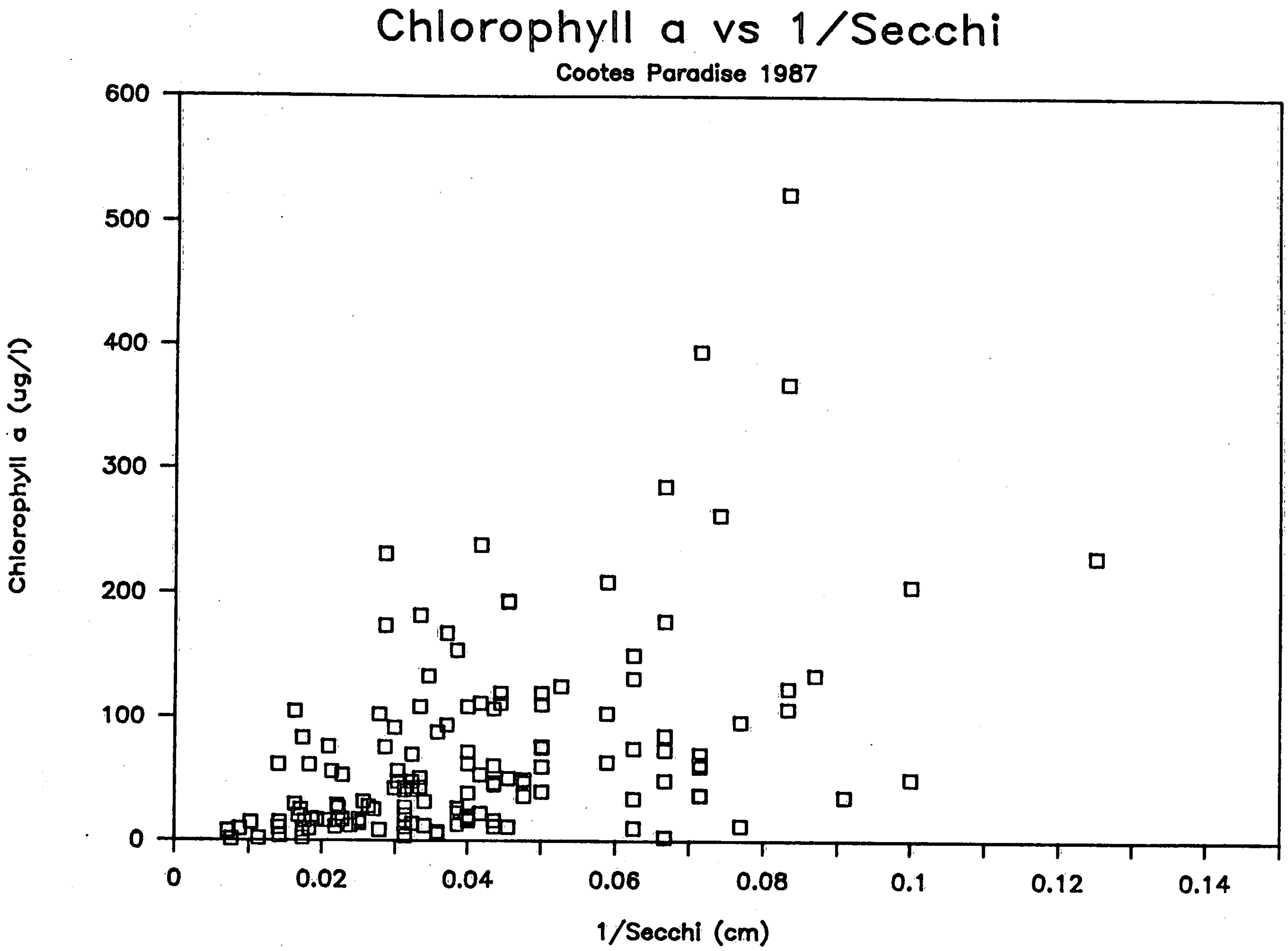

Chlorophyll a vs 1/Secchi
Cootes Paradise 1987
Chlorophyll a (ug/l)
600
500
400
300
200
100
0
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
1/Secchi (cm)

