AN EVALUATION OF THE POTENTIAL IMPACTS OF SOME PRINCE EDWARD ISLAND IMPOUNDMENTS ON SALMONID HABITAT

by

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Abstract

In 1994, a two year study was initiated to determine the impact of small, surface discharge impoundments in Prince Edward Island, Canada, on salmonid habitat. Eight man-made impoundments, varying in size from 2.7 to 34 ha, were chosen to represent a cross section of impoundment types across the Province. Limnological data collected included water temperature, dissolved oxygen, suspended particulate matter, and chlorophyll *a*. Concentrations of suspended particulate inorganic matter and nutrients were higher in impoundments situated in drainage basins with intensive agricultural land use, however a short water residence time within some impoundments reduced the potential for excessive eutrophication. The impoundments had a positive influence on primary productivity, as indicated by concentration of chlorophyll *a*, with higher concentrations at the pond and outlet sampling stations in all but one study site. Impoundments in areas of intensive agricultural land use were functioning as sediment traps, with a decrease in suspended particulate inorganic matter from impoundment inlet to outlet. Stratification of dissolved oxygen and water temperature occurred at all impoundments studied, although wide, shallow impoundments had weaker stratification than narrow, deep impoundments. Dissolved oxygen concentration in the hypolimnion of impoundments with long water residence times fell below minimum requirements for salmonids. Supersaturated oxygen concentrations were recorded at three sites, with saturation exceeding 200% at one impoundment with high phytoplankton chlorophyll *a* biomass and extensive growth of submergent vegetation. Impoundments elevated summer water temperatures, particularly those with a long water residence time. Water temperatures in slow flowing streams with multiple impoundments were found to exceed temperatures deemed suitable for salmonids, both upstream and downstream from the impoundment. The extent of water cooling downstream from impoundments varied, and temperatures downstream from some impoundments remained above maximum acceptable levels for salmonids. General comments and management implications concerning the impoundments studied are presented.

Acknowledgements

I would like to thank my supervisor at Acadia, Dr. Mike Brylinsky, for his patience and assistance and Dr. David Caims for his help in revising this manuscript. Financial support was received from the P.E.I. Wildlife Federation, with assistance from the P.E.I. Watershed Improvement/Recreational Fisheries Development Program. The Department of Fisheries and Environment, Water Quality Division, made me feel welcome in their laboratories and were generous with equipment and technical assistance. I would particularly like to thank Roy Coffin and Nancy Reeves at the Research Station, and Anna Marie MacFarlane and her staff at the downtown lab. My apologies to the Chemistry Department at U.P.E.I. for the lingering odour of burning organic matter in their combustion oven. My field and laboratory assistant in 1995, Heidi MacLean, was cheerful and indispensable. The U.P.E.I. Biology Department was extremely helpful, and I would like to thank Terry Hardwick, Fr. Charlie Cheverie, Pat Doyle, Gilbert Blatch, Dr. Donna Giberson, and Kaye Ross for their much appreciated support over the past four years. Bobby MacAulay and the boys at the U.P.E.I. Physical Plant were extremely helpful in manufacturing various pieces of field equipment. I wish Dr. Louis Hanic, professor emeritus at U.P.E.I., best wishes in his new life in B.C. and thank him for sharing his knowledge and equipment. Congratulations to John MacMillan on the birth of his son and thanks for the assistance in the early years of this project. To Ron Gray, of ASE Consultants Inc., my sincere thanks for offering employment and support. My friends and colleagues in studying impoundments, Ron Gray, Daryl Guignion, Todd Dupuis, and Rob Redmond shared a lot of donuts, hamburgers, chinese food, pizza, and stories during our late nights in the lab. Ted Currie, D.F.O. Moncton, could always be counted on for encouragement. Ben Hoteling's technical assistance and moral support were much appreciated. Graham MacKay's maps were a great addition. My old friends Laura Bain and Terry Stevenson stuck with me and kept me reasonably sane. I dragged any willing participant to the field, and my parents were no exception. Their assistance and unfailing support went beyond the call of duty. My mom knows the importance of comfort food in times of stress. Other family members, including my sisters and brothers, kept the pressure on and pushed me to finally finish this thesis.

An Evaluation of the Potential Impacts of Some Prince Edward Island Impoundments on Salmonid Habitat

1.0 INTRODUCTION

Although there have been numerous studies on the environmental impact of large dams (Baxter 1977, Baxter and Glaude 1980, Lignon et al. 1995, Petts 1980), the impact of small dams and their impoundments on aquatic habitat is less well documented. The abundance of small impoundments in Canada's smallest province, Prince Edward Island (P.E.I.), makes it an ideal location for study. The over 800 man-made impoundments on P.E.I. range in size from less than one hectare to over 100 hectares (ASE Consultants Inc. 1997). This study was undertaken to investigate small, surface discharge impoundments and their impact on salmonid habitat on P.E.I.

Many of the dams on P.E.I. were originally constructed by European settlers to provide a source of power for operation of saw, grist, woolen, and starch mills. Dams were later built to create ponds for recreational activities such as hunting and fishing. By the mid-1900s, many former mill pond dam structures had fallen into disrepair with the decline of water-powered milling. In the 1970s and 1980s, wetlands creation and enhancement initiatives prompted the development of numerous impoundments to provide habitat for waterfowl and other wildlife species. Many of these modern structures were built on or near the sites of old mill ponds. In addition to a new dam structure, concrete fishways were often added, providing fish passage in many streams where upstream migration had previously been impeded.

The numerous short, spring-fed streams on P.E.I. favour salmonid production. In comparison to other provinces in the maritime region of Canada, there are relatively few species of freshwater sport fish. The principal species, brook trout (*Salvelinus fontinalis*), can be found in virtually every stream. Water quality in P.E.I. streams, including an abundance of groundwater and nutrient rich runoff from agricultural land, combined with availability of estuarine habitat and a general lack of competition from other fish species, are factors responsible for the high level of trout production (Smith 1958). Remnant populations of Atlantic salmon *(Salmo salar)* remain in certain streams and a stocking program has created a "put-and take" fishery for Atlantic salmon in selected rivers. Rainbow trout (*Oncorhynchus mykiss)* have established themselves in some rivers, with successive introductions since 1925. The only other sportfish or commercial species which commonly occupy freshwater on Prince Edward Island for some stage of their life are American eel (*Anguilla rostrata*), rainbow smelt (*Osmerus mordax*), white perch (*Morone americana*), gaspereau or alewife (*Alosa pseudoharengus*), and blueback herring (*Alosa aestivalis*).

Although there have been various studies of Prince Edward Island impoundments, they were initially focussed on the effect of impoundments on fish populations, primarily in relation to yield and catch or fish movement (Saunders 1960, Smith 1947, Smith 1954, Smith 1963, Smith and Saunders 1967). Various impoundments have been monitored with respect to waterfowl production (Curly and Duffy 1989 and 1990, Curley and MacKinnon 1988), and a wetland inventory classified all freshwater wetlands and salt marshes (Dibblee 1994). In the late 1980s, water temperature downstream from some impoundments was found to be substantially warmer than inlet temperatures (Ducks Unlimited Canada 1988 and 1989, Guignion et al. 1990, Thompson et al. 1990). An MSc study was initiated in 1994 to examine the thermal effects of impoundments on salmonids, including behavioural strategies of brook trout in response to elevated water temperature (MacMillan 1998). The concern expressed by wildlife groups and angling organizations regarding the potential impact of impoundments on fish migration and aquatic habitat ultimately resulted in a literature review (ASE Consultants Inc. 1994) and a consultants' study which examined the impact of impoundments on resident and anadromous fish species on P.E.I. and devised a classification system to rank impoundments as fish habitat (ASE Consultants Inc. and Department of Biology, University of Prince Edward Island 1997). The objective of the current study was to evaluate the potential impacts of impoundments on salmonid habitat. A number of physical, chemical, and biological variables were assessed, with emphasis on:

- the effect of impoundments on water temperatures, both within the impoundment and downstream from the dam;
- the extent of stratification within impoundments with regard to water temperature and dissolved oxygen;
- the role of impoundments in the transportation and deposition of suspended solids;
- the impact of impoundments on the productivity of Prince Edward Island stream systems.

2.0 METHODS

2.1 Study Area

A total of eight impoundments, representing eight different drainage basins, were studied (Figures 1-5). The Midgell and Valleyfield rivers were monitored in 1994 (Figure 1). In the 1995 field season, six rivers were studied - Clarks Creek, Grovepine, Naufrage, Winter, Wilmot, and Dunk (Figure 1). Roughly 48 percent of P.E.I. is cleared and another 48 percent under forest cover (Anonymous 1990). The eight drainage basins included in this study were chosen to represent a cross section of drainage basin types across Prince Edward Island. They range from cleared areas under intensive agricultural production to more forested regions of the province (Table 1). All of the study areas have the gently undulating terrain characteristic of Prince Edward Island, where roughly 75% of the land is less than 45 m above sea level (MacDougall et al. 1988).

Both the Dunk and Wilmot Rivers lie in the heart of the "potato belt" in southeastern Prince County, with the Wilmot River watershed identified as having the greatest proportion of cleared land on Prince Edward Island (Anonymous 1990). The Winter River flows northward from the central part of the province into the Gulf of St. Lawrence, and along with its agricultural usage, this watershed supplies groundwater for the capital city of Charlottetown. Like the Winter River, the Valleyfield River has a mixture of cleared and forested land and drains a more hilly region in the southeastern part of the province. Wiseners Pond is situated in the headwaters of Clarks Creek, one of many streams draining into the largest watershed

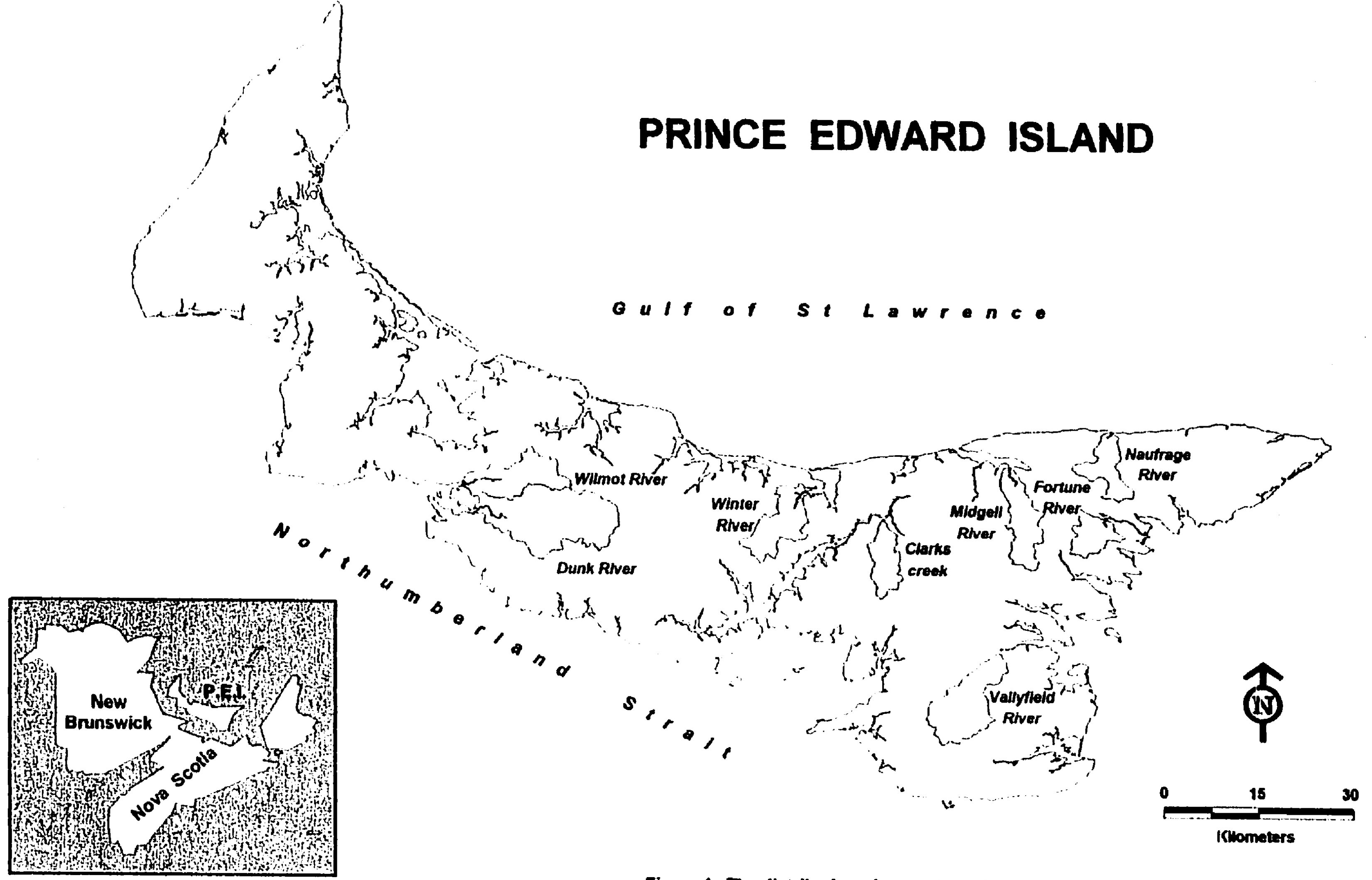
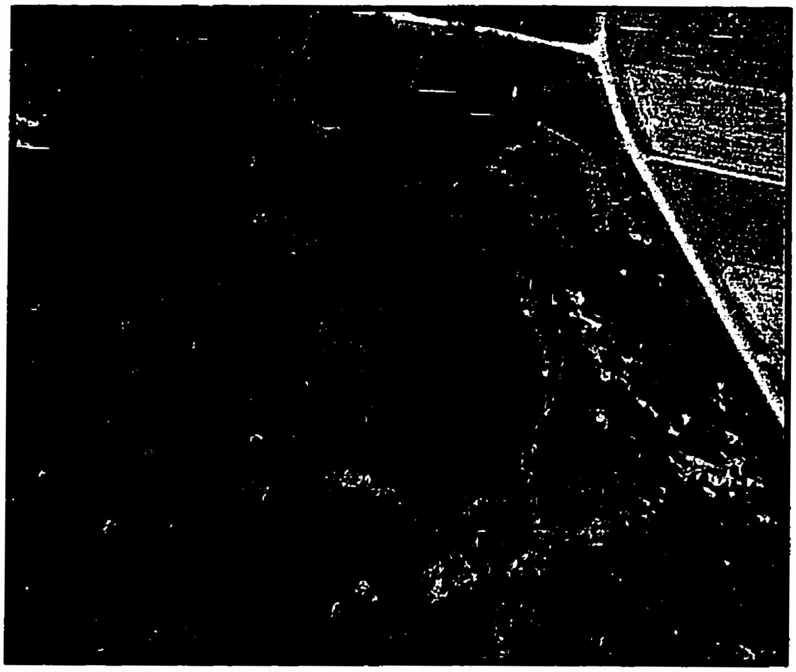


Figure 1. The distribution of watersheds included in the study.

A



B

Figure 2. Maritime Electric Pond, Valleyfield River (A) and MacDonalds Pond, Midgell River (B)

A

B

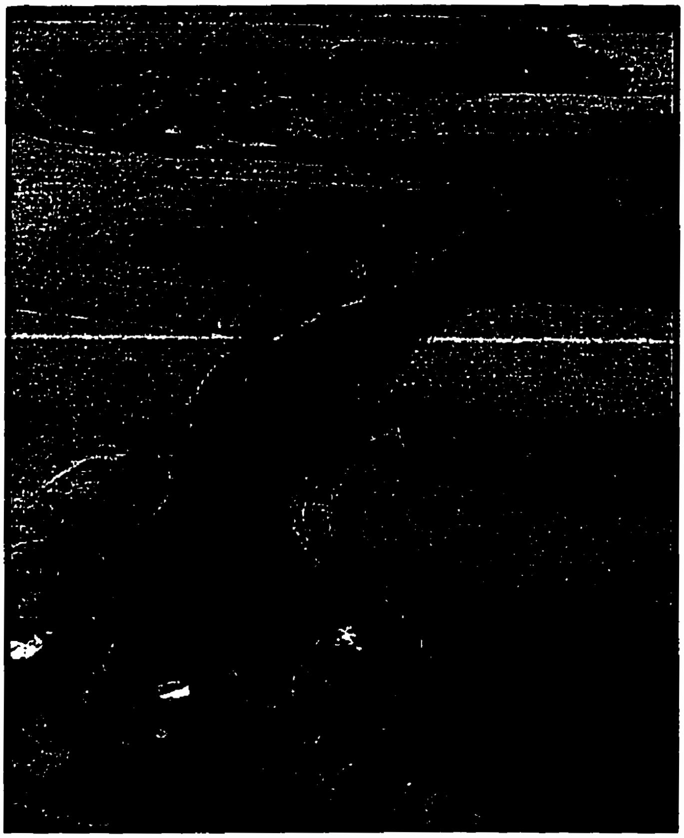
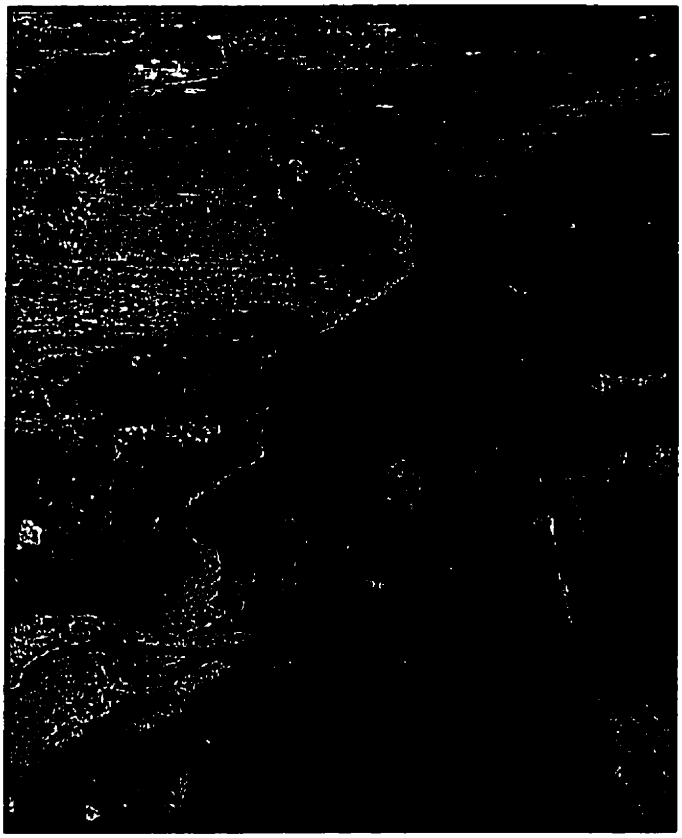


Figure 3. Arsenaults Pond, Wilmot River (A) and Scales Pond, Dunk River (B).

A



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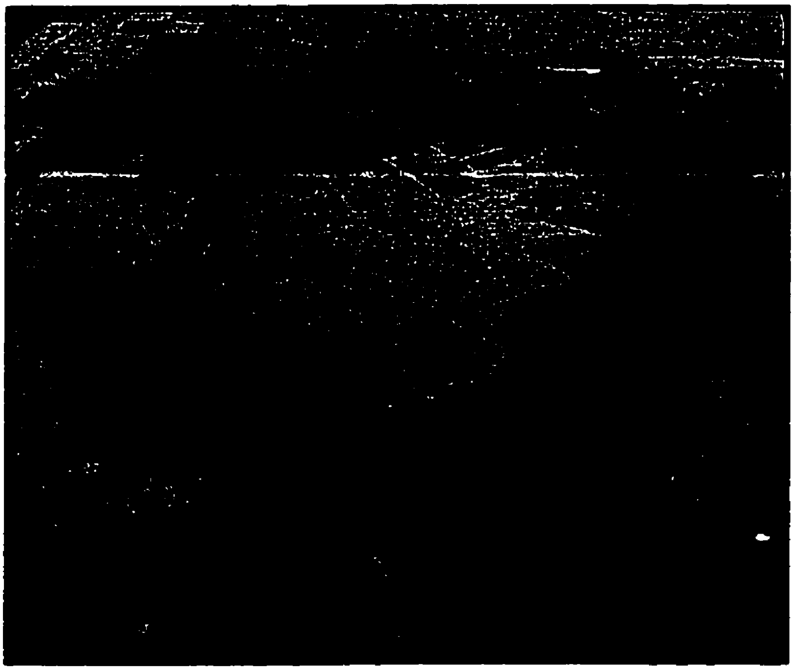


Figure 4. Officers Pond, Winter River (A), and Wiseners Pond, Clarks Creek (B).

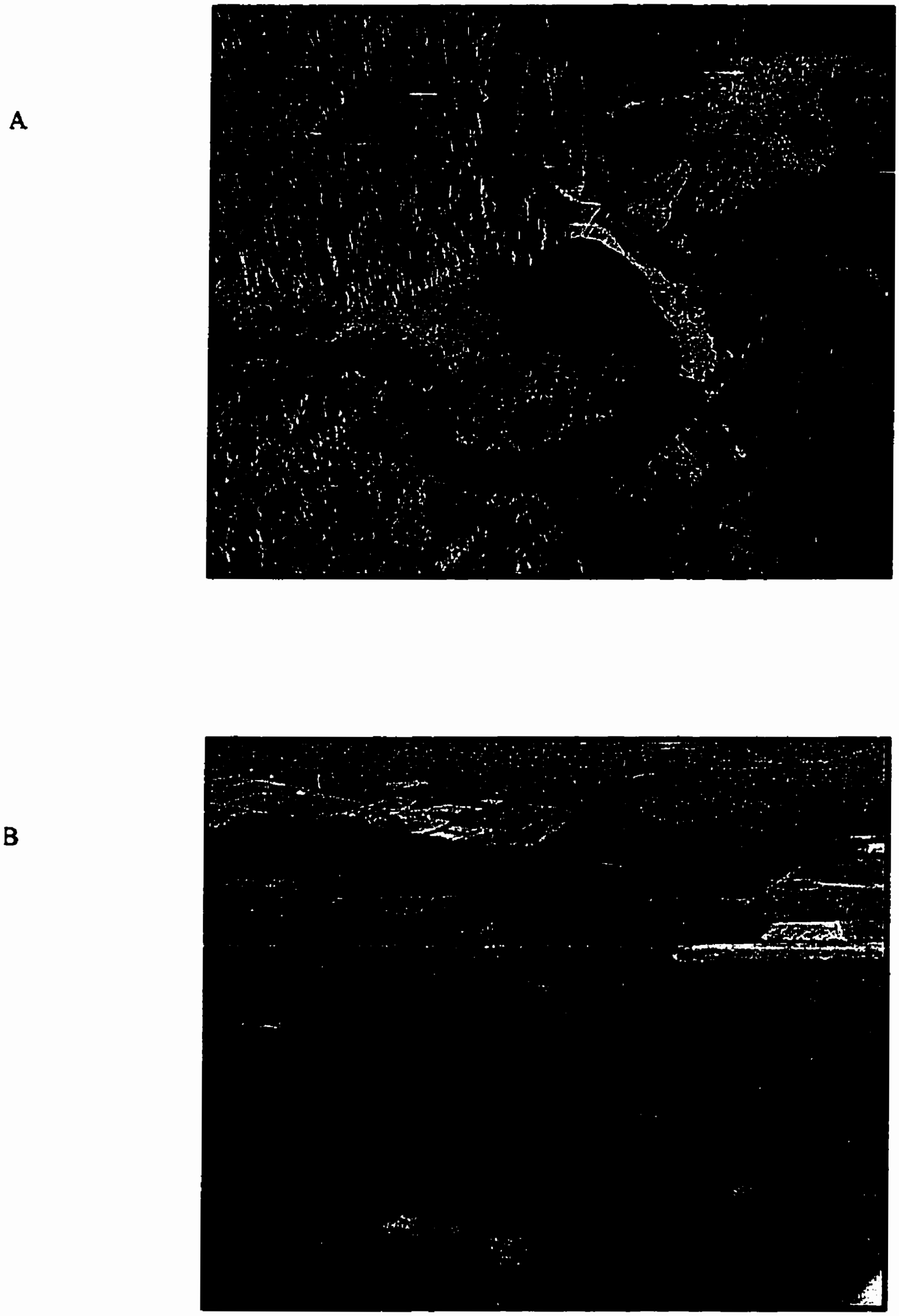


Figure 5. Grovepine Pond, Fortune River (A), and Larkins Pond, Naufrage (B).

Table 1. Percentage of cleared and forested land within each drainage basin and for Prince Edward Island as a whole.

Site	Drainage Basin	Cleared (%)	Forested (%)	Other (%)
Larkins	Naufrage	11	83	6
Grovepine	Fortune	19	75	6
MacDonalds	Midgell	19	76	5
Maritime Electric	Valleyfield	37	58	5
Wiseners	Clarks Ck	41	55	4
Officers	Winter	46	47	7
Scales	Dunk	69	27	4
Arsenaults	Wilmot	83	12	5
Prince Edward Island		48	48	4

Source: Prince Edward Island Department of Agriculture and Forestry complex on Prince Edward Island, the Hillsborough River. The Midgell, Naufrage, and Grovepine Rivers in central/eastern King's County have little disturbance and have the highest percentages of forested area. All three of these rivers drain low, boggy areas, as evidenced by the "tea coloured" humic acid nature of the water.

Five of the ponds studied, MacDonalds, Larkins, Officers, Arsenaults, and Wiseners were originally mill ponds. In the 1970s and early 1980s, new dams were constructed and the ponds are now jointly managed by Ducks Unlimited Canada and the Provincial Department of Technology and Environment. Grovepine impoundment was constructed by Ducks Unlimited Canada and the provincial Fish and Wildlife Division for waterfowl enhancement. Scales Pond and Maritime Electric Pond were previously used for generation of electrical power, although Scales Pond was originally constructed and used as a mill pond. Both ponds are now managed by the provincial Department of Technology and Environment.

2.2 Sampling Stations

On each system, a sampling station was established at the impoundment inlet and outlet and a site located downstream from each dam (Figures 6-13). In addition, an intensive sampling station was located close to the dam in the deepest portion of each impoundment. In the 1994 field season only, two sampling stations were located downstream from MacDonalds Pond and the Maritime Electric Pond. During winter sampling for dissolved oxygen, an additional impoundment station was monitored at the upper ends of MacDonalds, Grovepine, Wiseners, and Officers.

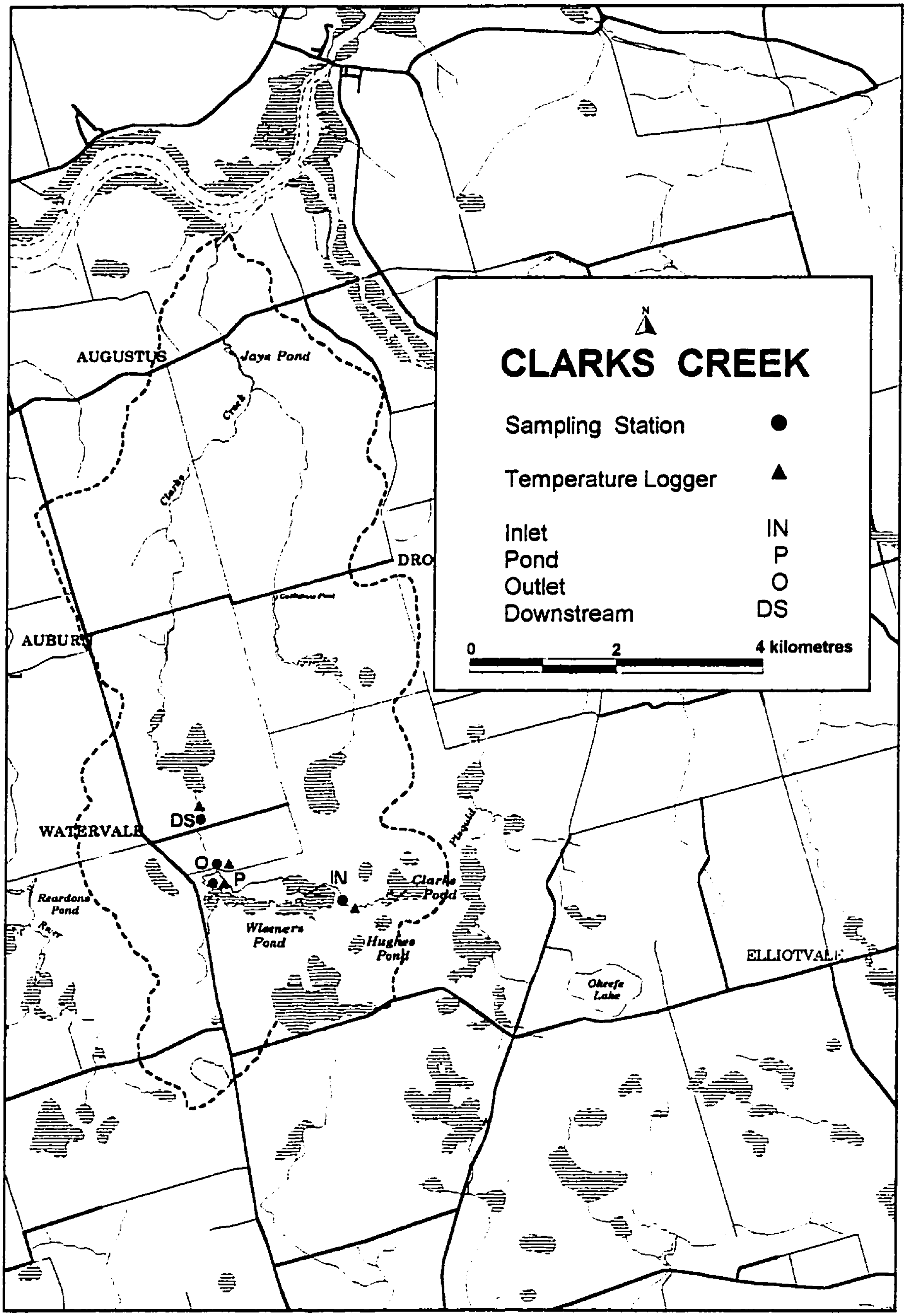


Figure 6. Location of sampling stations and water temperature loggers on Clarks Creek

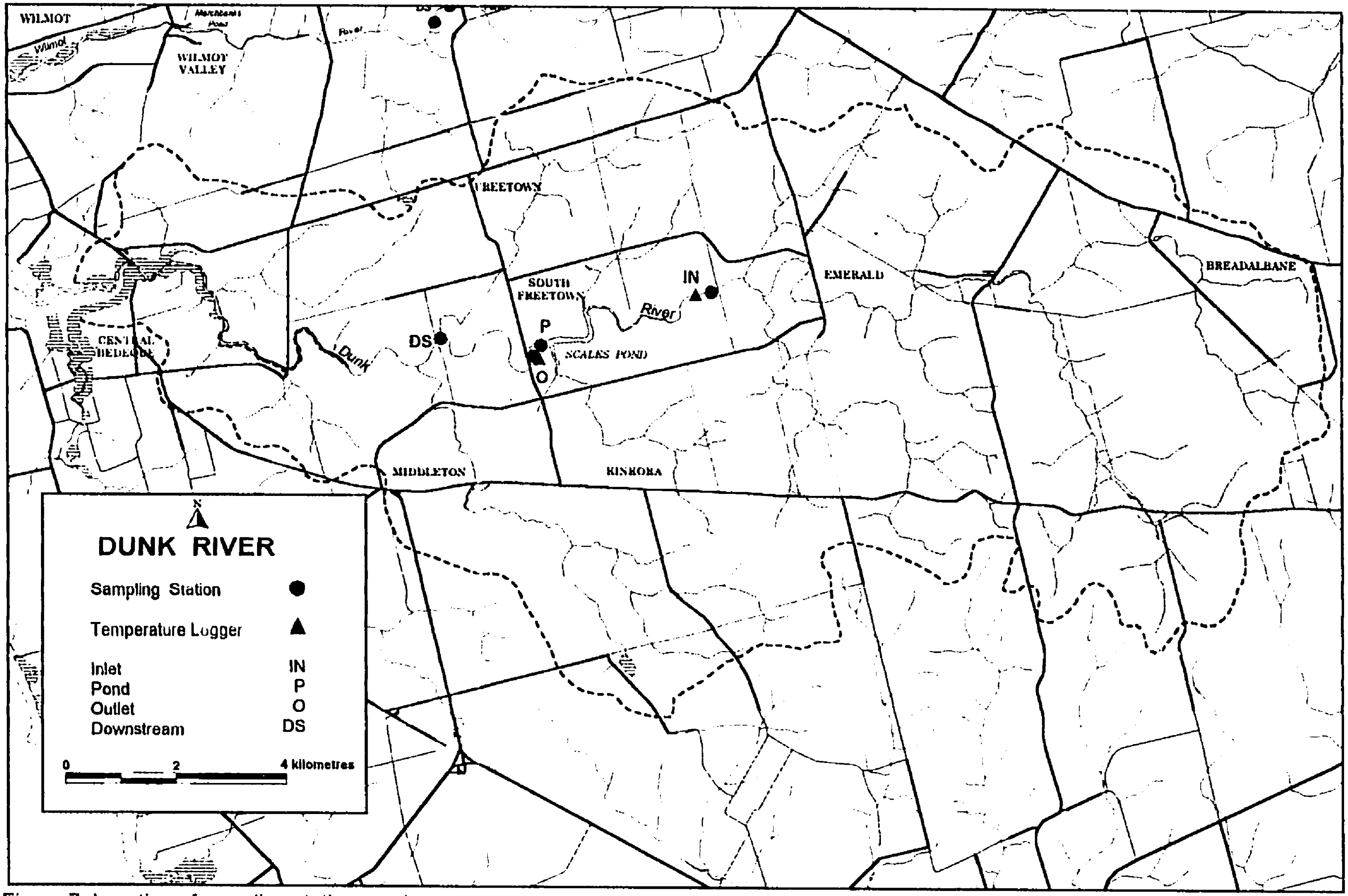


Figure 7. Location of sampling stations and water temperature loggers on the Dunk River

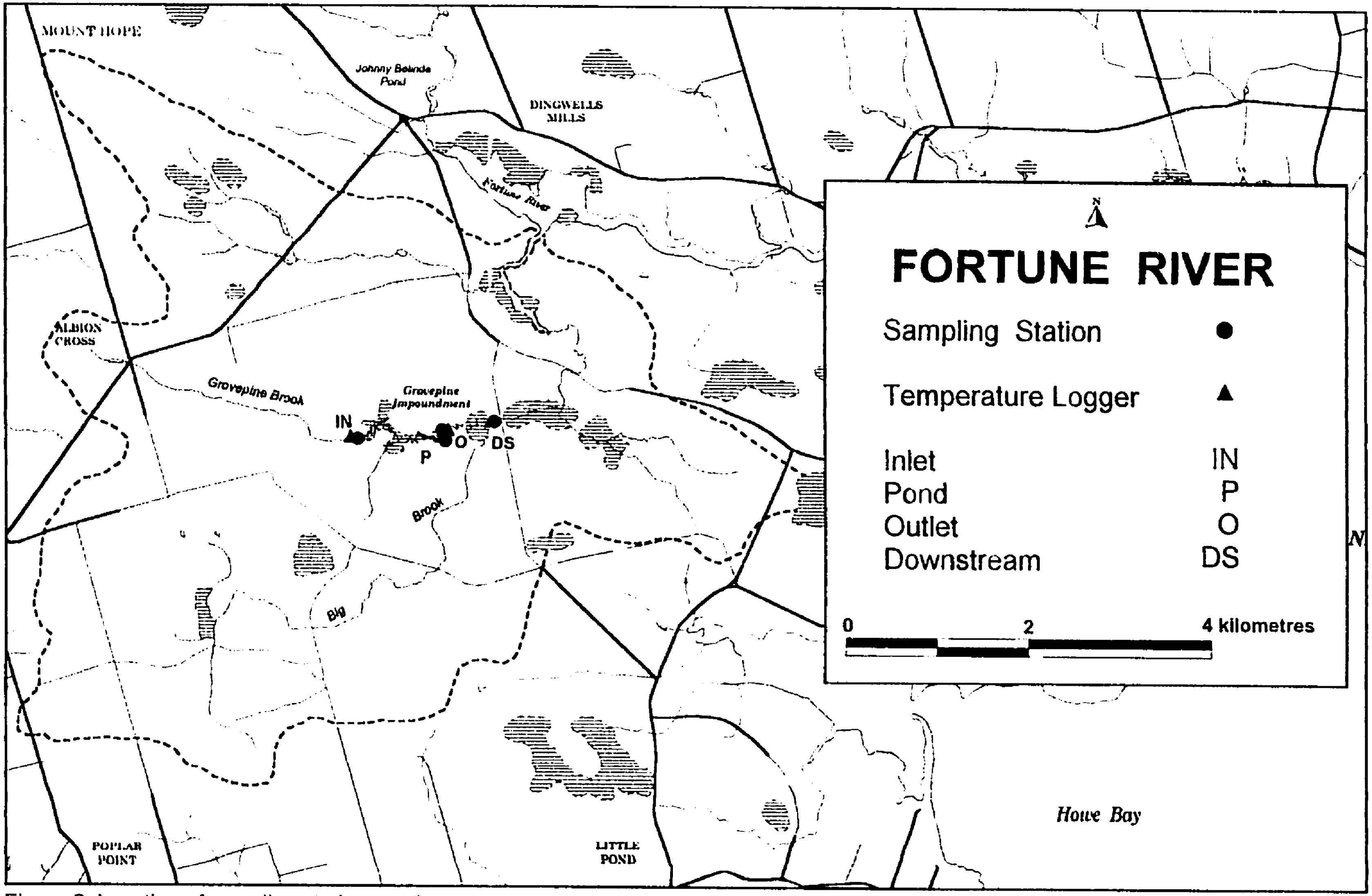


Figure 8. Location of sampling stations and water temperature loggers on the Fortune River.

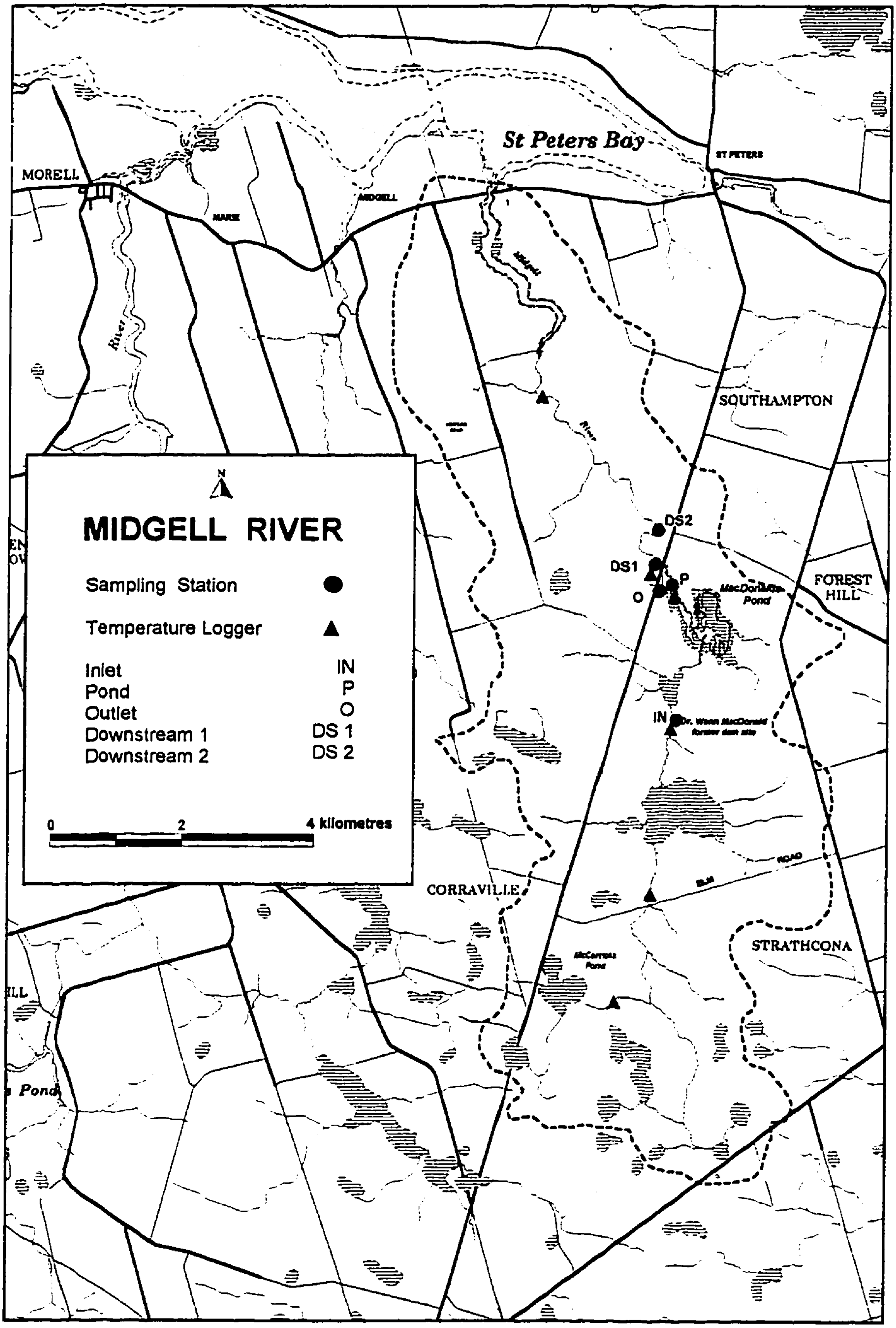


Figure 9. Location of sampling stations and water temperature loggers on the Midgell River.

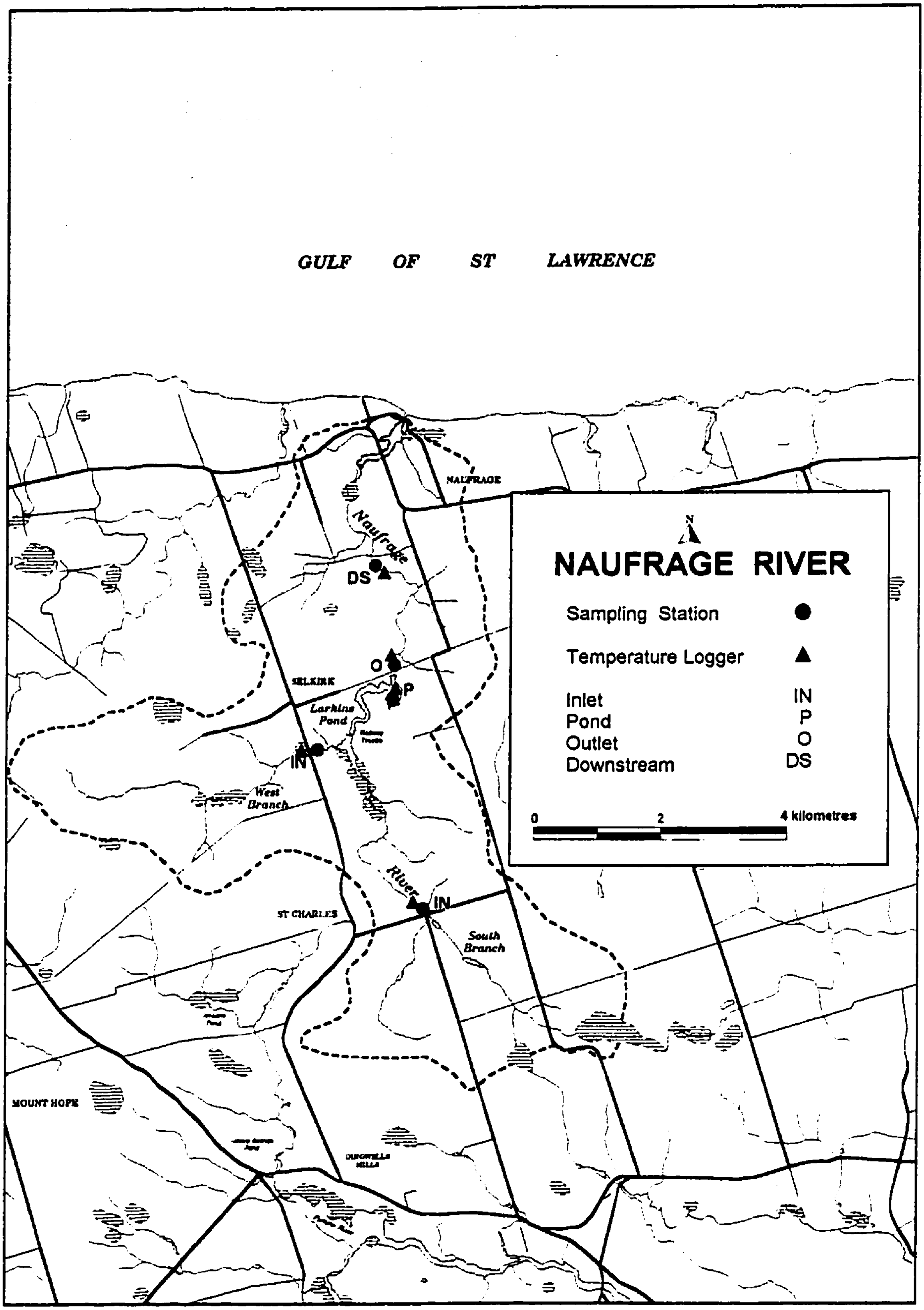


Figure 10. Location of sampling stations and water temperature loggers on Naufrage River.

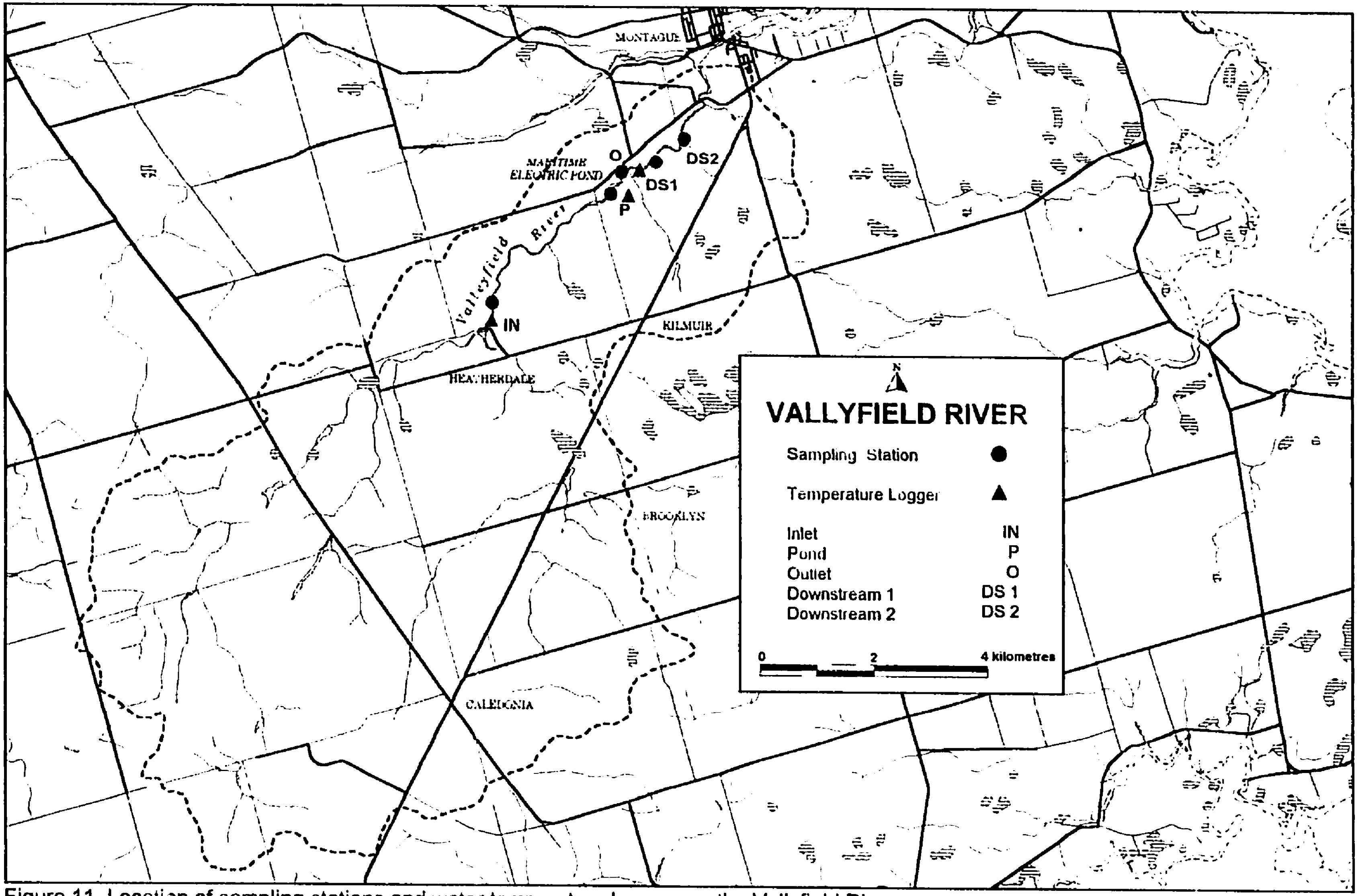


Figure 11. Location of sampling stations and water temperature loggers on the Vallyfield River.