Figure 67

Extinction Coefficient vs Secchi

Cootes Paradise 1987

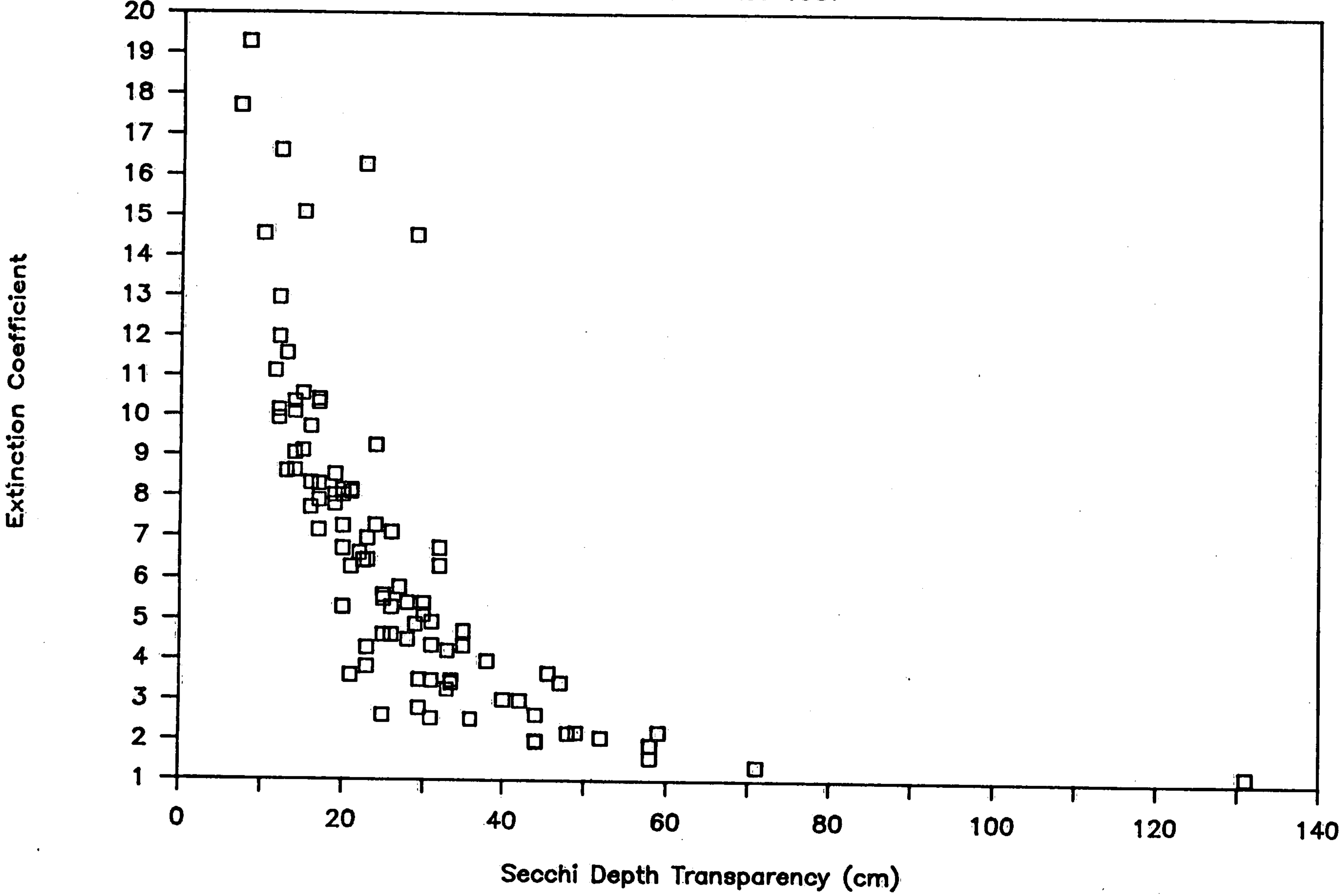
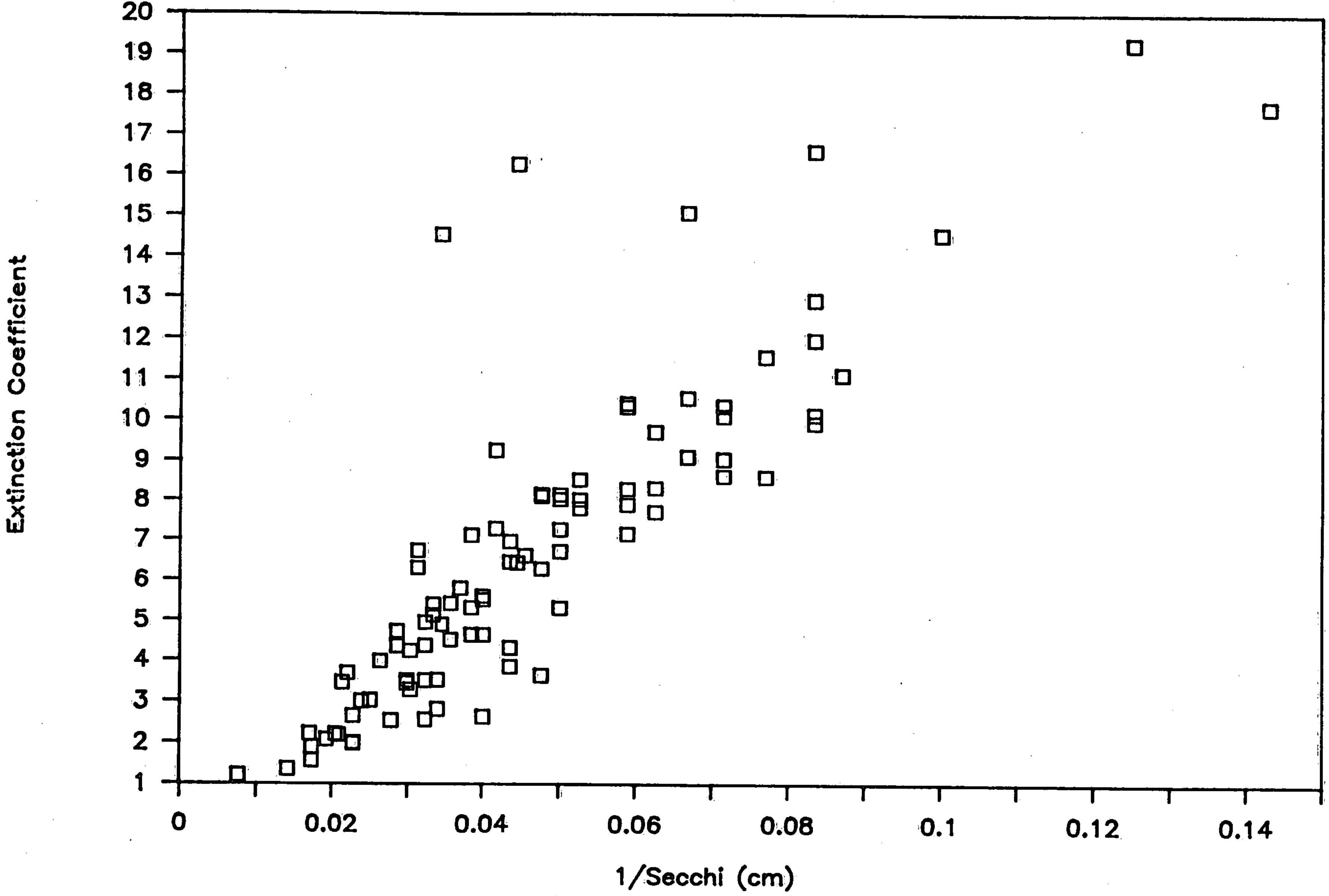