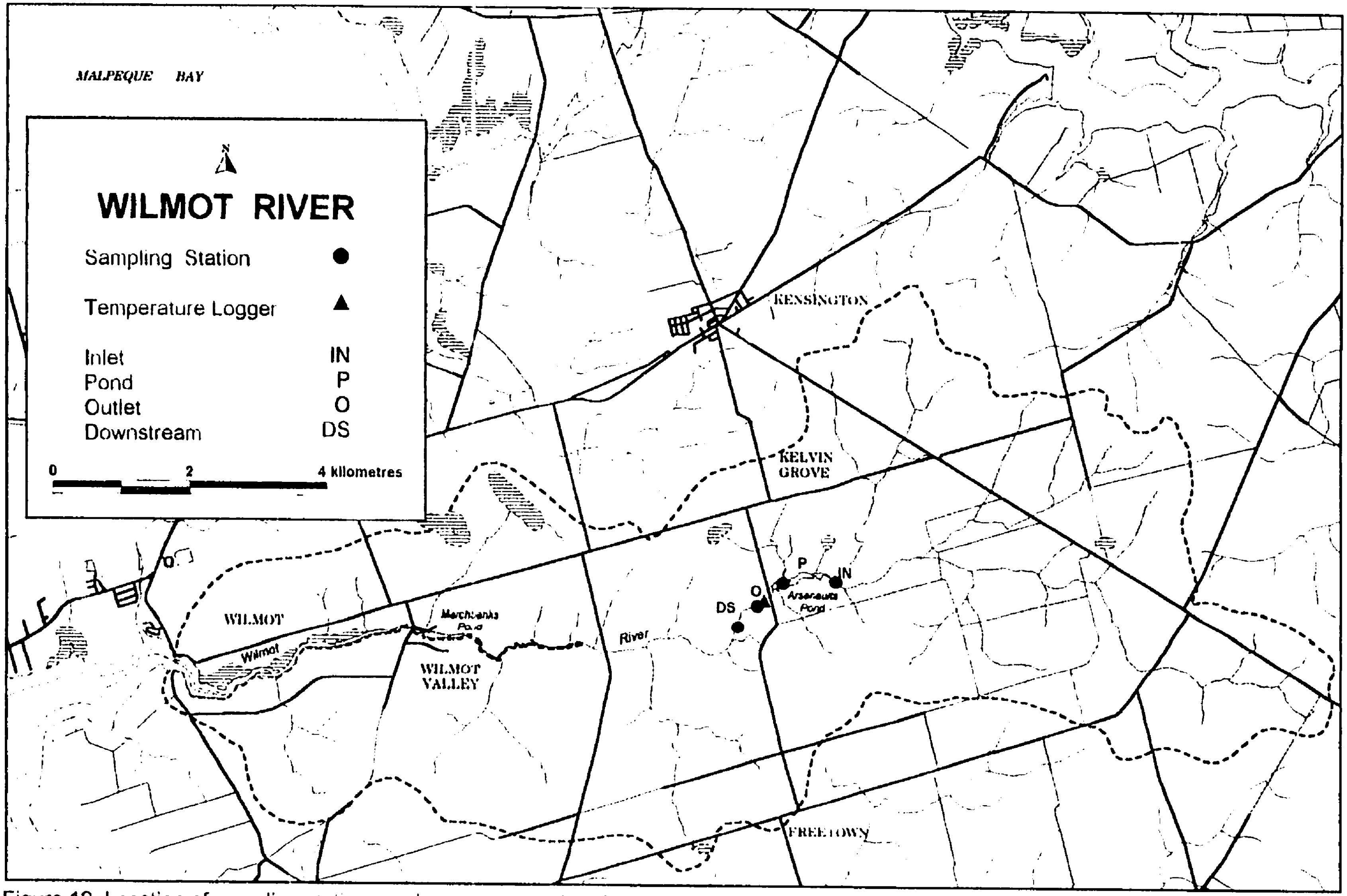


Figure 12. Location of sampling stations and water temperature loggers on the Wilmot River

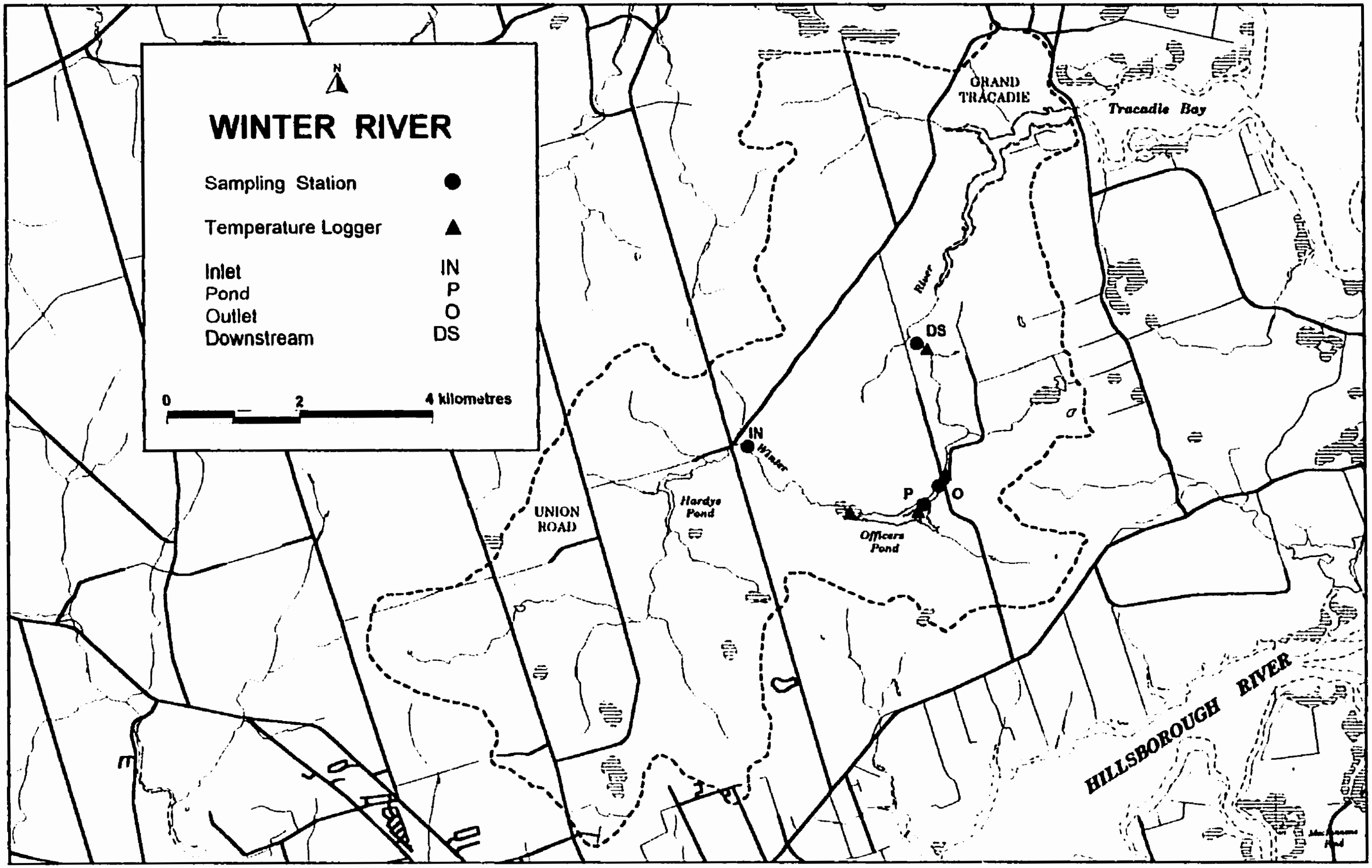


Figure 13. Location of sampling stations and water temperature loggers on the Winter River.

The combined average of the two inflowing streams at Larkins Pond was used as the inlet value in analyses of chlorophyll *a*, suspended particulate matter, and water temperature.

2.3 Sampling Regime

Sampling was conducted biweekly from 31 May - 8 August in 1994 and from 6 June - 1 September in 1995. Additional water temperature, dissolved oxygen, and chemical data from Officers Pond, Grovepine, and Wiseners Pond were made available from an impoundment study recently completed for the Department of Fisheries and Oceans (ASE Consultants Inc. and the University of Prince Edward Island Department of Biology 1997).

2.4 Stream Gradient and Impoundment Morphology

Topographic maps (1:50,000) of Prince Edward Island (25' contour) were used to determine approximate stream gradient (metres fall/km stream) for each river, both upstream and downstream from the impoundment studied.

A bathymetric survey was completed for each impoundment. Depths were measured with a calibrated line at 10 metre intervals along transects 100 m apart. All sites, with the exception of Grovepine, Officers, and Wiseners, were surveyed during the summers of 1994 and 1995. The remaining impoundments had previously been surveyed with weighted line through the ice during the winter of 1994. Contour maps (Figures 14-21) and hypsographic curves (Appendix I) were constructed for each impoundment. Although the 1968 Province of Prince

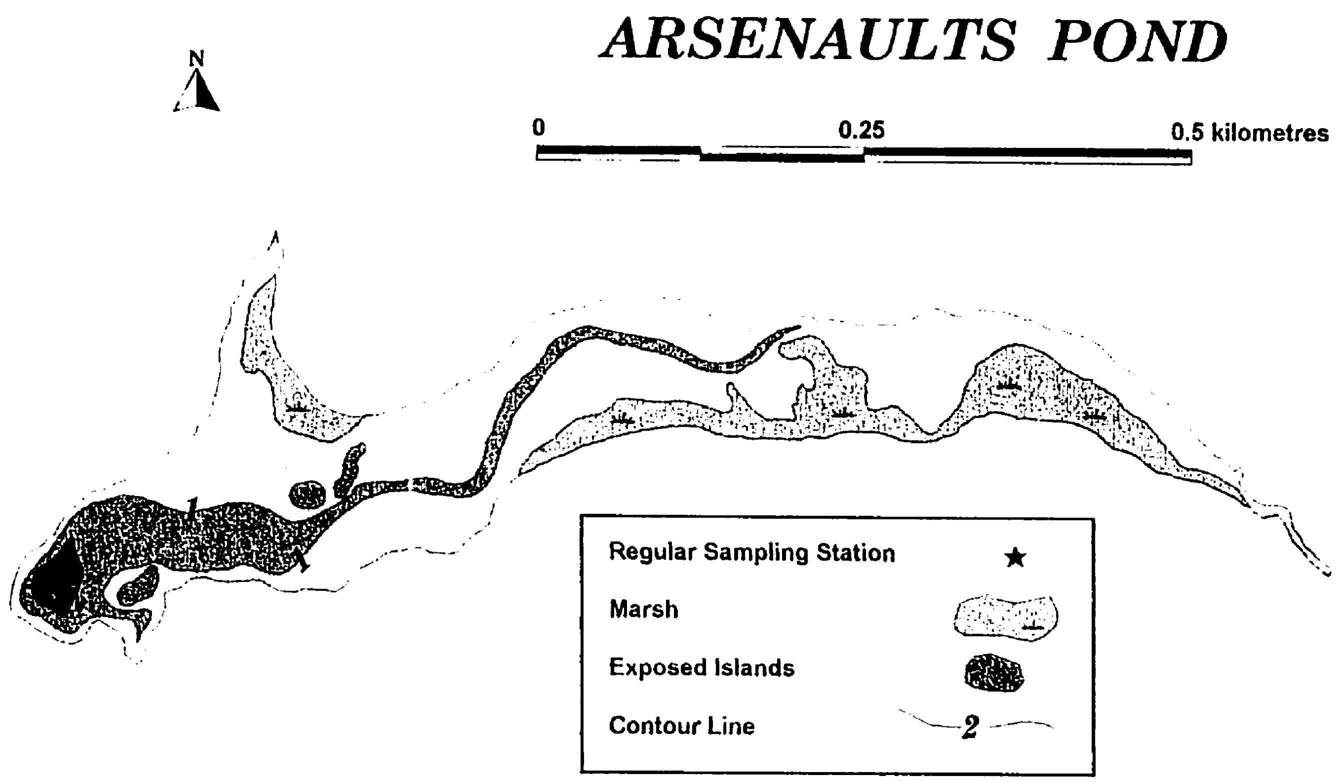


Figure 14. Bathymetric map of Arsenaults Pond, Wilmot River, with depth contours at 1.0 metre.

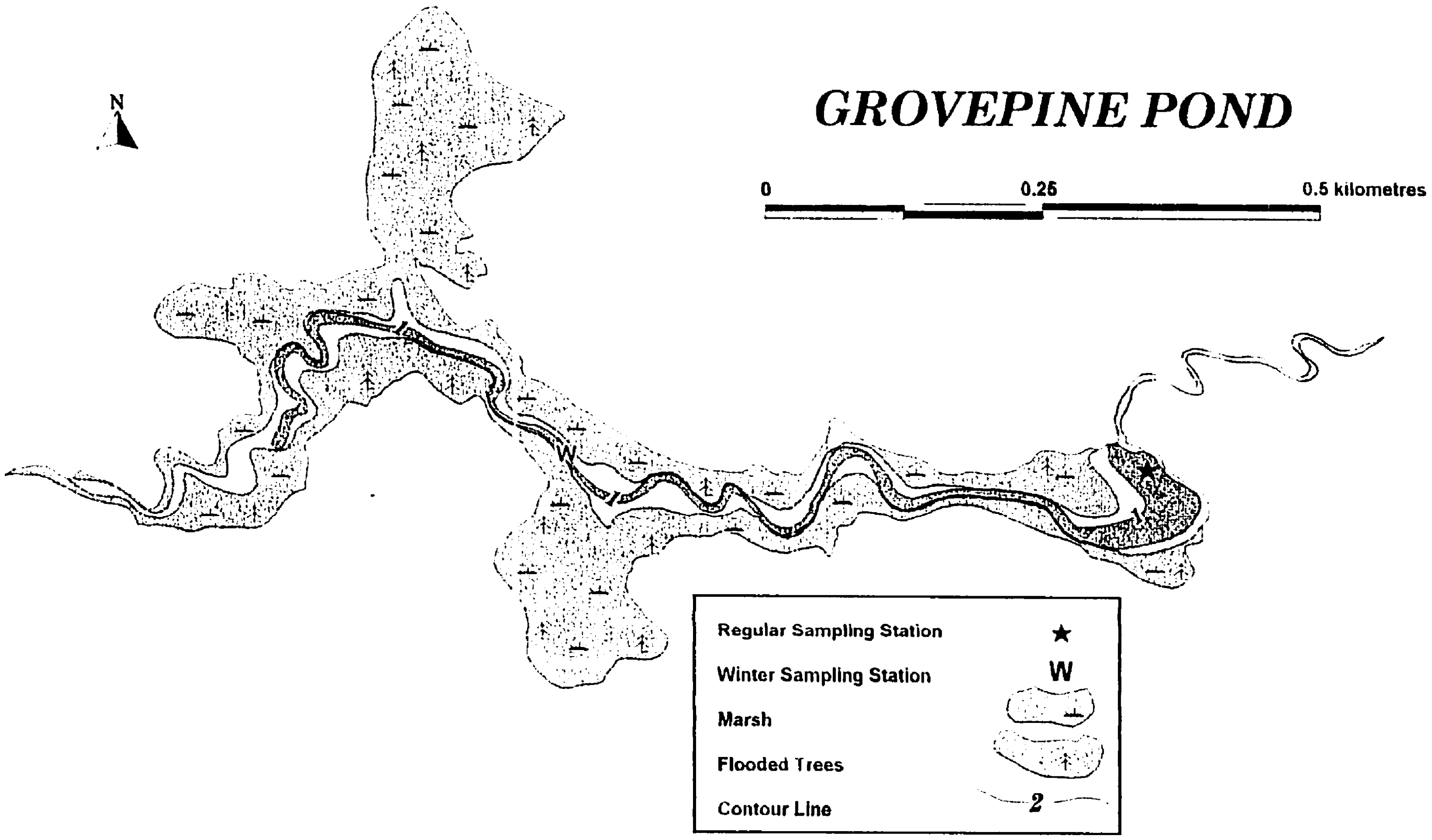


Figure 15. Bathymetric map of Grovepine Pond, Fortune River, with depth contours at 1.0 metre.

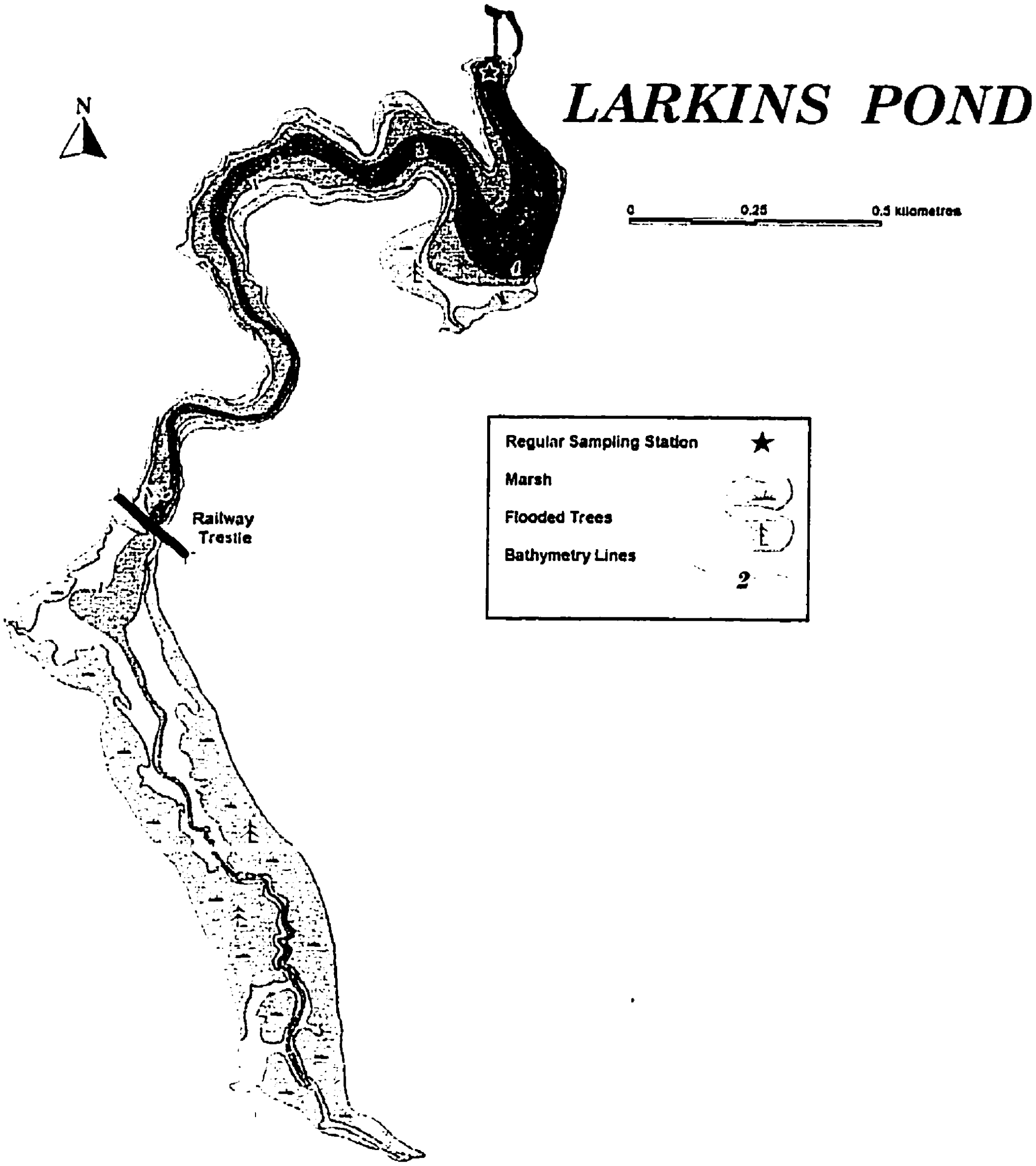


Figure 16. Bathymetric map of Larkins Pond, Naufrage River with depth contours at 1.0 metre.

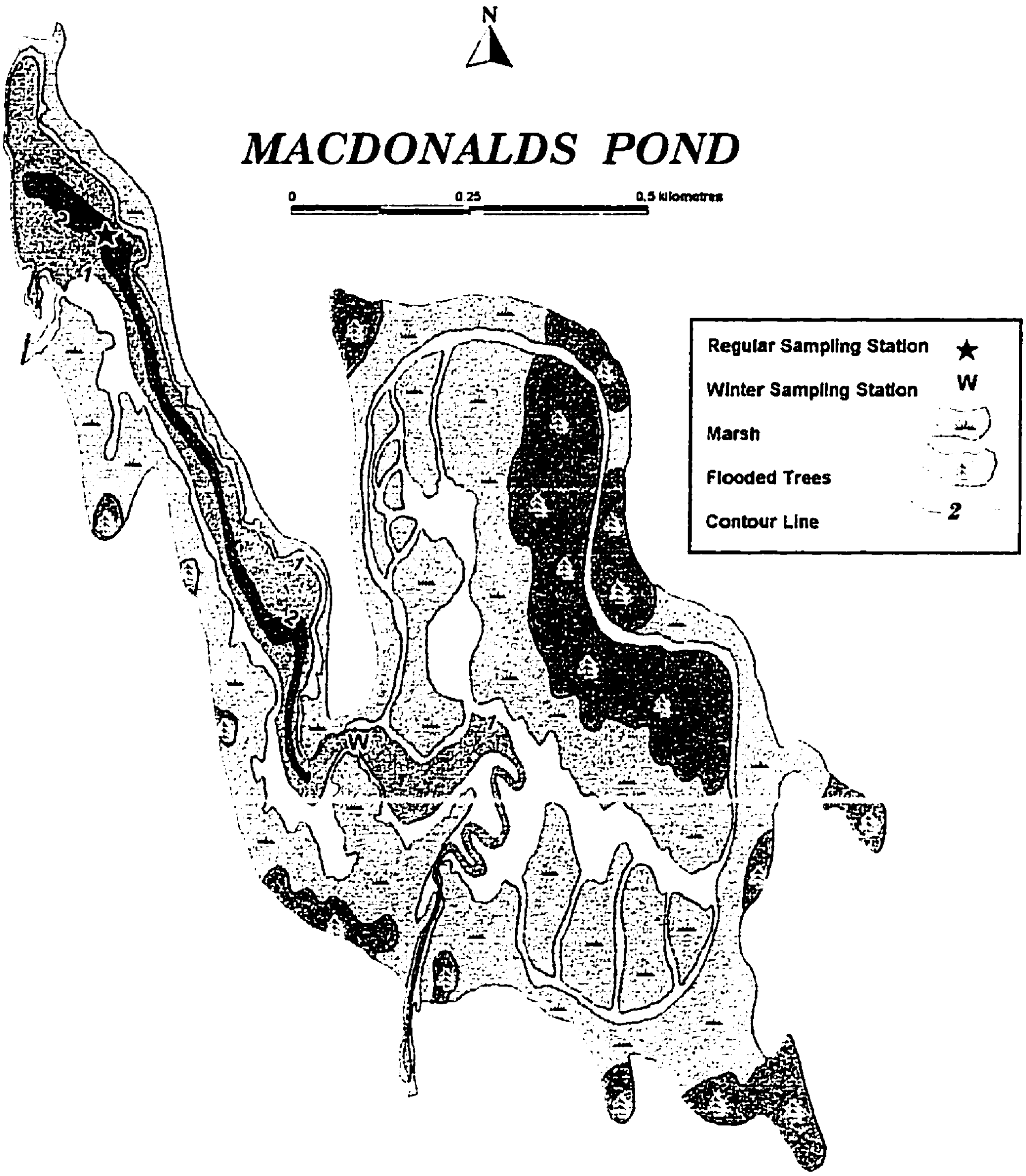


Figure 17. Bathymetric map of MacDonalds Pond, Midgell River with depth contours at 1.0 metre.

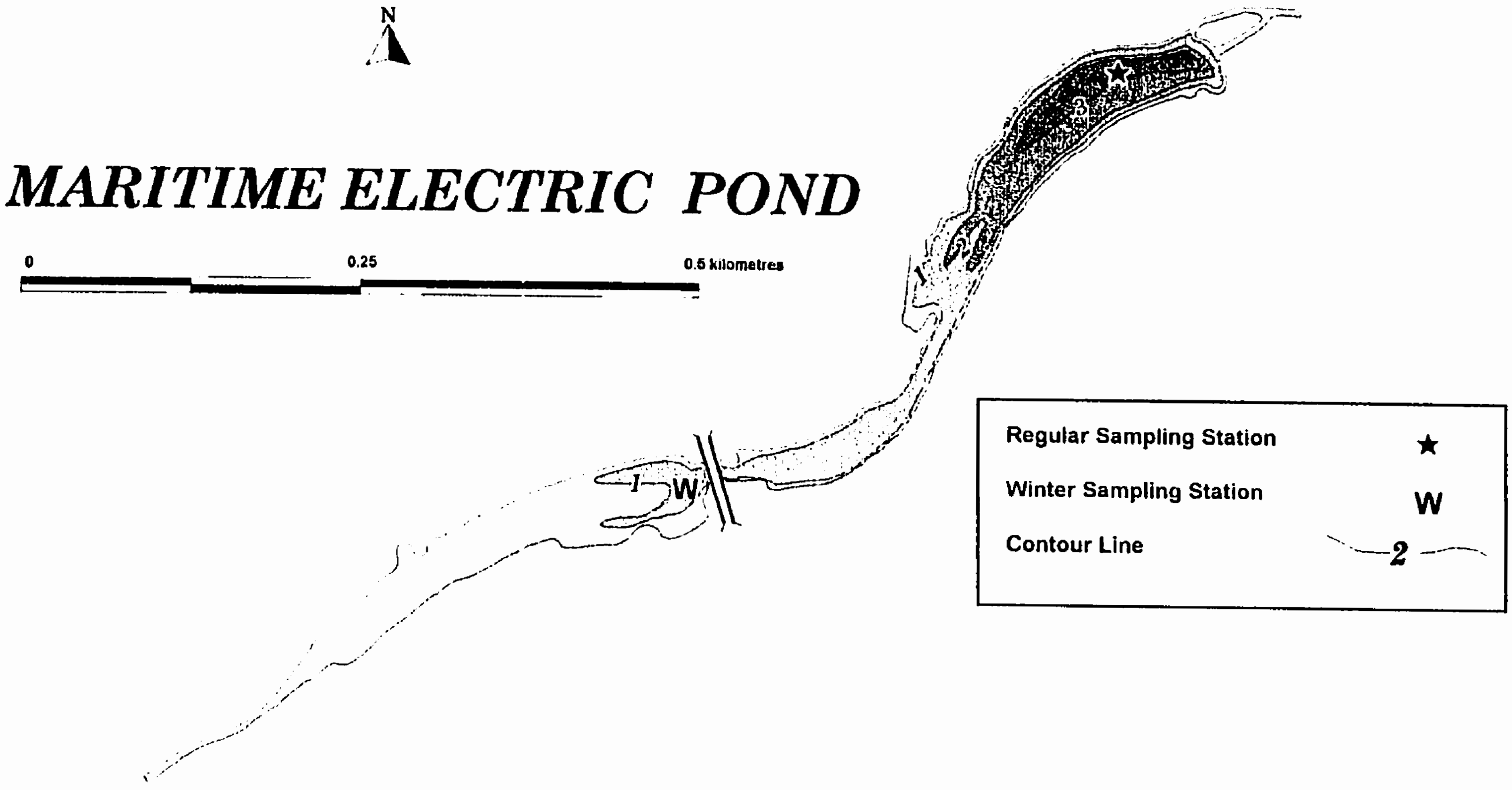


Figure 18. Bathymetric map of Maritime Electric Pond, Valleyfield River, with depth contours at 1.0 metre.

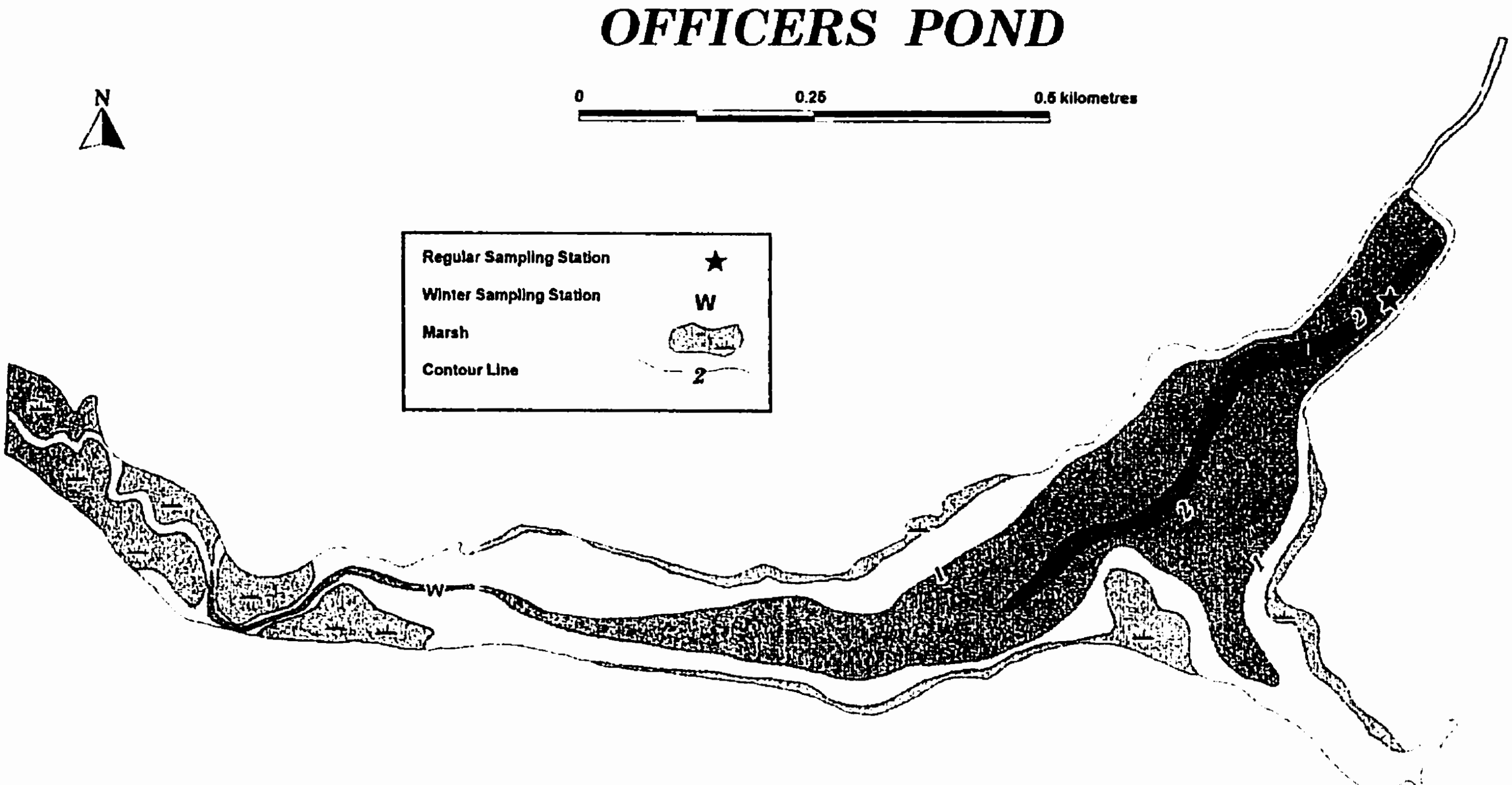


Figure 19. Bathymetric map of Officers Pond, Winter River, with depth contours at 1.0 metre.

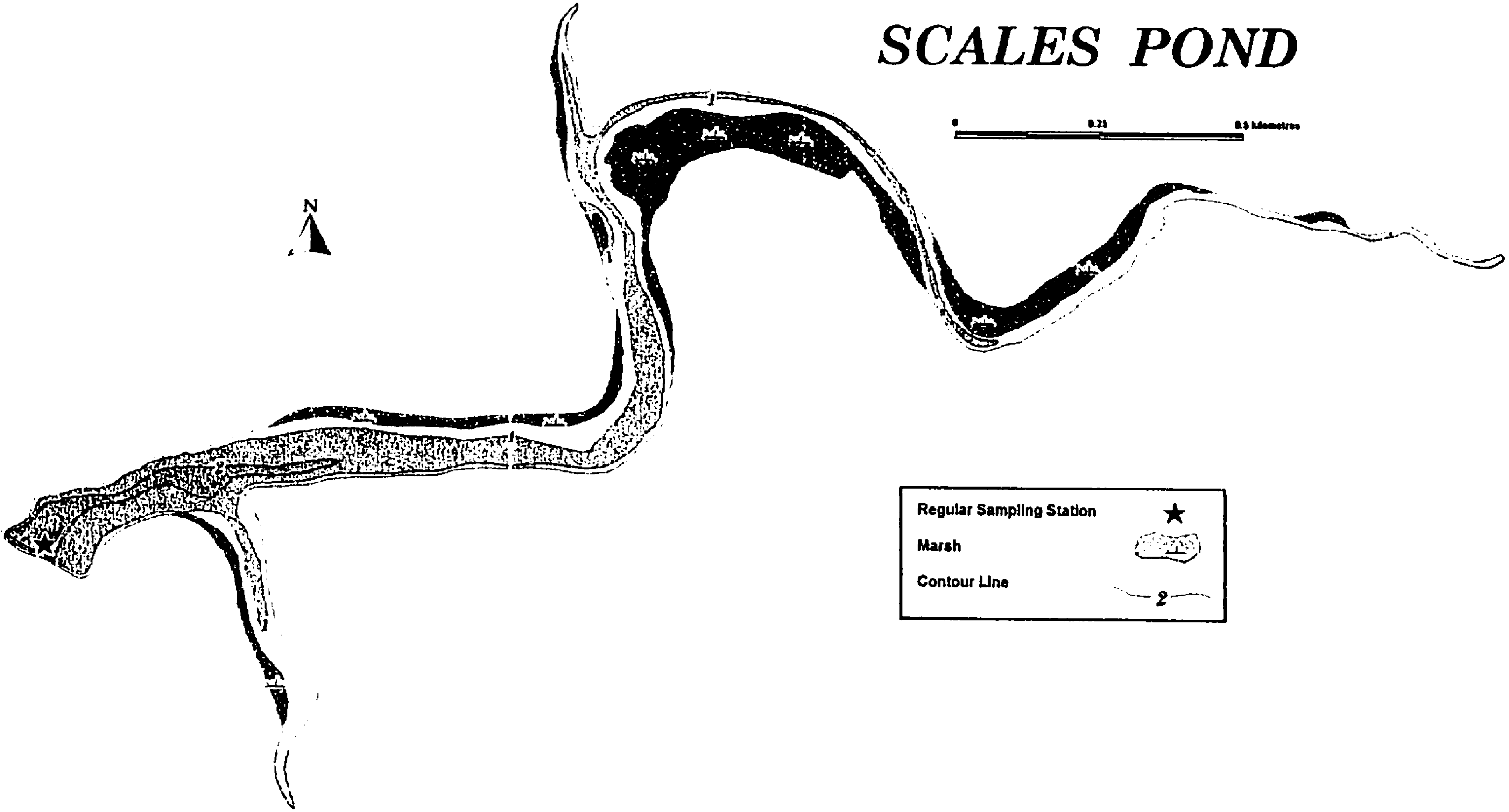


Figure 20. Bathymetric map of Scales Pond, Dunk River, with depth contours at 1.0 metre.

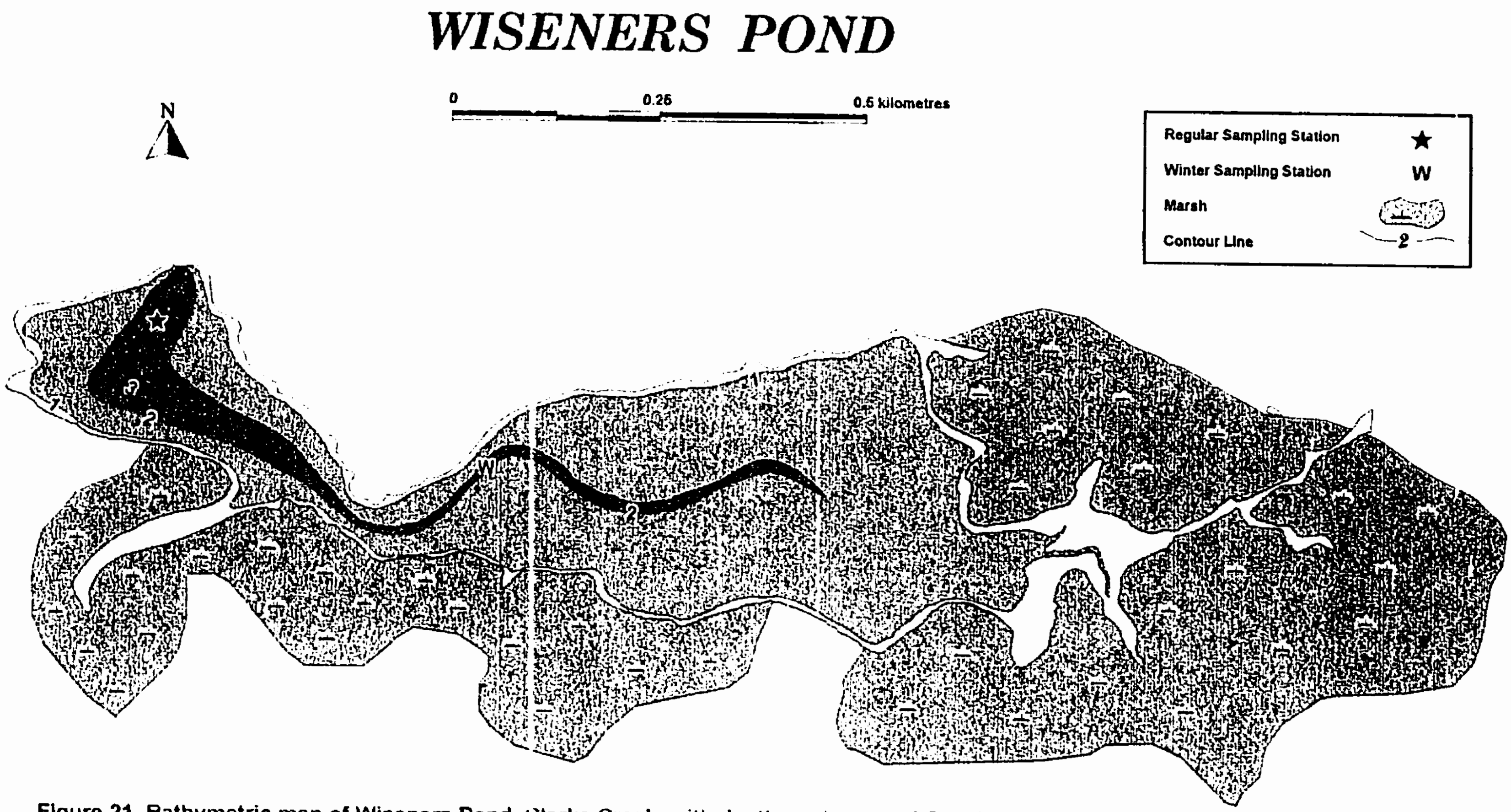


Figure 21. Bathymetric map of Wiseners Pond, Clarks Creek, with depth contours at 1.0 metre.

Edward Island Agricultural Series 1:5000 ortho photos were used as base maps, final contour maps were drawn using shoreline data obtained in field measurements.

Morphometric parameters were measured as follows:

- Surface Area: A compensating polar planimeter was used to measure the surface area at each 1.0 m contour on the impoundment map
- Volume: A hypsographic curve was constructed by plotting the area within each contour line against its depth. The area between this curve and the axes is proportional to pond volume. A compensating polar planimeter was used to measure the area.
- Shoreline Length: A digital map measurer was used to determine the length of shoreline from the impoundment map.
- Maximum Length: A ruler was used on a map of the impoundment to determine the distance on the impoundment surface between the two most distant points on the impoundment shore.
- Maximum Breadth: A ruler was used on a map of the impoundment to find the maximum distance on the impoundment surface at a right angle to the line of maximum length between the shores.
- Shoreline Development Index: This was calculated as the ratio of the length of shore line to the circumference of a circle of area equal to that of the impoundment.
- Mean Depth: This was calculated as the volume divided by the surface area
- Relative depth: Relative depth was calculated as the ratio of the maximum depth as a percentage of the mean diameter of the pond at the surface, and expressed as a percentage.

2.5 Impoundment Water Residence Times

The flushing or water residence time of each impoundment was determined using Environment Canada's 47 year average precipitation records from the Charlottetown weather station. Calculations made for December, April, and August are included for comparison in the results. During low flow periods in summer 1995, twenty velocity measurements were obtained on a cross sectional transect near the outlet of each impoundment using a Marsh-McBirney Model 200 digital flow meter. From these velocity measurements, the discharge of water (m^3/s) was determined at all eight study sites and the water residence time during low flow was determined using the following calculation:

- Water Residence Time (days):

$$RT = \frac{\text{volume}}{(x)\,(\text{discharge})} \qquad \text{where,}$$

RT = Residence Time
x = conversion to days
Discharge = m^3/days

2.6 Physical Characteristics

2.6.1 Water Transparency

Water transparency was measured at all sites biweekly with a Secchi disk.

2.6.2 Sedimentation Rates

In 1995, suspended sediment traps (Figure 22), similar to those described by Gardner (1980) and Kirchner (1975), were suspended one metre from the bottom in the deepest portion of each impoundment. The traps were made of acetyl butyl styrene (ABS) pipe with a plexiglass bottom and were 28.0 cm tall and 7.8 cm in diameter. The aspect ratio of the traps was 3.6. At each site, two traps were suspended from buoys on opposite ends of electrical pipe and

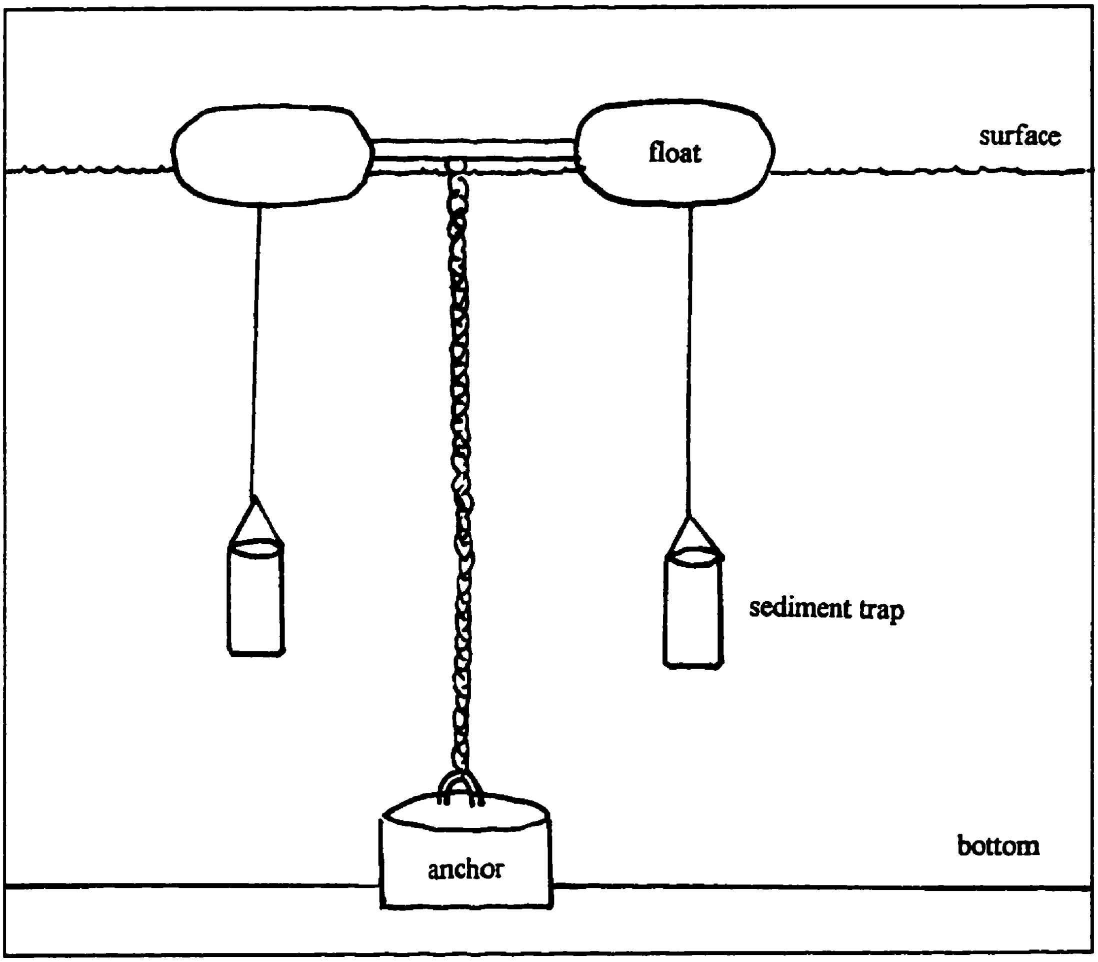


Figure 22. Suspended sediment trap.

anchored to the pond bottom (Figure 22). Fresh water in each trap was underlain with a saturated salt solution to reduce turbulent resuspension. The traps were checked during regular biweekly sampling and analysed for particulate organic and inorganic matter as described below. The mean concentration of suspended particulate matter in the two traps was converted to mg/m^2 using a conversion value of 0.00478 calculated from the pipes' dimension.

2.6.3 Suspended Particulate Matter

Water samples for determination of suspended particulate matter were collected at all river sampling stations, as well as midway in the water column at the impoundment station. Determination of particulate organic and inorganic matter followed the procedure outlined in American Public Health Association (1985) using one litre samples filtered through precombusted (500°C) Whatman GF/C glass fiber filters. Samples were dried for 1.5 hours at 103°C and combusted at 500°C for 2 hours. All statistical comparisons made between sampling stations were done using the *t* test.

2.6.4 Water Temperature and Thermal Stratification

A YSI Model 33 S-C-T meter was used to monitor water temperature at 0.5 m intervals throughout the water column in the pond station and at each stream sampling site. Three types of temperature data loggers - Hobo™ and Optic StowAway™ (Onset Computer Corporation), and Minilog-T™ (Vemco Ltd.) - were used to monitor water temperature on an hourly basis at depths of 0.5 m from the surface and bottom of the deepest portion of the pond, as well as at the inlet, outlet, and downstream stations of MacDonalds (Figure 9) and the Maritime Electric Pond (Figure 11) in 1994 and Wiseners (Figure 6), Grovepine (Figure 8), and Officers (Figure 13) ponds in 1995. Loggers also recorded water temperature at the inlet and outlet of Scales Pond (Figure 7) and the outlet of Arsenaults Pond (Figure 12). Water temperature at upstream and downstream locations on the Naufrage River was recorded using Sealog-T (Vemco Ltd.) temperature loggers (Figure 10).

2.7 Chemical Characteristics

2.7.1 Dissolved Oxygen

A vertical profile of dissolved oxygen was taken every 0.5 m from surface to bottom in each impoundment using a YSI Model 51B dissolved oxygen meter or a YSI Model 55 handheld meter. A Van Dorn sampler was used to collect water samples from the surface (upper 0.5 m) and bottom (lower 0.5 m) of the impoundment station. Oxygen measurements (mg/L) were made on 300 ml samples using the azide modification of the Winkler method (Hach Water Analysis Handbook 1992). The amount of dissolved oxygen at the stream sampling stations on the Midgell and Valleyfield Rivers was regularly determined using the oxygen meter. In addition, spot checks of dissolved oxygen were made at various stream locations on Grovepine.