Figure 68



Extinction Coefficient vs 1/Secchi

Cootes Paradise 1987

Figure 69

Seston vs. 1/Secchi

Cootes Paradise 1987

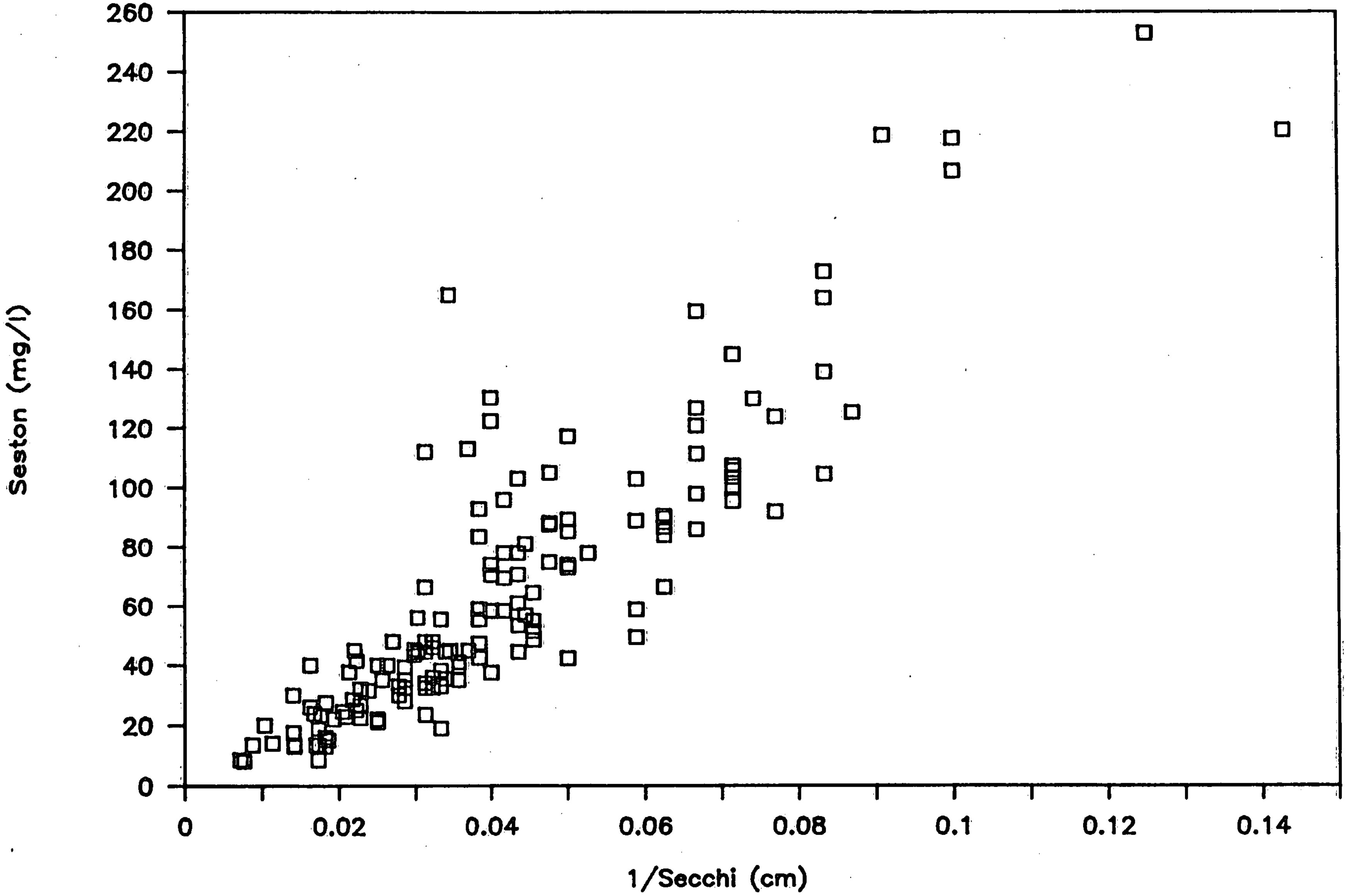
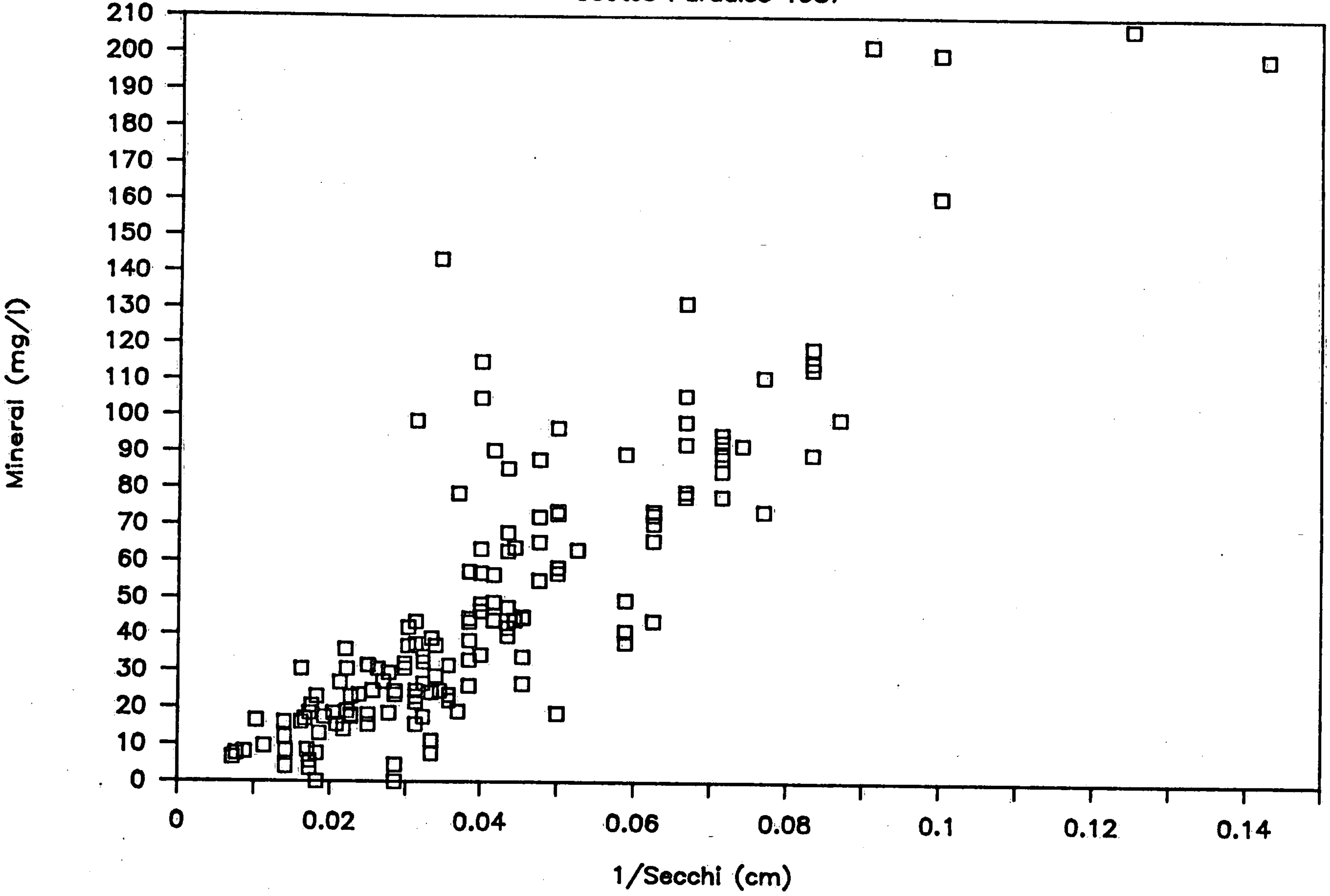