2.7.2 Other Chemical Characteristics

In 1994, water samples were collected biweekly at all stations for analysis of pH, alkalinity, ammonium nitrogen, nitrate nitrogen, total nitrogen, inorganic phosphorus, and total phosphorus. Analysis of cations and anions was carried out three times throughout the study period, during June, July, and August. In 1995, nutrient analysis was completed a total of three times throughout the study, twice in May, and once at the end of August. Nutrient, anion, and cation data for Officers Pond, Wiseners Pond, and Grovepine were also obtained in late July. Conductivity was measured at all sites, including a vertical profile every 0.5 m within each impoundment using a YSI Model 33 S-C-T meter. Nutrient and chemical analyses were performed by the Prince Edward Island Department of Technology and Environment - Water Resources Division. Cations and anions, with the exception of chloride, were analysed using an Inductively Coupled Argon Plasma spectrophotometer (ICAP 1100). All other analyses of chemical properties followed procedures described in Environment Canada (1979).

2.8 Biological Characteristics

2.8.1 Chlorophyll *a*

Samples for determination of chlorophyll *a* were taken at the inlet and outlet stations and from the upper 0.5 m of the impoundment station. Impoundment samples in 1994 were taken in triplicate. In 1994, samples were refrigerated until the following day when 90 ml and 150 ml were filtered through Whatman GF/F filters. After the filter was ground in 4 ml of 90% acetone, an additional 3 ml of 90% acetone was added and the sample kept refrigerated in the dark for 24 hours. Samples were centrifuged and the clarified extract was analyzed on a Turner Designs 10-AU fluorometer. In 1995, samples were transported in a cooler to the laboratory where 250 ml was filtered through Whatman GF/F glass fiber filters and individually frozen until the extraction procedure was performed. The filter was ground in 4 ml of 90% acetone, with an additional 6 ml 90% acetone added prior to refrigeration. Once again, a Turner Designs 10-AU fluorometer was used for all chlorophyll *a* analysis.

2.8.2 Zooplankton

Zooplankton samples were collected biweekly at each site. A known volume of water (between 50 litres and 100 litres, depending on the site) was poured through a 200 μm plankton net. The sample was transferred to a glass jar and fixed with concentrated formalin. Subsamples (2 ml or 4 ml) were analyzed using a stereomicroscope.

3.0 RESULTS

3.1 Stream Gradient and Impoundment Morphology

There was considerable variation in morphological features among the impoundments (Table 2). Surface areas ranged from 2.7 x 10^4 m^2 at Maritime Electric to 34.1 x 10^4 m^2 at Wiseners. All of the ponds were shallow, particularly in the upper end, with maximum depth less than 4.0 metres in all but Larkins and Maritime Electric. Mean depths ranged from 0.8 m at Arsenaults Pond to 1.4 m in Wiseners and Larkins. Volume ranged from 3.5 x 10^4 m^3 at Grovepine to 4.8 x 10^5 m^3 at Wiseners. The shoreline development index at all sites was high, as is typical of river impoundments. The largest of the ponds, Wiseners, had the greatest maximum length (1,250 m) and maximum breadth (475 m), although Larkins also had a

Table 2. General morphometric characteristics of study sites.

Impoundment	Surface Area (ha)	Volume (m^3)	Shoreline Length (m)	Shoreline Dev'ment Index (m)	Relative Depth (%)	Mean Depth (m)	Max. Depth (m)	Max. Breadth (m)	Max. Length (m)
Arsenaults	4.7	3.9×10^4	1,855	2.4	1.06	0.83	2.60	120	625
Grovepine	3.7	3.5×10^4	3,200	4.7	0.83	0.95	1.8	100	125
MacDonalds	12.6	1.4×10^5	4,850	3.9	0.69	1.0	2.75	125	840
Maritime E.	2.7	3.8×10^4	1,700	2.9	2.10	1.3	3.95	55	380
Larkins	32.0	4.5×10^5	9,150	4.6	0.66	1.42	4.20	350	500
Officers	18.6	2.1×10^5	4,450	2.9	0.55	1.15	2.70	475	950
Scales	17.1	2.0×10^5	6,682	4.6	0.68	1.15	3.20	110	1,000
Wiseners	34.2	4.8×10^5	6,000	2.9	0.50	1.40	3.30	475	1,250

maximum breadth of 475 m. The Maritime Electric Pond and Grovepine impoundment both had low maximum length and breadth values.

Stream gradient varied among the impoundments (Table 3) and also between upstream and downstream reaches. The Fortune River had the lowest gradient, not exceeding 2.0 metres fall/km stream either upstream or downstream from the Grovepine impoundment. The Midgell River is also rather flat in topography, with 1.9 metres fall/km of stream both upstream and downstream from MacDonalds Pond (Table 3). The streams entering Arsenaults Pond on the Wilmot and the Maritime Electric Pond on the Valleyfield had gradients of 5.6 metres fall/km stream and 4.3 metres fall/km stream respectively (Table 3). The impoundments on the Wilmot and Valleyfield Rivers are located lower in the drainage basins, and gradients downstream from the dams are substantially lower, with 2.0 and 2.8 metres fall/km stream respectively (Table 3). Larkins Pond on the Naufrage and Officers Pond on the Winter River have higher gradients in downstream waters than in inflowing streams. Wiseners Pond is in the headwaters of Clarks Creek, and surrounding topography is flat. Downstream from the dam, however, there is a 3.7 metres fall/km stream to the head of tide (Table 3). Tributaries of the Dunk River drain a hilly section of Queens County known as the "Bonshaw Hills", and there is 3.4 metres fall/km stream leading into Scales Pond (Table 3). Downstream gradient is substantially lower at 2.1 metres fall/km stream.

Table 3. Stream gradient (metres fall/km stream) for all study sites.

Site	River	Gradient (metres fall/km stream)	
		upstream from dam	downstream from dam
Arsenaults	Wilmot	5.6	2.0
Grovepine	Fortune	2.0	1.3
Larkins	Naufrage		
South Branch		2.4	3.4
West Branch		3.1	
MacDonalds	Midgell	1.9	1.9
Maritime Electric	Valleyfield	4.3	2.8
Officers	Winter	2.3	3.8
Scales	Dunk	3.4	2.1
Wiseners	Clarks Ck.	2.0	3.7

3.2 Impoundment Water Residence Times

The theoretical water residence time within an impoundment can generally be calculated as the volume of the impoundment divided by the input of water into the impoundment (precipitation multiplied by the size of the drainage area). This formula relies on the assumption that all precipitation falling in the drainage basin within a given period of time will shortly thereafter flow through the impoundment. Thus, water residence times calculated using mean monthly precipitation will be shortest in December and show little variation from month to month. However, precipitation that falls in autumn and winter replenishes the water table and much is "stored" until the snow melts; by early fall, the water table is quite low. The mean monthly discharge in central and eastern Prince Edward Island is lowest in September, begins increasing in October, and reaches its greatest value in April (Anonymous 1989). As a consequence, monthly calculations of impoundment water residence time based on mean monthly precipitation do not accurately reflect seasonal flow conditions, but can serve as an index of residence time throughout the year. A calculation of residence time based on actual discharge measurements better reflects seasonal changes (eg. snow melt) and a fluctuating water table. These values are substantially higher than the index values (Table 4).

Regardless of the calculation used, the largest impoundment, Wiseners Pond, had a much longer water residence time (397.8 days) during summer, low water conditions than did all other study sites (Table 4). Water residence time at low flow in the other impoundments ranged from 0.4 days at Maritime Electric to 23.4 days at Larkins (Table 4). Residence times calculated using average monthly precipitation were much lower than the residence times

Table 4. Drainage basin area, volume, and water residence time calculated using discharge at low flow, and an index of water residence time calculated using mean monthly precipitation for December, April, and August, and average monthly precipitation.

Impoundment	Drainage basin area (km^2)	Volume (m^3)	Date of Discharge Measurement 1995	Residence Time (days)				
				low flow	December	April	August	avg monthly precip
Arsenaults	34.7	38,588	Sept 7	1.8	0.3	0.4	0.4	0.3
Grovepine	8.1	35,316	Aug 11	7.2	1.0	1.4	1.5	1.3
Larkins	25.4	453,543	Sept 8	23.4	4.2	5.9	6.3	5.4
MacDonalds	40.7	142,222	Sept 6	17.1	0.8	1.1	1.3	1.1
Maritime E.	77.2	38,333	Sept 6	0.4	0.1	0.2	0.2	0.2
Officers	37.0	212,617	Sept 8	13.6	1.3	1.9	2.0	1.7
Scales	95.8	197,500	Sept 7	2.9	0.5	0.7	0.7	0.6
Wiseners	11.7	481,250	Sept 8	397.8	10.0	14.3	14.3	12.5

calculated from impoundment discharge. Wiseners Pond and MacDonalds Pond had the greatest variation between the two values (Table 4). MacDonalds Pond had the third longest residence time based on discharge measurements but ranked fifth in the index value of water residence time. The order of the remaining impoundments from high to low residence times remained the same using both values.

3.3 Physical Characteristics

3.3.1 Water Transparency

Secchi disc transparencies varied considerably among impoundments (Table 5). Half of the ponds - Larkins, Wiseners, Arsenaults, and Grovepine - had mean Secchi disc transparency depths less than 60% of maximum depth (Table 5). The Maritime Electric Pond was clear throughout the study period and was the only site where the Secchi disc was consistently visible to the bottom of the pond (Figure 23). Arsenaults Pond was turbid throughout the summer. With the exception of the first sampling date which preceded heavy rainfall events, Secchi disc visibility at Arsenaults remained poor until late August (Figure 23). The seasonal pattern at Scales Pond was similar to Arsenaults (Figure 23). No consistent seasonal trends were evident for other impoundments (Figure 23).

3.3.2 Settling Rates of Suspended Particulate Matter

The mean settling rate of suspended particulate matter at Arsenaults Pond (1000 $g/m^2/2$ weeks) was more than twice that of all other impoundments, with particulate inorganic material (PIM) making up 85% of the total (Figure 24). Scales (301 $g/m^2/2$ weeks), Officers

Table 5. The range and mean Secchi disc transparencies and a comparison with maximum depth, 1994-95.

Pond	Maximum Depth (cm)	Secchi range (cm)	Secchi mean (cm)	Secchi % max depth
1994				
MacDonalds	275	170-275	227	83
Maritime Electric	395	>400	395	100
1995				
Wiseners	330	93-154	123	37
Grovepine	180	51-165	104	58
Larkins	420	89-173	137	33
Officers	270	153-250	193	71
Scales	320	152-282	224	70
Arsenaults	260	66-250	125	48

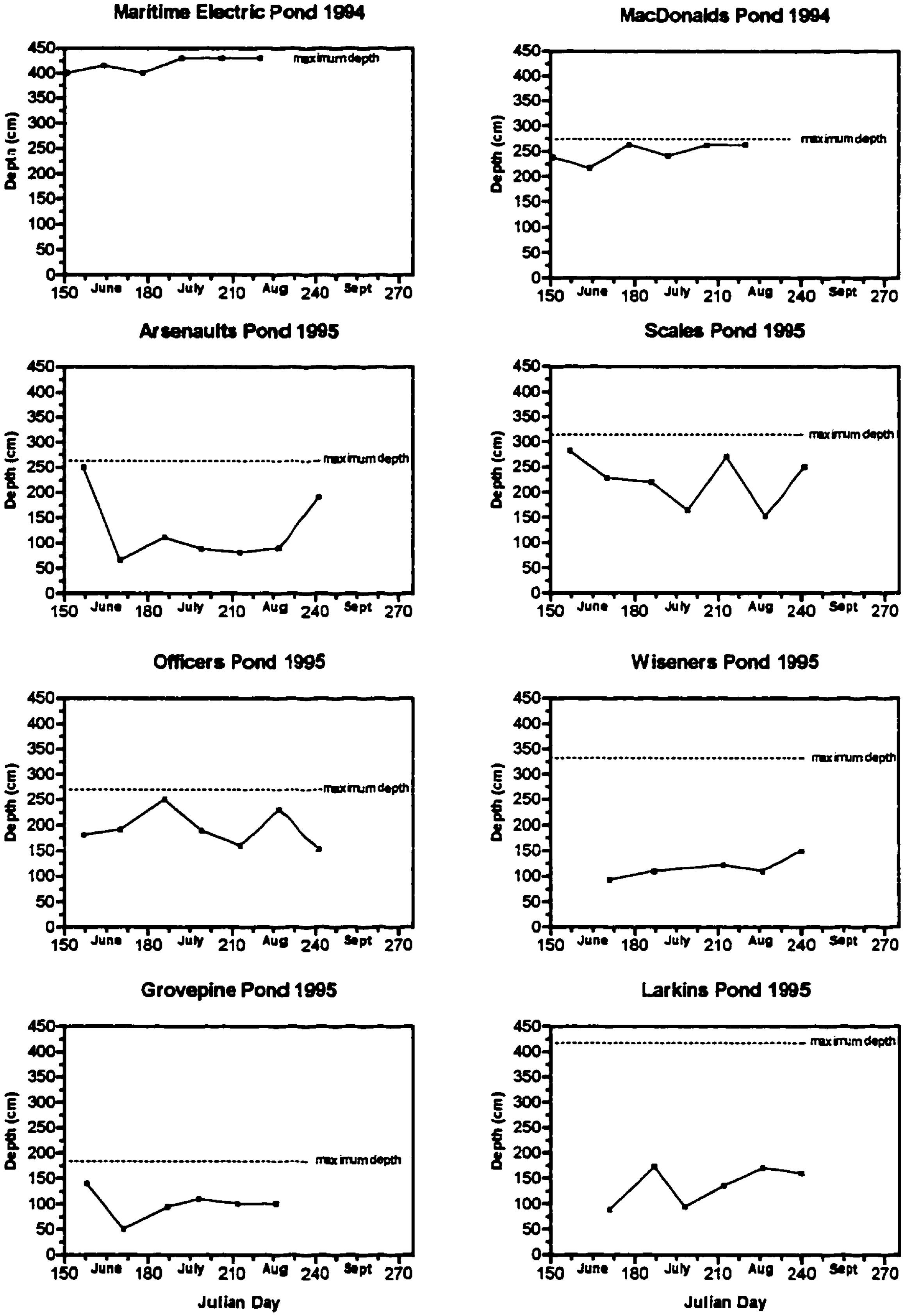


Figure 23. Seasonal variation in Secchi depth at all study sites, 1994-95.

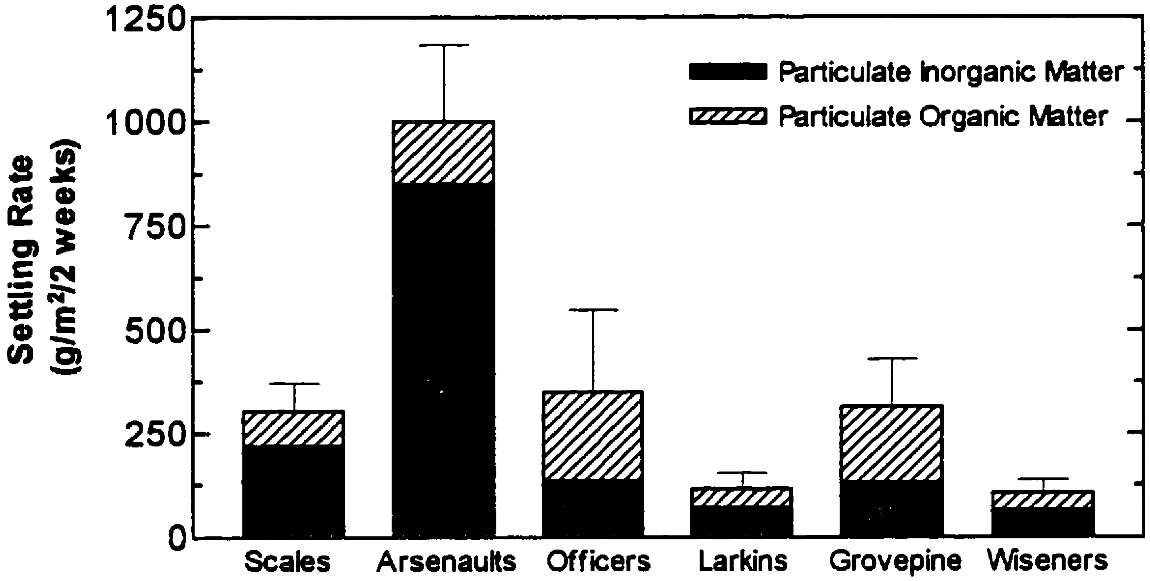


Figure 24. Comparison of mean PIM and POM (TPM) settling rate (g/m^2/2 weeks) at Scales, Arsenaults, Officers, Larkins, Grovepine, and Wiseners, 1995. Error bars represent one standard error of the mean.

(348 g/m^2/2 weeks), and Grovepine (313 g/m^2/2 weeks) had similar settling rates. Particulate organic material (POM) represented the greatest percentage of the total at Officers (61%) and Grovepine (59%), whereas inorganic material represented 72% of the total at Scales. Settling rates at Larkins (114 g/m^2/2 weeks) and Wiseners (106 g/m^2/2 weeks) were considerably lower than at other impoundments (Figure 24).

Officers, Larkins, and Grovepine all had peaks in settling rate in early July and, with the exception of Grovepine, another peak in mid August (Figure 25). Most of the variation in settling rate at Arsenaults and Scales was in inorganic matter, however there was no common seasonal trend between the two sites. Heavy rainfall in the first week of June (Figure 26) could account for high initial settling rates (>300 g/m^2/2 weeks) at Scales. Arsenaults Pond remained turbid throughout the summer, and settling rates of particulate inorganic matter at this site averaged 850 g/m^2/2 weeks for the summer. The greatest value of PIM at Arsenaults, 1,209 g/m^2/2 weeks, was recorded on 15 August.

3.3.3 Suspended Particulate Matter

The mean Total Particulate Matter (TPM) concentrations for the Midgell and Valleyfield rivers in 1994 were identical at 1.80 mg/L (Figure 27). The proportion of inorganic and organic matter, however, differed between the two systems. Organic material made up 43% of TPM on the Midgell River and 32% of TPM on the Valleyfield River. Particulate inorganic matter was consistently higher than particulate organic matter at all stations on the Valleyfield River (Figure 28). The components of TPM were more variable on the Midgell

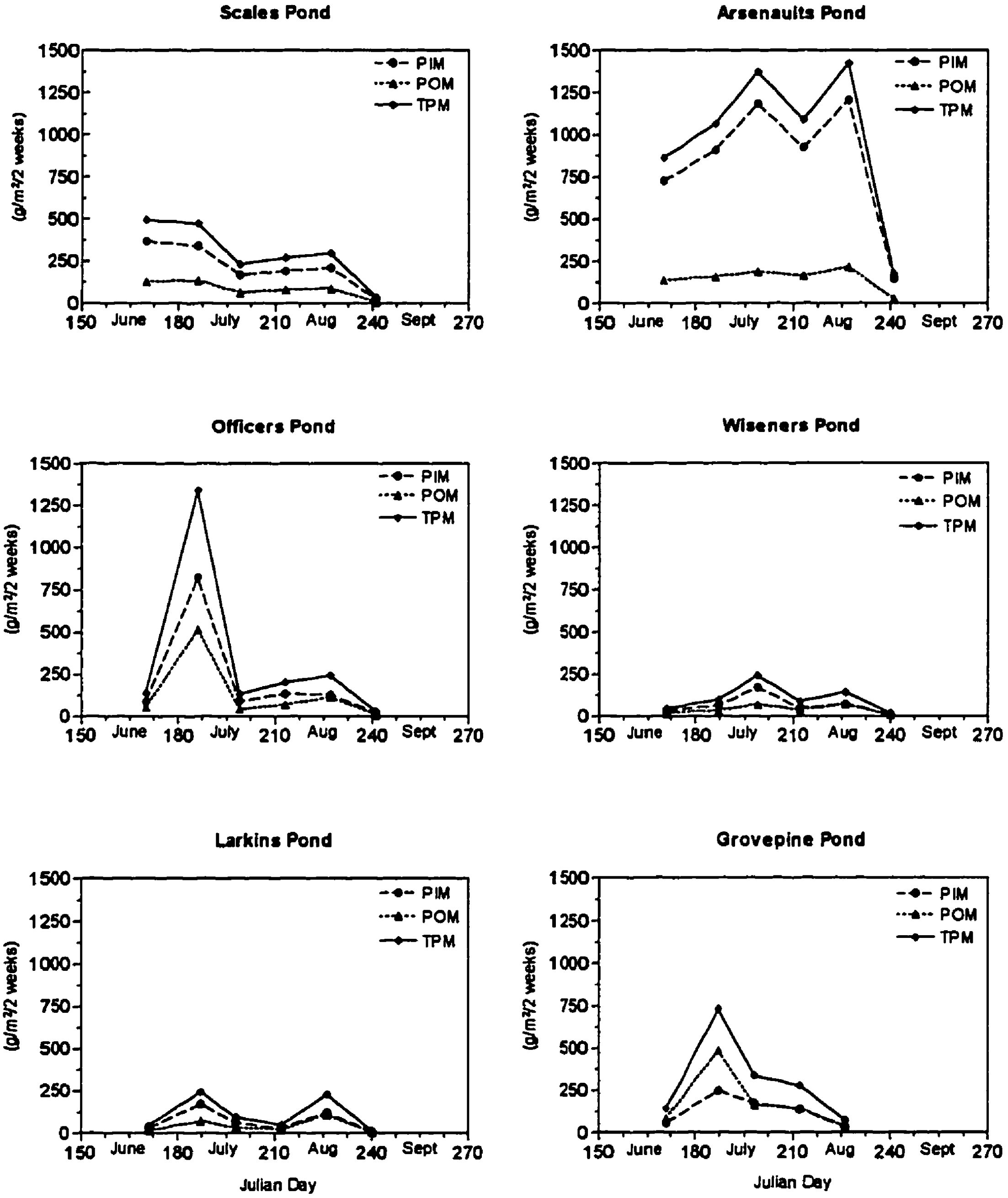


Figure 25. Seasonal variation in settling rate of particulate inorganic and organic matter (g/m^2/2 weeks) in suspended sediment traps, 1995.

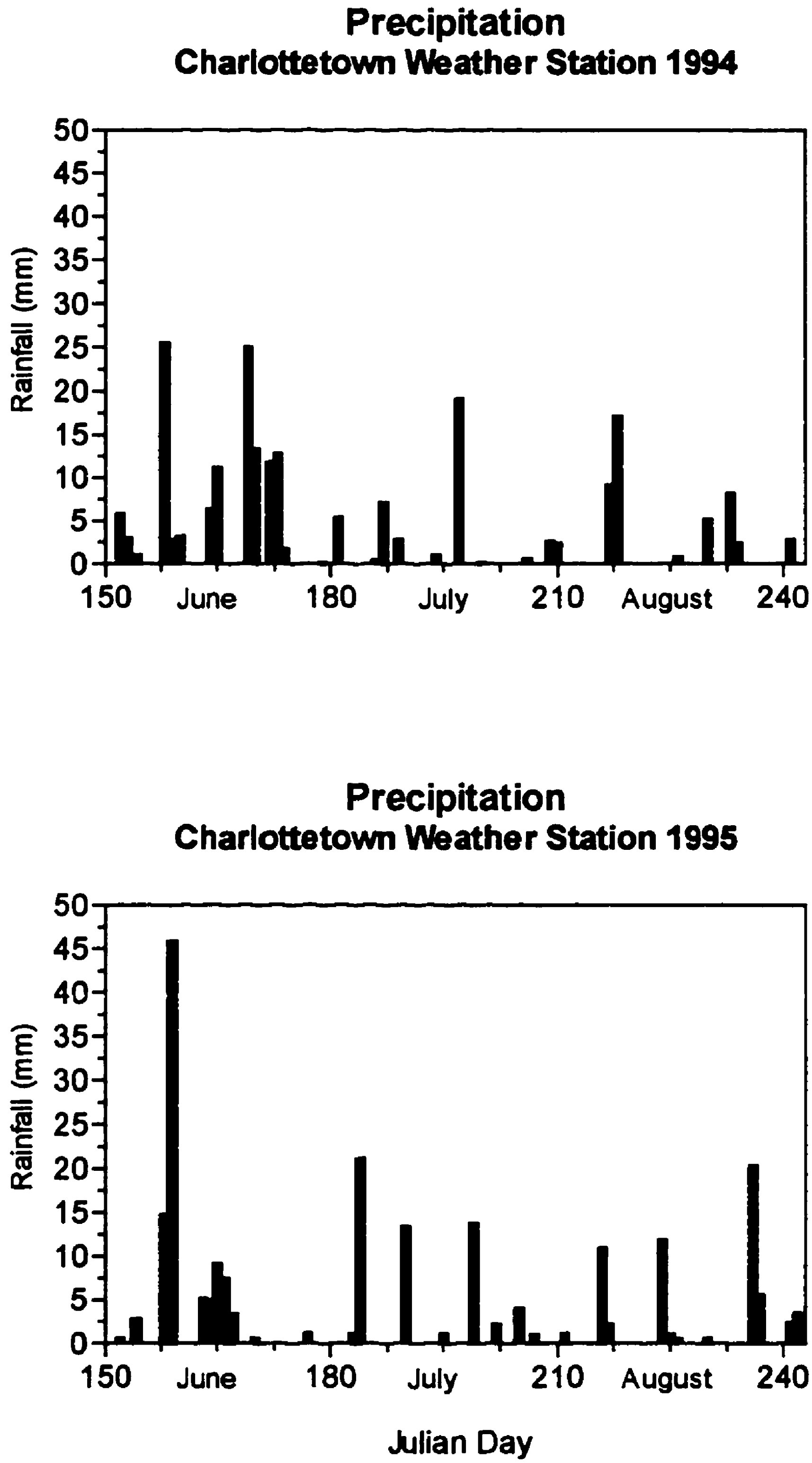


Figure 26. Daily total rainfall recorded at Environment Canada - Charlottetown Weather Station - from June to August, 1994 and 1995.

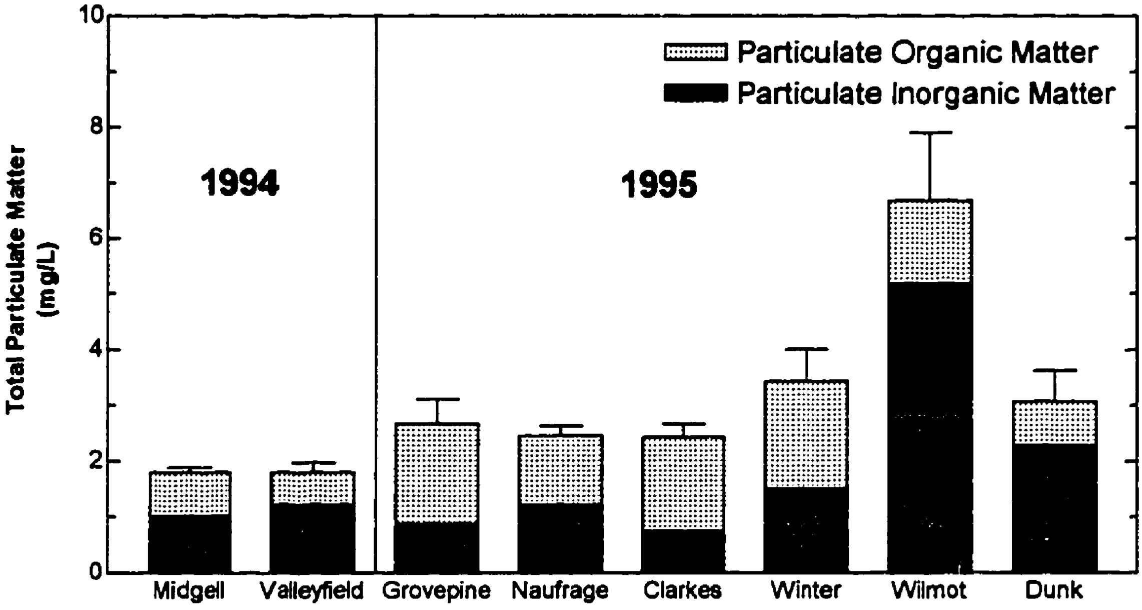


Figure 27. Mean total particulate matter (mg/L) at all stations for each study site, 1994-95. Error bars are one standard error of the mean.

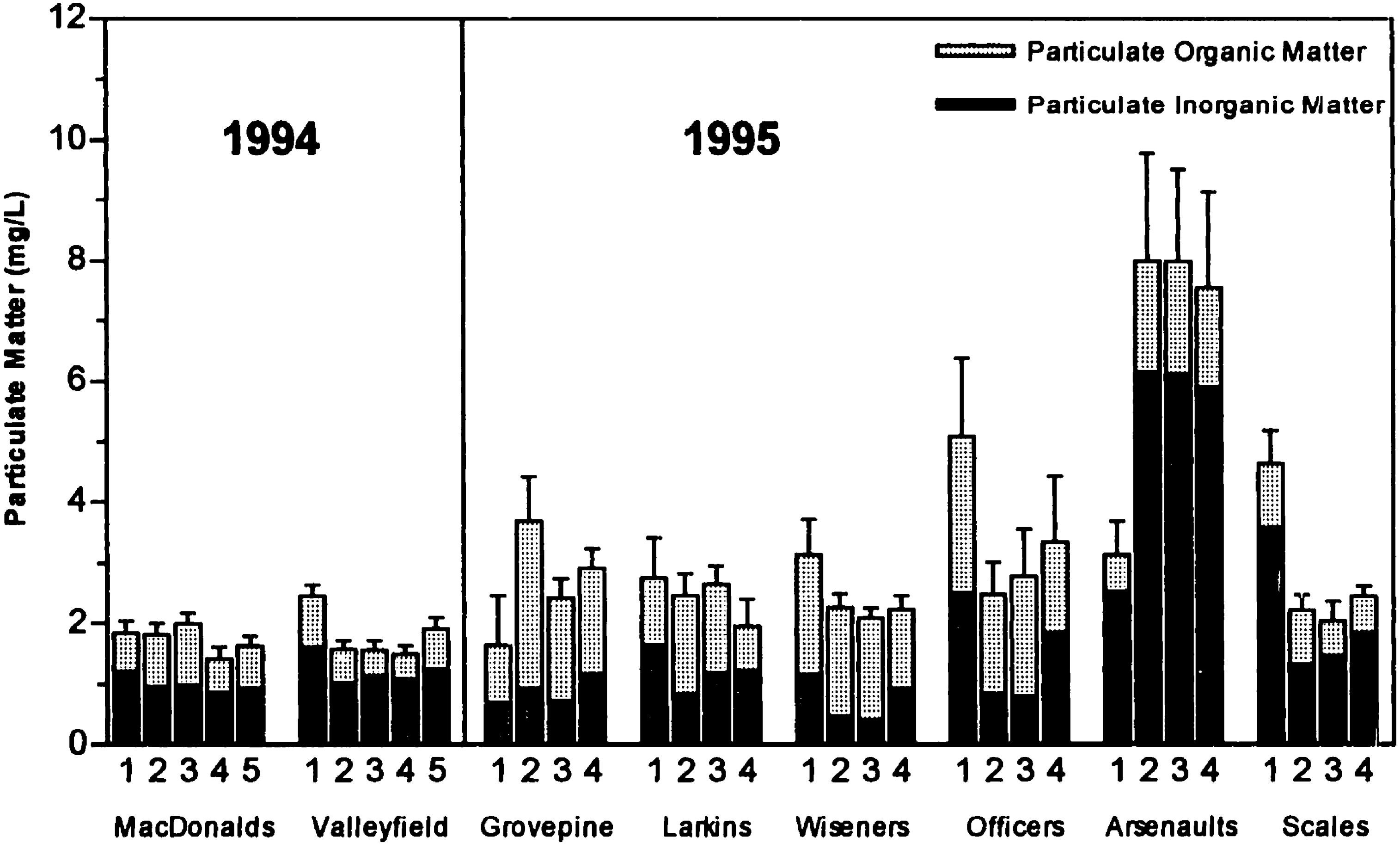


Figure 28. Mean total particulate matter at the inlet (1), pond (2), outlet (3), first downstream (4) and second downstream (5) sampling stations at all study sites, 1994-95. Error bars are one standard error of the mean.

River; PIM exceeded POM at the inlet and downstream stations, with a more even split evident at the pond and outlet. PIM significantly decreased from the inlet of the Maritime Electric Pond to the outlet (*t* test, p=0.03) and remained significantly lower at all downstream sites (Figure 28). This trend was not evident in the Midgell River. There was no obvious seasonal trend in concentration of PIM or POM at either site (Figures 29-30).

Mean concentration of total particulate matter on the Wilmot River (6.64 mg/L) was substantially higher than at all other sites in 1994 or 1995 (Figure 27). Although mean TPM concentrations were similar on the Winter and Dunk rivers for all stations (3.43 mg/L and 3.07 mg/L respectively), PIM made up 75% of TPM on the Dunk River and only 44% of TPM on the Winter River. Both Arsenaults and Scales had a greater proportion of inorganic as opposed to organic matter at all stations, unlike the other sites where PIM and POM were more evenly split or the organic matter component was more pronounced (Figure 28). There was a general trend at most sites for PIM to decrease from inlet to outlet stations, with a significant difference evident in the *t* test comparison between inlet and outlet stations at Scales (p=.006) and Officers (p=.02). Arsenaults Pond stands out as the only site where PIM concentrations at the inlet (2.54 mg/L) were significantly lower than PIM at all other sampling stations. The change in POM from inlet to outlet stations also varied, depending on the site. There was a significant increase in POM from inlet to outlet at both Arsenaults (p=.01) and Grovepine (p=.05). Wiseners and Officers both had high POM values at the inlet in comparison to the inlet station at other impoundments (Figure 28). This may reflect export

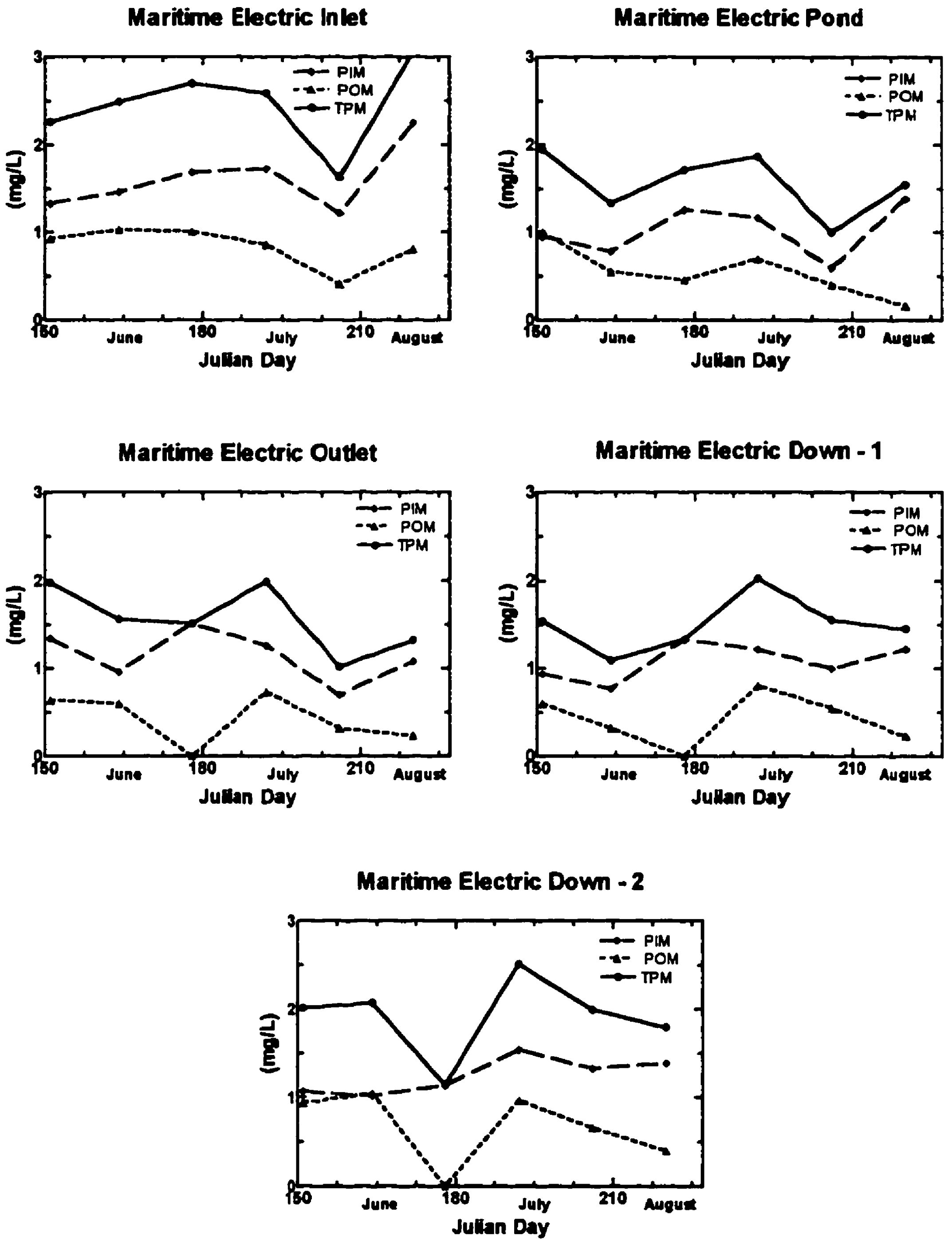


Figure 29. Seasonal variation in particulate matter at all sampling stations on the Valleyfield River, 1994.

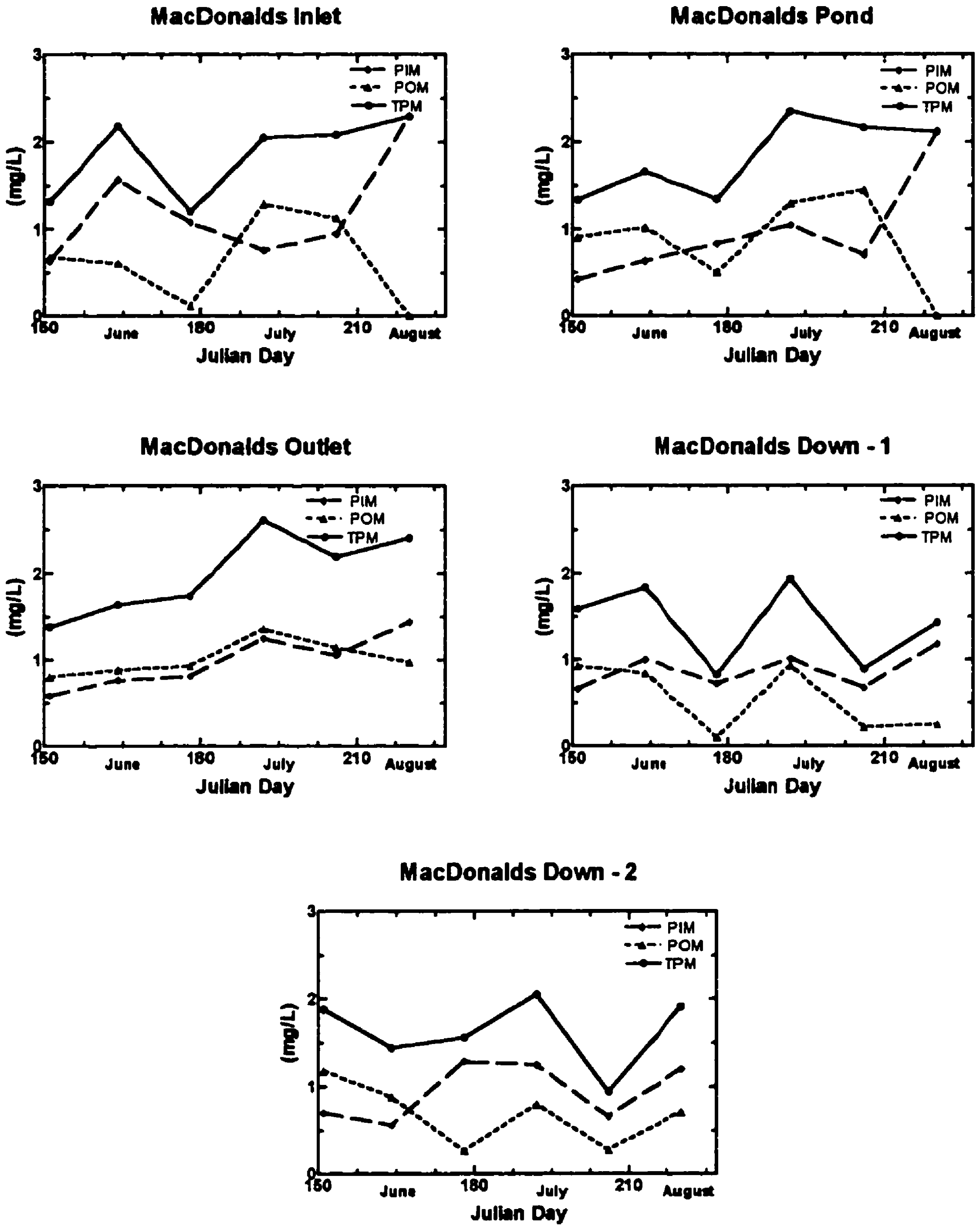
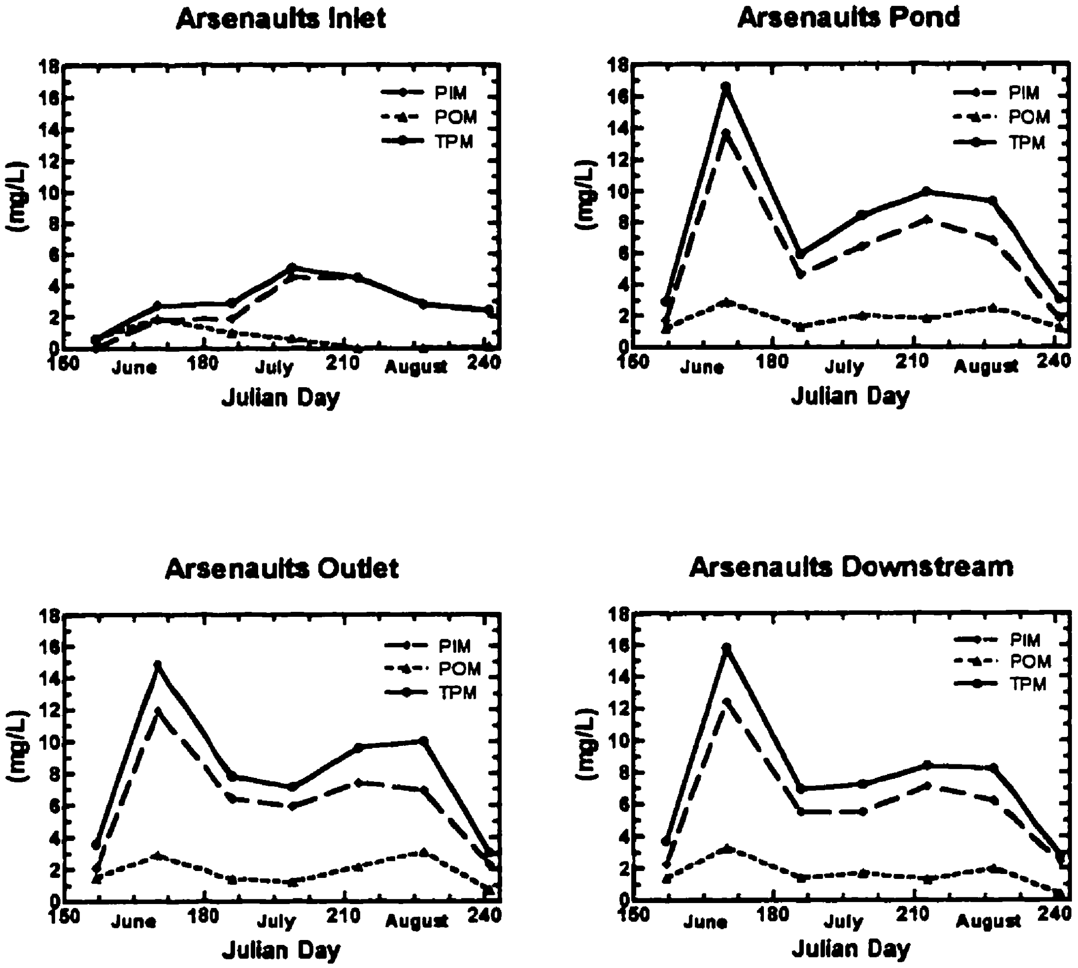


Figure 30. Seasonal variation in particulate matter concentration at all sampling stations on the Midgell River, 1994.

of organic matter from impounded water upstream from Wiseners and Officers. There were no consistent seasonal trends in particulate matter levels (Figures 31-36).

3.3.4 Water Temperature and Thermal Stratification

All of the impoundments were thermally stratified (Figures 37-43). However, only at the deepest impoundment, Larkins Pond, was the stratification strong enough to remain virtually unchanged throughout the summer (Figures 39 and 43). The mean difference between daily mean temperature at the surface and bottom at Larkins was 9°C and reached a maximum of 13°C. At other impoundments, stratification weakened with wind or rainfall events. In 1994, the breakdown in stratification took place in early August, with cool air temperatures and rainy weather (Figures 26,41). Although stratification re-established, water temperatures never returned to the high values recorded in July. In 1995, temperature stratification weakened at Officers, Wiseners, and Grovepine on days with low mean air temperature, windy conditions (>25 km/hr) and rainfall. For example, heavy rainfall on 8 June, 1995, was accompanied by maximum wind gusts of 37 km/hr (Environment Canada Atmospheric Environment Service). Thermal stratification at Officers and Wiseners was particularly susceptible to breakdown in windy conditions, probably because of their warmer bottom water temperatures and large breadth. In late August, 1995, the ponds destratified during a series of windy days, with wind gusts up to 56 km/hr (Environment Canada Atmospheric Environment Service). Mean surface water temperature followed the same pattern shown in mean daily air temperature, both in 1994 (Figure 41) and 1995 (Figure 44). Mean water temperature in the bottom layers of MacDonalds, Officers, and Wiseners ponds was warm,

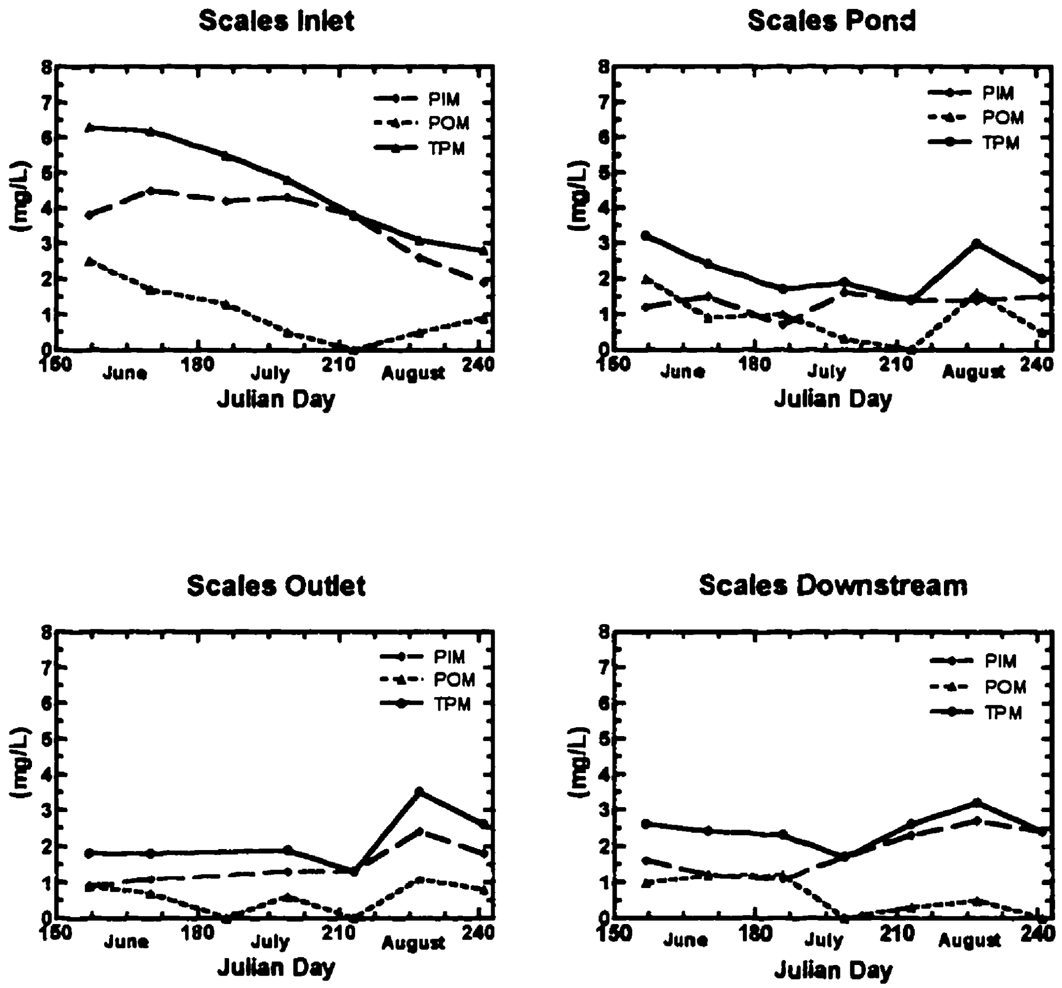

Arsenaults Inlet

Arsenaults Pond

Arsenaults Outlet

Arsenaults Downstream

Figure 31. Seasonal variation in particulate matter concentration at all sampling stations on the Wilmot River, 1995.



Scales Inlet

Scales Pond

Scales Outlet

Scales Downstream

Figure 32. Seasonal variation in particulate matter concentration at all sampling stations on the Dunk River, 1995.

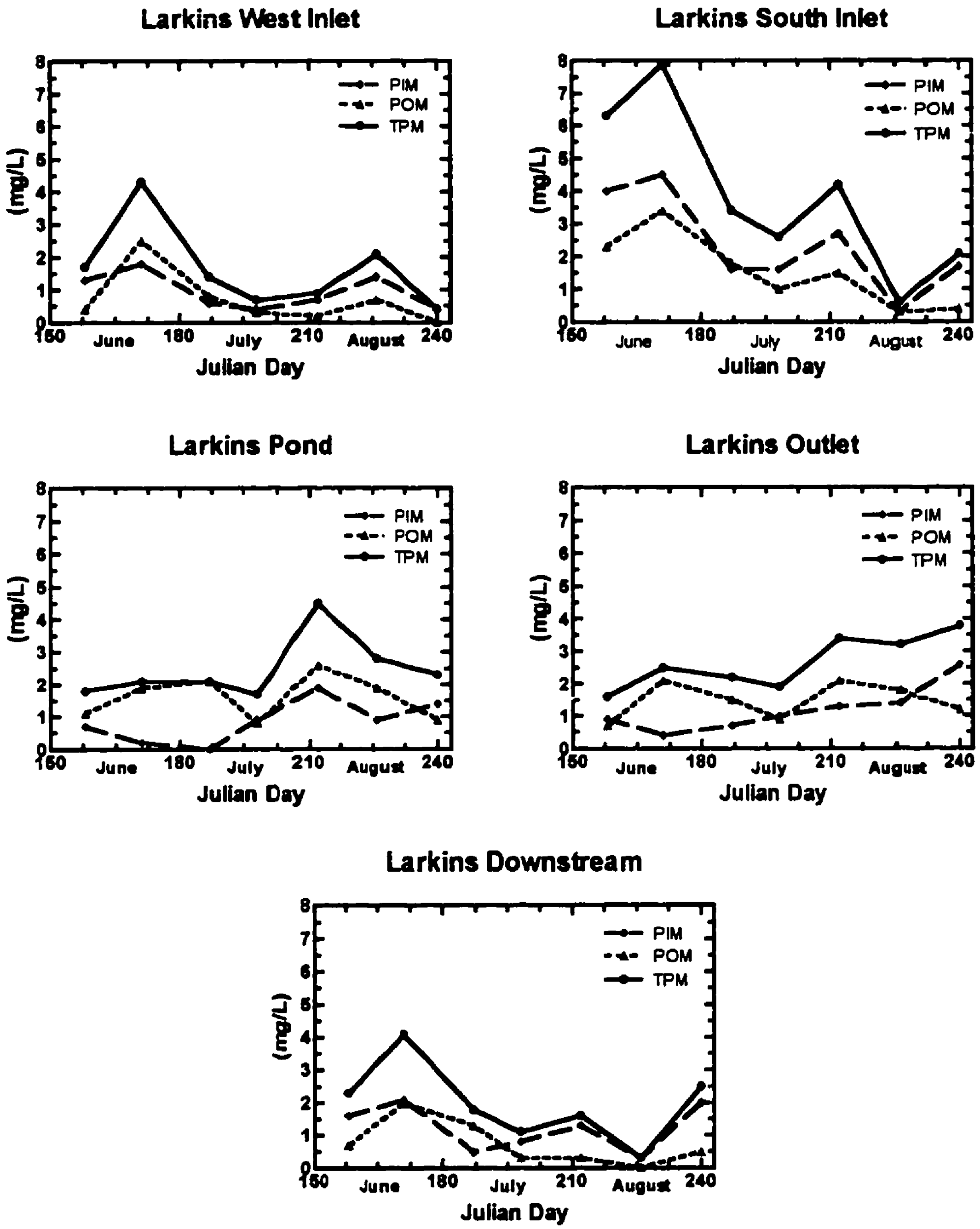


Figure 33. Seasonal variation in particulate matter concentration at all sampling stations on the Naufrage River, 1995.

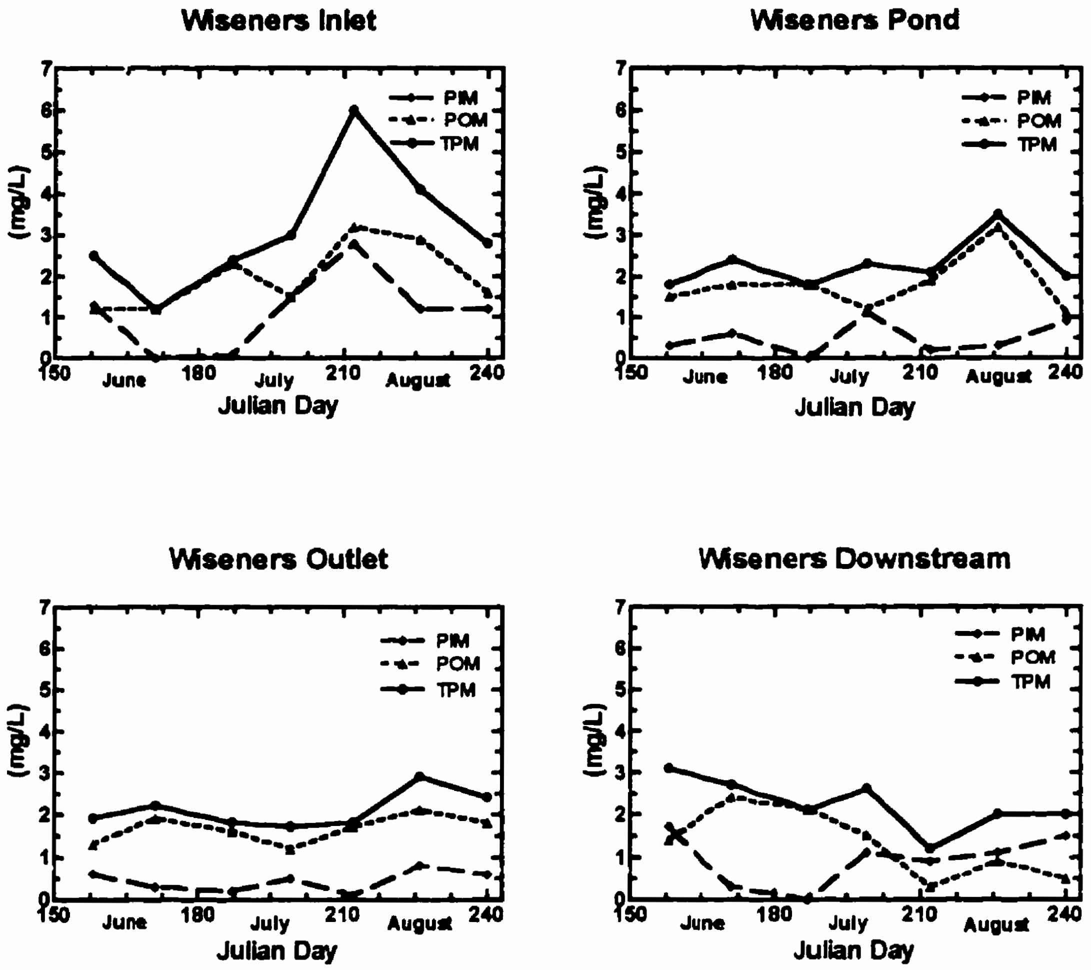


Figure 34. Seasonal variation in particulate matter concentration at all sampling stations on Clarks Creek, 1995.

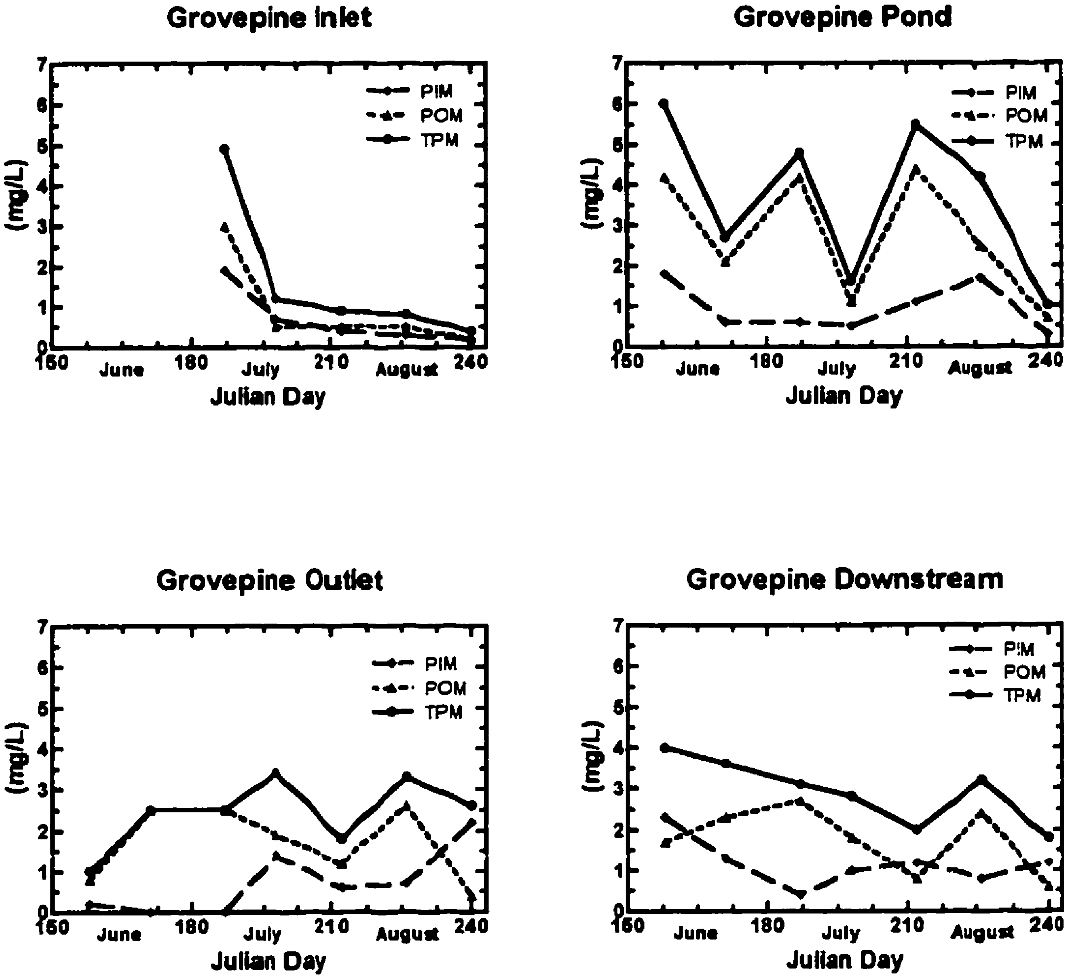
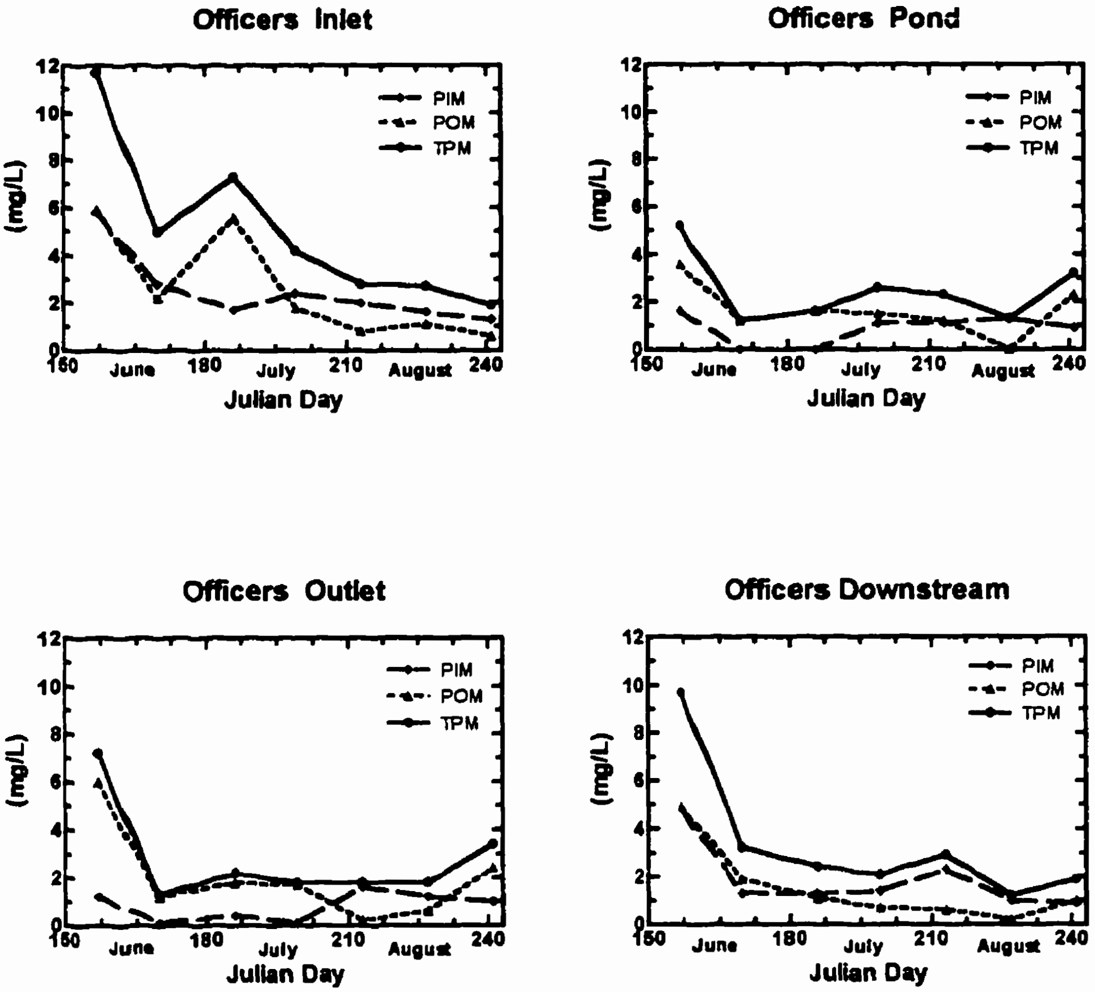


Figure 35. Seasonal variation in particulate matter concentration at all sampling stations on Grovepine Brook, 1995.


Officers Inlet

Officers Pond

Officers Outlet

Officers Downstream

Figure 36. Seasonal variation in particulate matter concentration at all sampling stations on the Winter River, 1995.

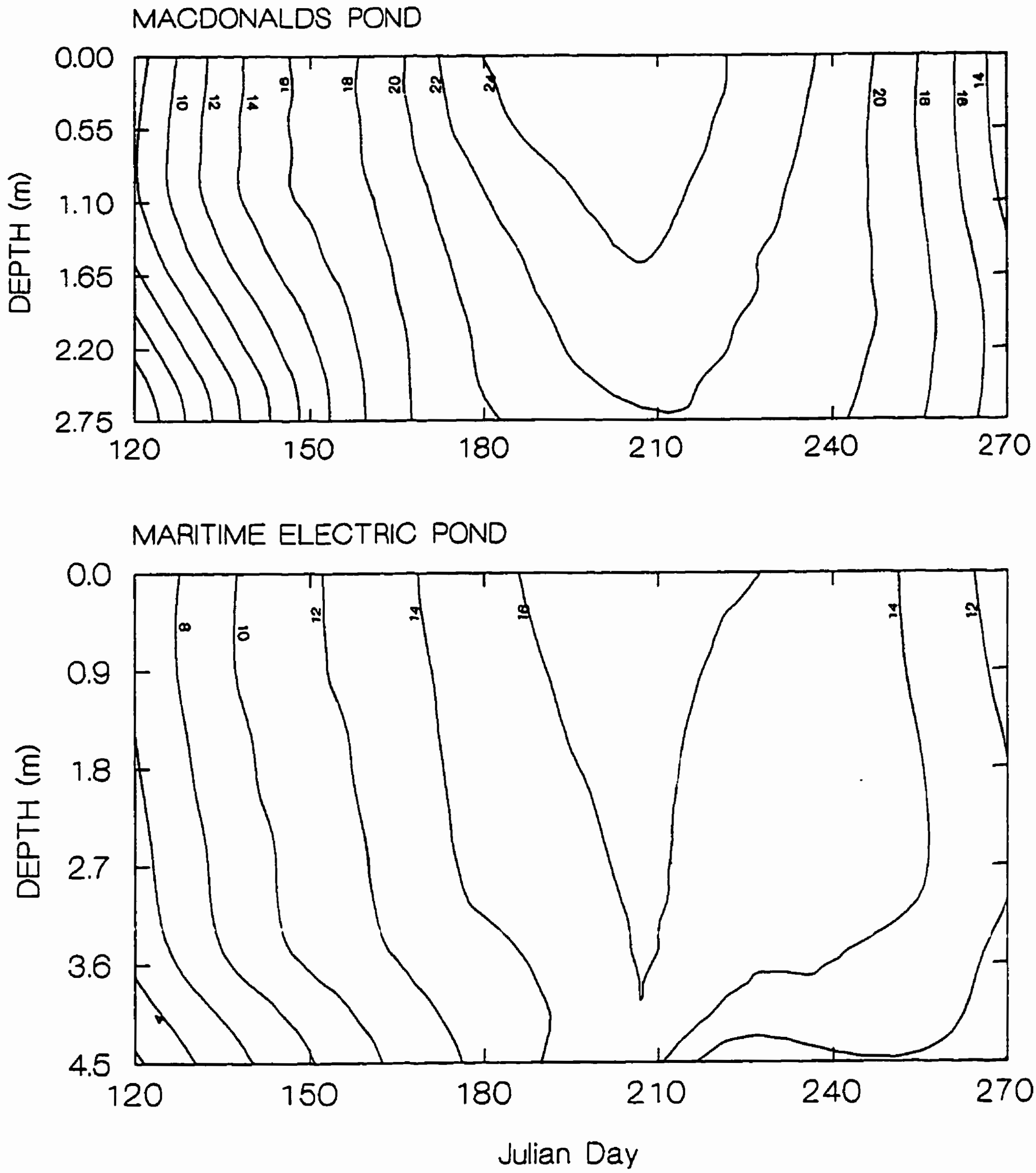


Figure 37. Seasonal water temperature isopleths for MacDonalds Pond and Maritime Electric Pond, 1994.

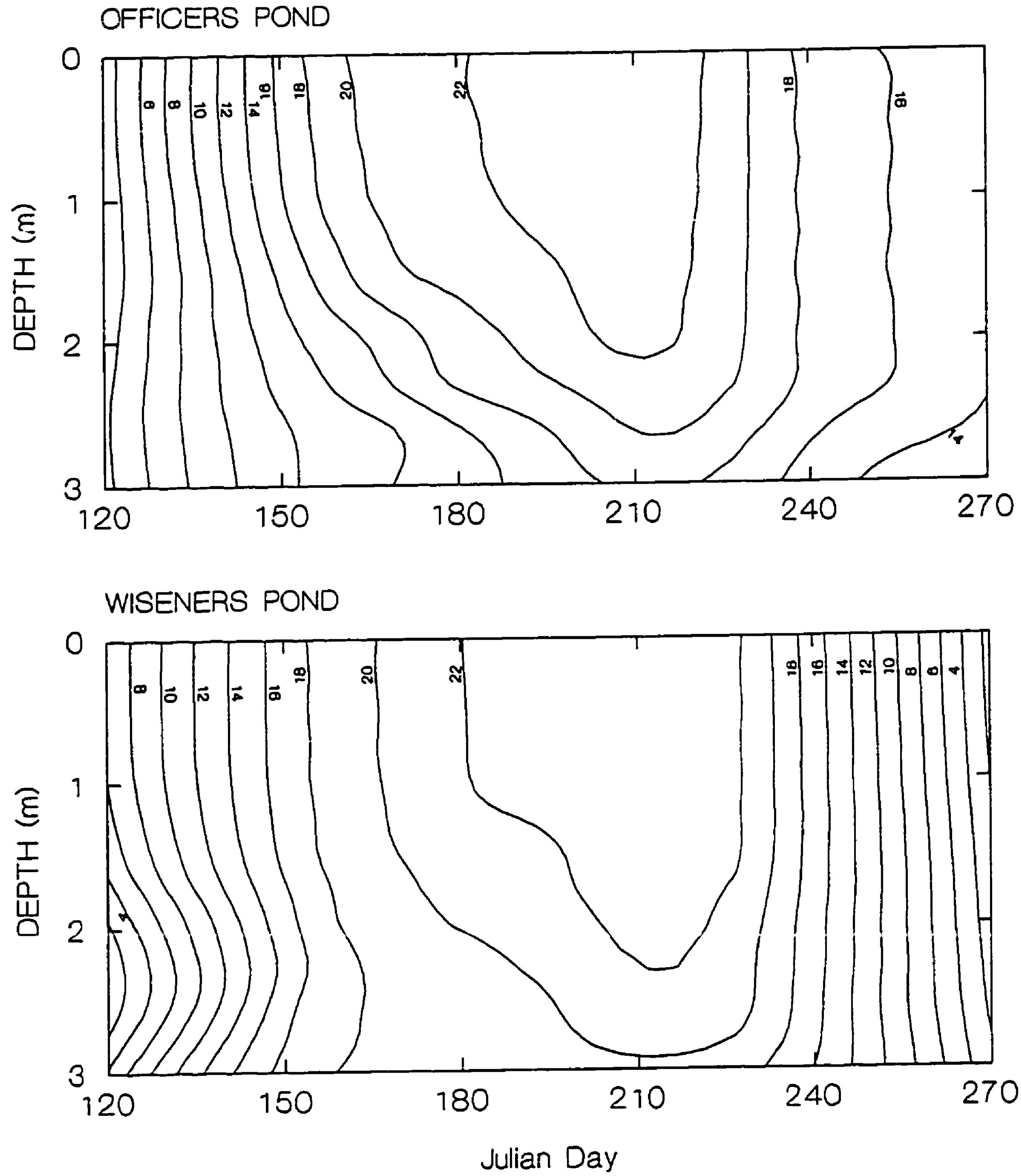


Figure 38. Seasonal water temperature isopleths for Officers Pond and Wiseners Pond, 1995.

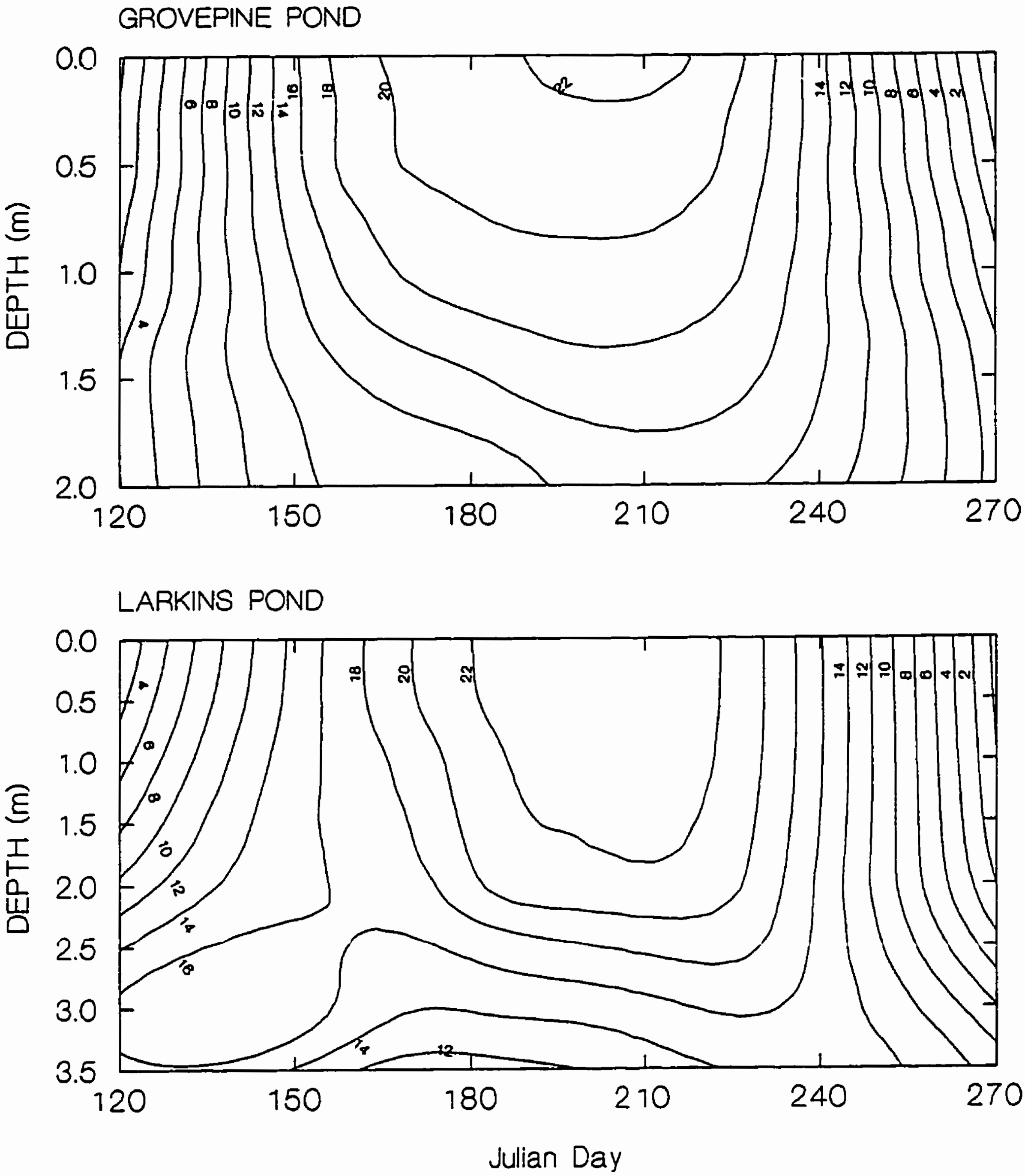


Figure 39. Seasonal water temperature isopleths for Grovepine Pond and Larkins Pond, 1995.

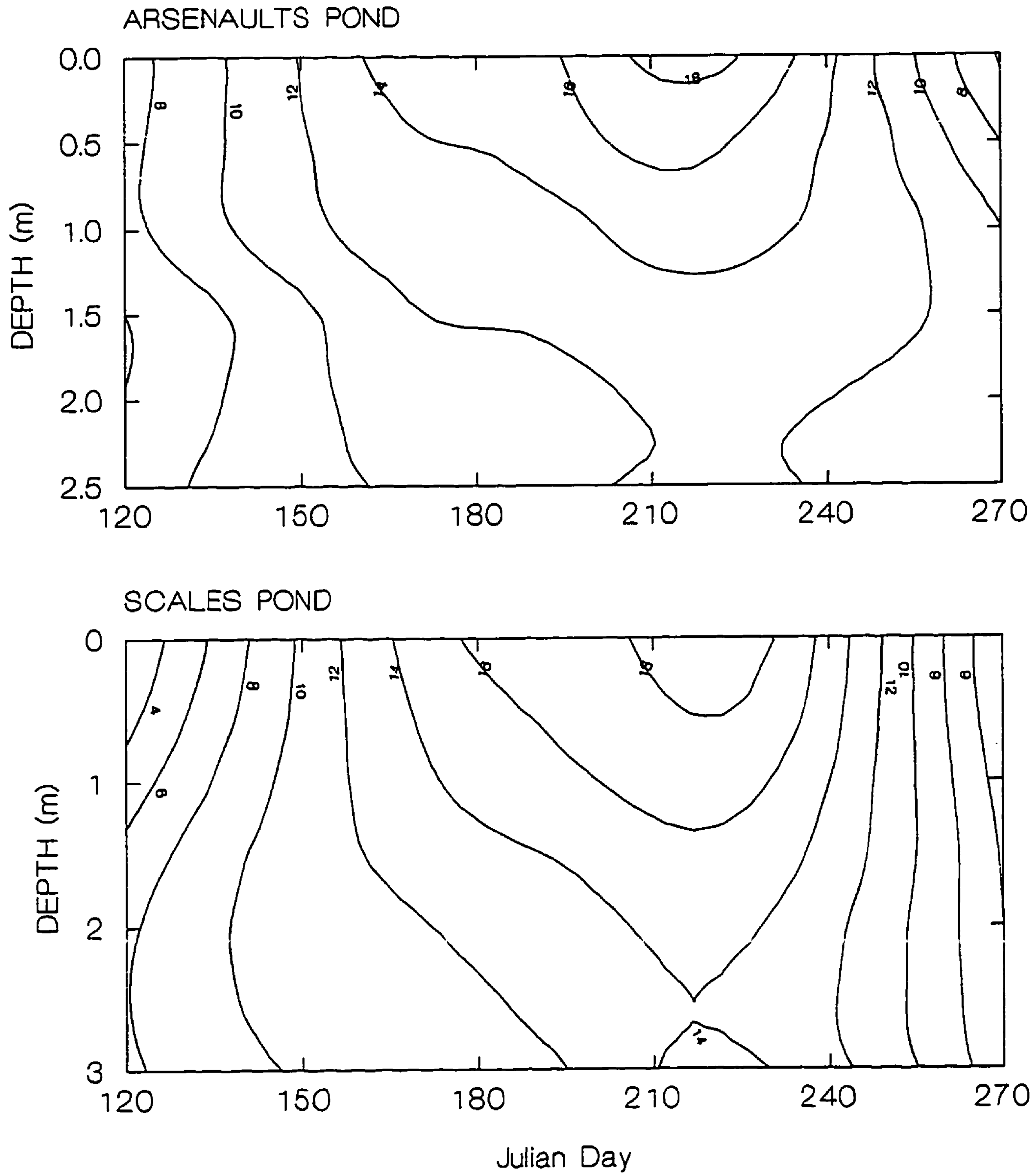


Figure 40. Seasonal water temperature isopleths for Arsenaults Pond and Scales Pond, 1995.

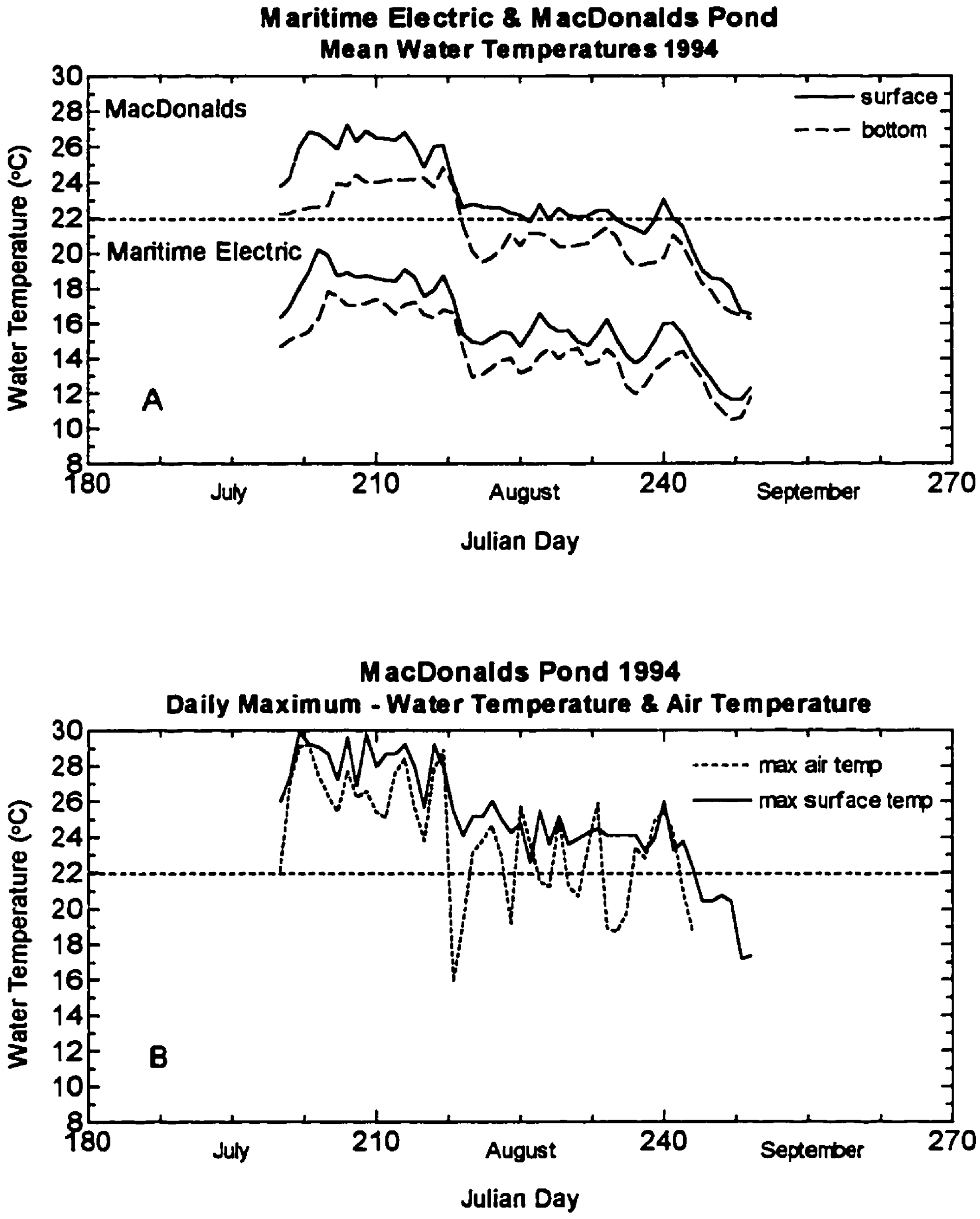
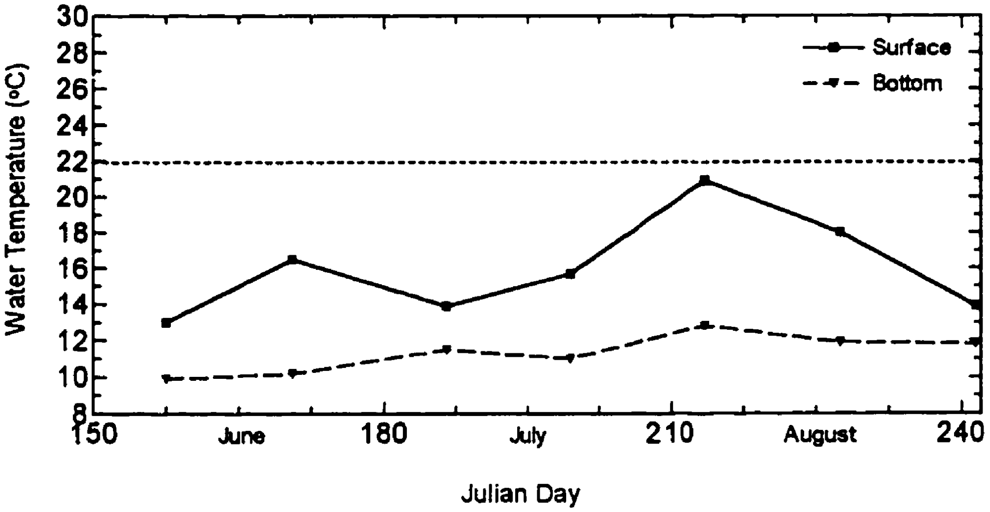


Figure 41. Mean daily surface and bottom water temperatures at MacDonalds Pond and Maritime Electric Pond (A), and comparison between daily maximum air temperature and daily maximum surface water temperature at MacDonalds Pond (B), 1994.

Arsenaults Pond 1995



Scales Pond 1995

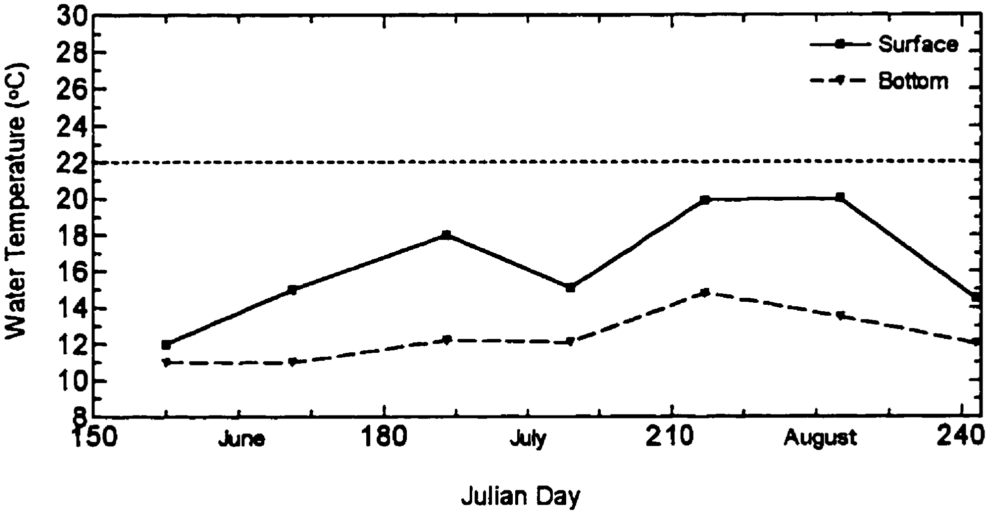


Figure 42. Seasonal variation in water temperature at the surface and bottom of Arsenaults and Scales, 1995.

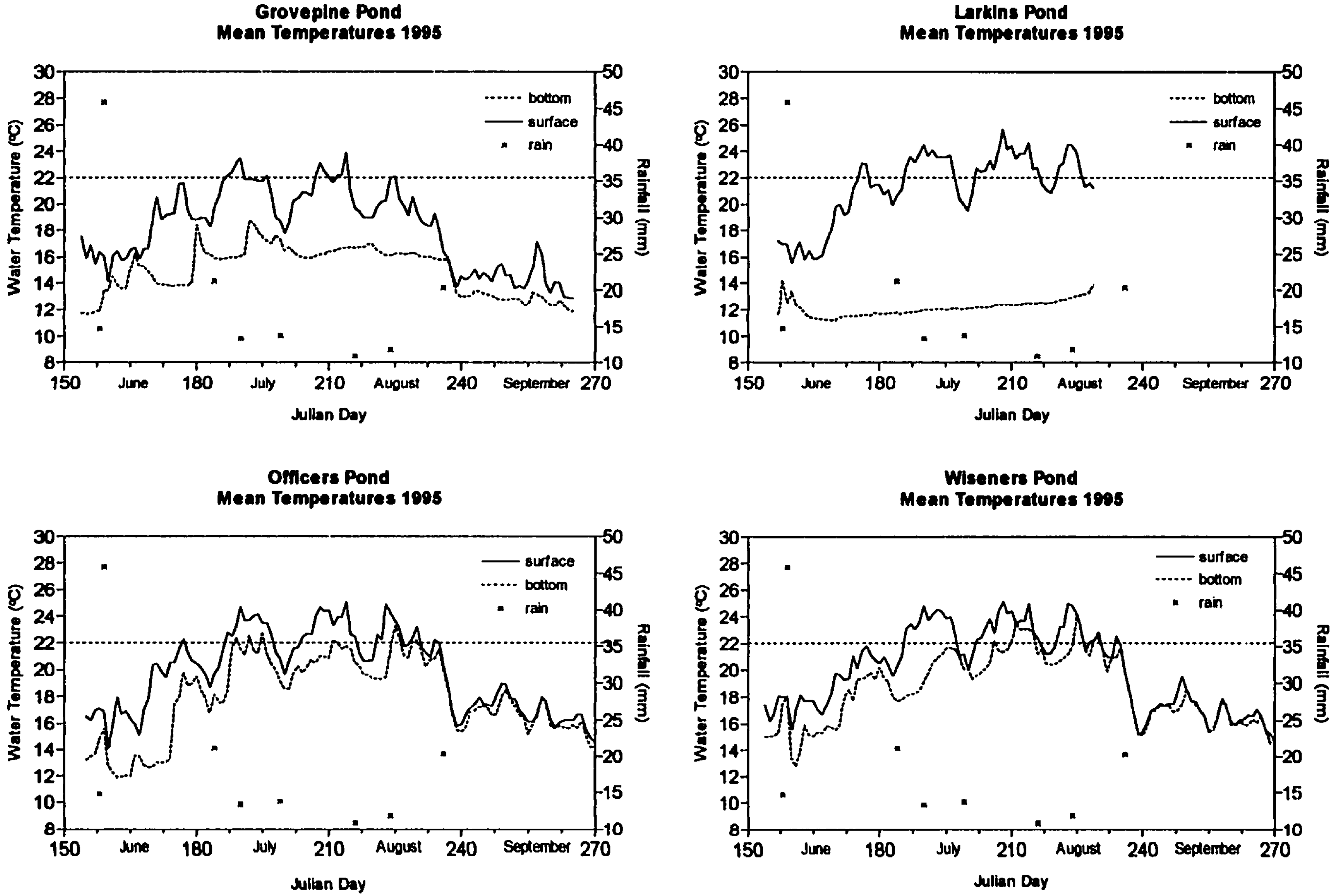


Figure 43. Thermal stratification and precipitation at Grovepine, Larkins, Officers, and Wiseners, 1995.

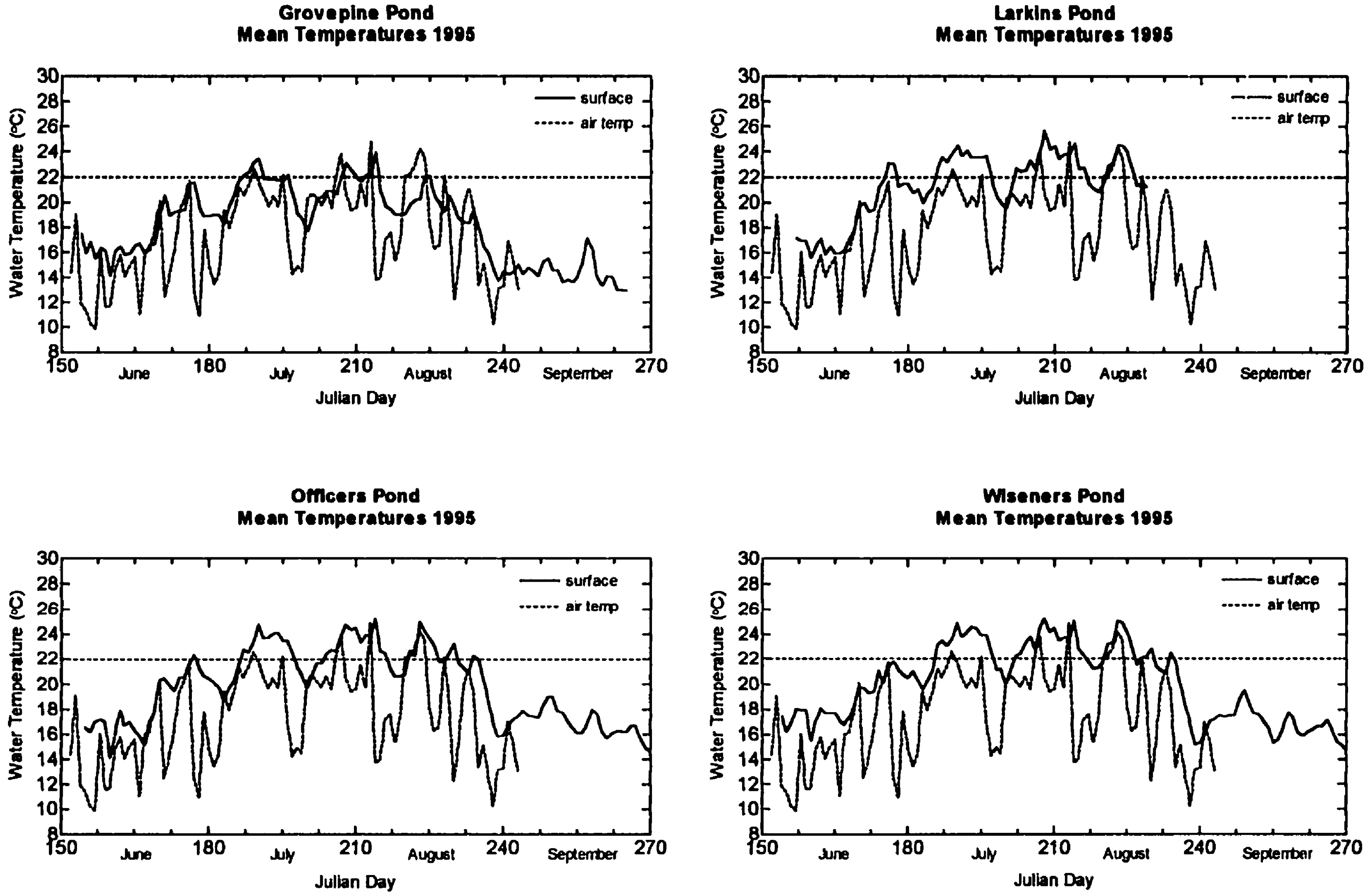


Figure 44. Relationship between mean air temperature and surface temperature at Grovepine, Larkins, Officers, and Wiseners, 1995

and reached or exceeded 22°C in July and August (Figures 41 and 43). In graphical analysis and interpretation of water temperature data, 22°C is identified as the upper tolerable water temperature for salmonids (MacMillan 1998, Sinokrot et al. 1995).

There was considerable variation in water temperature among the rivers studied. Water temperatures on the Valleyfield, Dunk, and Wilmot rivers were much cooler than the other systems (Figure 45). However, in all rivers, water temperature at the outlet of each impoundment was warmer than inflowing water (Figures 45-49). The mean temperature difference from inlet to outlet varied among impoundments, and ranged from 0.7°C in MacDonalds and Maritime Electric to 6.7°C at Officers (Table 6). Impoundments with a long residence time, for example Larkins and Officers, had a greater difference between inlet and outlet temperatures than ponds like Scales and Grovepine (Table 6). Although Wiseners Pond had the longest water residence time, there is another factor to take into consideration when examining its impact on water temperature. Midway through July, outflow at this impoundment diminished to a trickle, but groundwater at 7°C continued to flow through springs downstream from the dam. As a result, downstream water temperatures, which had been warmer than the inlet until mid-July, became cooler than the inlet until early August when outflow was restored (Figure 48). At this time, the temperature recorder, which had unknowingly become exposed from 22 July to 2 August in low flow conditions, was again submerged.