Figure 70

Mineral vs 1/Secchi Depth Transparency

Cootes Paradise 1987



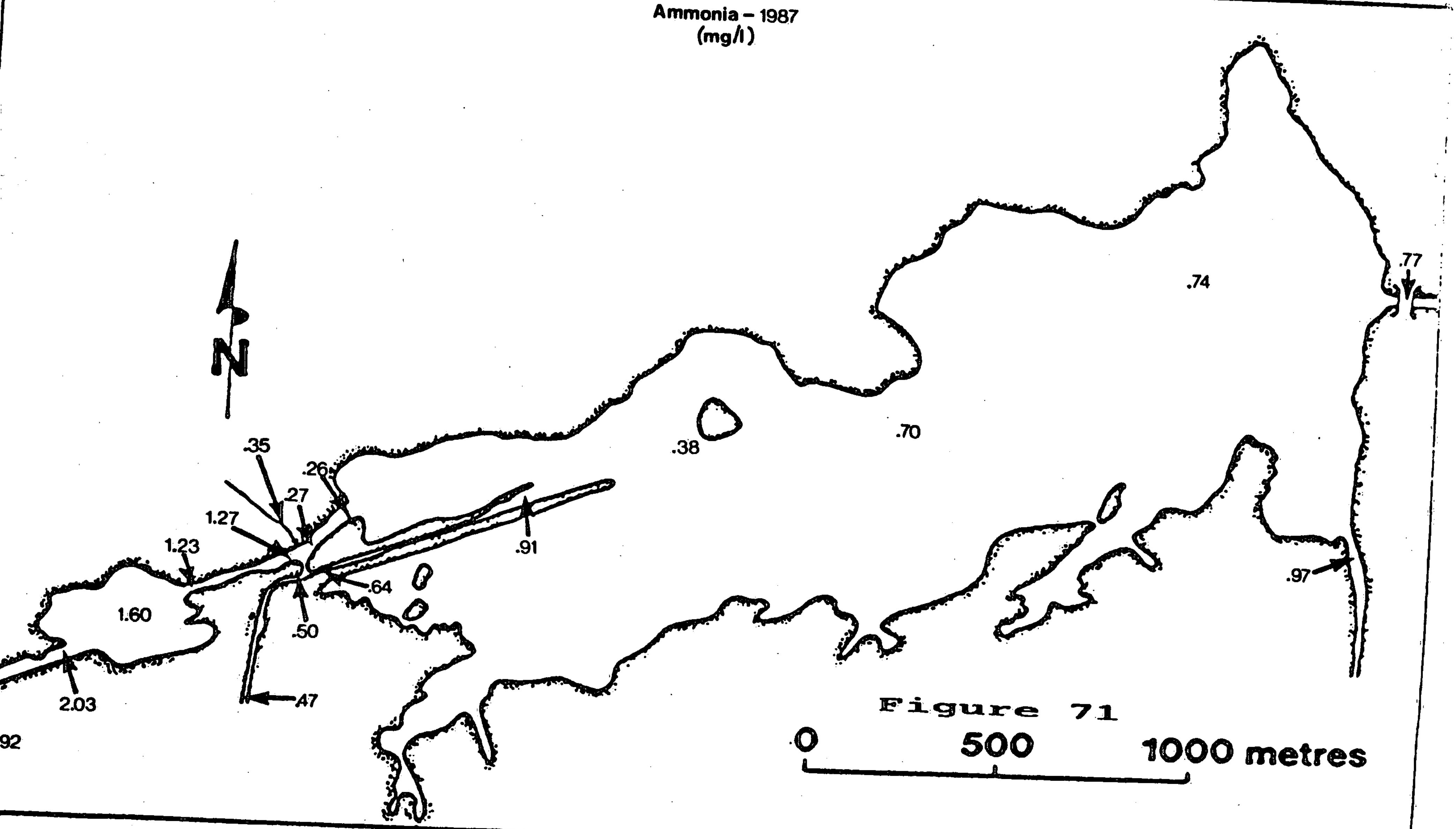

Ammonia - 1987
(mg/l)
N
.77
.74
.70
.38
.97
.91
.35
.26
.27
1.27
1.23
.64
.50
1.60
2.03
.47
0
500
1000 metres

Figure 71

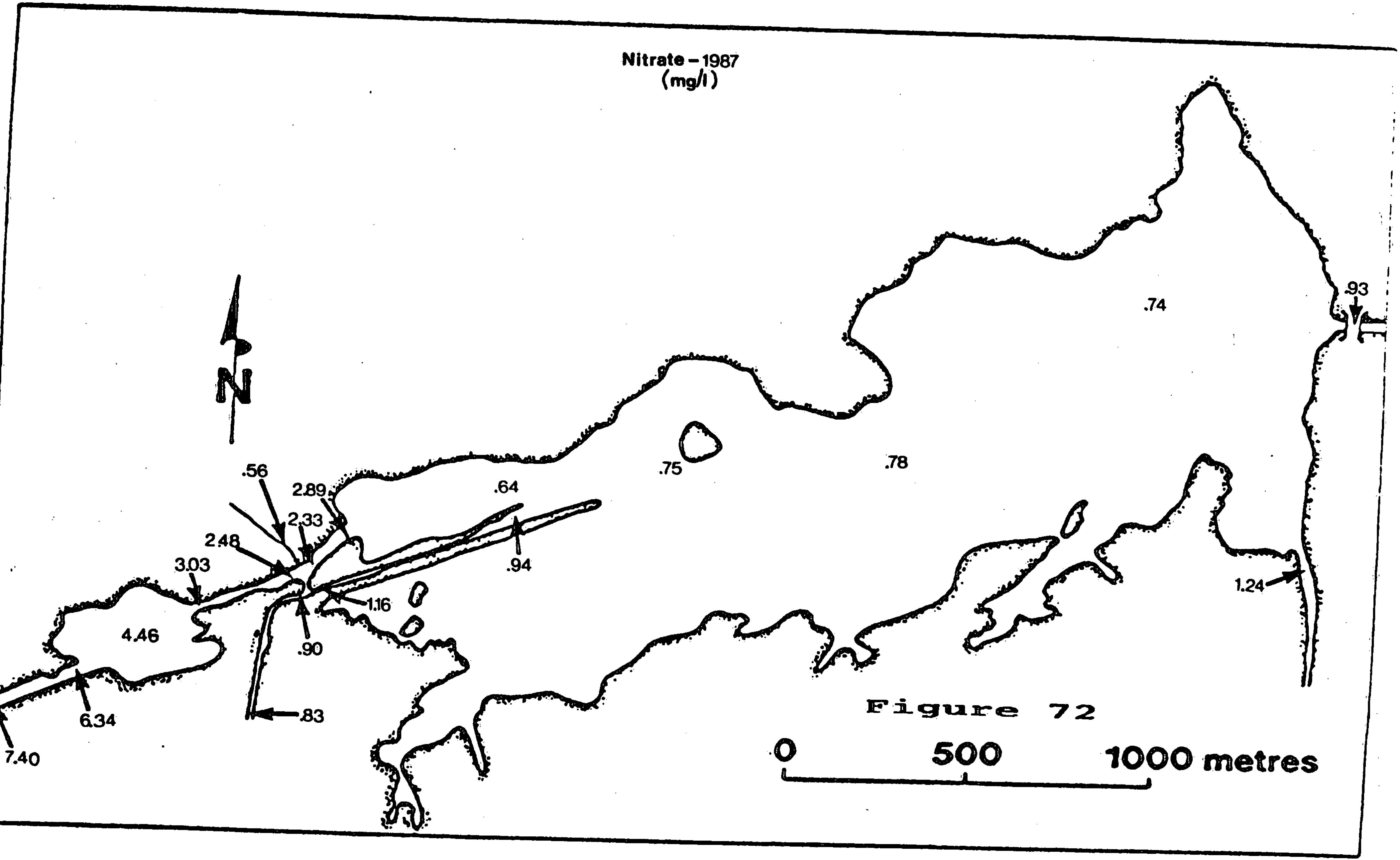

Nitrate - 1987
(mg/l)
N
.93
.74
1.24
.78
.75
.64
.94
.56
2.89
2.33
2.48
3.03
1.16
.90
4.46
.83
6.34
7.40
0
500
1000 metres

Figure 72

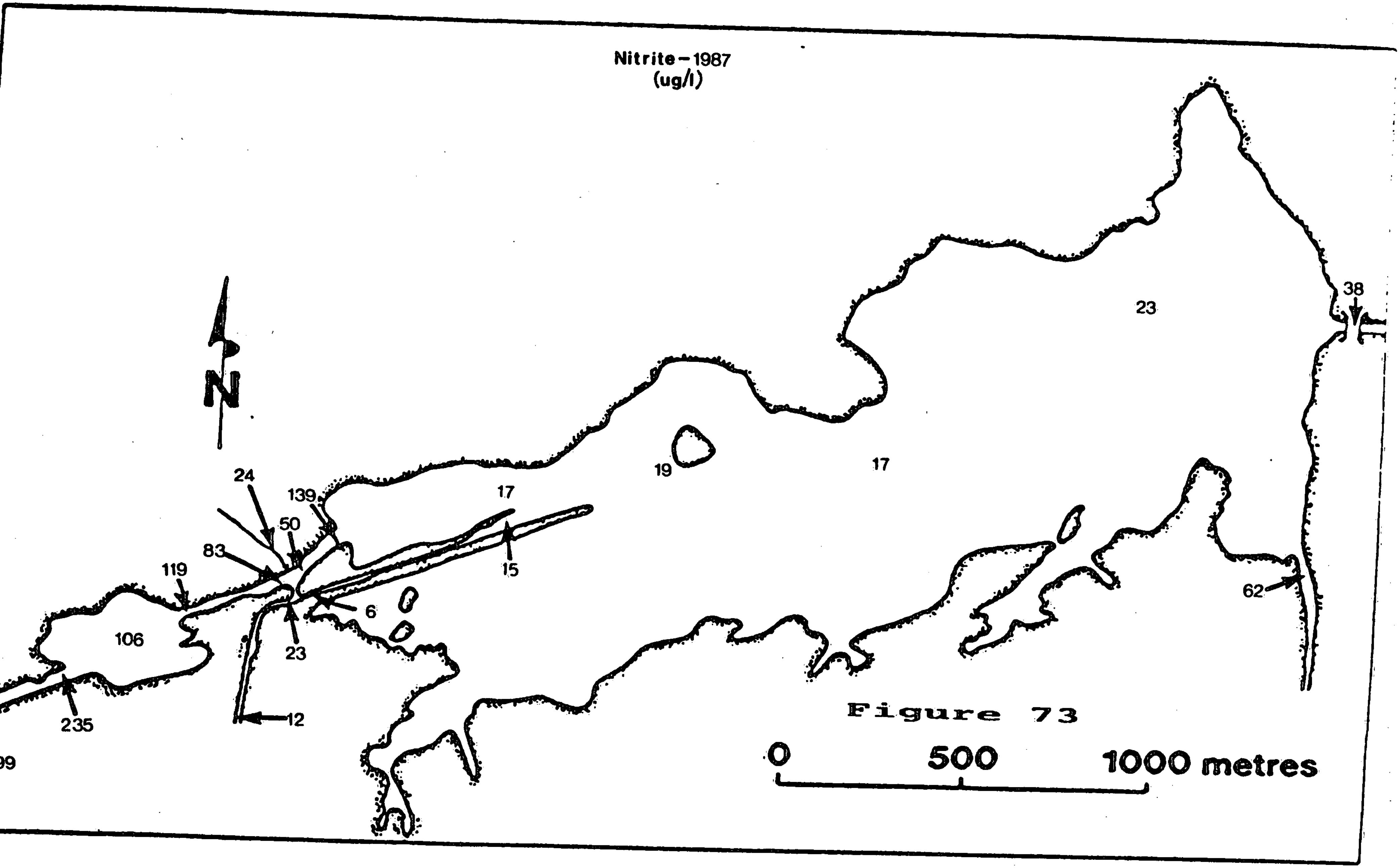

Nitrite-1987
(ug/l)
N
23
38
17
19
62
17
15
139
24
50
83
119
6
23
106
12
235
99
0
500
1000 metres

Figure 73

Total Kjeldahl Nitrogen - 1987
(mg/l)