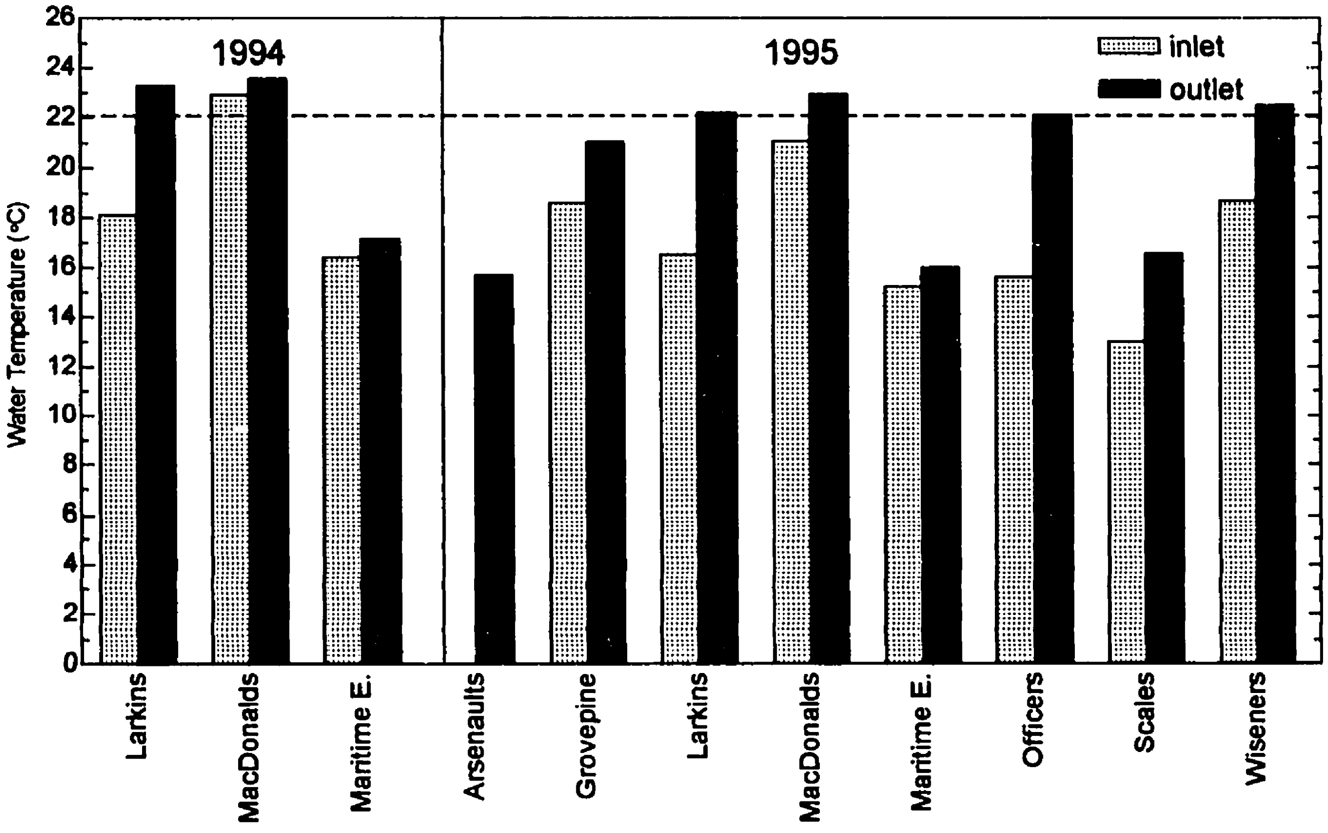
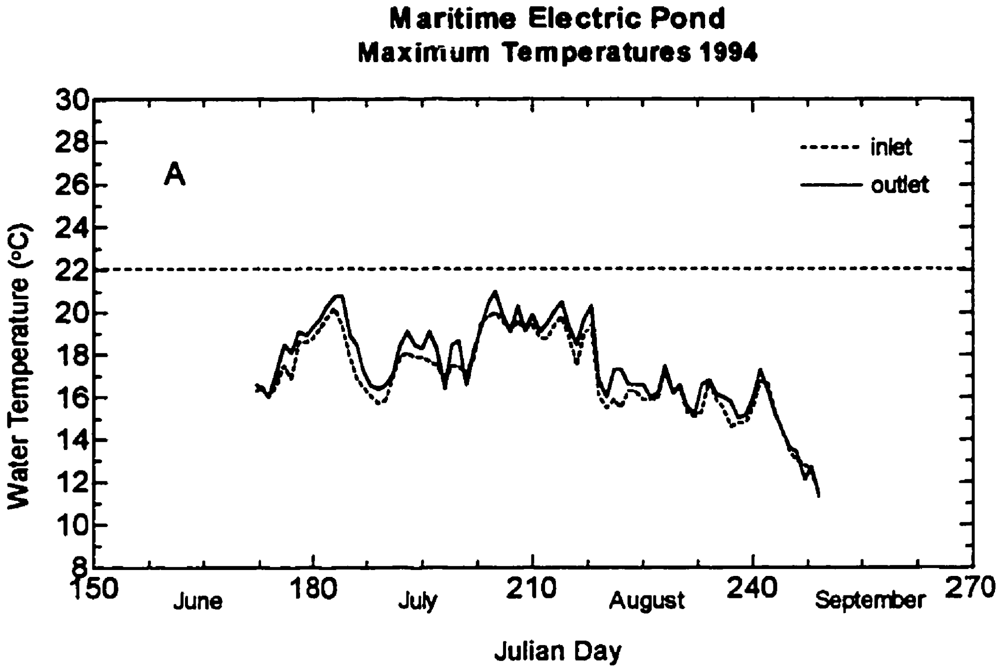


Figure 45. Mean July water temperature at impoundment inlets and outlets, 1994 and 1995. Complete data set of 31 days for all sites except MacDonalds 1995 (1-17 July), Grovepine (7-31 July) and Wiseners (1-20 July).



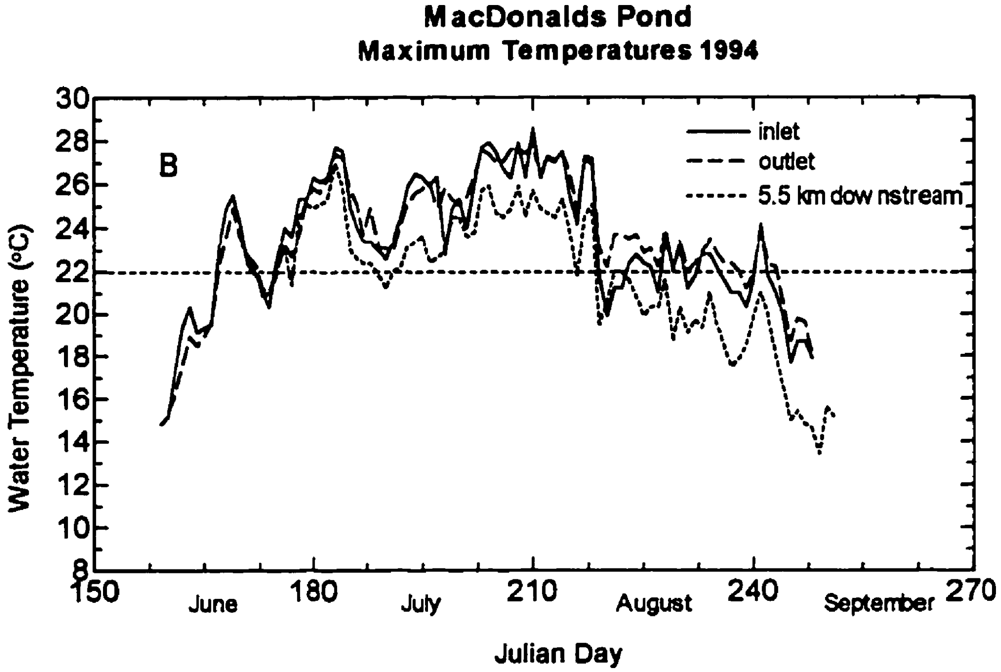
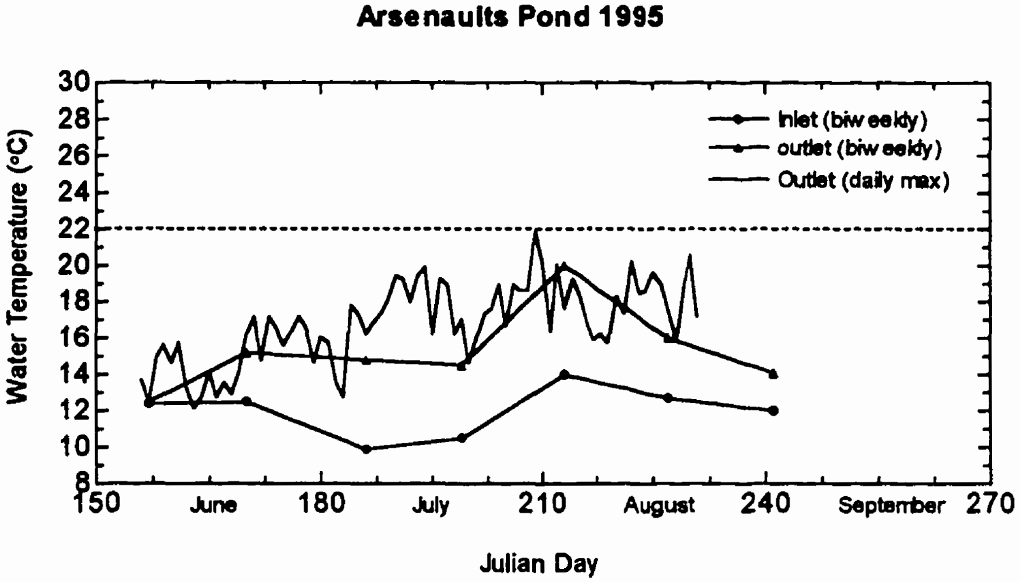


Figure 46. Maximum daily water temperatures at the inlet and outlet stations on the Valleyfield River (A), and at the inlet, outlet, and downstream stations on the Midgell River (B), 1994.



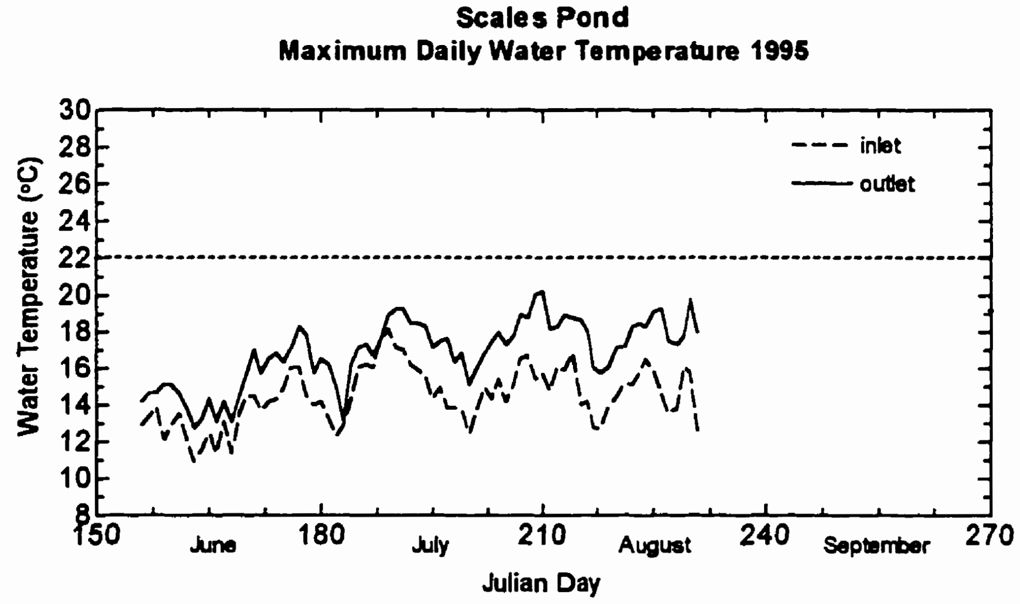
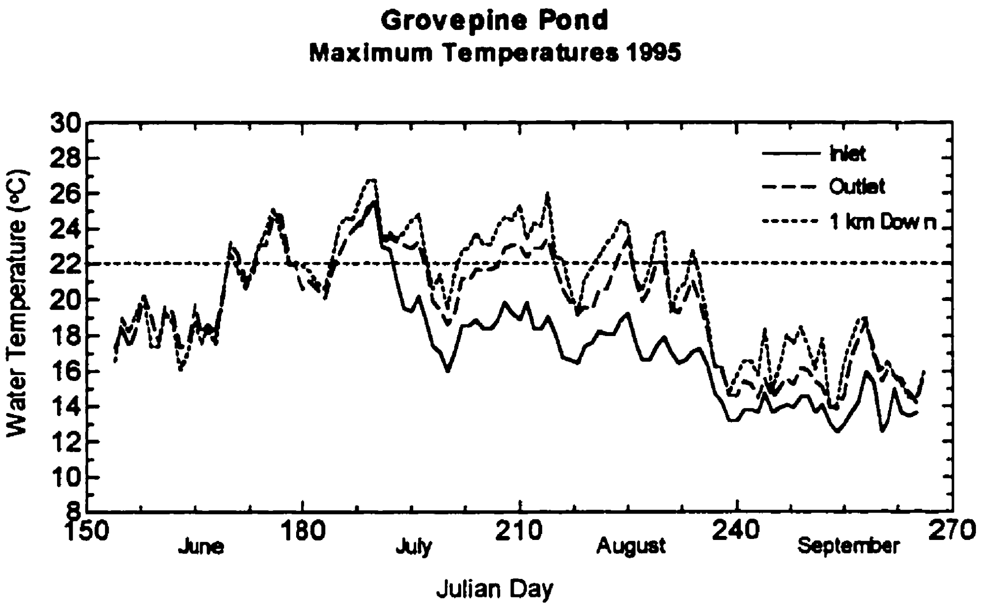


Figure 47. Seasonal varation in water temperatures at the inlet and outlet of Arsenaults Pond and Scales Pond, 1995.

Note: Manual temperature readings obtained during biweekly sampling at the inlet and outlet at Arsenaults are included, as the inlet temperature logger data were not available.


Grovepine Pond
Maximum Temperatures 1995

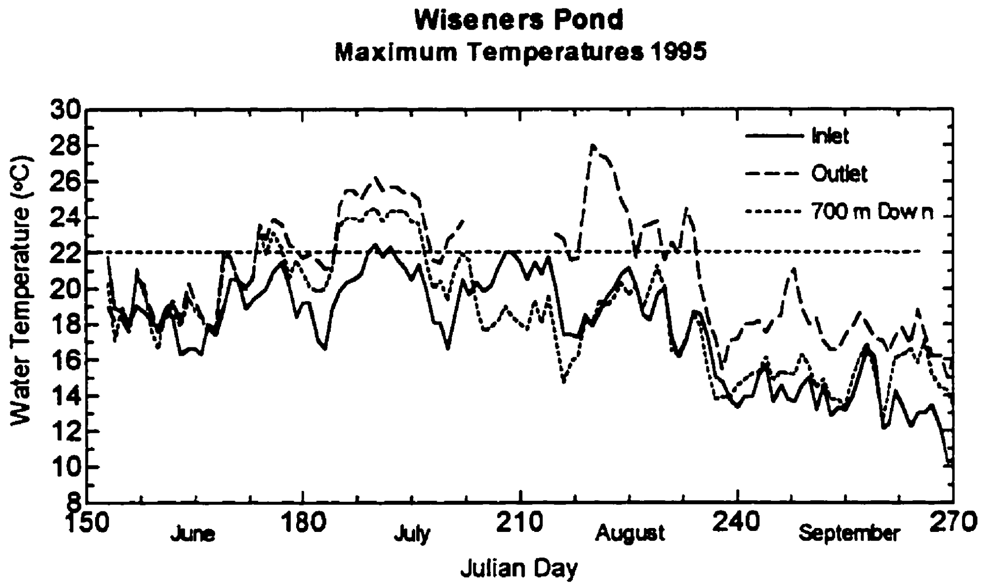

Wiseners Pond
Maximum Temperatures 1995

Figure 48. Daily maximum water temperatures at the inlet, outlet, and downstream stations at Grovepine Pond and Wiseners Pond, 1995.
Note: data gap at Wiseners outlet station between 22 July to 2 August.

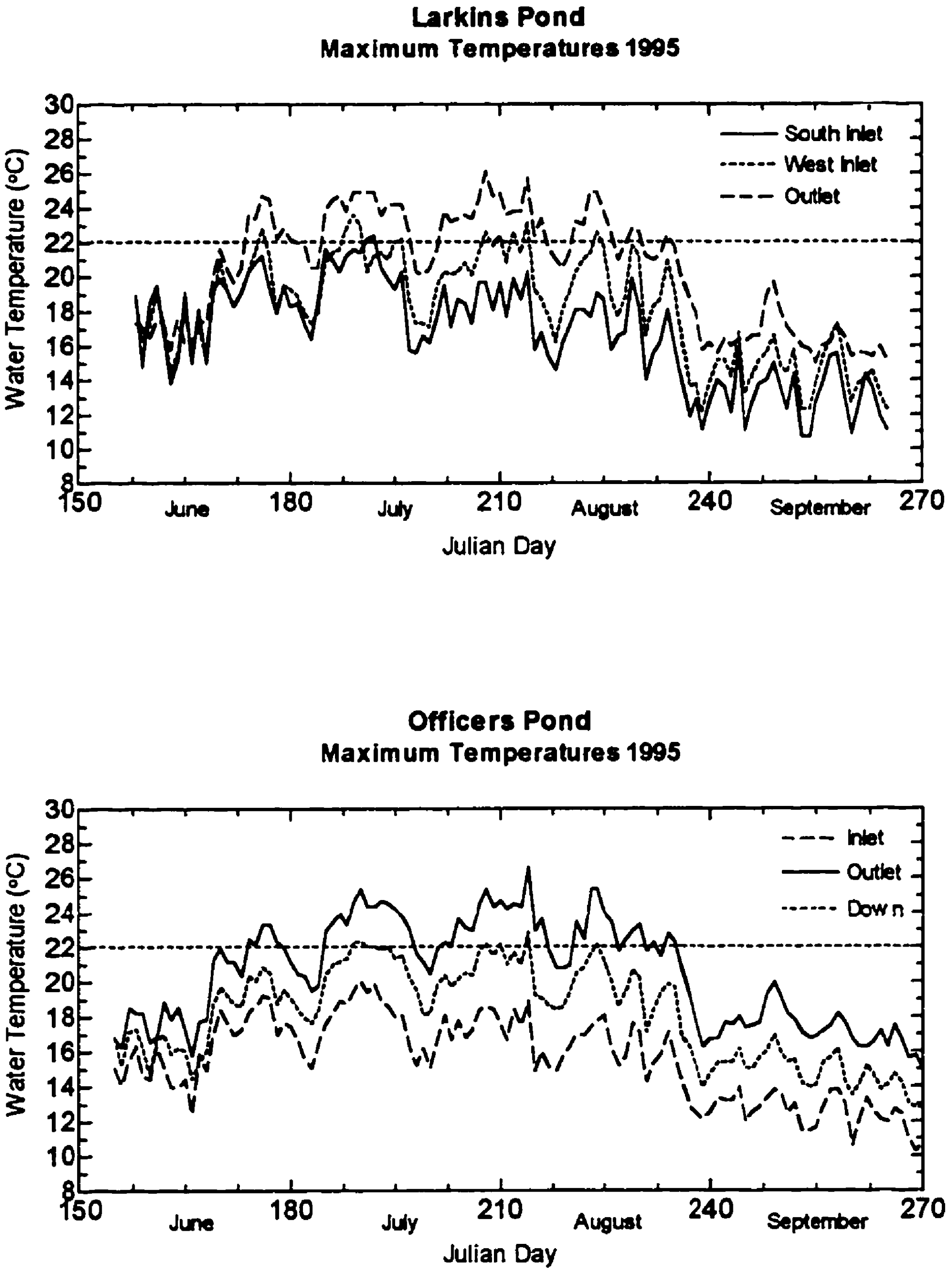


Figure 49. Seasonal variation in water temperature at the inlet(s), outlet, and downstream stations at Larkins Pond and Officers Pond, 1995.

Table 6. Comparison of impoundment surface area, water residence time at low flow, and mean temperature increase from inlet to outlet at seven impoundments, 1994 and 1995.

Impoundment	**Surface Area (m^2)**	**Residence Time (days)**	**Mean Temperature Increase from Inlet to Outlet (°C)**		
			July	**August**	**July & August**
1994					
MacDonalds	126,000	17.1	0.7 ± 0.6 (n=31)	0.9 ± 0.7 (n=31)	0.8 ± 0.7 (n=31)
Maritime E.	27,000	0.4	0.8 ± 0.2 (n=31)	0.7 ± 0.3 (n=31)	0.7 ± 0.3 (n=31)
1995					
Grovepine	37,000	7.2	2.5 ± 1.0 (n=25)	2.5 ± 0.9 (n=31)	2.5 ± 0.9 (n=56)
Larkins	320,000	23.4	5.7 ± 0.6 (n=31)	5.7 ± 1.1 (n=31)	5.7 ± 0.9 (n=62)
Officers	186,000	13.6	6.5 ± 1.0 (n=31)	6.7 ± 1.2 (n=31)	6.6 ± 1.1 (n=62)
Scales	171,000	2.9	3.6 ± 0.7 (n=31)	4.1 ± 0.8 (n=19)	3.8 ± 0.8 (n=50)
Wiseners	342,000	397.8	3.7 ± 0.8 (n=21)	3.6 ± 1.5 (n=28)	3.6 ± 1.3 (n=49)

Inflowing streams to MacDonalds, Wiseners, and Larkins already had elevated water temperatures before entering the impoundments. On the Midgell River, water temperature actually warmed slightly in the approximately 4 km of stream between the Elm Road and MacDonalds Pond (Figure 50). For example, mean water temperature at the Elm Road in July 1994 was 1.8°C cooler than temperatures recorded at the inlet to MacDonalds Pond for the same time period. Larkins Pond has two main inflowing streams. In July 1995, water temperatures on the West Branch were on average 2.5°C higher than the South Branch and met or exceeded the 22°C mark in July and August (Figure 49). Water temperatures in 1995 were cooler than in 1994 (Figure 51). The South and West inlets both had high water temperatures in 1994. Water temperatures in 1993 at Larkins outlet and the West inlet were substantially lower, and reflected the cool, wet conditions in July (Table 7).

Downstream water temperatures did not always recover from the high value at the impoundment outlet. On the Naufrage River, downstream water temperature remained almost identical to the temperature at the outlet (Figure 51), even after the stream passed through approximately 3 km of forest. The mean July water temperature downstream from Larkins Pond in 1994 was only 0.2°C cooler than mean outlet water temperature during this period. Water temperatures in 1994 were so warm at the downstream site, both maximum and minimum daily temperatures were at or above 22°C for extended periods in July and August (Figure 51).

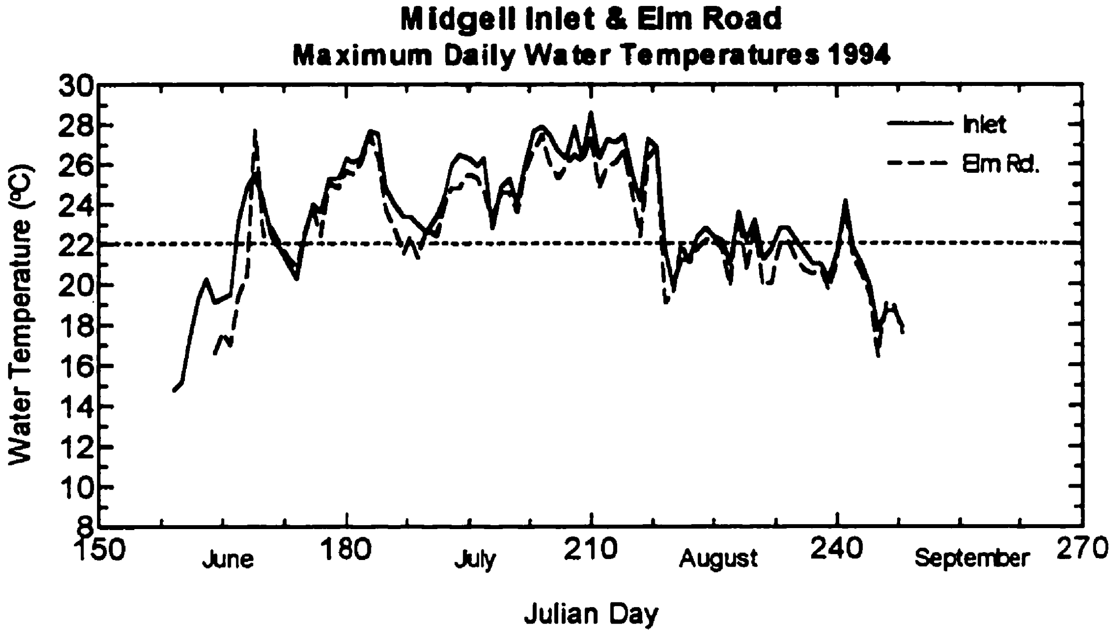


Figure 50. Maximum daily water temperatures at the Elm Road and inlet to MacDonalds Pond, Midgell River, 1994.

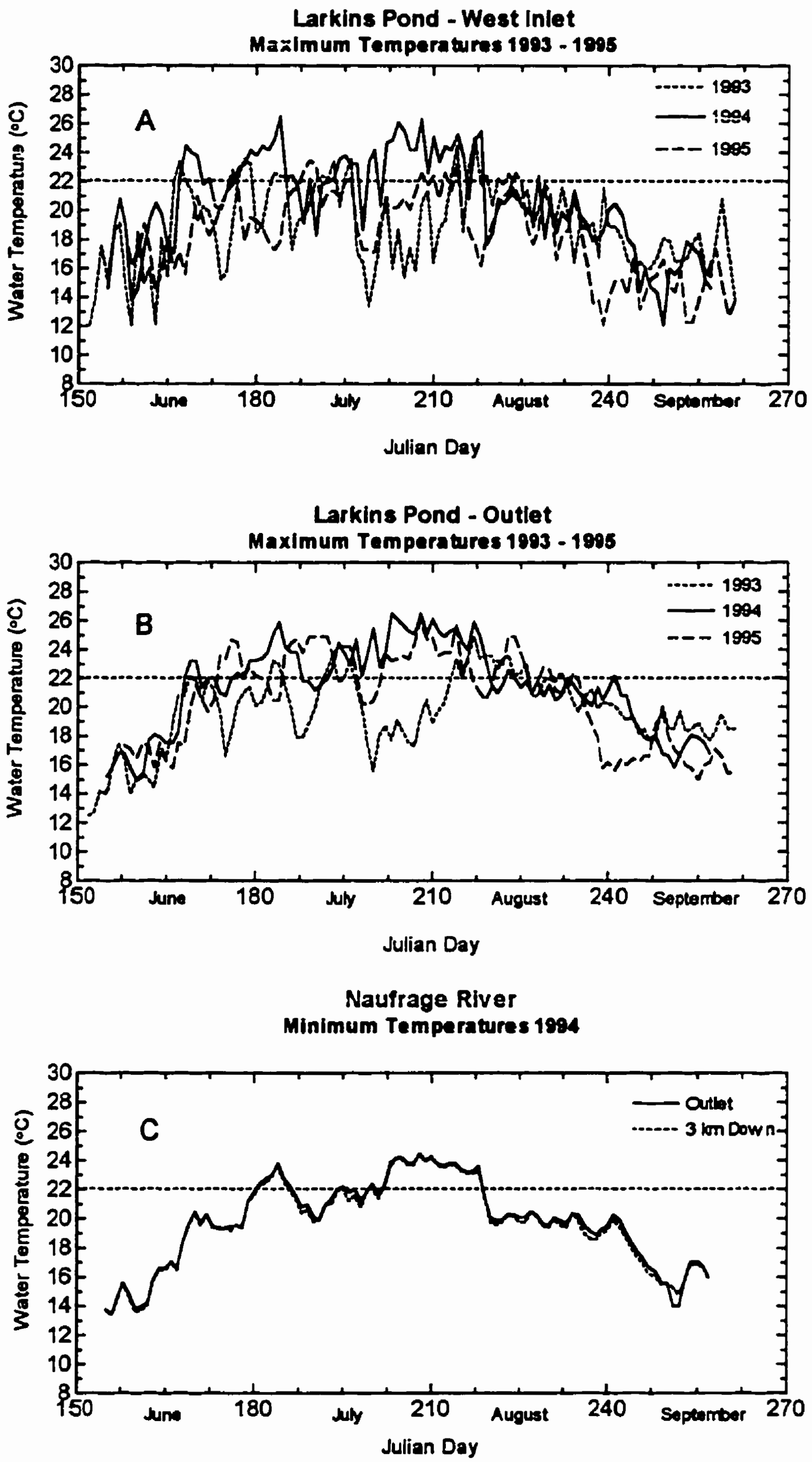


Figure 51. Seasonal variation in daily maximum water temperatures from 1993-95 at the west inlet (A) and outlet (B), and 1994 daily minimum water temperatures downstream (C) from Larkins Pond.

Table 7. Precipitation and mean temperature at the Charlottetown weather station, June-August[1], 1993-95.

	Precipitation (mm)			**Mean Temperature (°C)**		
	June	**July**	**Aug**	**June**	**July**	**Aug**
1993	99.6	89.8	28.4	13.7	16.2	18.3
1994	129.4	36.4	45.8	15.5	20.3	17.9
1995	96.2	59.2	59.3	14.9	19.7	17.4
Long term mean (1943-1990)	91.1	81.6	88.6	14.4	18.4	18.0

[1] Environment Canada - Atmospheric Environment Service. Monthly meteorological summary.

Downstream water temperatures at Officers and Grovepine had the opposite response, in terms of temperature changes from the outlet. At Officers, water temperatures leaving the impoundment were high, but cooled considerably after travelling approximately 3 km (Figure 49). In July 1995, mean water temperature downstream from Officers Pond had cooled 3.2°C. At Grovepine, outlet water is immediately impounded by a beaver dam approximately 200 m downstream. Although the mean difference between daily maximum temperatures in July, 1995 was 1.2°C greater at the downstream station than at the outlet (Figure 48), the difference between mean temperatures during this period was marginal (<1.0°C). Thus, the daily fluctuation in water temperature was greater at the downstream location. Spot checks of temperature at the downstream sampling station, Big Brook tributary, and the road crossing downstream from the confluence of Big Brook and Grovepine, showed that Big Brook was, on average, 3.7°C cooler than Grovepine. Water temperature at the road crossing was approximately the average combined temperature of the two tributaries.

Water temperature in flowing streams showed greater fluctuation in temperatures from daily maximum to minimum than did impounded or outlet waters. At Officers Pond, for example, water temperature at the inlet dropped by over 4°C during the evening, whereas the daily temperature change at the outlet was generally about 2°C (Figure 52). Heat stored in a large body of impounded water is more slowly dissipated, and since all of the impoundments discharge water from the epilimnion, the temperature recovery at night is less at the outlet than in free flowing streams.

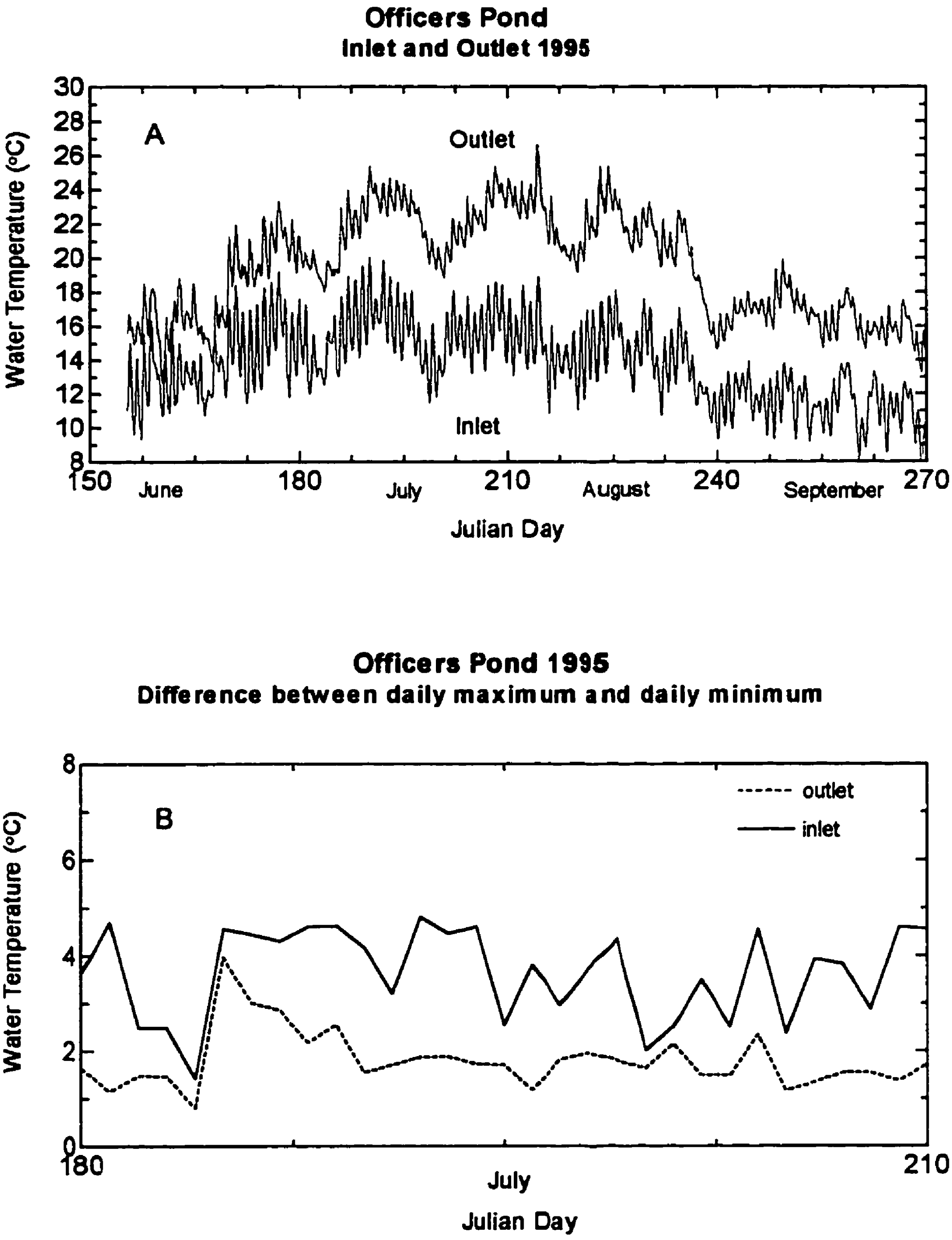


Figure 52. Seasonal variation in water temperature at the inlet and outlet of Officers Pond (A) and difference between daily maximum and daily minimum temperatures at these stations (B), July 1995.

3.4 Chemical Characteristics

3.4.1 Dissolved Oxygen

All ponds exhibited some oxygen stratification (Figures 53-63), but it was most persistent at the deepest impoundment, Larkins Pond. Larkins Pond maintained a considerable difference between surface and bottom oxygen concentrations from mid-June until late August (Figures 54, 60). The bottom 1.5 metres of Larkins had less than 5 mg/L dissolved oxygen and less than 50% saturation during this time. The maximum difference between surface and bottom oxygen concentration at Larkins, 8.1 mg/L, was recorded on July 31, 1995. MacDonalds, Officers, and Wiseners also had low oxygen concentrations in the hypolimnion, but only in the bottom 0.5 metre of the ponds and for a short time during the summer (Figures 56, 58). The greatest seasonal fluctuation in dissolved oxygen occurred at Wiseners and Officers (Figure 55). In graphical analysis and interpretation of dissolved oxygen data, 5 mg/L and 50% oxygen saturation are identified as the minimum acceptable level for salmonids (Dobson et al. 1974, U.S. EPA 1986, cited by Canadian Council of Resource and Environment Ministers 1987).

Saturation values at the coolest of the impoundments, Scales, Arsenaults, and the Maritime Electric Pond, remained high throughout the summer (Figures 53-54). Arsenaults Pond and Scales Pond had similar oxygen profiles throughout the summer, and oxygen saturation on the surface of both ponds approached 170% in early August. Although the seasonal pattern was different at Officers Pond, saturation values were also high, exceeding 19 mg/L or 200% in early June (Figure 55). Grovepine was the only impoundment with anoxic conditions from

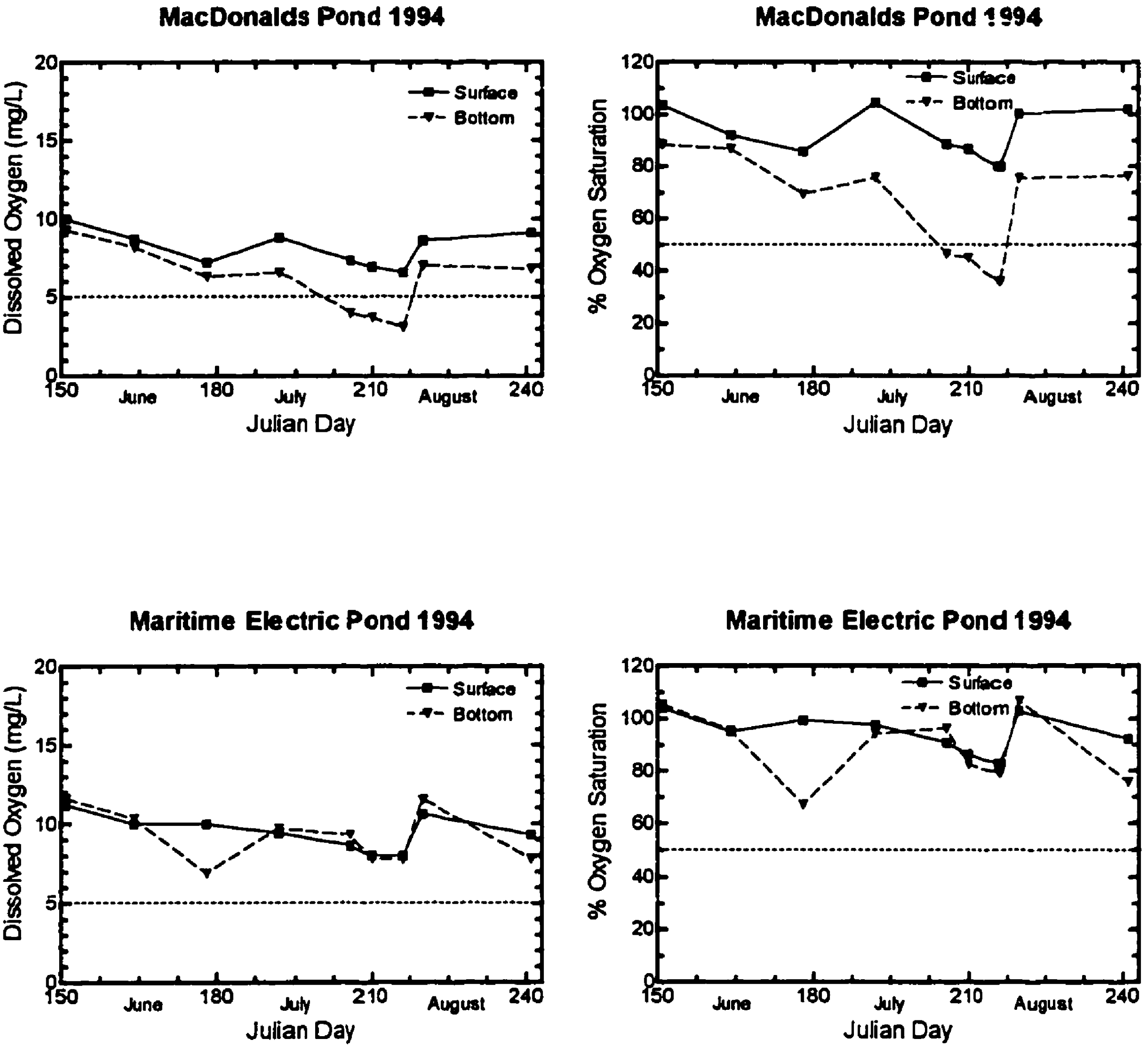
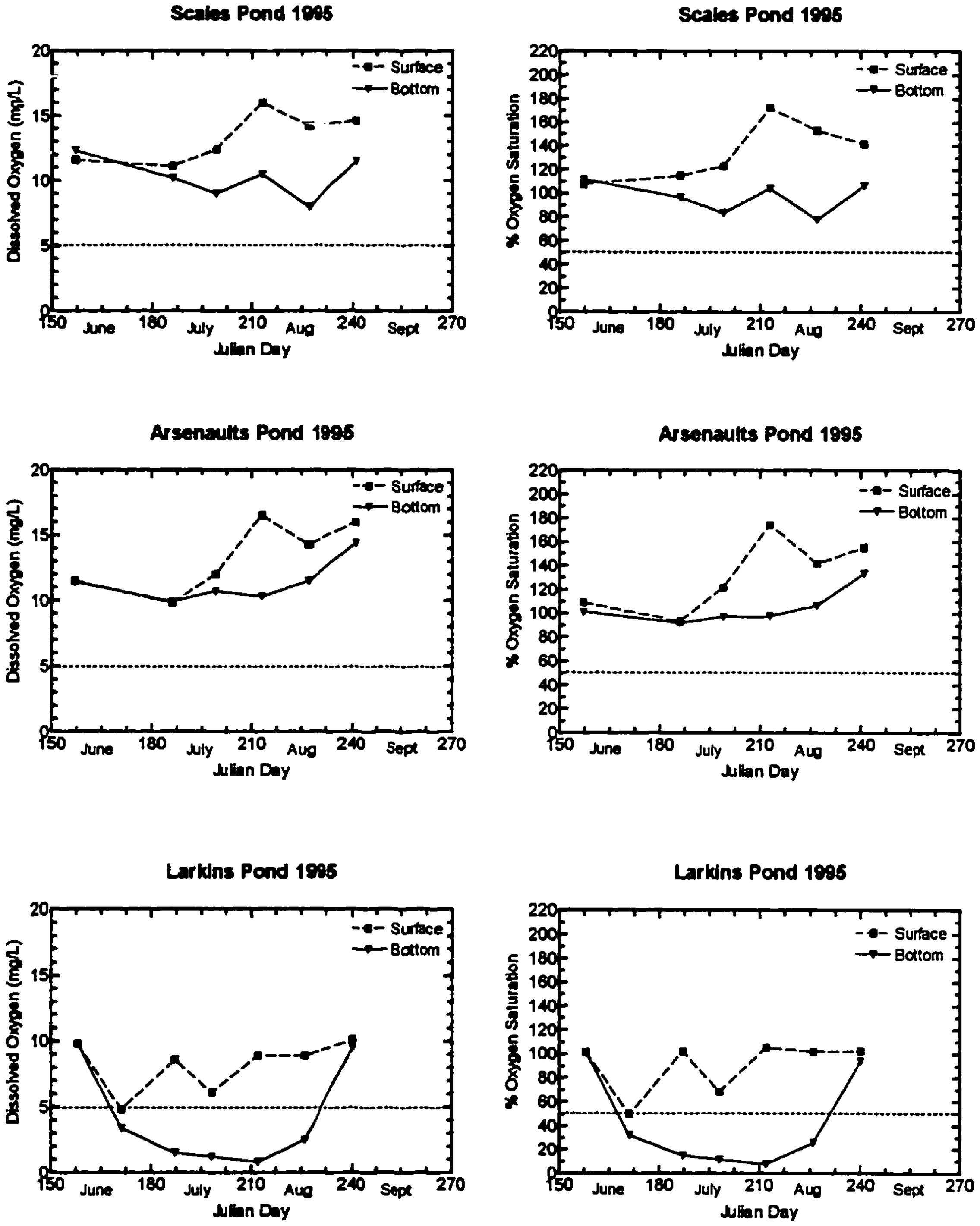


Figure 53. Seasonal variation in dissolved oxygen concentration and percent saturation at MacDonalds Pond and Maritime Electric Pond from 31 May to 29 August, 1994.



Scales Pond 1995

Scales Pond 1995

Arsenaults Pond 1995

Arsenaults Pond 1995

Larkins Pond 1995

Larkins Pond 1995

Figure 54. Seasonal variation in dissolved oxygen concentration and percent saturation at Scales, Arsenaults, and Larkins impoundments from 6 June to 29 August, 1995.

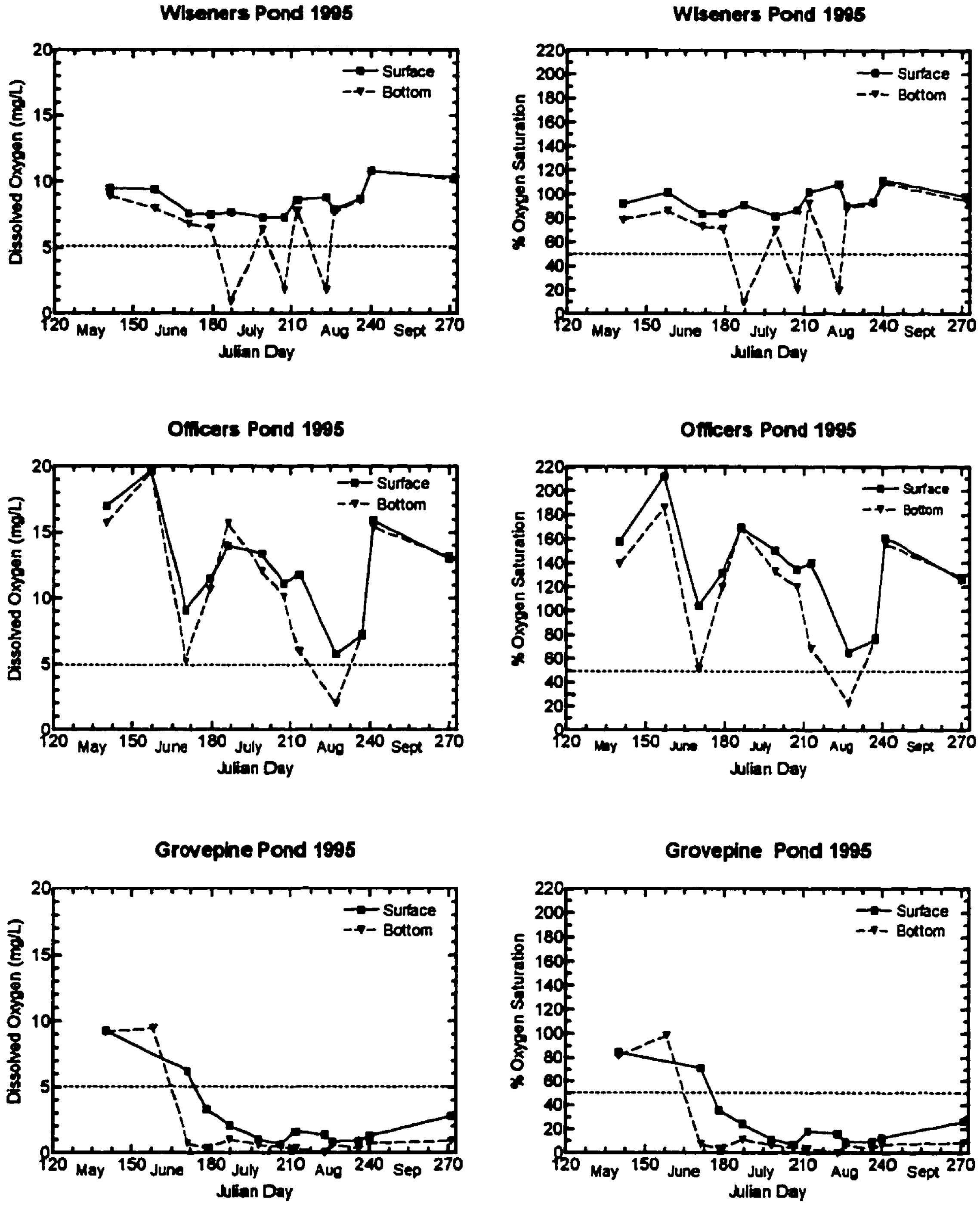


Figure 55. Seasonal variation in dissolved oxygen concentration and percent saturation at Wiseners, Officers, and Grovepine from 6 June to 29 August, 1995.