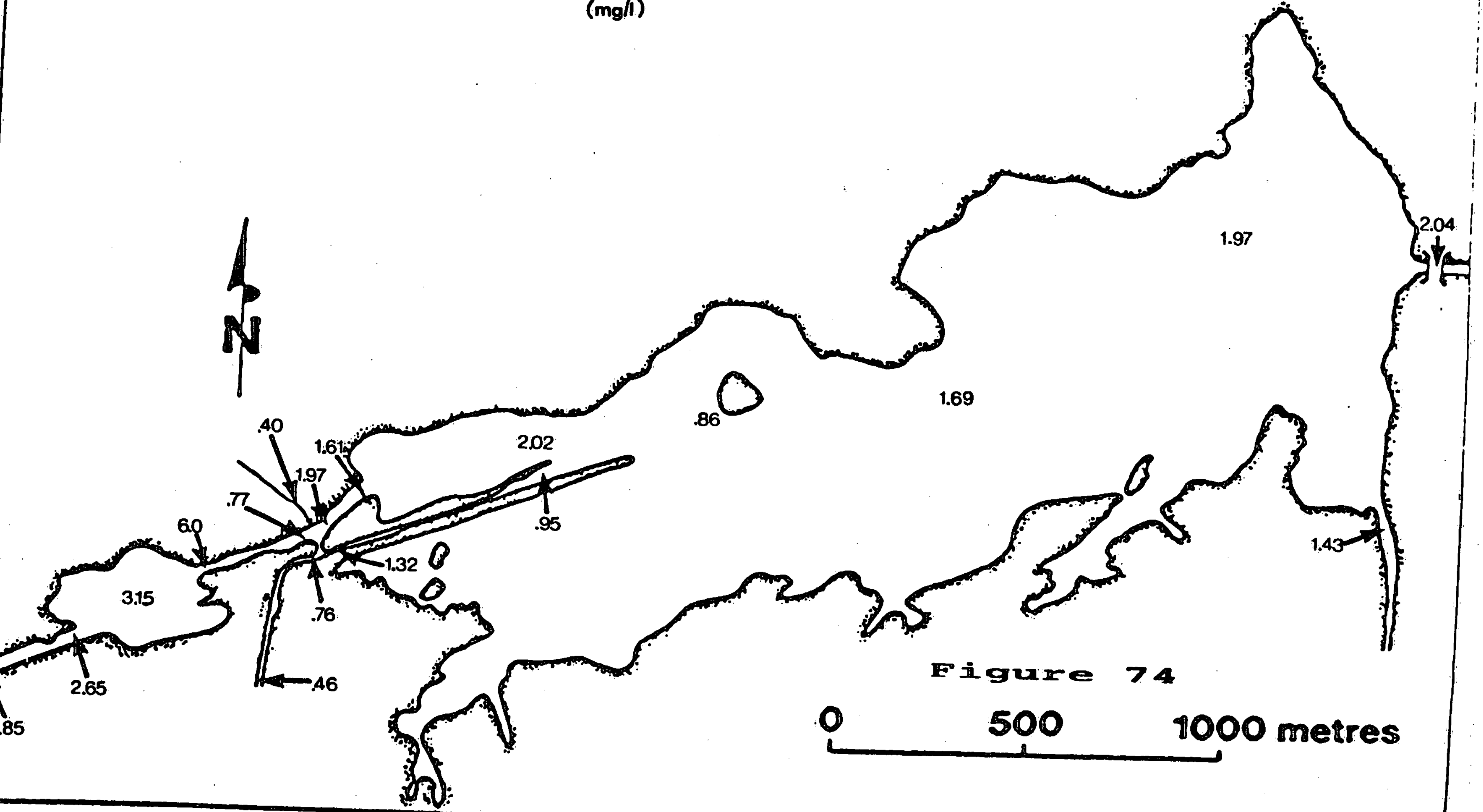


Figure 74

Soluble Phosphorus - 1987
(µg/l)