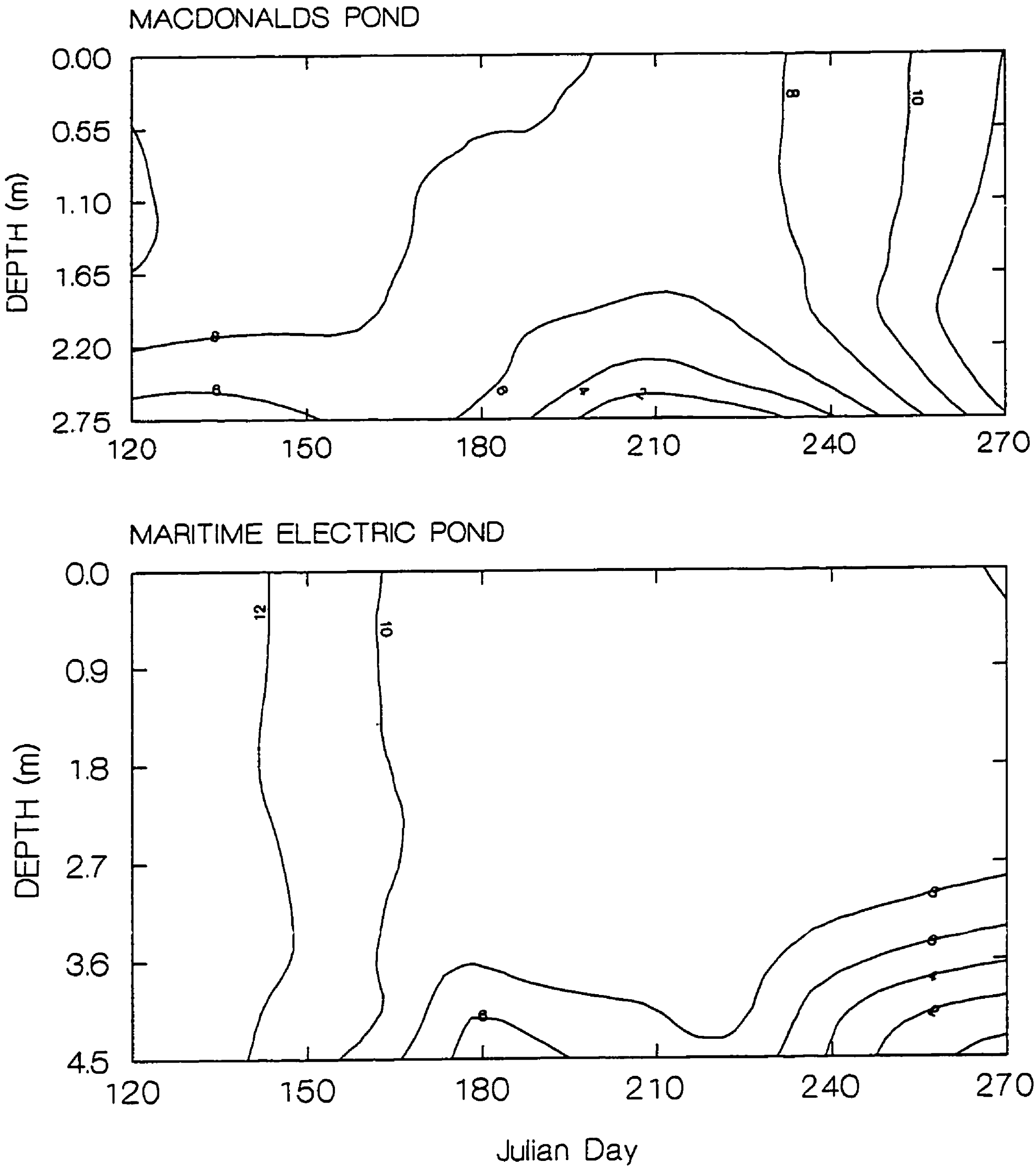


Figure 56. Seasonal dissolved oxygen (mg/L) isopleths for MacDonalds Pond and the Maritime Electric Pond, 1994.

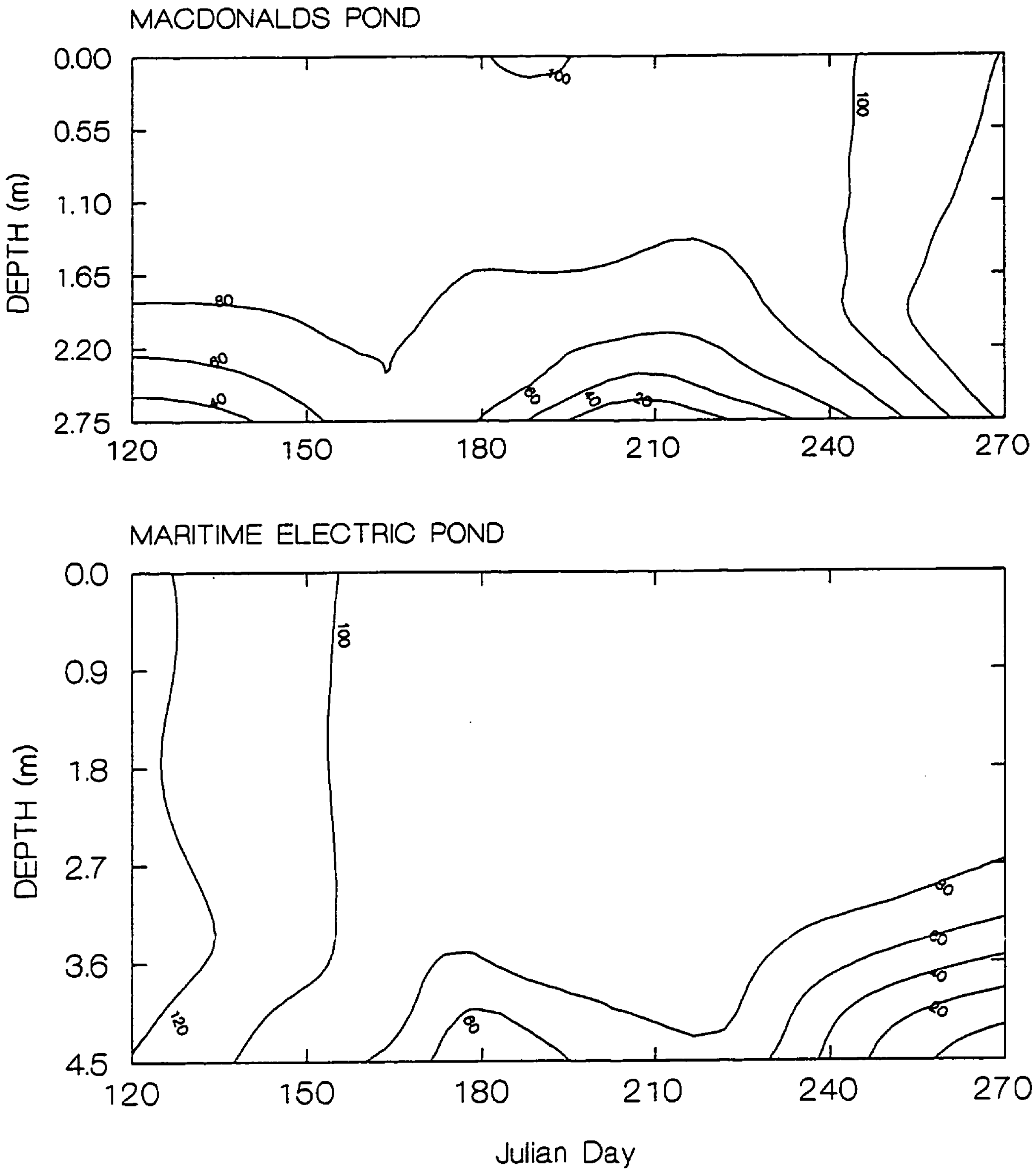


Figure 57. Seasonal dissolved oxygen (% saturation) isopleths for MacDonalds Pond and the Maritime Electric Pond, 1994.

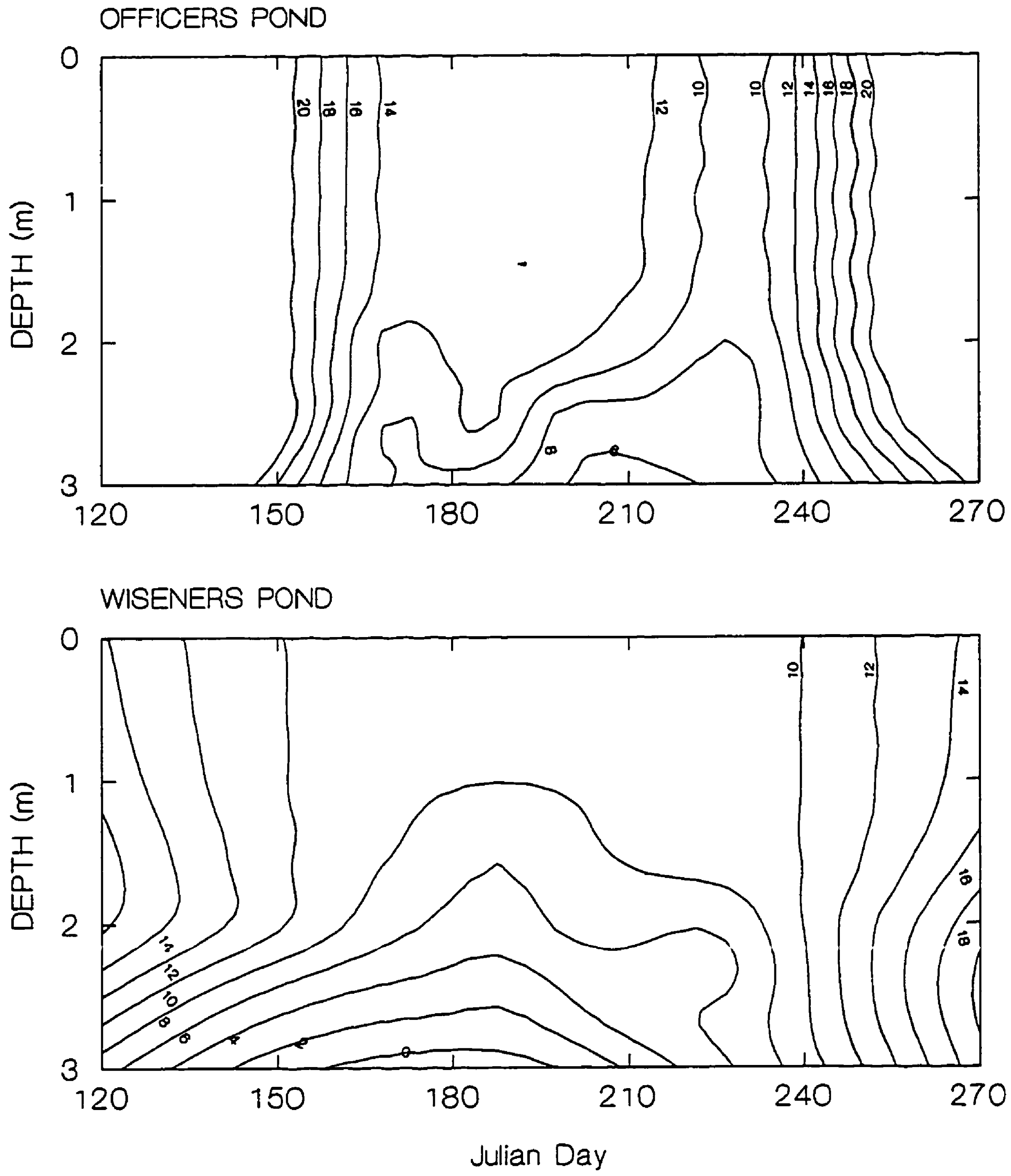


Figure 58. Seasonal dissolved oxygen (mg/L) isopleths for Officers Pond and Wiseners Pond, 1995.

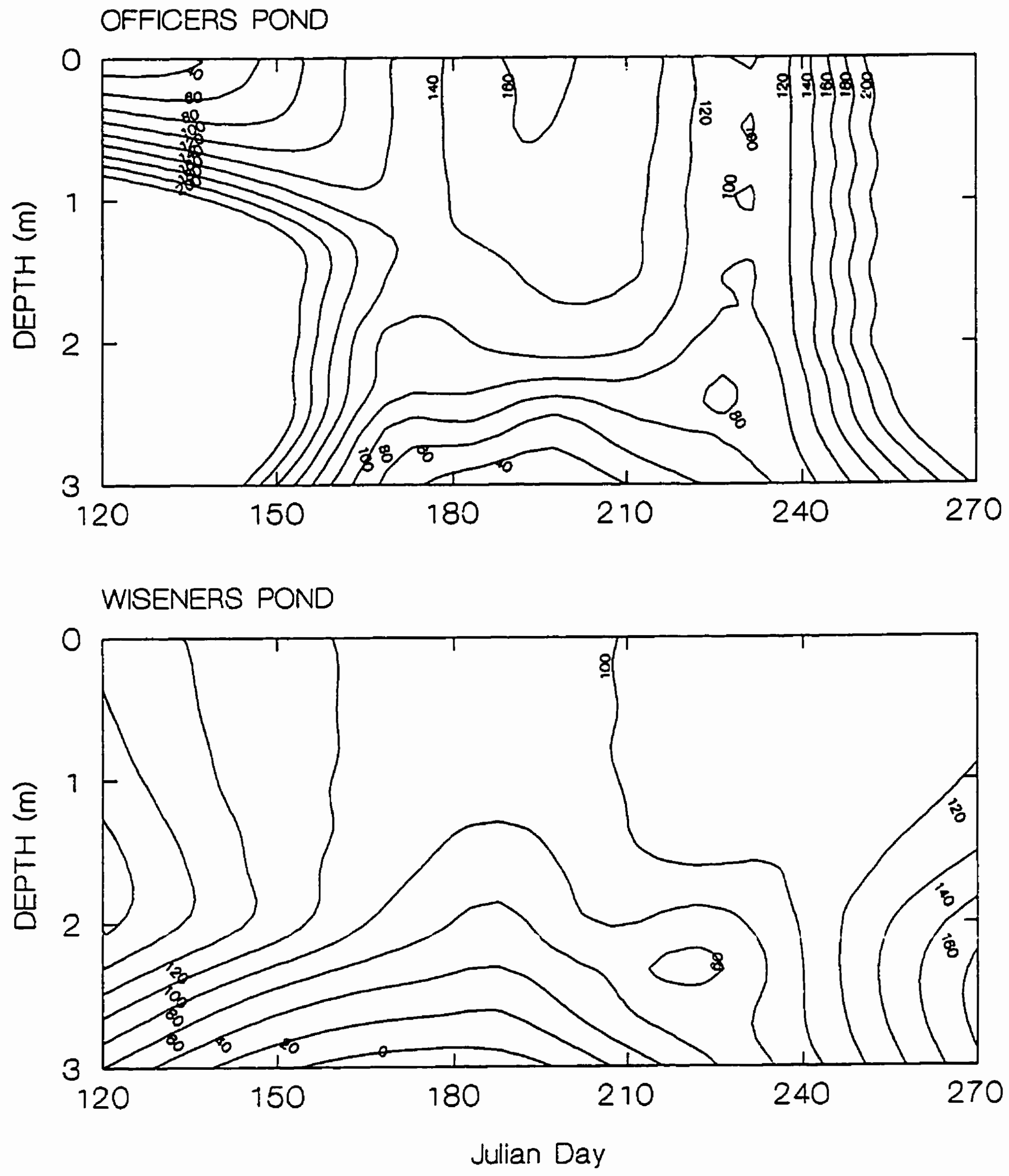


Figure 59. Seasonal dissolved oxygen (% saturation) isopleths for Officers Pond and Wiseners Pond, 1995.

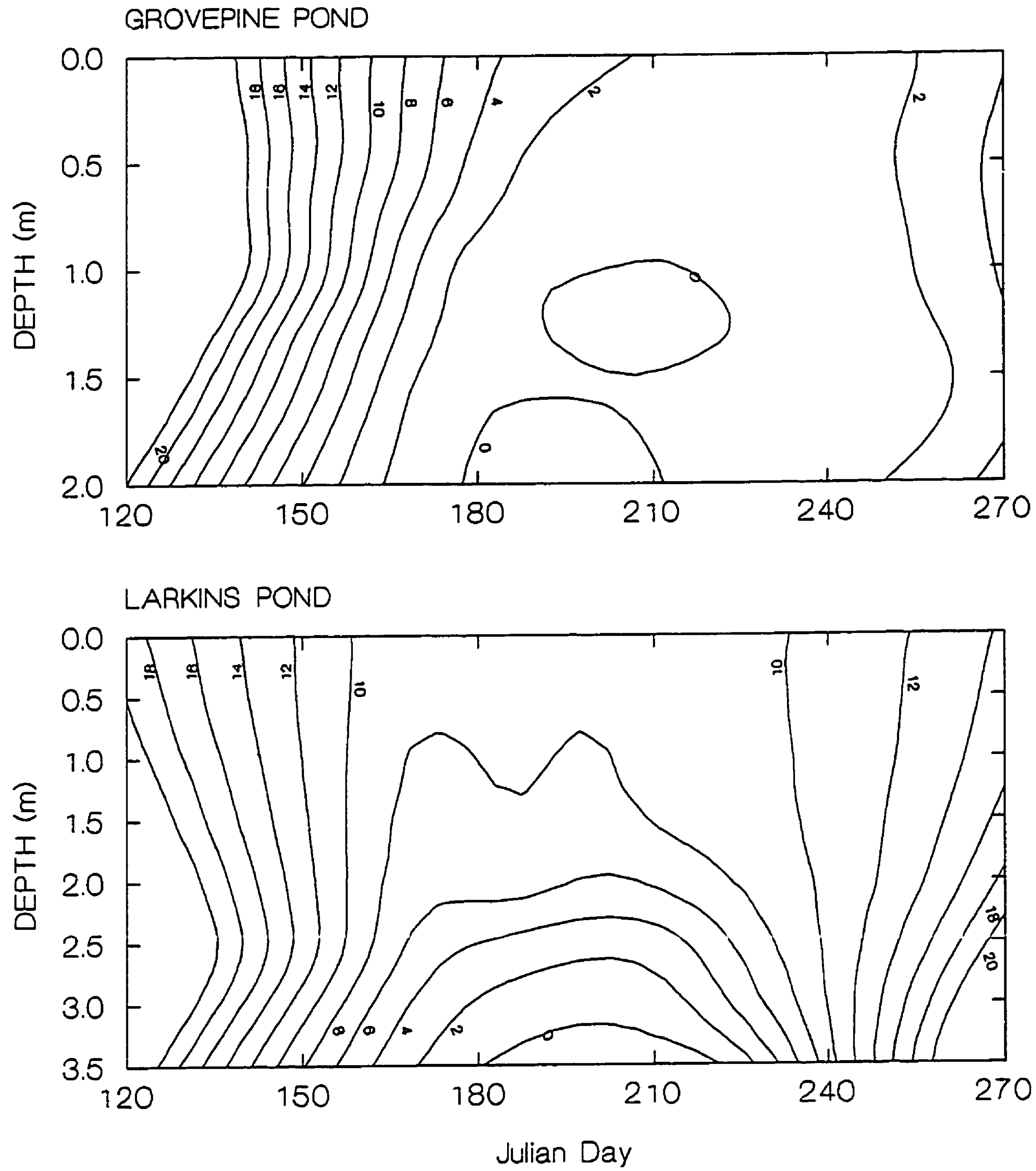


Figure 60. Seasonal dissolved oxygen (mg/L) isopleths for Grovepine Pond and Larkins Pond, 1995.

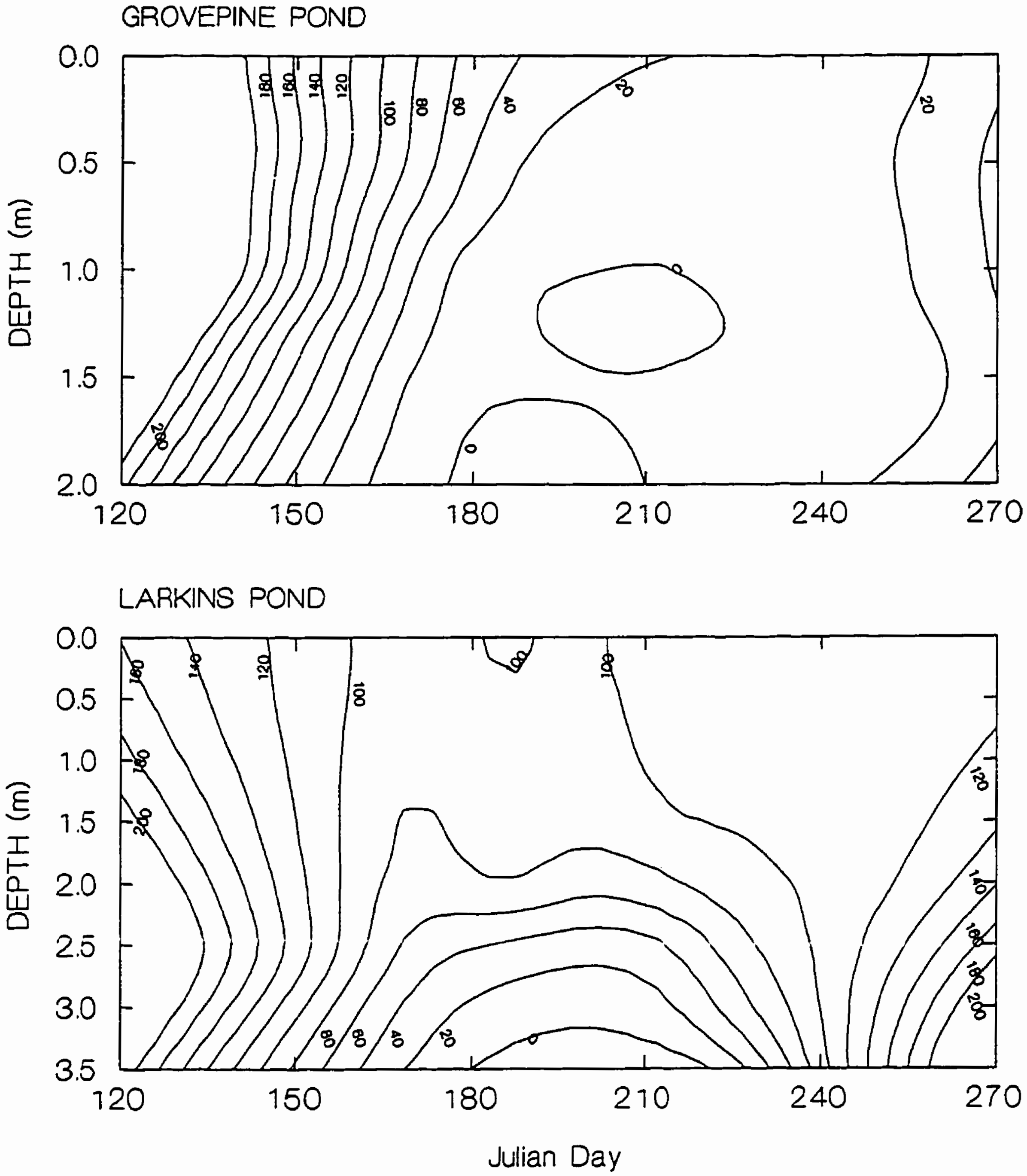


Figure 61. Seasonal dissolved oxygen (% saturation) isopleths for Grovepine Pond and Larkins Pond, 1995.

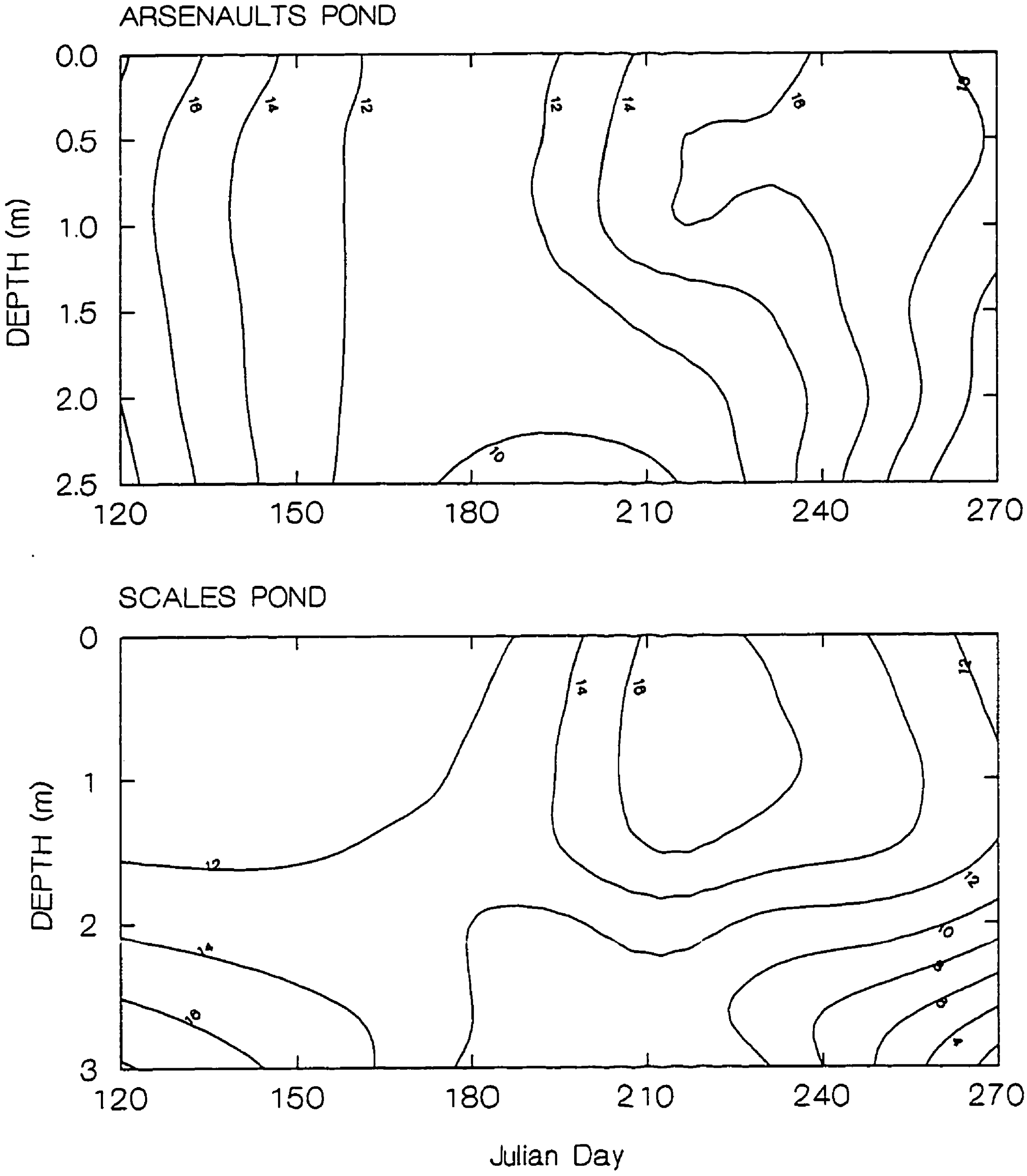


Figure 62. Seasonal dissolved oxygen (mg/L) isopleths for Arsenaults Pond and Scales Pond, 1995.

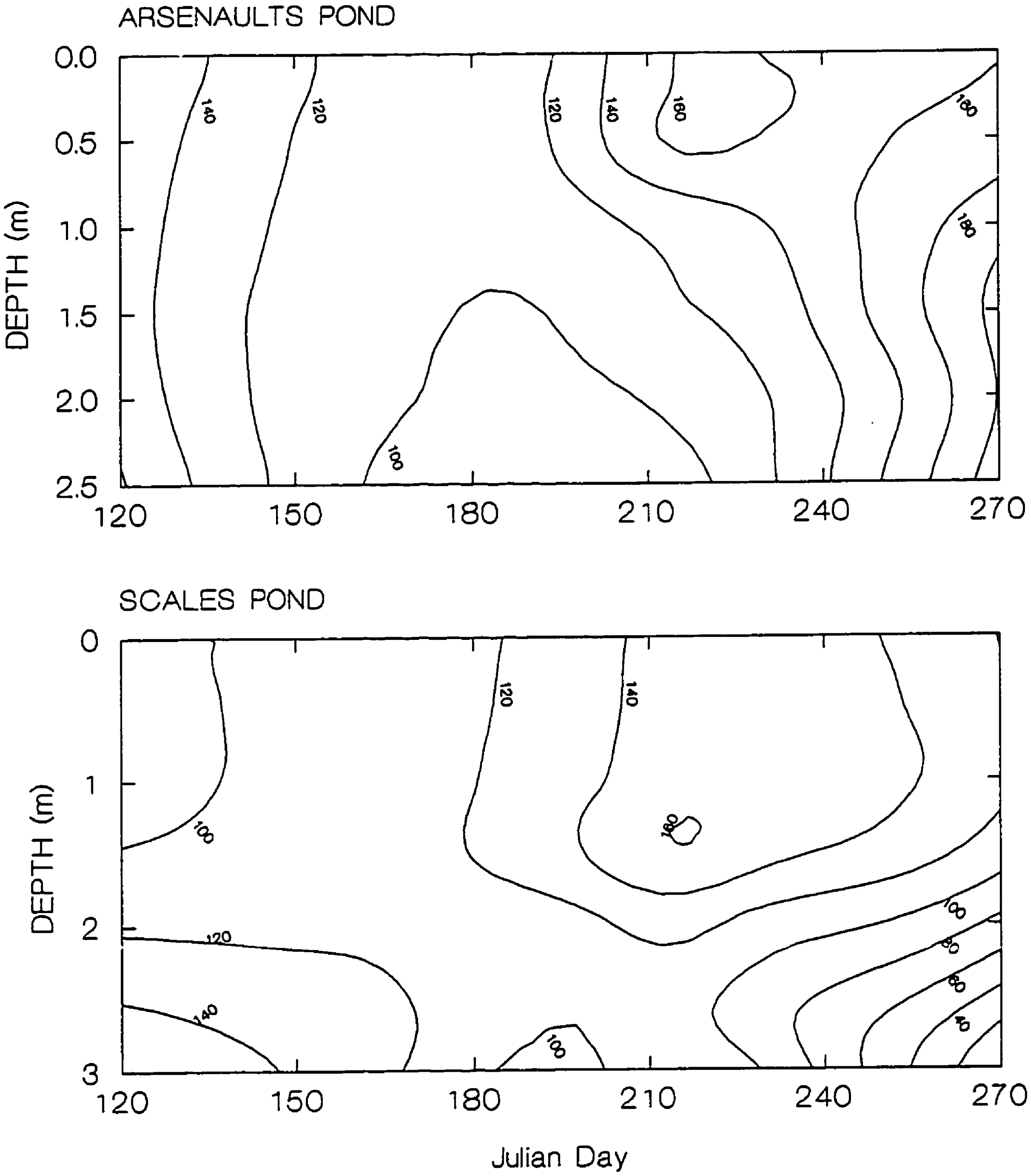


Figure 63. Seasonal dissolved oxygen (% saturation) isopleths for Arsenaults Pond and Scales Pond, 1995.

surface to bottom, and maintained this state from late June until the end of September (Figure 55).

Inlet and outlet concentrations of dissolved oxygen were monitored on the Valleyfield and Midgell Rivers in 1994. All of the stream stations on the Valleyfield River had high oxygen concentrations, ranging from 8.5 mg/L to 11.6 mg/L. Dissolved oxygen at the outlet to MacDonalds Pond was not always fully saturated and fell to 6.8 mg/L (76% saturation) in late August. Inlet oxygen levels changed during the summer, ranging from 9.0 mg/L (97% saturation) on 31 May to 3.4 mg/L (41% saturation) on 25 July. The first downstream station had a minimum concentration of 6.8 mg/L while oxygen at the second downstream station always exceeded 7.6 mg/L.

The development of anoxic conditions within the Grovepine impoundment prompted the examination of dissolved oxygen concentrations at the outlet and downstream stations. The outlet to Grovepine had less than 1.0 mg/L of dissolved oxygen on 3 July, whereas the Big Brook tributary, which enters about 20 m below the downstream sampling station, had 10.1 mg/L of oxygen. At the bridge downstream from the confluence of the two streams, dissolved oxygen concentration was 6.0 mg/L. A spot check on 11 August showed similar results. Dissolved oxygen concentration at the outlet and downstream sampling stations were 2.3 mg/L and 3.7 mg/L respectively. The Big Brook tributary had an oxygen level of 9.6 mg/L. Within a beaver impoundment about 200 m downstream from Grovepine dam, oxygen concentrations on 11 August were lower than 1.0 mg/L.

The change in dissolved oxygen concentration throughout the 1994-95 winter at MacDonalds, Wiseners, Officers, and Grovepine, (Figures 64-67) resembled the summer trends at these impoundments. Once again, dissolved oxygen concentrations were lowest in Grovepine Pond. Although Grovepine had 100% oxygen saturation in November, levels dropped in mid-December and remained well below 5 mg/L and 50% saturation until sampling terminated in mid-March (Figure 67). The Maritime Electric impoundment was the only one which maintained high oxygen concentrations throughout the winter (Figure 64). MacDonalds, Wiseners, and Officers were fully saturated in November, but experienced saturation values at or below 50% saturation, particularly in later December and early January (Figures 64-66). Dissolved oxygen levels at the more shallow upper sampling stations were higher than in the deeper lower stations. All upper sampling stations, with the exception of Wiseners Pond, had saturation values above 50% throughout the winter (Figures 64-67).

3.4.2 Conductivity, Major Cations and Anions

Conductivities at all sites were high, which is typical of streams heavily influenced by groundwater. Mean conductivity values ranged from 92.5 μmho/cm at Arsenaults to 215 μmho/cm at Wiseners. Conductivities corresponded with the degree of agricultural use of drainage basins, with Arsenaults, Officers, and Scales showing the highest values (Figure 68). All ponds, with the exception of Valleyfield and Wiseners, showed weak conductivity stratification (Figures 69-72).

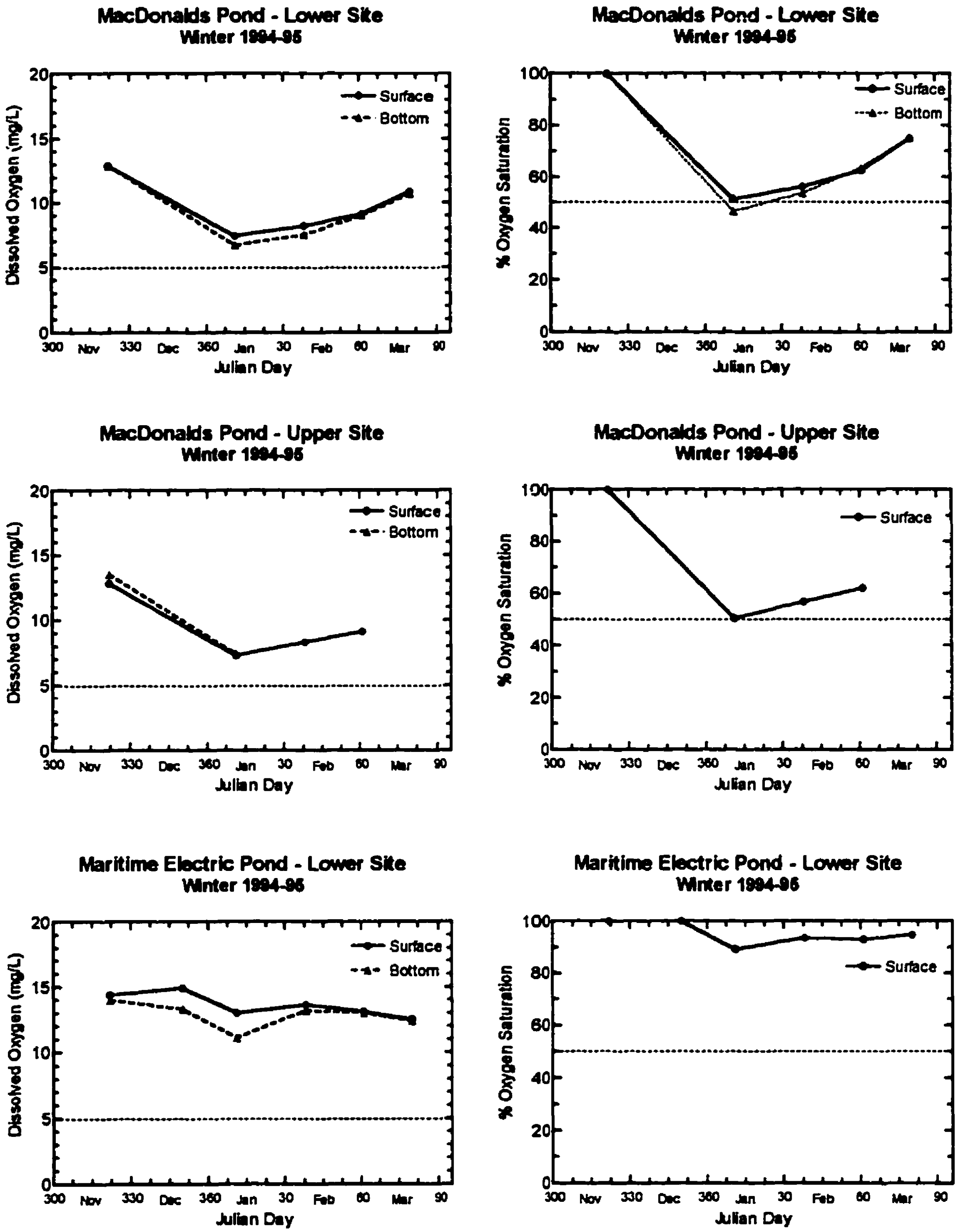


Figure 64. Dissolved oxygen concentration and percent saturation at MacDonalds Pond and Maritime Electric Pond from 18 November, 1994 to 16 March, 1995.

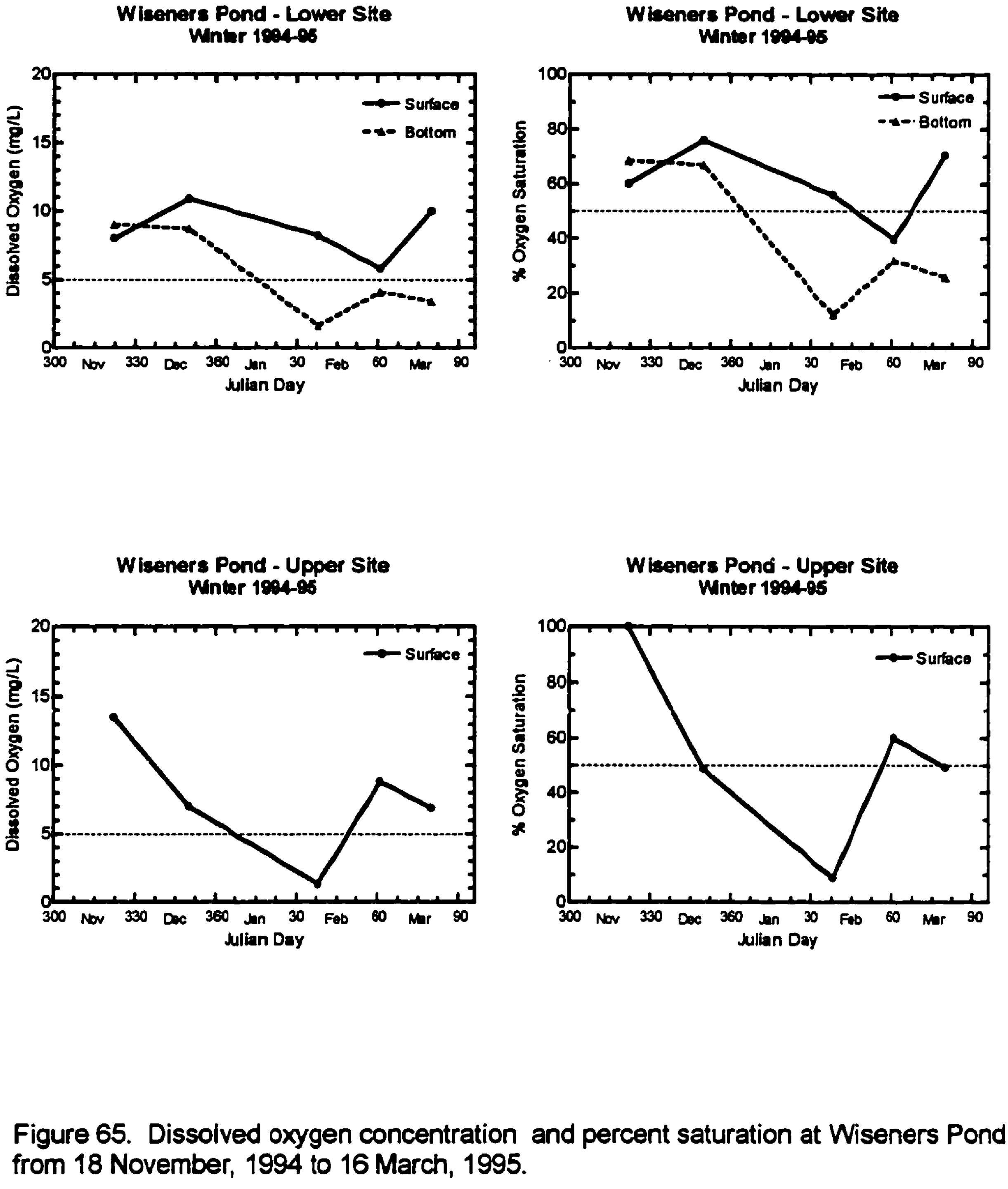


Figure 65. Dissolved oxygen concentration and percent saturation at Wiseners Pond from 18 November, 1994 to 16 March, 1995.

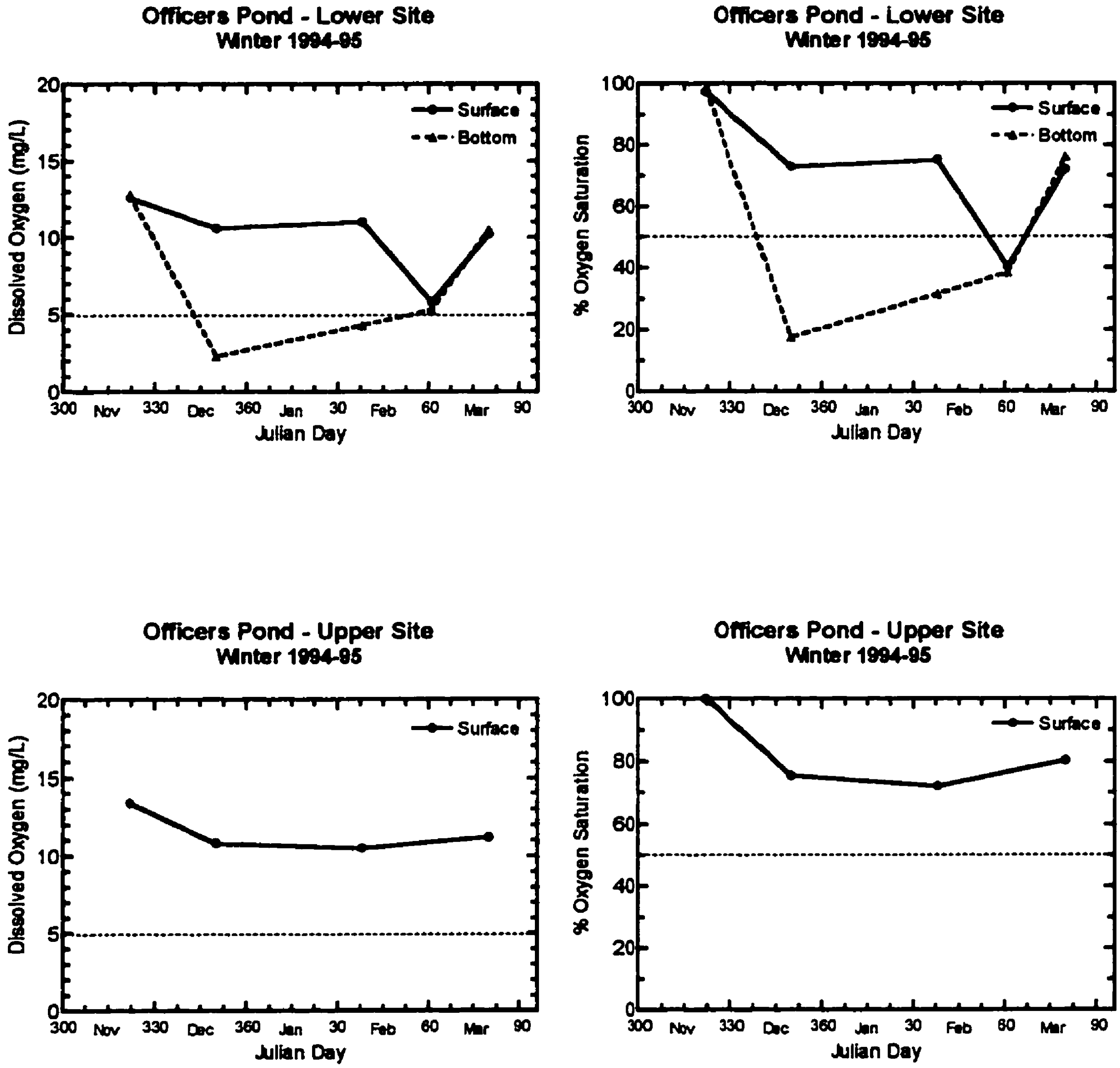


Figure 66. Dissolved oxygen concentration and percent saturation at Officers Pond from 18 November, 1994 to 16 March, 1995.

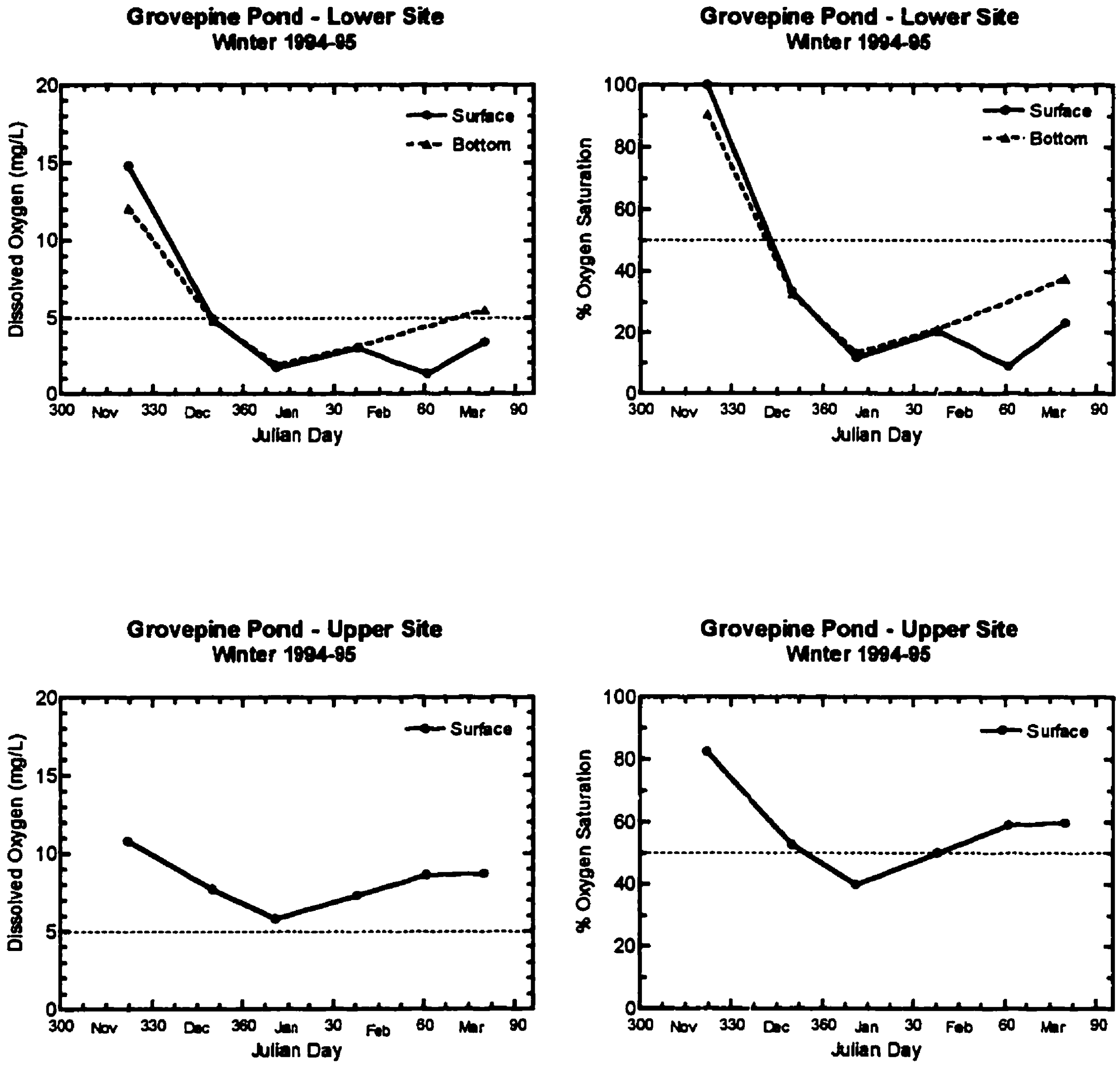


Figure 67. Dissolved oxygen concentration and percent saturation at Grovepine Pond from 18 November, 1994 to 16 March, 1995.

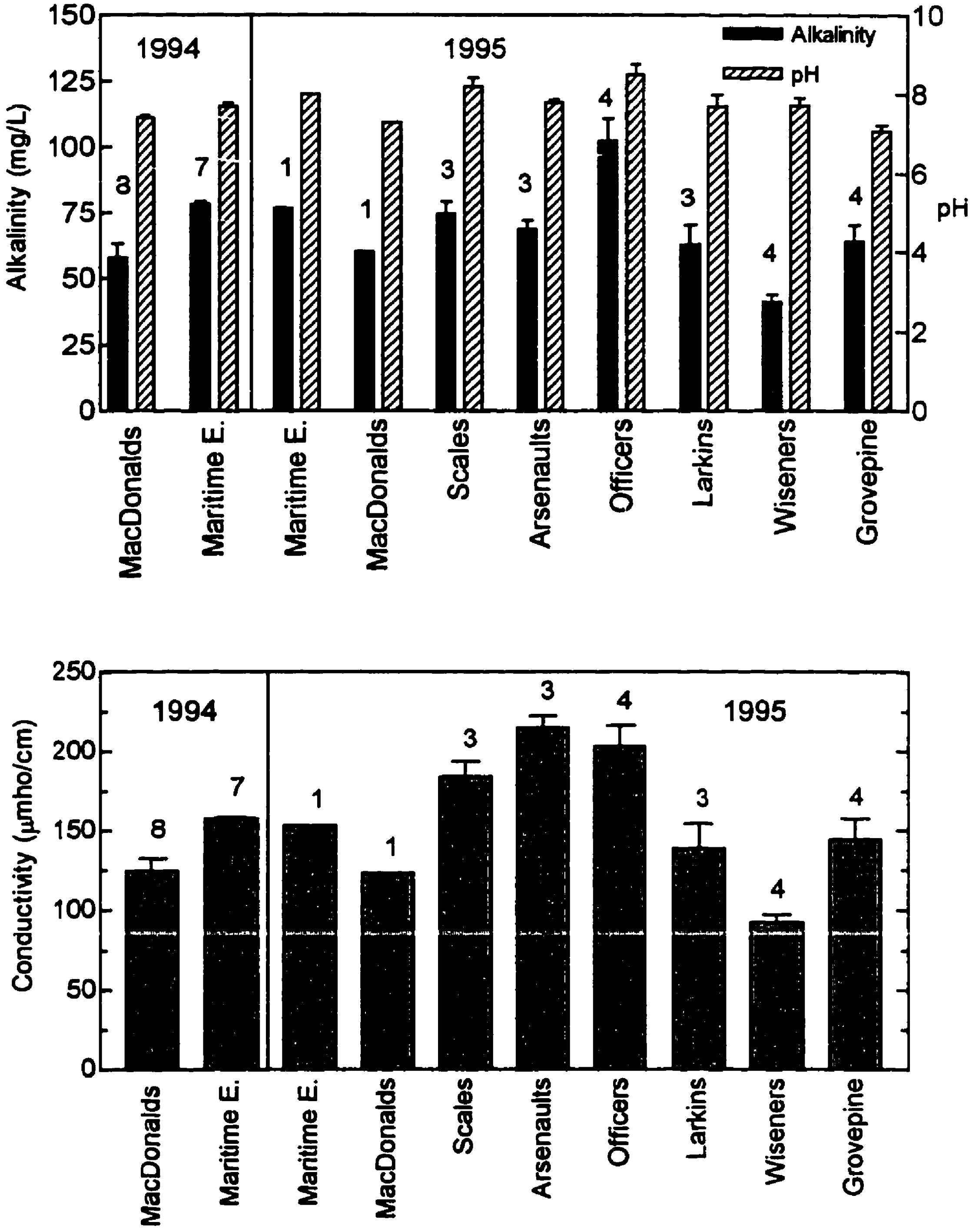
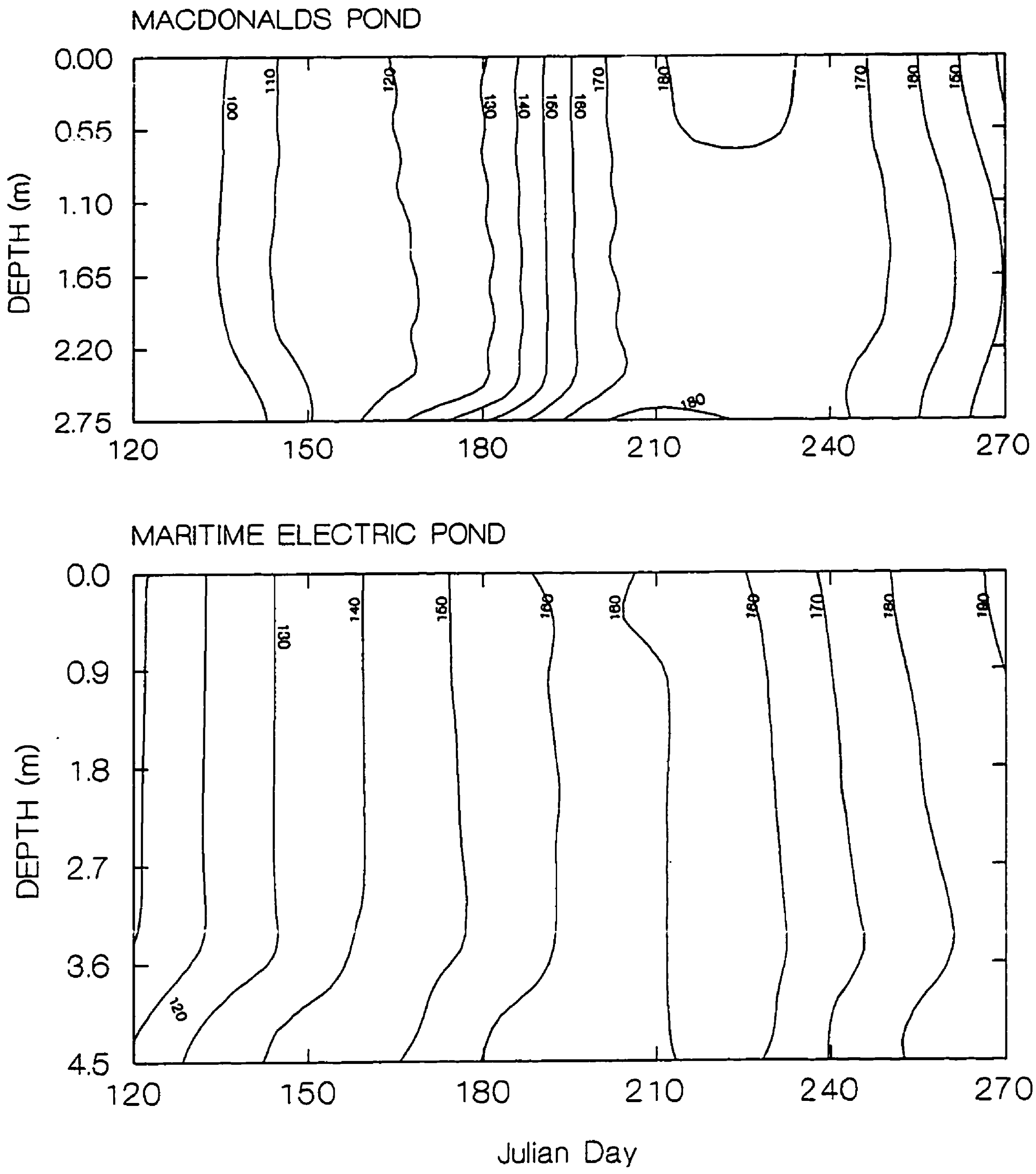


Figure 68. Mean conductivity, pH, and alkalinity values for all eight impoundments, 1994 and 1995 (error bars are one standard error of the mean). Measurements were taken from 18 May to 29 August, 1994 and from 6 June to 1 August, 1995. The number of sampling dates is included.



MACDONALDS POND

MARITIME ELECTRIC POND

Figure 69. Seasonal conductivity isopleths for MacDonalds Pond and Maritime Electric Pond, 1994.

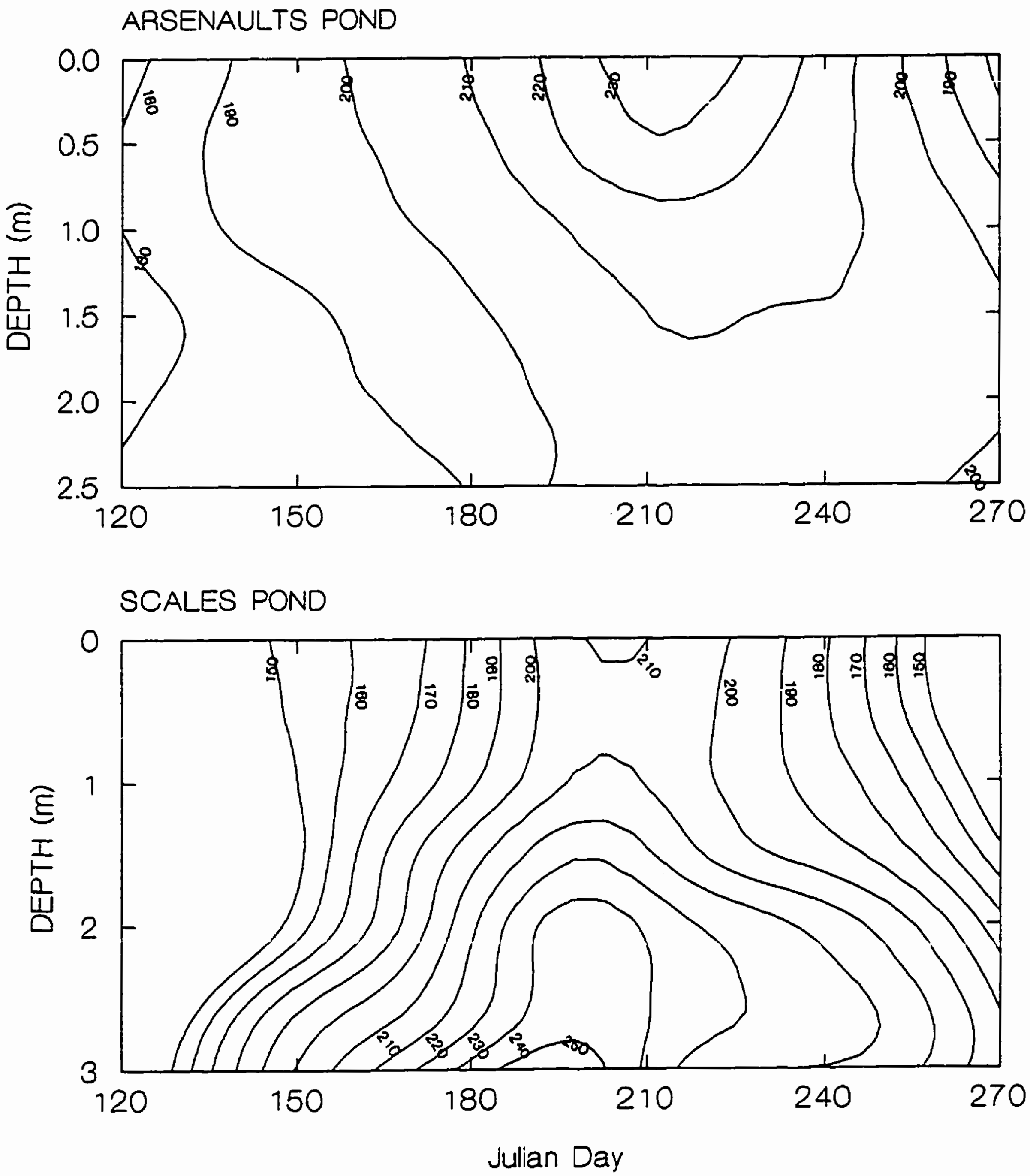


Figure 70. Seasonal conductivity isopleths for Arsenaults Pond and Scales Pond, 1995.

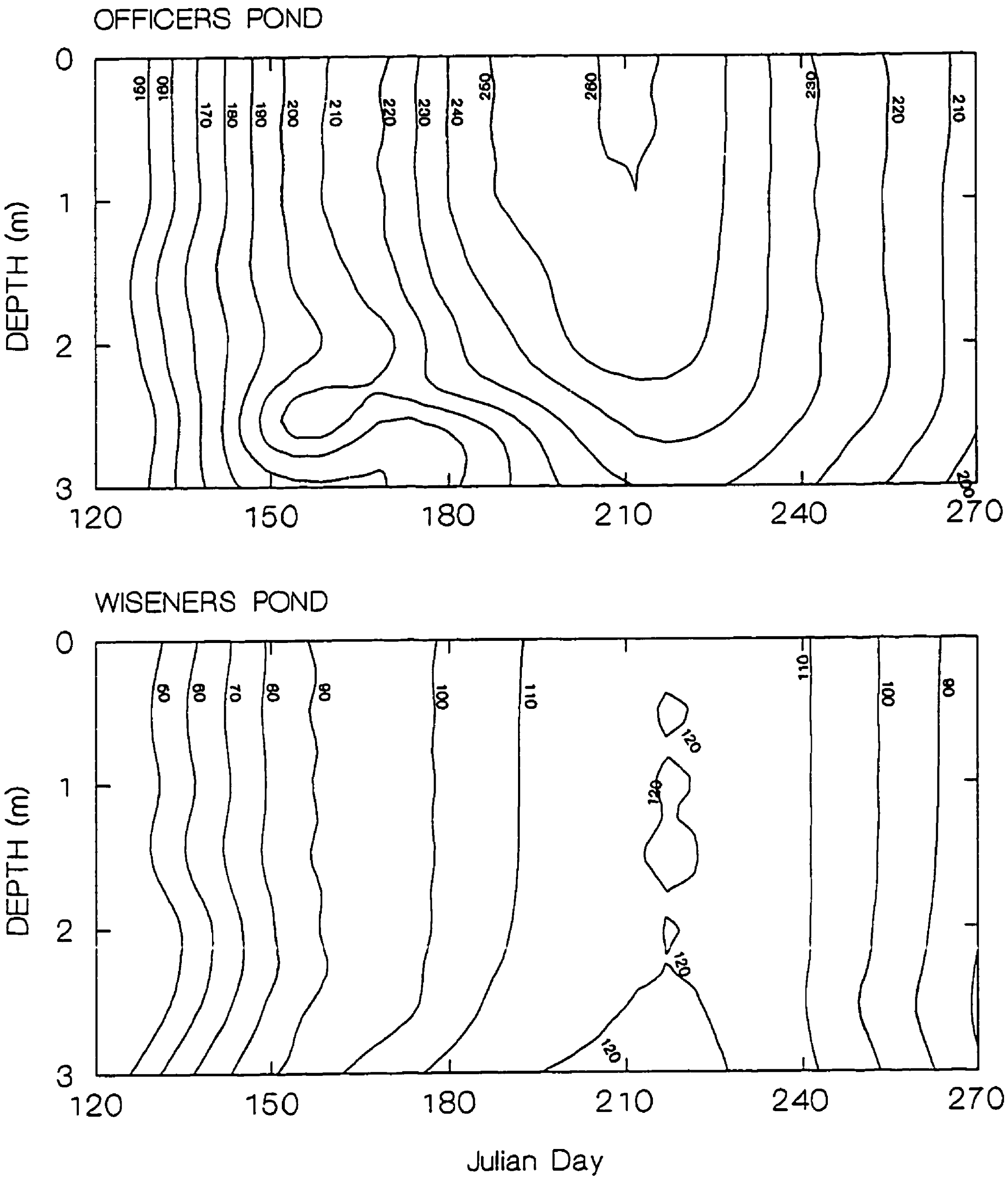


Figure 71. Seasonal conductivity isopleths for Officers Pond and Wiseners Pond, 1995.

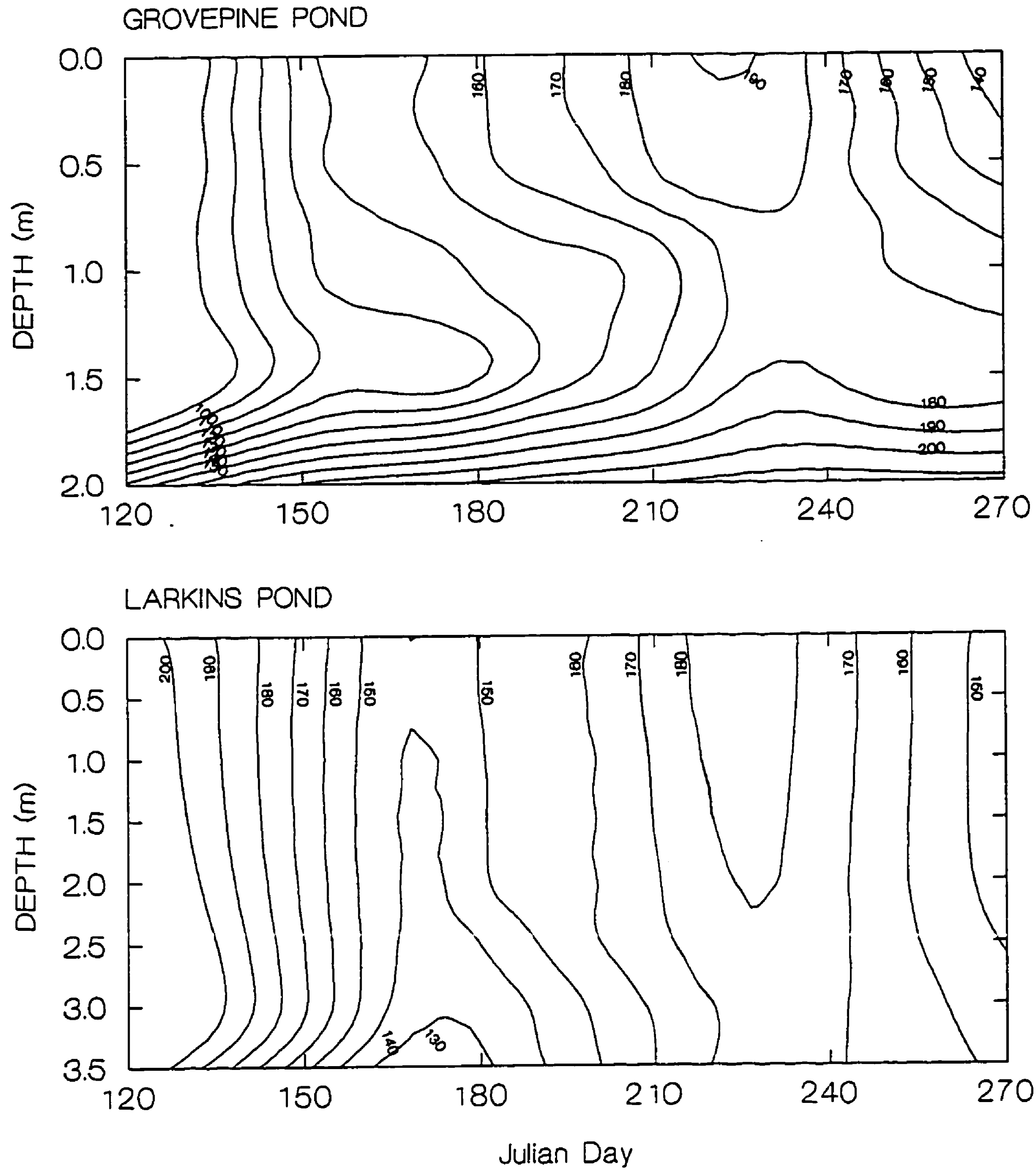


Figure 72. Seasonal conductivity isopleths for Grovepine Pond and Larkins Pond, 1995.

Prince Edward Island waters are primarily calcium or calcium-magnesium bicarbonate in composition (McNeely and Neimanis 1978). The order of dominance for the major ions in each impoundment was typical of Prince Edward Island waters (McNeely and Neimanis 1978), with the major cation at all sites in 1994 and 1995 being calcium, followed closely by magnesium (Figure 73). Officers Pond was the only exception, where magnesium slightly exceeded calcium. The major anion at all sites was carbonate, followed by chloride.

3.4.3 pH and Alkalinity

Alkalinity and pH values were high at all impoundments (Figure 68). Mean total alkalinity varied from a low of 41.3 mg/L at Wiseners Pond to 102.5 mg/L at Officers Pond. Officers Pond also had the highest pH (8.5) while Grovepine had the lowest (7.1). Both alkalinity and pH tended to be lower in impoundments such as Larkins, Grovepine, MacDonalds, and Wiseners which have tea-coloured water typical of the humic acid discharge from areas with a large proportion of coniferous vegetation (Figure 68). The highest values of both pH and alkalinity were found at Officers, Scales, Maritime Electric, and Arsenaults (Figure 68).

3.4.4 Nutrients

Mean total phosphorus concentrations at all eight ponds were high (> 25 μg/L), and fall into the range typical of mesotrophic-eutrophic systems (Cooke et al. 1993, Wetzel 1983). The impoundments within drainage basins with greater soil loss from erosion (eg. Officers, Arsenaults, and Maritime Electric) had greater nutrient concentrations than impoundments in more undisturbed watersheds (Figure 74). Grovepine, the impoundment with the highest

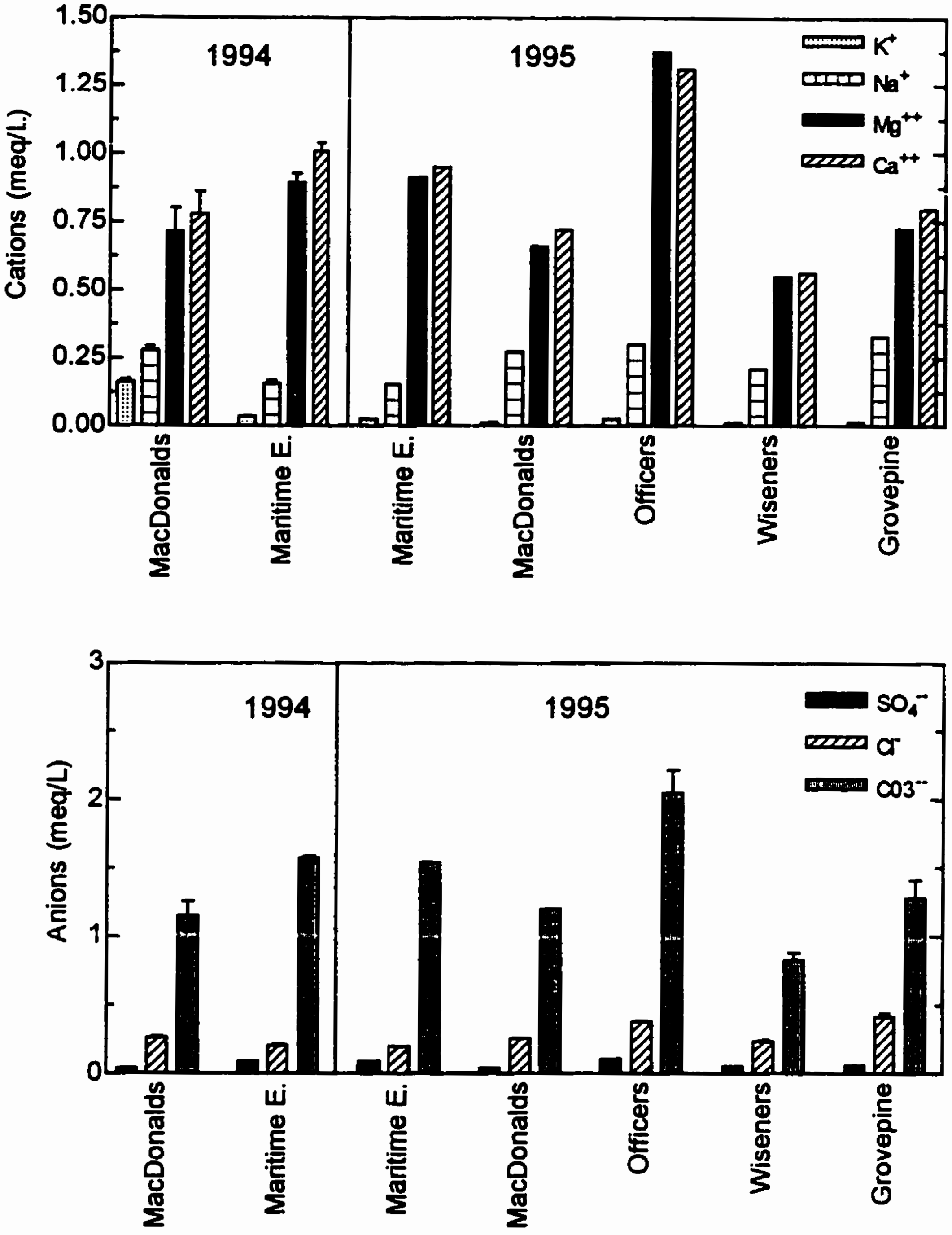


Figure 73. Mean values of major cations and anions at five impoundments, 1994-95 (error bars are one standard error of the mean). Sampling dates for cations and anions were 13 June, 25 July, and 29 August, 1994. The 1995 data are derived from one sampling (25-26 July), with the exception of Cl^-, which had two additional sampling periods (6-7 June, 31 July-1 August, 1995).

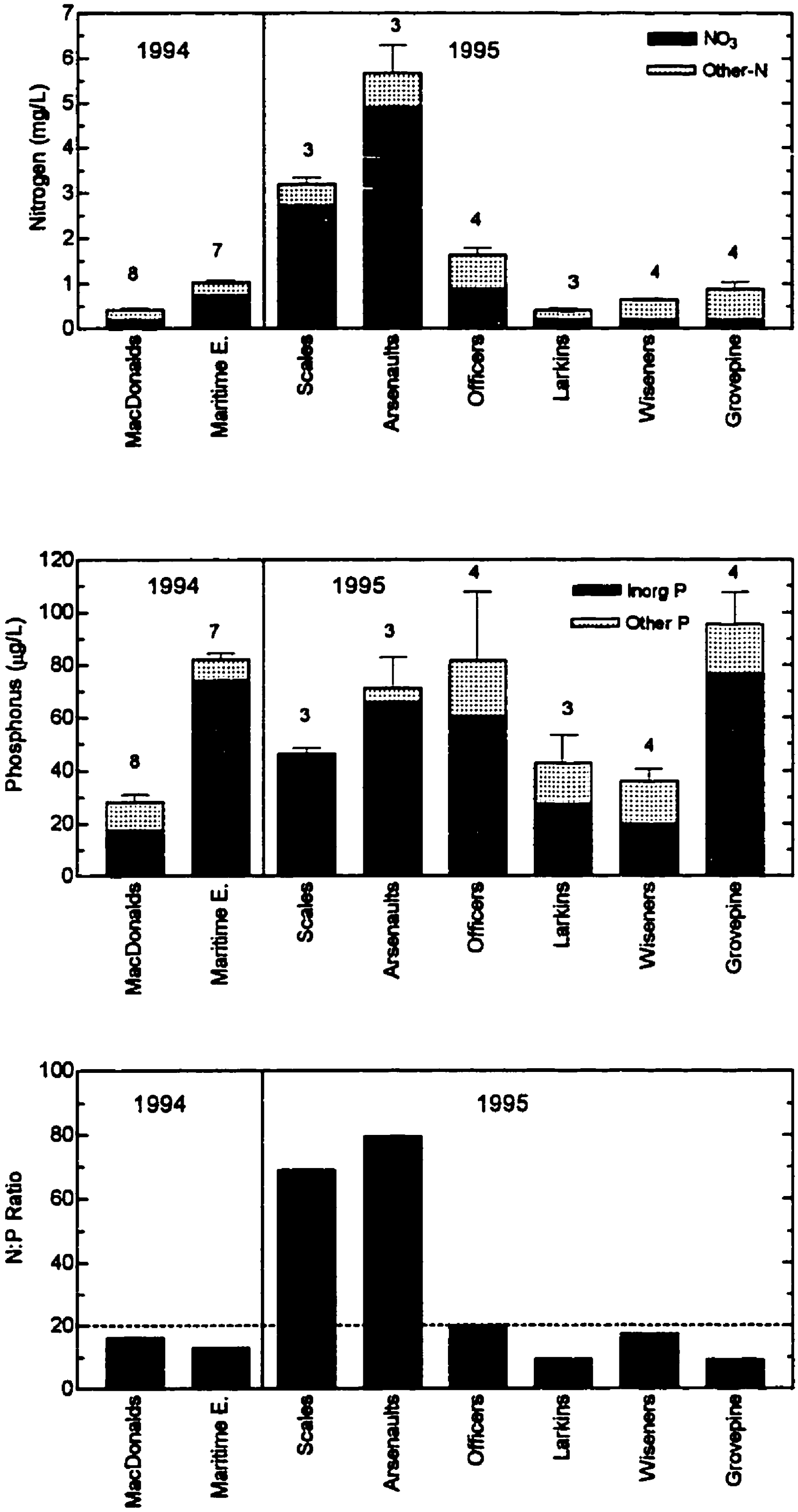


Figure 74. Mean concentration of nitrogen and phosphorus and N:P ratio at each impoundment, 1994-95 (error bars are one standard error of the mean). Samples were taken from 18 May to 29 August, 1994 and from 6 June to 1 August, 1995. The number of sampling dates is included above each bar.

mean concentration of total phosphorus, was a notable exception (Figure 74). Although Grovepine is relatively isolated and would not receive substantial dissolved nutrients from land wash, it is rich in organic matter. Microbial degradation of dead particulate organic matter and the anoxic conditions persistent with Grovepine impoundment contribute to "internal phosphorus loading", and phosphorus concentrations were higher than anticipated.

Nitrogen concentrations also closely reflected land use with each drainage basin. Arsenaults, Scales, Officers, and Maritime Electric had the highest concentrations of total nitrogen, of which greater than 50% was composed of $N0_3$-N (Figure 74). Total nitrogen concentrations ranged from 0.4 mg/L at Larkins to 5.7 mg/L at Arsenaults Pond. Grovepine and Wiseners had a greater percentage of forms of nitrogen other than $N0_3$-N, primarily NH_4+ (Figure 74). Ammonia, the end product of decomposition of organic matter, accumulates as the hypolimnion becomes anoxic (Wetzel 1983). Ammonia also made up approximately half of the total nitrogen at Larkins and MacDonalds. All impoundments had nitrogen concentrations that fall into the range typical of mesotrophic systems. The N:P ratios ranged from 9.2 at Grovepine to 79.4 at Arsenaults Pond (Figure 74). Grovepine, Wiseners, Larkins, MacDonalds, and Maritime Electric all had N:P values below 20.

Both the Maritime Electric Pond and MacDonalds Pond showed no significant difference in nutrient concentrations between the inlet, pond, and outlet sampling stations (Figure 75).

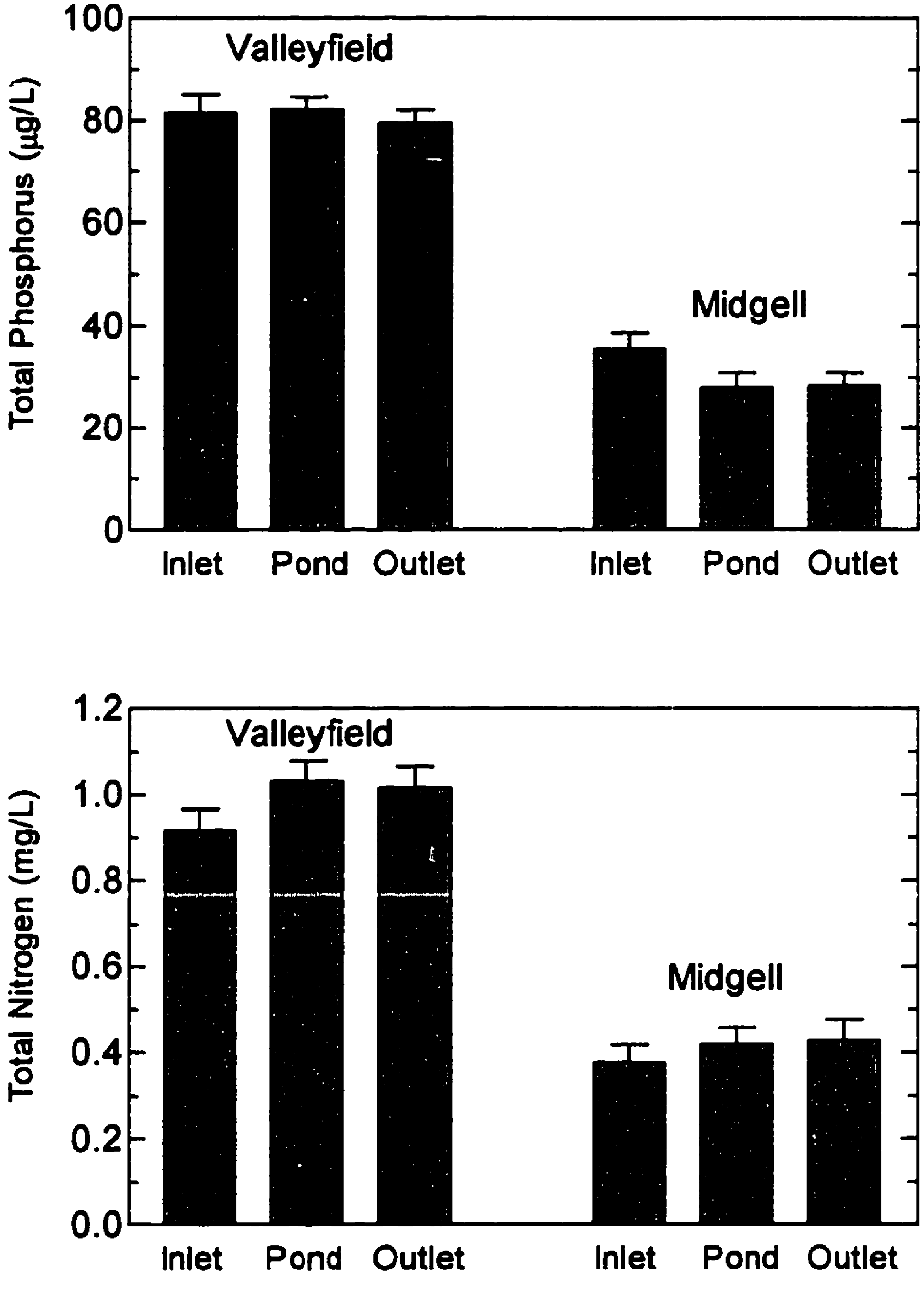


Figure 75. A comparison of total phosphorus and total nitrogen between the inlet, pond,and outlet at MacDonalds and Maritime Electric Pond from 18 May to 29 August, 1994 (error bars are one standard error of the mean).

3.5 Biological Characteristics

3.5.1 Chlorophyll *a*

Mean concentrations of chlorophyll *a* were lower than expected, considering the high nutrient values. Concentrations of chlorophyll *a* ranged from less than 1 μg/L at Maritime Electric to 9 μg/L at Officers Pond (Figure 76). Although all of the impoundments can be classified as mesotrophic-eutrophic, based on the concentration of total phosphorus, the chlorophyll *a* concentration is more typical of mesotrophic systems (Cooke et al. 1993). The Maritime Electric Pond, for example, had a high concentration of phosphorus (82.1μg/L), but its chlorophyll a concentration was so low as to categorize the impoundment as oligotrophic (Cook et al. 1993). The short turnover time at Maritime Electric, Arsenaults, and Scales could explain why productivity, as reflected in chlorophyll *a* concentration, was not as high as total phosphorus concentration would predict (Table 8).

Chlorophyll *a* concentration was higher in the pond than the inlet at all sites, with the exception of Maritime Electric where chlorophyll *a* was low at all stations (Figure 76). Mean concentration of chlorophyll *a* at the pond and outlet stations at MacDonalds, Larkins, Arsenaults, and Grovepine was significantly greater than the mean concentration at inlet stations (Figure 76). There was an increase in mean chlorophyll *a* concentration at the pond and outlet stations at Wiseners and Scales Ponds, however the difference was not significant at the 95% confidence level (Figure 76). Chlorophyll *a* concentration at the outlet was greater than inlet values, but less than pond levels, at all sites with the exception of Grovepine (Figure 76). At Grovepine, the significantly higher concentration at the outlet may have been

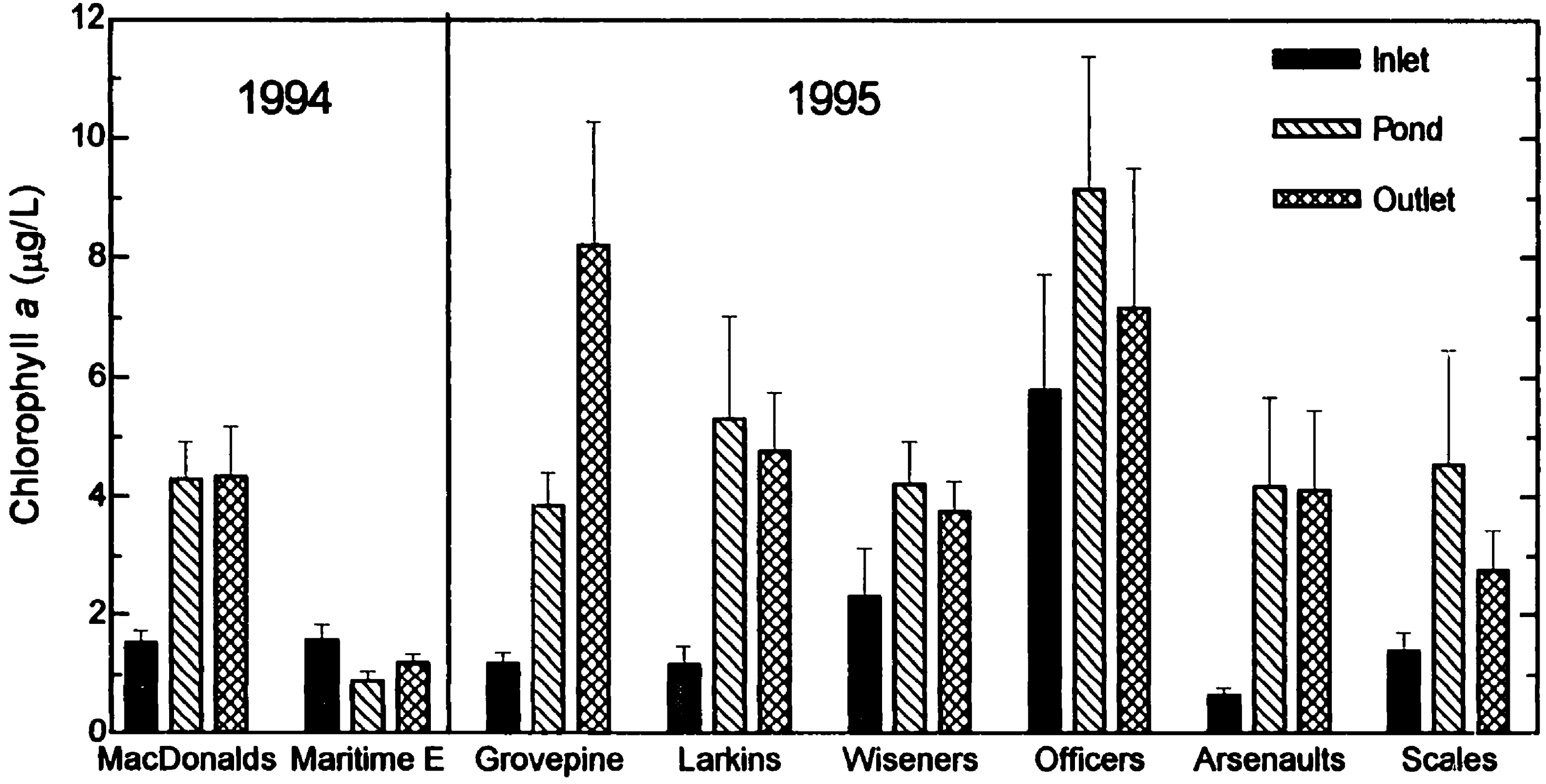


Figure 76. Mean chlorophyll *a* concentrations at the inlet, pond, and outlet sampling stations of each impoundment, 1994-95 (error bars are one standard error of the mean).

Table 8. Comparison of impoundment surface area, water residence time, total phosphorus and nitrogen concentrations, and chlorophyll *a* at all study sites, 1994 and 1995.

Impoundment	**Surface Area (m^2)**	**Flushing Rate (days)**	**Mean TP (μg/L)**	**Mean TN (mg/L)**	**Mean Chl *a* (μg/L)**
Maritime E.	27,000	0.4	82.1 ± 2.5 (n=7)	1.0 ± 0.1 (n=7)	0.9 ± 0.2 (n=6)
Arsenaults	47,000	1.8	71.3 ± 11.6 (n=3)	5.7 ± 0.6 (n=3)	4.2 ± 1.5 (n=5)
Grovepine	37,000	7.2	95.5 ± 26.3 (n=4)	0.9 ± 0.2 (n=4)	3.9 ± 0.5 (n=5)
Scales	171,000	2.9	48.0 ± 2.3 (n=3)	3.2 ± 0.2 (n=3)	4.5 ± 1.9 (n=5)
Officers	186,000	13.6	81.5 ± 12.0 (n=4)	1.6 ± 0.2 (n=4)	9.2 ± 2.2 (n=5)
MacDonalds	126,000	17.1	28.0 ± 2.9 (n=8)	0.4 ± 0.0 (n=8)	4.3 ± 0.6 (n=6)
Larkins	320,000	23.4	42.7 ± 11.0 (n=3)	0.4 ± 0.1 (n=3)	5.3 ± 1.7 (n=5)
Wisceners	342,000	397.8	36.0 ± 4.6 (n=4)	0.6 ± 0.1 (n=4)	4.2 ± 0.7 (n=5)

a result of stagnant conditions and enhanced productivity in shallow waters near the dam because of a beaver impoundment approximately 200 metres downstream.

There appeared to be two distinct periods of elevated chlorophyll *a* concentration at Larkins, Scales, and Wiseners (Figure 77). The first occurred in mid-July, which was followed by a second peak in mid-August. At Officers Pond, chlorophyll *a* increased in July, dropped in mid-August, and reached its highest value at the first of September. Grovepine was the only impoundment in which chlorophyll *a* concentration in the pond and outlet increased as the summer progressed (Figure 77). This increase may have been a response to the internal loading of phosphorus as the hypolimnion became anoxic. Total phosphorus concentrations at Grovepine increased from 73 μg/L in late June to 162 μg/L by late July.

3.5.2 Zooplankton

The zooplankton was predominately composed of rotifers at all impoundments (Figure 78). Wiseners Pond had far greater numbers of rotifers per litre (1,506) than did any of the other sites, followed by Larkins (140), Officers (64), and Grovepine (21). Officers Pond had greater diversity than the other impoundments, and had a number of cladocerans and immature copepods, as well as rotifers. Scales and Arsenaults Ponds had few zooplankton.

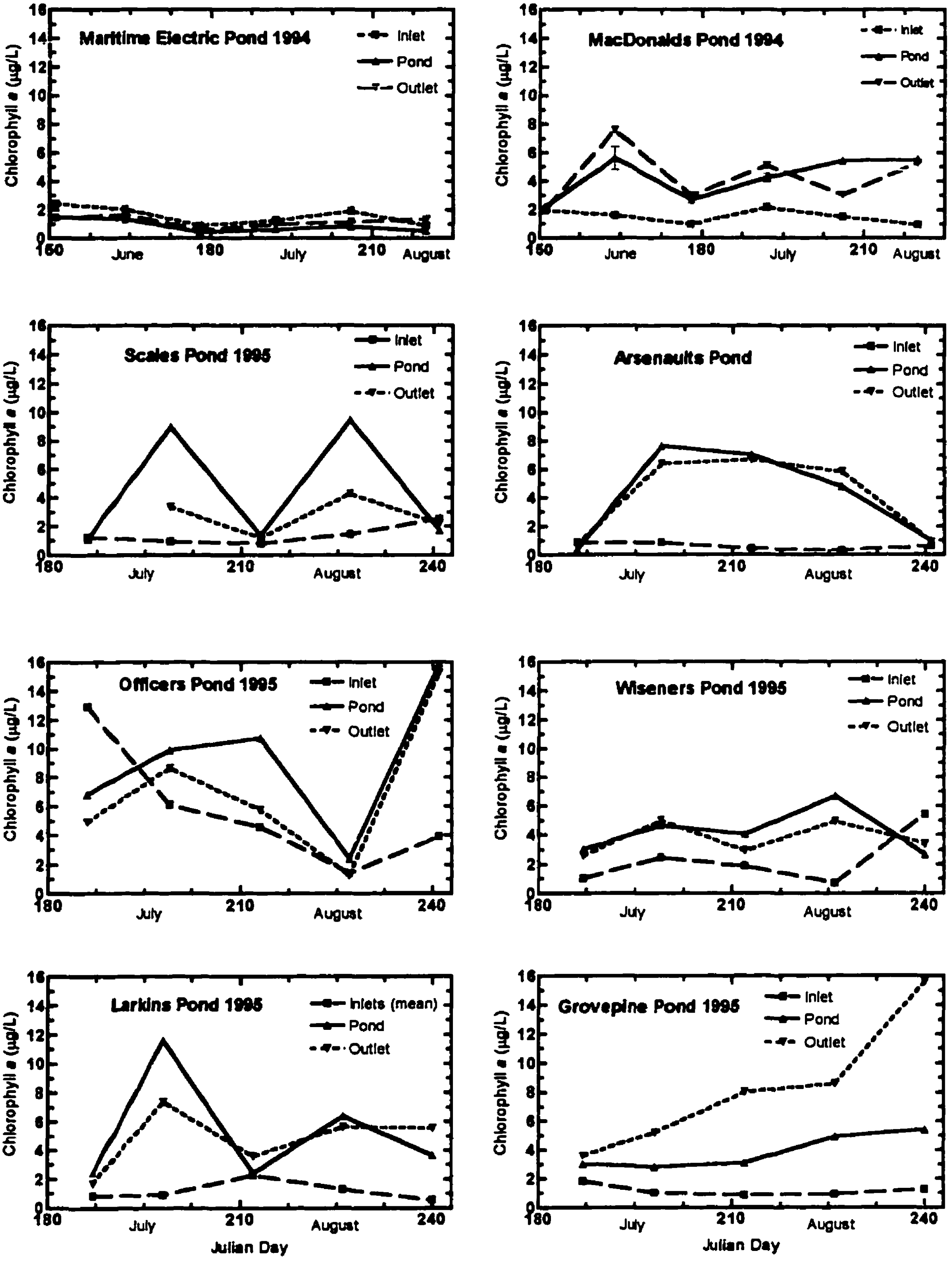


Figure 77. Seasonal changes in chlorophyll *a* concentration at the inlet, pond, and outlet of each impoundment in 1994 at Maritime Electric Pond and MacDonalds Pond and in 1995 at all other sites (error bars are one standard error of the mean).

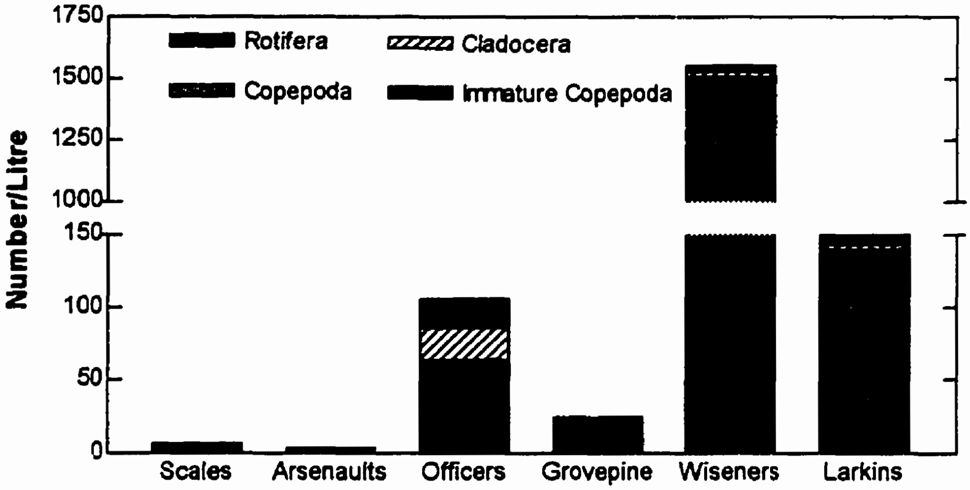


Figure 78. Mean zooplankton density at each site, 1995.