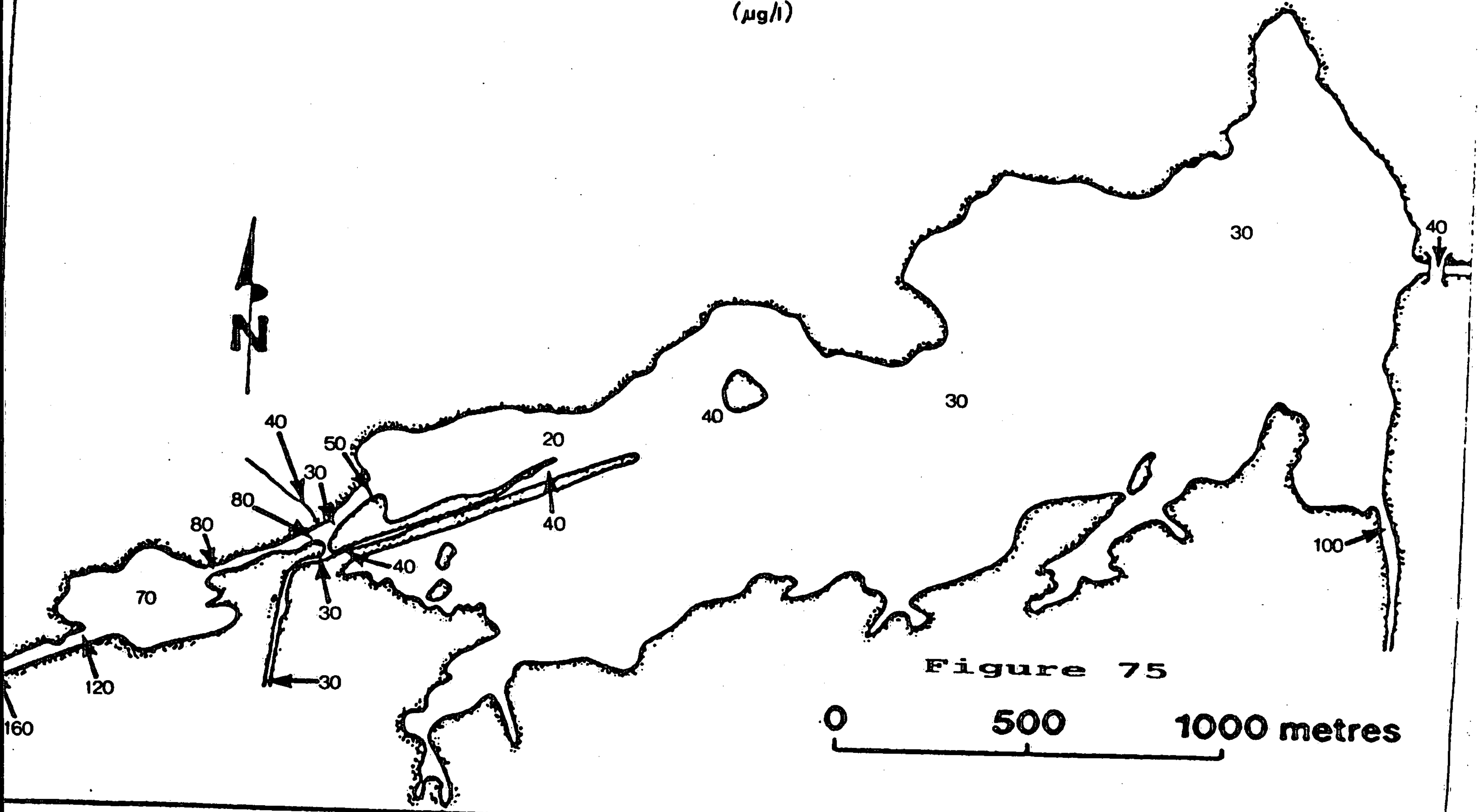


Figure 75

Total Phosphorus - 1987
(mg/l)

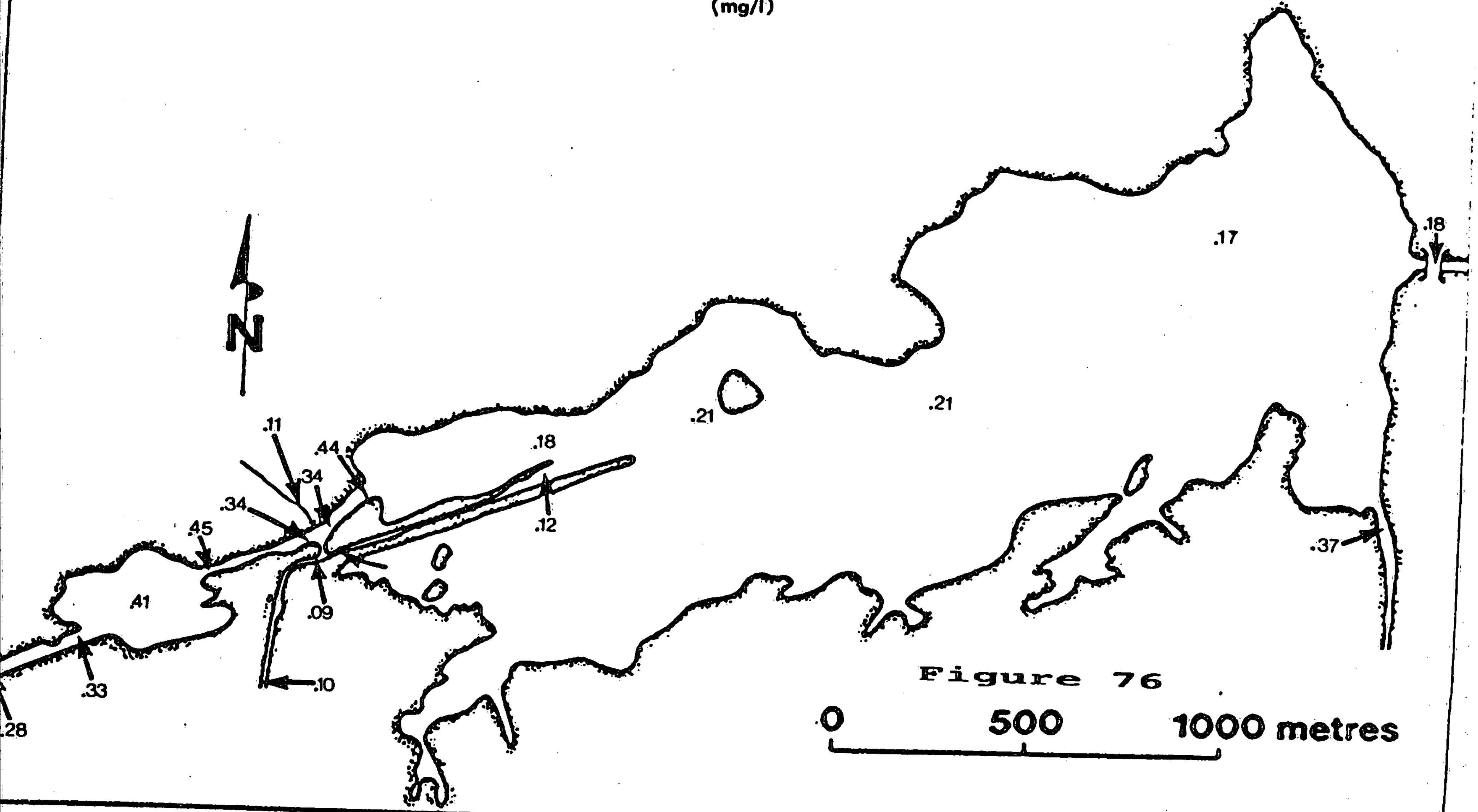


Figure 76

Total Dissolved Solids - 1987
(mg/l)