4.0 DISCUSSION

4.1 Water Temperature

There are a number of habitat requirements for any species, but for cold water fish like brook trout and Atlantic salmon, water temperature is one of the most important factors in determining habitat suitability. Barton et al. (1985) examined 38 streams in southern Ontario, concluding that "the only environmental variable which clearly distinguished between trout and nontrout streams was weekly maximum water temperature." Although the documented lethal limit varies depending on the conditions of the particular study (laboratory or field) and age of the fish being studied, there is a generally accepted range of temperature that is deemed "optimal" for brook trout. Creaser (1930) concluded that "the maximum temperature for natural self-sustaining brook-trout waters is now well established at about 19°C." Needham (1969) suggested that "Streams showing maximum temperatures of over 75°F [24°C] should not be considered brook trout waters...they thrive best in streams that show mid-summer maximum temperatures around 66°F [19°C]." According to Young and Maughan (1980), upper lethal temperature limits for brook trout range from 21.0 to 26.0 °C, with 14-19 °C preferred by the species. The upper tolerance limit for brook trout has been listed as 22.1°C (Sinokrot et al. 1995). ASE Consultants Inc. (1994) prepared an extensive literature review concerning the impact of impoundments on fish habitat, concluding that optimum water temperatures for brook trout on Prince Edward Island probably range from 13 - 16°C. After reviewing the literature and relevant data from Prince Edward Island (MacMillan 1998), I have selected 22°C as the upper tolerable temperature for salmonids.

With up to 70% of stream flow comprised of baseflow on P.E.I. (Francis 1989), and springs maintaining a temperature of approximately 7°C year round, water temperature has generally been overlooked as a factor influencing salmonid populations in P.E.I. streams. Thus, when Smith (1958) described the trout fishery on Prince Edward Island, he wrote, "Because of the nature of the soils and their development in depth, springs and spring seepages are widespread. These result in a good flow of cool water in most streams throughout the summer. The cool aquatic climate in the streams satisfies the temperature preferences of the trout at that season." Francis (1989) also partly attributes the productivity of the trout population in Prince Edward Island streams to "...the moderating effect of groundwater baseflow on water quality, water temperatures, and maintenance flow." Recent studies, however, document elevated water temperature downstream from impoundments and water temperatures outside the optimal range for salmonids (Ducks Unlimited Canada 1988 and 1989, Guignion et al. 1990, MacMillan 1998, Thompson et al. 1990).

Brook trout have the ability to seek refuge in times of temperature stress, and will seek out cooler water when temperature approaches 20°C (Elson 1942, Gibson 1966, Power 1980) and stay in these locations for extended periods of time. Brook trout on the Midgell River were observed moving into a large spring at the head of MacDonalds Pond when water temperatures averaged 20-21°C over a one to four day period prior to sampling (MacMillan 1998). One concern is that younger year classes of salmonids have to seek refuge with larger fish, and may be susceptible to increased predation, not only from other fish, but also from avian and mammalian predators which concentrate in the refuge areas (MacMillan 1998).

Salmonids leaving suitable feeding habitat to move into refugia are also forced to alter their feeding behaviour in a temperature below the optimal feeding range. Although salmonids may continue to eat at low or high temperatures, growth is reduced (Bjornn and Reiser 1991).

Although each drainage basin has its own geographical characteristics which influence water temperature, streams in regions of higher relief tend to remain cooler than those which drain low areas. For this reason, the Valleyfield, Wilmot, and Dunk Rivers had the coolest water temperatures of the eight sites in this study.

Solar energy is the major contributor to water temperature warming (Chamberlin et al. 1991, Houston 1982), and slow flowing streams with a large surface area of open water are particularly susceptible to warming. The Midgell River above MacDonalds Pond, for example, not only has a number of beaver dams, but also has a Ducks Unlimited impoundment (McCarricks Pond), and a former dam site. Although this dam washed out approximately ten years ago, streamside vegetation is primarily grass and the stream remains unshaded for 6 km upstream to the Elm Road. This could explain the high stream temperature at the inlet to MacDonalds Pond and the < 1 °C difference between inlet and outlet temperatures. In 1988, Ducks Unlimited monitored inlet and outlet water temperatures at MacDonalds Pond. Inlet temperatures were, on average, cooler than the outlet by approximately 5 °C in July and about 4°C in August (Ducks Unlimited Canada 1988). Since this study, the number of beaver dams on inflowing tributaries to MacDonalds Pond have increased (1968 & 1990 aerial photos).

With aging, these beaver impoundments have been left open and exposed to solar radiation, possibly resulting in warmer stream temperatures entering MacDonalds Pond.

The impact of impoundments on water temperature is evident in a comparison of inlet and outlet water temperatures at all of the impoundments studied. With the exception of the 1994 MacDonalds Pond data, outlet water temperatures were greater than temperatures at the inlet. All of the impoundments discharge water from the epilimnion. Ducks Unlimited monitored a number of Prince Edward Island impoundments, including Wiseners, Officers, and MacDonalds from 1987 to 1989, concluding that there were significant increases in water temperature at the surface of the impoundments and downstream (Ducks Unlimited Canada 1988).

The water residence time within an impoundment is a major factor in the heating of impounded waters. Surface water in impoundments with a long water residence time will have more time of exposure to solar radiation and will increase in temperature more than impoundments with a high flushing rate. Wiseners, Larkins, MacDonalds, Officers, and Grovepine had the longest water residence time and the greatest increases in water temperature from inlet to outlet. Although Scales Pond and Officers Pond have similar surface areas, Officers has a longer water residence time. The temperature increase from inlet to outlet at Officers Pond was 3 °C greater than the increase recorded at Scales Pond.

All of the impoundments, even shallow ones like Grovepine, developed temperature stratification in the summer. Morphometric characteristics play an important role in determining the degree and strength of stratification. The large open expanse of Officers and Wiseners ponds exposed the water to wind action and as a result, stratification periodically broke down. Although Larkins Pond is also large, it has a smaller maximum length and maximum breadth and greater shoreline development index than Wiseners and Officers; once stratification was established, it remained throughout the summer.

Even with stratification, bottom water temperatures in some impoundments were above the optimal range for salmonids. Temperature at the bottom of MacDonalds Pond was elevated, probably because of warm inlet temperatures and the lack of notable groundwater input within the impoundment (MacMillan 1998). Periodic destratification can also raise bottom temperatures above optimum levels by mixing cool bottom water with warmer water in the epilimnion. Thus, Officers and Wiseners Ponds became uniformly warm from top to bottom when the impoundments destratified during wind induced turbulence.

Stream water temperatures are affected by a number of variables, such as the intensity of shade overhead, as well as the amount of groundwater input in downstream waters (Smith and Lavis 1975). The nature of the substrate also has an effect on water temperature; a shallow stream with a bedrock substrate can act as a significant energy sink for incoming solar radiation (Brown 1969). Downstream temperatures on the Midgell River dropped slightly but still exceeded 22°C at the head of tide about 5.5 km from the outlet. Outlet and downstream maximum temperatures on the Naufrage River were almost identical after a distance of almost 3 km. In both cases, there is extensive stream canopy on each side of the river, but the stream leaving the impoundment is wide and open to warming from solar radiation. Few springs are present to assist in cooling the water. Water temperatures 3 km downstream from Officers Pond, however, showed an appreciable decrease from outlet temperatures, probably due to major groundwater input in this section. It would appear that Tebo (1975) was correct in stating that heat loss from a thermally loaded stream is site-specific, depending upon the factors mentioned above.

Where there are multiple impoundments, water temperature can increase rather than decrease downstream from a dam. When water leaves Grovepine Pond, it is immediately impounded by a beaver dam about 200 m downstream. Water temperatures recorded at the downstream site were higher, rather than lower, than temperatures recorded at the outlet and were above optimal levels for brook trout. By mid-summer, streamflow at the downstream station had dropped substantially, and evaporation is likely high from all impounded waters.

Some large headwater impoundments with a small drainage area have little outflow during warm summer months. Ducks Unlimited Canada (1989) categorized Wiseners Pond as an impoundment with a large pond area:watershed area ratio which experienced significant decreases in outflow. Not only does Wiseners Pond provide a large surface area for solar radiation and evaporation, but there are numerous beaver dams and two man-made impoundments on the small incoming tributaries. The decrease in discharge from an impoundment can actually result in cooler water temperatures downstream from the dam. In 1995, outflow at Wiseners Pond diminished to a trickle and the water temperature downstream became cooler rather than warmer than the inlet temperature. The amount of water originating from springs became proportionally greater than streamflow and exerted more influence on stream temperature. Once flows began to increase in late September, the inlet water temperature was once again cooler than the temperature downstream from the dam. Water temperatures may have been cooler during periods of reduced discharge, but surface area of stream habitat is drastically reduced.

Water temperatures peak during the day but can cool substantially in the evening. It was not unusual for inlet water temperatures to have greater diel fluctuation than temperatures within an impoundment or at the outlet, as heat stored in a large body of water is more slowly dissipated. At some locations, for example the outlet and downstream stations at Grovepine, daily maximum temperatures were greater than 22°C; daily minimum temperatures, however, were at or below 22°C. All river sites on the Naufrage and the outlet at Wiseners also had temperatures exceeding 22°C but less than 22°C at night.

Monitoring water temperatures for one summer provides an indication of conditions for that year, but other summers may vary. The three years of temperature monitoring on the Naufrage River demonstrate the variation in stream temperatures with respect to weather conditions. Although August 1993 had greater mean air temperature than August 1994 and 1995, June and July were both cooler than normal that summer. As a result, summer water temperatures in 1993 were cooler than either of the two following years. Long term monitoring provides a more complete understanding of the range of stream temperatures under different conditions.

4.2 Dissolved Oxygen

Dissolved oxygen concentration in lotic habitats is not generally identified as a problem when considering classic salmonid habitat - cool, flowing streams with a coarse substrate. In lakes, reservoirs, and ponds, however, dissolved oxygen can become a limiting factor for salmonid populations. There is no single threshold at which low dissolved oxygen becomes lethal to salmonids, because tolerance varies with species, life stage, and acclimation history. After a series of summer field studies, Moore (1942) concluded that a dissolved oxygen concentration of 3.5 mg/L will kill northern fishes confined to those waters. The minimum dissolved oxygen concentration recommended to maintain good populations of cold water fish is 5.0 mg/L (U.S. EPA 1986, cited by Canadian Council of Resource and Environment Ministers 1987). The concentration of dissolved oxygen is dependent on water temperature, and the solubility decreases as water temperature rises. The percentage oxygen saturation is as important as the absolute amount of dissolved oxygen. According to Dobson et al. (1974), dissolved oxygen values less than 50% saturation are hazardous to fish. Aquaculturalists strive to maintain dissolve oxygen levels at saturation (McLarney 1984). The optimal range of oxygen levels for salmonids will be substantially greater than the lethal limit. For the purposes of this study, I have assumed that dissolved oxygen concentration less than 5.0 mg/L and saturation values less than 50% are detrimental to salmonids.

The development of anoxic conditions in lakes and reservoirs is well documented (Gunnison 1981, Gunnison et al. 1983, Mackie et al. 1983, Summers 1985). Microbial activity, respiration, and decomposition of organic matter, particularly in the hypolimnion, all contribute to lowered oxygen levels. In a stratified impoundment, wind and wave action on the warmer epilimnion can aerate the surface, but the hypolimnion may remain unmixed for extended periods, providing little opportunity for reaeration. Larkins Pond is a deep, temperature stratified impoundment and its elongated shape and relatively long water residence time were factors in establishing strong oxygen stratification over the summer. The impoundments with weak oxygen stratification, Arsenaults, Scales, and Maritime Electric, had cooler water temperatures, weaker temperature stratification, and shorter water residence times than the other impoundments studied. Dissolved oxygen concentration and saturation values in these impoundments were within the preferred range for salmonids.

Dissolved oxygen concentration in winter at Grovepine, Wiseners, Officers, and MacDonalds became depressed in the hypolimnion, particularly in late December and early January at the sampling station closest to the dam. The Maritime Electric Pond, however, maintained high oxygen concentrations throughout the winter. The short water residence time and lack of submerged macrophytes may explain why the Maritime Electric Pond maintained high oxygen saturation under ice in winter. MacDonalds, Wiseners, Officers, and Grovepine are shallow, their water residence times are longer, and there is an abundance of decomposing organic material to depress dissolved oxygen concentrations.

Oxygen levels above saturation are not unusual and can occur under a variety of conditions. Blue-green algae, such as *Oscillatoria*, are often associated with oxygen supersaturation, particularly in the metalimnion during stratification (Wetzel 1983). All three impoundments with elevated dissolved oxygen levels, Scales, Arsenaults, and Officers, had high nutrient concentrations and conditions favouring algal growth, although chlorophyll *a* concentration was high only at Officers. Scales and Officers Ponds had extensive growth of rooted aquatic plants which probably contributed to the high concentration of dissolved oxygen. Livestock also have access to both Scales and Officers for watering. At Officers, there is a piggery located next to the dam and a cattle feedlot near a tributary to the southeast. Dense mats of algae are visible on this branch of the pond and could indicate enrichment as a result of manure runoff.

Excess gases, including oxygen, can lead to "gas bubble disease" in fish and other aquatic life - a condition similar to "the bends" in divers (D'Aoust and Smith 1974). Much of the literature concerning gas bubble disease deals with supersaturation as a result of "unnatural" causes, such as sudden heating of water temperature in power plant cooling (D'Aoust and Clark 1980) or water under pressure at the spillway of dams (Lindroth 1957). Oxygen supersaturation of pond water because of photosynthetic activity is not uncommon, and fish will move from supersaturated surface waters to other depths where oxygen saturation is less (Boyd 1982). At Officers Pond and Scales Pond, anglers appeared to focus their efforts in summer at the upper ends of the ponds where water temperature was cooler and dissolved oxygen levels lower. It is unclear whether water temperature, dissolved oxygen, or a combination of both is responsible for fish movement.

Both Officers and Wiseners Ponds had fluctuations in concentration of dissolved oxygen throughout the summer. At Wiseners, the fluctuation was in the hypolimnion. This could be caused by the large surface area and great breadth which allow wind and wave action to periodically mix surface and bottom. The breaks in oxygen stratification corresponded with breaks in thermal stratification. At Officers, surface and bottom waters fluctuated throughout the summer. Both depths were often supersaturated and the fluctuation in oxygen at this pond was probably a result of seasonal changes in phytoplankton production. This is discussed in greater detail in Section 4.3.

Grovepine was constructed in 1990 and is the newest impoundment in this study. A new impoundment often experiences a surge in productivity, as nutrients are leached from the soil or released upon decomposition of drowned vegetation and woody debris (Baxter and Glaude 1980). Decomposition and respiration in Grovepine create anoxic conditions within the impoundment in both summer and winter. In such an anaerobic environment, there is potential for release of hydrogen sulphide (H_2S), a substance poisonous to salmonids at concentrations as low as 0.002 ppm (Wedemeyer 1977, cited by Piper et al. 1982). During winter sampling for dissolved oxygen at Grovepine, there was a strong rotten-egg odour of H_2S at the outflow, and the odour was particularly powerful when a hole was cut in the ice

(Todd Dupuis, Atlantic Salmon Federation, P.O. Box 2000, Charlottetown, PE, C1A 7N8, personal communication).

Most free flowing streams have oxygen levels near saturation. All of the eight impoundments studied discharge water from the epilimnion, and with water spilling over a dam and the re-establishment of stream conditions, dissolved oxygen at the outlet and downstream from the impoundments was not expected to be a problem. In 1994, all stream stations on the Valleyfield River had oxygen levels at or near saturation values. Saturation levels on the Midgell were not as high but exceeded 75% at the outlet and downstream stations. At the inlet station, however, low water flow conditions and warm temperatures may have been responsible for the low concentration of dissolved oxygen, which fell below 5.0 mg/L in late July and early August. In low gradient areas like that of the Fortune River drainage basin, multiple impoundments appear to have a profound effect on stream oxygen levels. Water leaving Grovepine impoundment is immediately impounded by a series of beaver dams and oxygen concentrations remained low at all downstream stations monitored. Dissolved oxygen concentration in water leaving the fishway at Grovepine was occasionally as low as 1 mg/L and did not improve until the Big Brook tributary joined the Grovepine stream.

4.3 Water Chemistry and Productivity

Prince Edward Island's streams are largely considered to be productive, primarily because of the large input of mineral-rich groundwater and nutrient rich run-off from agricultural land (Brandon 1966). A comparison of water quality between streamflow and groundwater in the

Winter River prompted the suggestion that "Even during flood periods, the streamflow is essentially diluted groundwater" (Francis 1989). Groundwater has a high conductivity (>250 μmhos/cm), and high total alkalinity, in the 50-250 mg/L range (ASE Consultants Inc. 1994). All of the impoundments studied had chemical characteristics comparable to results of previous studies of wetlands on Prince Edward Island (Curley and Duffy 1990, (Curley and MacKinnon 1988).

The chemical nature of river water is also closely related to the hydrology of the drainage basin. Runoff from surrounding land can be a major contributor of nutrients to the watercourse (Artola et al. 1995, Harper 1992). The degree of erosion and export of nutrients are directly influenced by the topography of the catchment basin (Wetzel 1983). Nutrient losses from an undisturbed terrestrial ecosystem are quite low, but "increase in proportion both to the intensity and frequency of disturbance" (Harper 1992). While it is difficult, if not impossible, to find undisturbed regions on Prince Edward Island, some watersheds have more intensive agricultural use than others. Row-crop cultivation, particularly for potatoes, is the staple of agriculture on Prince Edward Island, and exposed fields in winter and spring lend themselves to serious soil erosion. Livestock operations in close proximity to streams can also be source of nutrients. Of the eight impoundments studied, those with more cleared land within their watersheds had higher concentrations of both nitrogen and phosphorus than those with more forested drainage basins. According to Vollenweider's trophic state classification (Harper 1992), where productivity is related to phosphorus concentration, all of the impoundments, with the exception of MacDonalds Pond, can be classified as eutrophic; MacDonalds falls into the meso-eutrophic category.

Although runoff is a primary source of nutrients to an impoundment, nutrients can also be released from within the reservoir itself. There are higher concentrations of phosphorus in lake sediments than in overlying water (Kadlec 1989, Wetzel 1983) and under the right conditions, "internal" loading of phosphorus can occur. Internal phosphorus loading and release of iron under anoxic conditions in water near the sediment interface has been well documented (Carignan and Lean 1991, Devito and Dillon 1993, Fabre 1988, Grizzard et al. 1982) and could explain the high concentration of phosphorus at Grovepine. Chemical data from November, February, March, May, and July 1994/95 (ASE Consultants Inc. 1995) show that total phosphorus concentrations at Grovepine were highest in July, more than five times the concentration in March and May. At the same time, iron concentration was four times the concentration in February, March, and May. Phosphorus can also be released from sediments under aerobic conditions (Fabre 1988), particularly when the water and sediments are stirred by wind turbulence. This could account for elevated phosphorus concentrations in a large, open impoundment like Wiseners Pond. Phosphorus concentrations in Clarks Pond, upstream from Wiseners, are substantially higher than in Wiseners (ASE Consultants Inc. 1995). Internal phosphorus loading from anoxic sediments in Clarks Pond appears to be more substantial than any contribution from sediments in Wiseners Pond.

Chlorophyll *a* has long been used as an indicator of productivity in lakes and reservoirs (Dillon and Rigler 1974). Although it does not represent the exact amount of algal biomass in the system (LaBaugh 1995), chlorophyll *a* concentration does serve as a useful approximation of phytoplankton biomass (Jones and Hoyer 1982). Lotic water is lower in particulate organic matter and plankton than lentic water but carries relatively high concentrations of nutrients into an impoundment (Ejsmont-Karabin et al. 1993). The impoundments provide favourable conditions for an increase in primary and secondary productivity. All of the impoundments studied, with the exception of the Maritime Electric Pond, had an increase in mean chlorophyll *a* from the inlet to the pond station. Kondratieff and Simmons (1984) observed that chlorophyll *a* concentrations at the outlet to a reservoir in Virginia were an order of magnitude greater than water upstream and downstream from the dam. Officers and Wiseners Ponds both have impoundments upstream from the inlet, so the inlet mean concentration of chlorophyll *a* was greater than at other sites and is representative of the production occurring upstream. The higher concentration of chlorophyll *a* at the outlet to Grovepine in comparison to the pond station might be explained by favourable conditions for continued production as a result of the beaver impoundment downstream.

The concentration of particulate organic material can also give an indication of production and export of organic matter. Most of the impoundments had greater POM at the pond and outlet, as compared to the inlet station; Wiseners, Officers, and Scales had slightly greater concentrations of POM at the inlet than in pond and outlet stations. The impoundments upstream from Wiseners and Officers could be contributing to the high concentration of particulate organic matter in inflowing waters. Vannote et al. (1980) described the changes in lotic habitat from the headwaters to the mouth of a river, calling this concept "the river continuum." The biological community of the shaded upper reaches of a stream is supported largely by allochthonous input of detritus, as conditions do not favour primary production. Further downstream, as the river becomes larger and more sunlight is available, the plankton community develops. Impoundments serve to interrupt the river continuum, providing areas of increased primary production in the headwaters, and the outflowing water gradually reverts to riverine conditions (Palmer and O'Keefe 1990).

The flushing rate of an impoundment has a major influence on productivity (Dillon 1975), not only by warming water temperatures, but also by allowing a longer time for uptake of nutrients by phytoplankton. Dillon (1975) suggested that a high flushing rate can counteract phosphorus loading. This could explain the greater concentration of chlorophyll *a* in MacDonalds Pond as compared to the Maritime Electric Pond, although nutrient concentrations were higher in the latter and mean chlorophyll *a* concentrations were the same in both inflowing streams. Arsenaults Pond had twice the concentration of total phosphorus as did Larkins Pond but had less productivity as indicated by concentrations of chlorophyll *a*. Water residence time at Larkins Pond is roughly ten times as long as at Arsenaults.

Flushing rate may be one factor in determining the productivity of an impoundment, but the availability of nutrients is another. Most of the phosphorus entering streams from catchment runoff is particulate phosphorus adsorbed to inorganic matter, particularly clay particles, and is less available to phytoplankton than soluble phosphorus (Rodriguez 1985). Hoyer and Jones (1983) found an inverse relationship between the concentration of suspended inorganic sediments and chlorophyll *a* concentration when phosphorus concentration was held constant. Scales and Arsenaults had high concentrations of nutrients, but the concentration of chlorophyll *a* within each impoundment, although higher than inlet values, was not as great as the concentration in other impoundments studied. Both Scales and Arsenaults had the highest concentration of particulate inorganic matter of all sites and the greatest amount of inorganic material in suspended sediment traps. Although there is a possibility that increased turbidity could decrease the light available for photosynthesis (Riera and Armengol 1995), the Secchi depths at both impoundments indicate that the euphotic zone, estimated to be two to three times the Secchi depth (Cole 1983), extends to the bottom. Thus, while flushing rate appears to be a strong predictor in the productivity of an impoundment, we should not discount the phosphate adsorption reactions which could affect the availability of phosphorus.

A comparison of zooplankton in the eight ponds monitored in 1995 indicated that impoundments with a longer residence time, Wiseners, Larkins, and Officers, had greater numbers of zooplankton per litre than did the impoundments with a higher flushing rate. Ejsmont-Karabin et al. (1993) also found that reservoirs with a longer residence time had far greater numbers of zooplankton than did reservoirs with a rapid time of water exchange. They discuss the effect of zooplankton foraging on phosphorus sedimentation in small impoundments and postulate that reservoirs with a short residence time can be "...a kind of a trap for nutrients excluded from cycling in running waters..." as conditions do not favour the development of high phytoplankton populations which would be involved in nutrient cycling (Ejsmont-Karabin et al. 1993). However, they point out that a reservoir with a long residence time can also have a high phosphorus sedimentation rate if phytoplankton densities exceed zooplankton demands and sedimentation of dead algal cells remove phosphorus from circulation. My 1994 data did not indicate that nutrient levels at the outlet were any different from inlet values at MacDonalds and Maritime Electric. Schreiber and Rausch (1979), however, reported that small impoundments can slow downstream eutrophication by reducing ortho-P concentrations in the outlet waters by as much as 64% of inflow concentrations. Dorioz and Ferhi (1994) also observed a significant decrease in nutrients leaving wetlands and concluded that "...wetlands seem to have an important part in the improvement of water quality from agricultural areas and act as a nutrient sink."

4.4 Sediment Transport and Deposition

About 70% of the land area on Prince Edward Island is made up of podzol soils (MacDougall et al. 1988) with an underlying rock formation of Permo-Carboniferous red sandstone (Saunders and Smith 1965). This soil is easily moved by wind or water, and soil erosion has been identified as the most serious environmental problem on P.E.I. (Anonymous 1987). Forestry activities and runoff from poorly surfaced roads contribute sediments to watercourses, however "the production and transport of sediment to streams, among all sources, is greatest from row crops and other cultivated fields" (Waters 1995). In 1996, approximately 44,000 ha were in potato production alone (Round Table on Resource Land

Use and Stewardship 1996). Annual soil erosion rates of 25 tonnes/ha are common, although annual rates as high as 750 tonnes/ha have been recorded (Round Table on Resource Land Use and Stewardship 1996).

Impoundments do not have a finite lifespan and inevitably fill with sediment. However, Prince Edward Island impoundments are infilling at an rapid rate. It has been estimated, for example, that about 30% of the original water surface at the Maritime Electric Pond has been lost due to infilling (ASE Consultants Inc. and Department of Biology, University of Prince Edward Island 1997). In other impoundments, such as Larkins, Grovepine, and Wiseners, the infilling is less a result of sedimentation but rather natural pond aging and subsequent encroachment of cattail marsh. In all cases, as the impoundments infill, their potential as fish habitat will become limited.

To fully understand the transportation and deposition of sediments in Prince Edward Island streams and impoundments, one would monitor concentrations of suspended sediments in spring when erosion and runoff are greatest. Although this study was conducted in the summer and concentrations of particulate inorganic matter at all sites were relatively low, it does offer a good comparison between cleared watersheds with heavy agricultural usage and more wooded drainage basins. The streams entering Arsenaults, Scales, and Officers Ponds had considerably greater concentrations of inorganic matter than inlet streams at other sites. Scales and Officers are functioning as sediment traps, as evidenced by the significantly lower concentration of particulate inorganic matter in both ponds as compared to the inlet.

Arsenaults Pond was the only site to have far higher concentrations of particulate inorganic matter in the pond, outlet, and downstream station than the inlet. In a small impoundment with a short residence time, fine particles could be resuspended in the water column for considerable periods. Another possibility at Arsenaults Pond is the resuspension of sediments by motor boats, as the pond is regularly used by anglers. In fact, the water at Arsenaults was a brown colour for such an extended time, anglers were openly wondering what was responsible for it. The particulate inorganic matter in both regular water samples and in the suspended sediment trap were greater at Arsenaults Pond than at any other site. Even during extended dry periods, the concentration of inorganic matter in the trap was very high, suggesting that fine particles are remaining in suspension. With both sides of the pond in row crop cultivation, wind erosion could be contributing sediments to the impoundment during dry periods. Diatoms are also known to produce golden brown discolourations of water. Although I did not do a quantitative analysis of phytoplankton as part of the study, I did observe large numbers of a centric diatom, *Stephanodiscus* in a water sample from Arsenaults Pond. Further study would be needed to partition the particulate inorganic matter into finer categories to see if the colloidal fraction is responsible for the continued turbidity within the impoundment and an analysis of phytoplankton would determine if diatoms are a cause of discolouration.

5.0 SUMMARY AND MANAGEMENT IMPLICATIONS

Regardless of size, impoundments change lotic habitat into lentic habitat, and affect the physical, chemical, and biological environment within a stream or river. Whether or not these changes are beneficial or detrimental to salmonid habitat depends on a number of factors. The characteristics of the surrounding drainage basin - its topography and nature of land use - are of major consideration. Soil erosion has been identified as the most serious environmental problem on Prince Edward Island, and the impact of large amounts of fine sediment in streams is presumed to be a major limiting factor in salmonid production. Sediment has been shown to reduce reproductive success of salmonids by covering spawning redds, smothering embryos and sac fry, and preventing emergence of fry (Waters 1995). Deposited sediment also affects the depth of holding pools and can reduce rearing habitat of salmonid fry and parr by infilling interstitial spaces within gravel/cobble substrate (Waters 1995). Impoundments in areas with extensive soil erosion could function as sediment traps and protect salmonid habitat downstream. The down side to this sediment trapping function is the reduced life span of the impoundment. Many Prince Edward Island impoundments are heavily infilled, and their capacity to act as sediment traps and as holding areas for salmonids is becoming limited. The reduced depth of some impoundments due to infilling may also exacerbate summer water temperature warming in certain streams.

Many estuaries on Prince Edward Island are showing signs of enrichment - high nutrient concentrations and anoxic conditions in summer (Bruce Raymond, P.E.I. Department of

Technology and Environment, Water Resources Division, P.O. Box 2000, Charlottetown, PE, C1A 7N8, personal communication). The lucrative shellfish industry in estuaries around P.E.I. is dependent upon good water quality. Although my limited monitoring of nutrient concentrations in the Midgell and Valleyfield Rivers did not show reduced concentrations in outlet waters, other studies have indicated that impoundments serve to trap incoming nutrients and release “cleaner” water downstream (Dorioz and Ferhi 1994, Schreiber and Rausch 1979). This would certainly be of benefit to rivers and estuaries in agricultural drainage basins. However, the internal release of phosphorus from bottom sediments in some impoundments has been shown to increase outflow concentrations of phosphorus in summer (Grizzard et al. 1982). Estuarine or head of tide impoundments that develop anoxic conditions in summer could be releasing oxygen-poor, nutrient-rich water into estuaries.

Streams in areas of higher relief have more groundwater influence and, as indicated in this study, cooler summer water temperatures than streams in low relief areas. An impoundment constructed in a region of high relief is shorter, smaller, and often deeper than an impoundment in flatter terrain. Thus, impoundments located on relatively high gradient, cool streams are less likely to have a water temperature problem. Water temperature warming also becomes more pronounced in low gradient streams with multiple impoundments, either natural or man-made. I have emphasized the contribution of groundwater discharge to baseflow and the water temperature refugia provided to salmonids. However, springs are of critical importance to brook trout reproductive success, as brook trout spawn almost exclusively in upwelling areas (Ricker 1932, Webster and Eiriksdottir 1976). Headwater springs traditionally used by spawning brook trout can become inundated with water from impoundments or access to the springs may be blocked by impassable dams.

The results of this study indicate that water residence time within an impoundment appears to influence water temperature warming, nutrient uptake, and dissolved oxygen concentrations. Water residence time is a function of drainage basin size and impoundment volume. Larger drainage basins have a greater volume of water entering the impoundment. Thus, impoundments located in the headwaters of a stream have a greater likelihood of water quality problems associated with reduced flushing than do impoundments in middle reaches. This relationship has been expressed in different ways. For example, "watershed area ratios" refers to the ratio of pond surface area to watershed area (Ducks Unlimited Canada 1988). Impoundments with large pond area : watershed area ratios were shown to have decreased outflow in summer (Ducks Unlimited Canada 1989). ASE Consultants and Department of Biology, University of Prince Edward Island (1997) took this concept a step further and compared the surface area of lentic habitat to lotic habitat within an entire drainage basin, concluding that this ratio can "...be a yardstick in determining the suitability of an impoundment for fish, as water residence time, dissolved oxygen, and water temperature are affected by this ratio." The consultants recommended a ratio of 2:1 or less to ensure suitable habitat for salmonids. Grovepine and Wiseners have ratios in excess of 10:1; Arsenaults, Scales, and Maritime Electric have ratios below 1:1, and ratios at Officers, MacDonalds, and Larkins range from 3:1 to 6:1 (ASE Consultants and Department of Biology, University of Prince Edward Island 1997). With some refinement, the lentic to lotic ratio could be a useful indicator of water quality within and downstream from existing impoundments and a tool in planning the most suitable location for a proposed impoundment.

The data collected and personal observations support the following comments about the effects of the eight impoundments on salmonid habitat.

5.1 Scales, Arsenaults, and Maritime Electric

The impoundments on cold water systems, Scales, Arsenaults, and Maritime Electric, are serving as sediment traps and protect downstream fisheries habitat by reducing suspended sediment loads in outlet waters. However, the signs of sediment infilling are obvious at the upper ends of these impoundments, and in the high concentration of inorganic matter collected in sediment traps at Arsenaults and Scales. Shallow water reduces salmonid habitat by contributing to water temperature warming, as well as increasing the risk of predation and limiting overwinter habitat under the ice. The shallow water depth in Scales Pond has contributed to a lush growth of submerged aquatic macrophytes which interferes with angling activity on the pond. Unless the rate of soil erosion in the surrounding drainage basins is drastically curbed through adoption of more sustainable land use practices, these ponds will continue to infill and their potential as both sediment traps and fish habitat will be severely limited.

5.2 Wiseners Pond

The size of Wiseners Pond and its small drainage basin result in an extended water residence time, particularly during low discharge conditions. The broad expanse of open water is subject to warming through solar radiation, and evaporation exacerbates low summer stream discharge. Stream habitat downstream from such an impoundment is reduced. Water temperatures almost one kilometre downstream from Wiseners still exceeded the optimum range from salmonids until impoundment outflow became reduced, when spring water became proportionately greater than outflow.

The hunting/angling organization that leases the pond, the 4:30 Club, has been unsuccessfully stocking the pond with brook trout. Although temperature and oxygen levels within the pond do not provide ideal conditions for brook trout, rainbow trout might be a more viable option. The effect of the impoundment on downstream water quality is minimized because of the abundant groundwater inputs.

5.3 Officers Pond

Officers Pond is also leased by a hunting/angling organization, the Haviland Club. This group has expressed concern about water temperatures on the Winter River. Unlike the inlets to MacDonalds Pond and Larkins Pond, the inflowing stream at Officers Pond has relatively cool water temperatures. A number of springs at the upper end of the pond provide refuge areas for salmonids during periods of thermal stress. Three kilometres from the outlet, the stream temperature has cooled substantially, but is still at the upper tolerance level for salmonids.

Periodically drawing the pond down completely for one year may help to redefine the stream channel. A partial draw down during warmest summer temperatures could also reduce the extent of temperature warming by increasing the flushing rate and allowing greater diel fluctuation in water temperature.

The obvious enrichment of impoundment water from surrounding agricultural land has provided conditions for extreme concentrations of dissolved oxygen, both elevated and depressed. Water quality within Officers Pond would benefit from a decreased nutrient concentration, particularly the run-off from nearby livestock operations.

5.4 Larkins Pond

Water temperature is the principal issue regarding impoundment management on the Naufrage River. Larkins has warm inflowing streams, particularly the west branch, and warm water leaving the impoundment adversely affects salmonid habitat for long distances downstream. The first consideration in managing this pond should be to reduce the temperature of water on incoming streams. The headwaters of the Naufrage River have been impounded by beaver dams and are open to warming from direct solar radiation. The removal of abandoned beaver dams should provide cooler water in inflowing streams.

The concrete walls of the fishway at Larkins Pond are beginning to weaken and are slated for repairs in 1999. The drawdown will be monitored to determine the extent of channelization in the upper end of the impoundment and the impact of drawdown on water temperatures.

A hydrological assessment should be made to determine the feasibility of bottom discharge of cooler water to alleviate the water temperature problem downstream in summer.

5.5 MacDonalds Pond

Management of MacDonalds Pond must also consider the other man-made and natural impoundments on the system. Removing inactive beaver dams and re-establishing a narrow stream channel should, in the long term, lower the water temperature entering MacDonalds Pond. The other Ducks Unlimited impoundment on an upstream tributary, McCarricks Pond, should be monitored to determine its impact on stream temperatures. Regular drawdowns, eg. every five years, would assist in maintaining the stream channel throughout the impoundment. Unless inlet water temperatures can be reduced, a partial drawdown in warm summer months would likely not reduce outflow water temperatures.

5.6 Grovepine

One of the objectives of the Grovepine/Big Brook Wildlife Management Plan was to "maintain/enhance the sport fishery in the Fortune River" (Eastern Habitat Joint Venture 1990). The management plan called for the removal of all beaver dams downstream from the dam and removal of inactive beaver dams upstream from the impoundment. A monitoring plan was outlined, including operation of a fish trap in the fishway and the assessment of stream temperatures, both upstream and downstream from the impoundment. Provincial government agencies and non-government organizations were represented on the management committee for the project. Little monitoring was done upon completion of the project, and today, numerous beaver dams impound water and block fish passage both upstream and downstream from the Grovepine impoundment. The impoundment on Grovepine Brook, as well as the stream below, are now uninhabitable for salmonids. Although Grovepine impoundment provides habitat for a number of waterfowl, furbearer, and wetland species, this has been accomplished at the expense of habitat loss for salmonids and other anadromous fishes, such as smelt and gaspereau. Even with intensive beaver management on the Grovepine tributary of the Fortune River, conditions within and downstream from the Grovepine impoundment will probably remain unsuitable for salmonids.

If one were to consider only fish habitat in making a management recommendation for the Fortune River, the impoundment should be removed. In the interim, the Big Brook tributary of the Fortune River should be managed primarily for salmonids to compensate for the habitat loss on the Grovepine stream.

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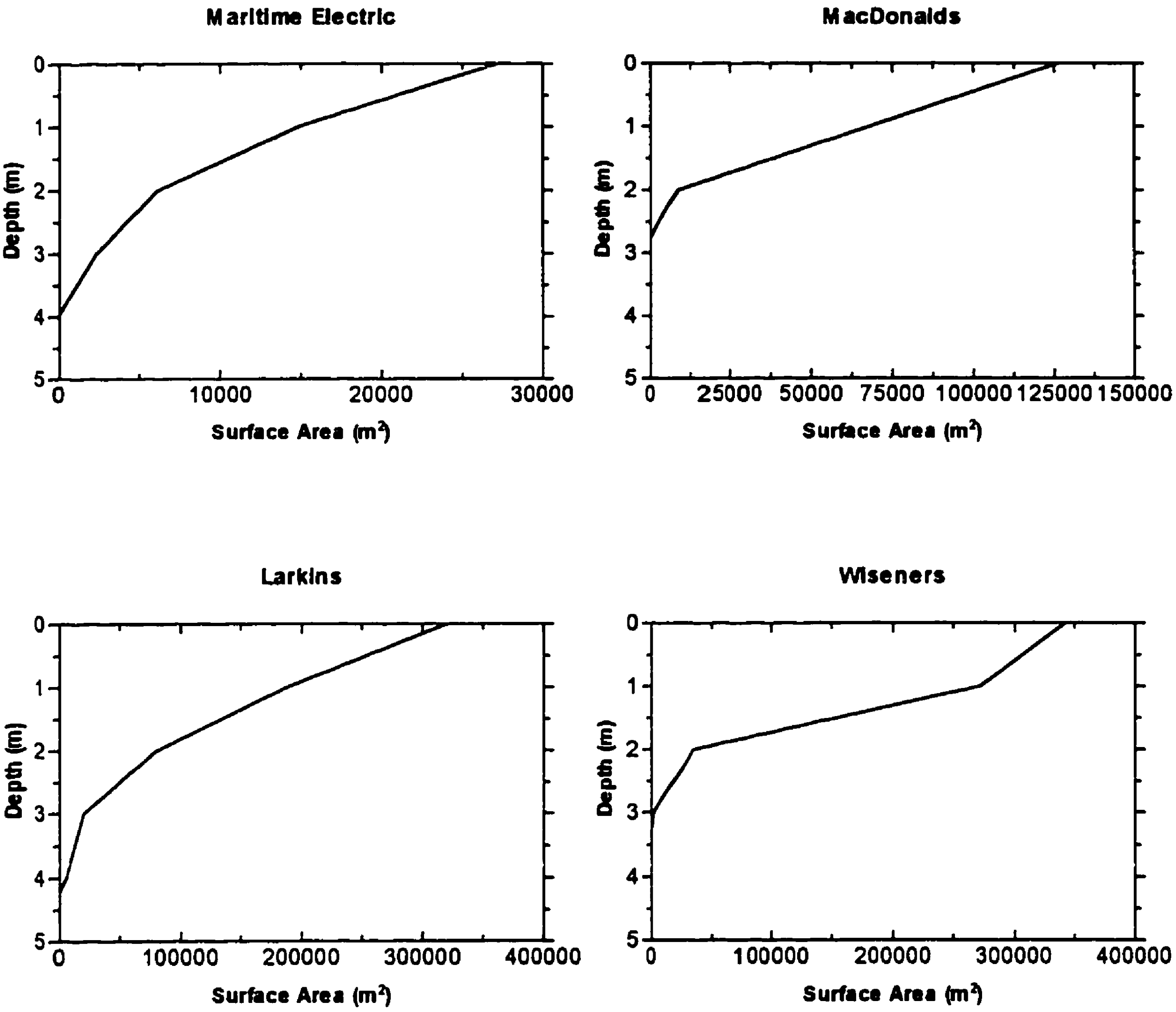
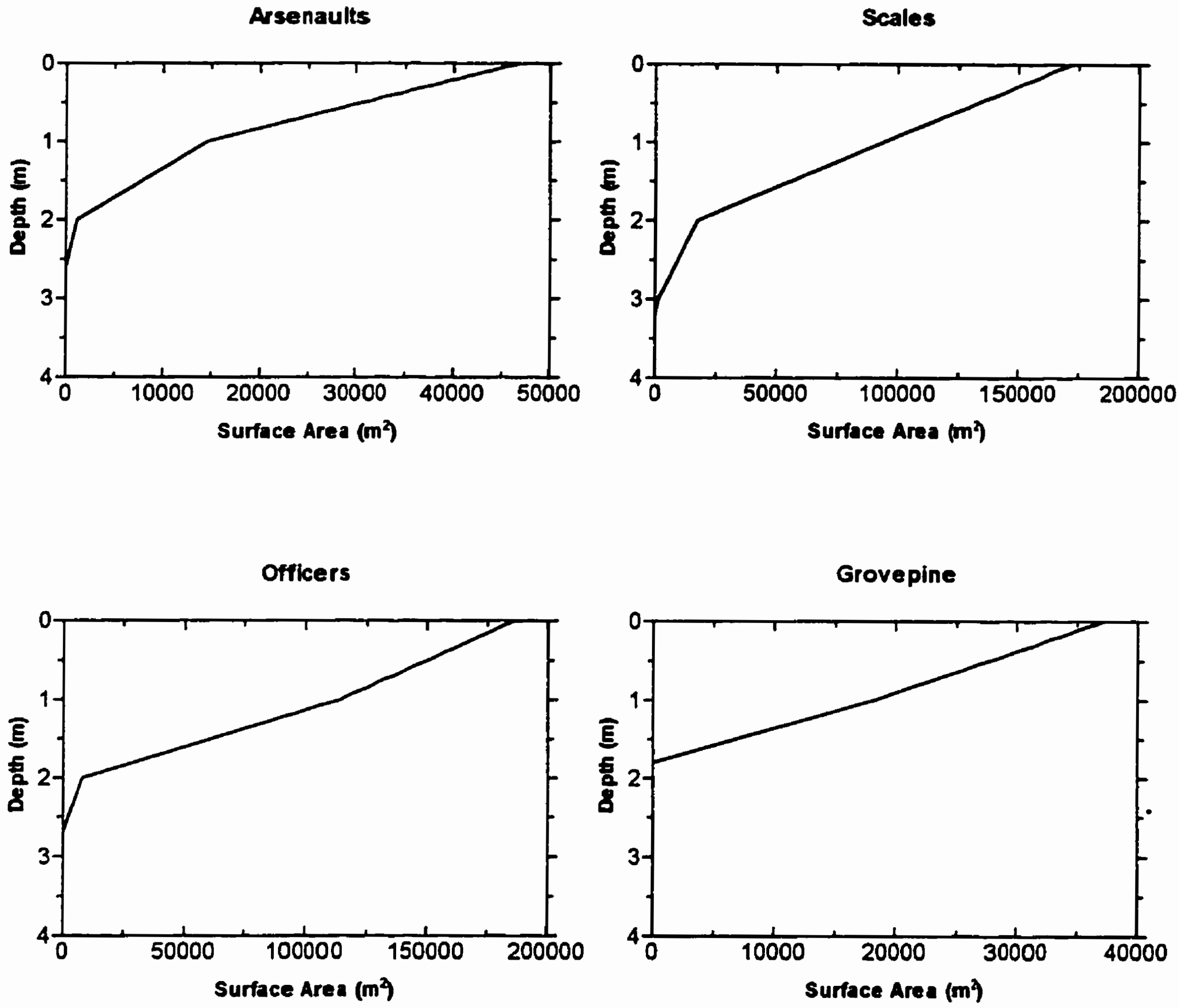
APPENDIX

Hypsographic Curves

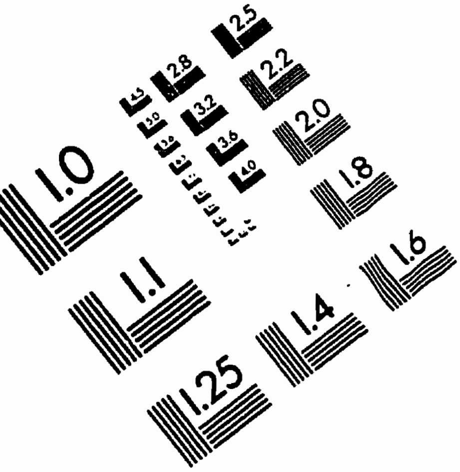


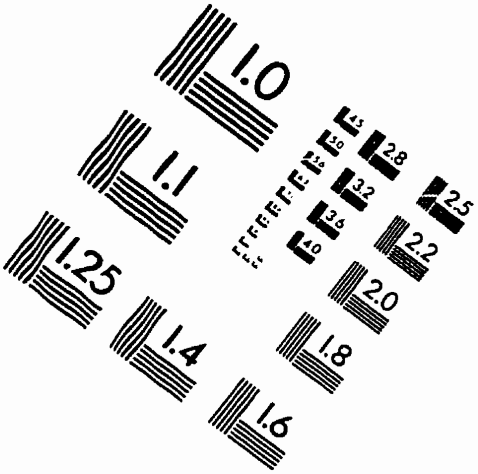
Hypsographic curves of Maritime Electric, MacDonalds, Larkins, and Wiseners.

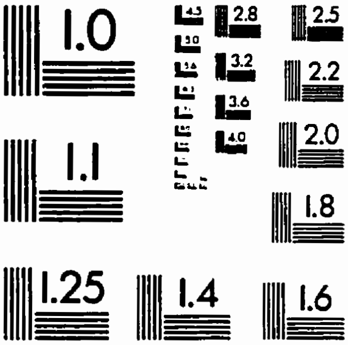


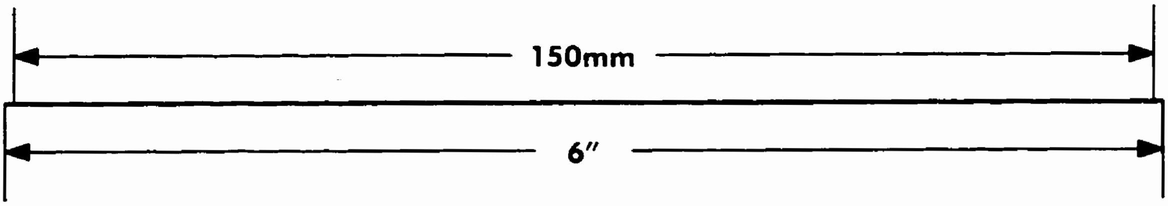
Hypsographic curves of Arsenaults, Scales, Officers, and Grovepine.

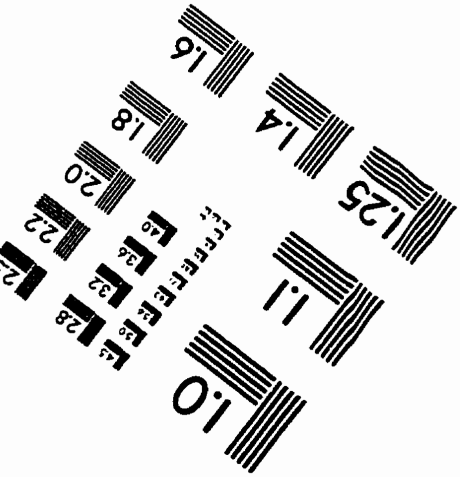
IMAGE EVALUATION
TEST TARGET (QA-3)

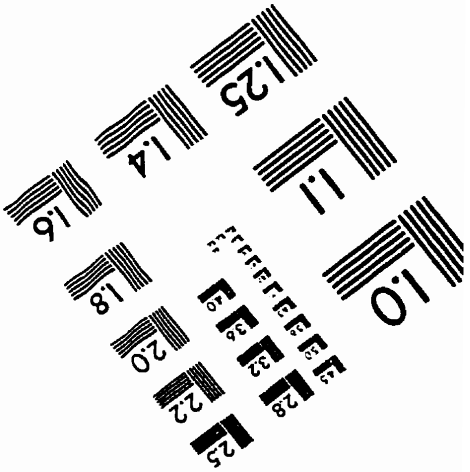












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