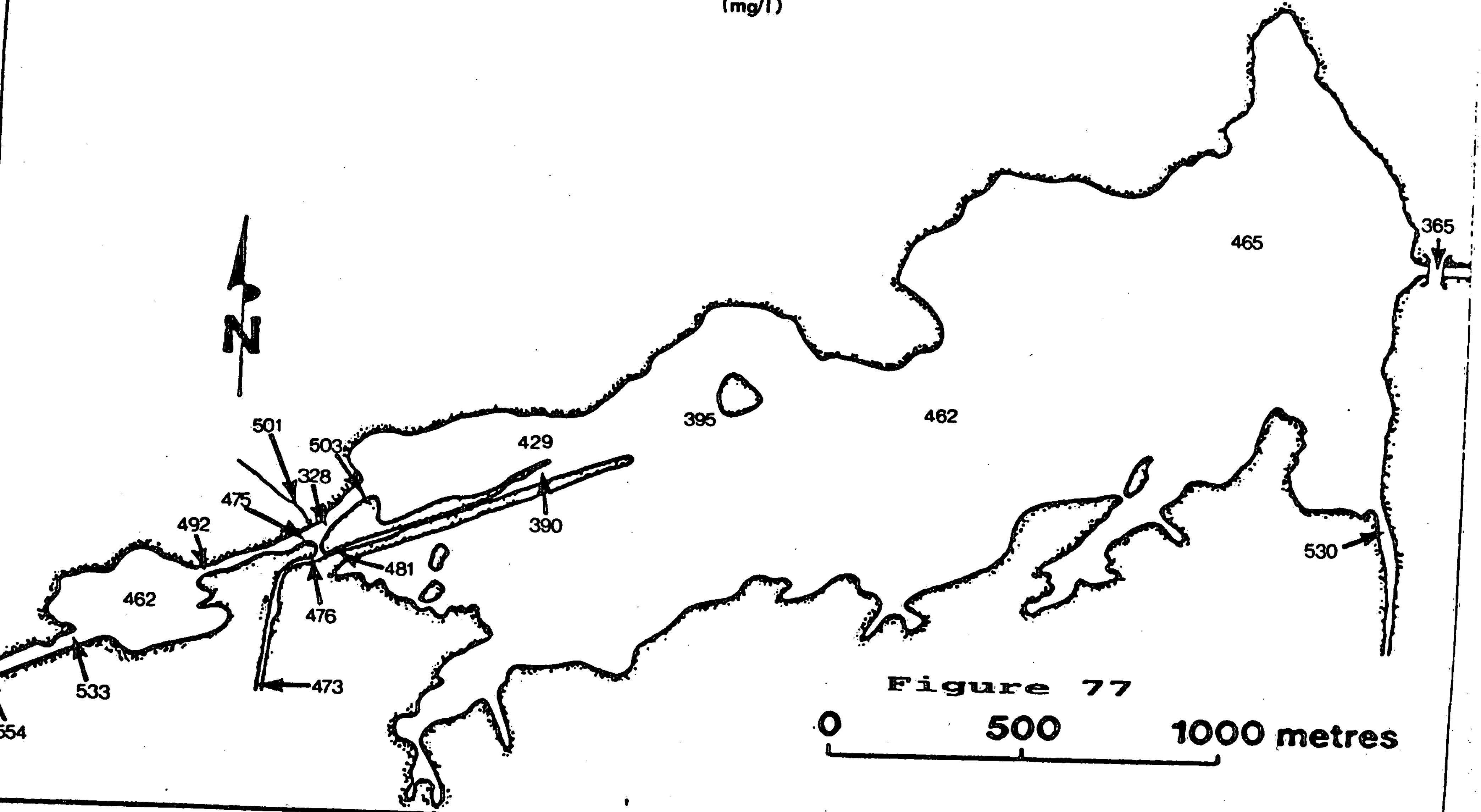
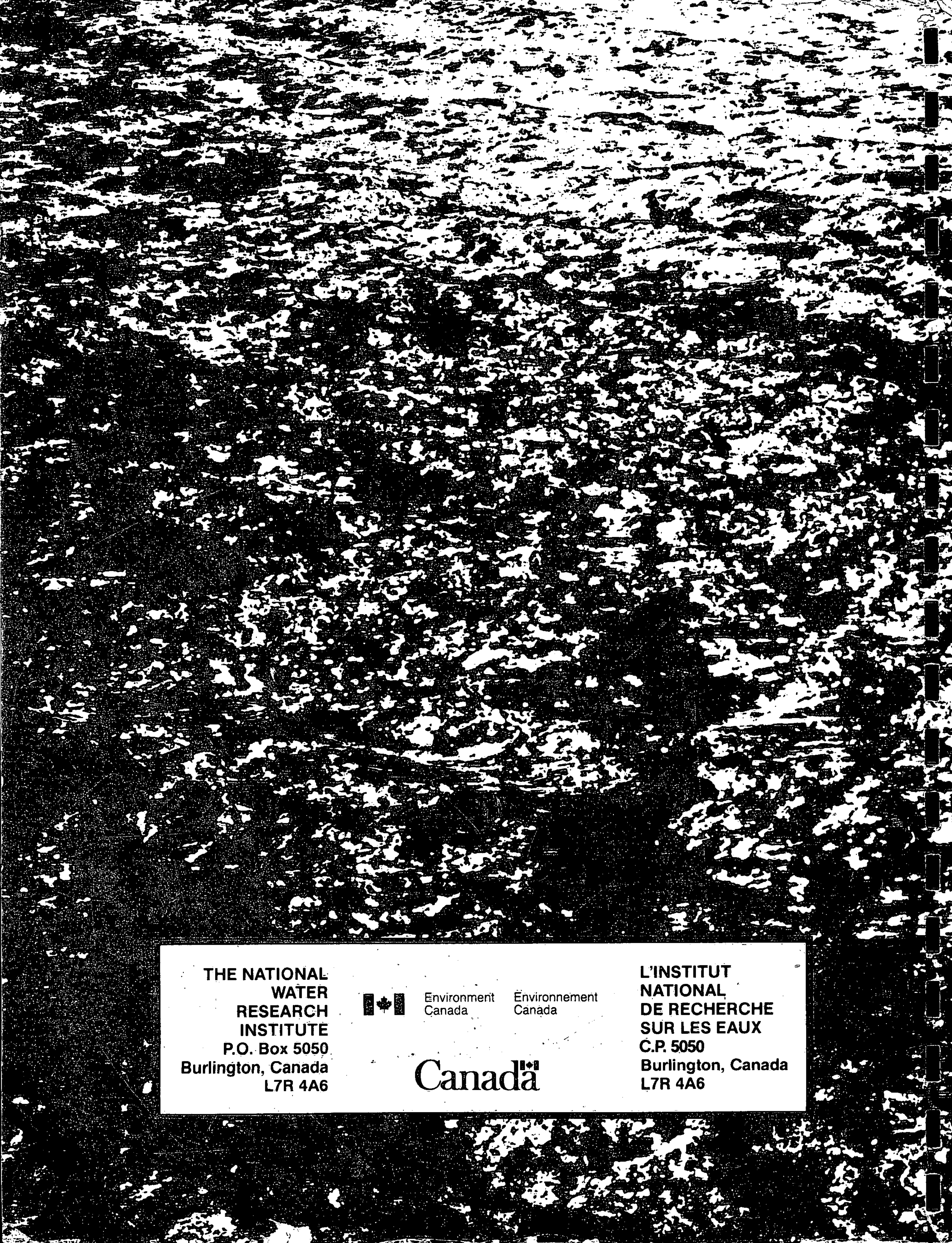


Figure 77



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