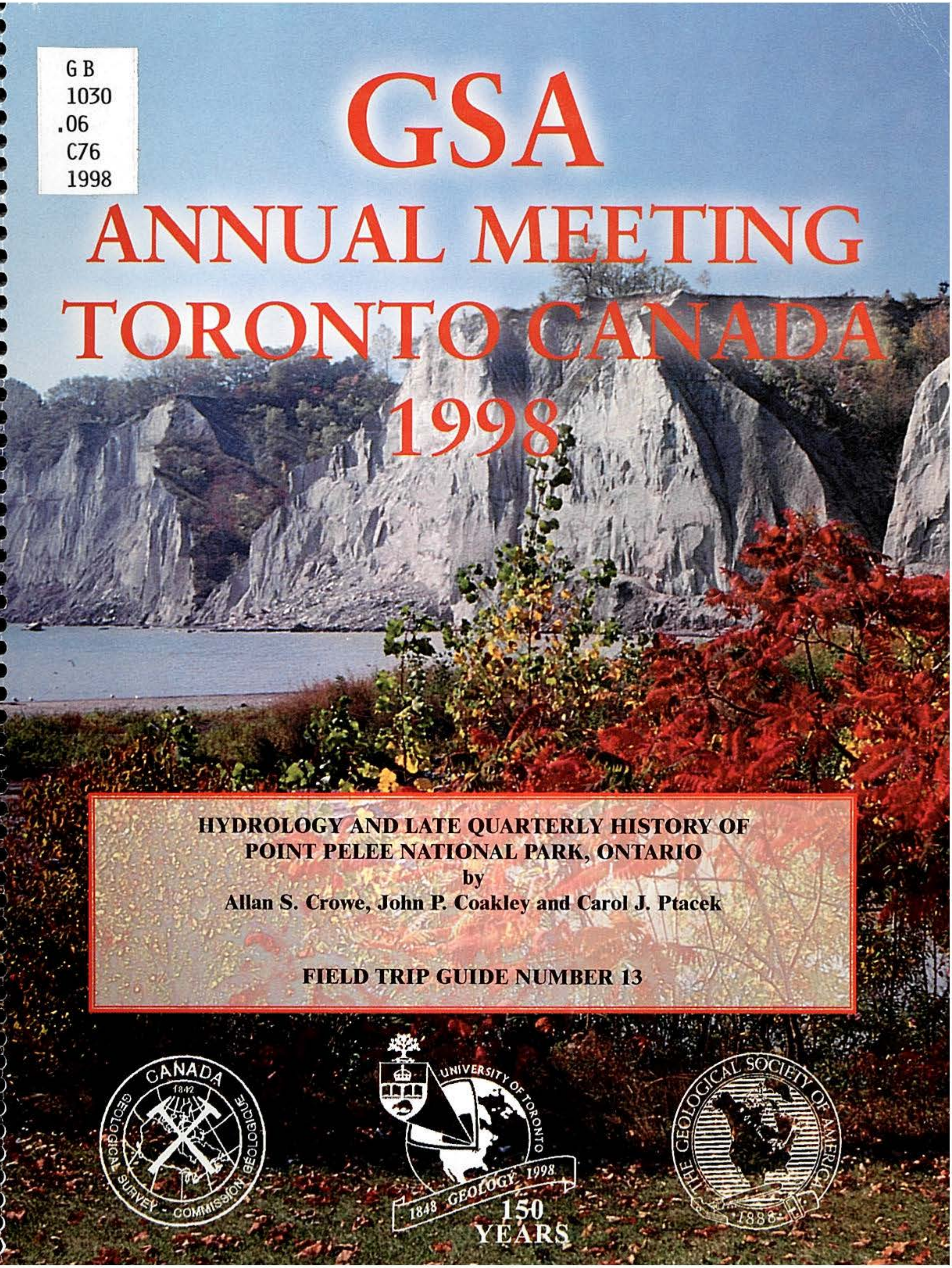

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HYDROLOGY AND LATE QUARTERLY HISTORY OF POINT PELEE NATIONAL PARK, ONTARIO

by

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Hydrogeology and Late Quaternary History of Point Pelee National Park, Ontario

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ABSTRACT

Point Pelee National Park occupies the most southerly 9 km of a cuspate foreland which extends 15 km into Lake Erie. Approximately 70% of the park consists of a marsh that is separated from Lake Erie by two barrier bars converging at the south to form Point Pelee's distinctive triangular shape. Although Point Pelee is Canada's smallest national park, it is internationally known as a world-class bird-watching site and a resting site for Monarch butterfly migration. Recent studies were undertaken to characterize the groundwater flow regime with the objective of assessing the potential for transport and the impact of septic-system derived nutrients on the marsh. The extensive drilling program yielded considerable subsurface data which was used to interpret the stratigraphy and lateral geometry of sedimentary units below the Point Pelee foreland, as well as the postglacial history of the western basin of Lake Erie. The field trip will highlight: (1) the complex groundwater flow regime within the western barrier bar, which exhibits a 180° reversal in the direction of flow twice each year, (2) the geochemistry of the septic-system derived contaminant's, its transport to, and impact on, the marsh, (3) displays and demonstrations of the monitoring instrumentation used, and (4) land forms and the geological history of Point Pelee. The trip will also include the drilling of a borehole to show the four major sedimentary units identified: a basal clay-rich till, a fine-grained glaciolacustrine sand, a medium-grained sand unit (subdivided into a poorly sorted shoreface sand and an aeolian (dune) sand derived from the shoreface sand), and an organic marsh (gyttja) deposit. There will also be short visits to the other two major cuspate forelands on the north shore of Lake Erie; Pointe-aux-Pins and Long Point.

INTRODUCTION

Point Pelee National Park is Canada's most southerly point of mainland, located at latitude 41° 58' N. It is located on the southern 9 km of a triangular spit which extends southward approximately 15 km into the western end of Lake Erie (Fig.1). The Park occupies an area of approximately 20 km^2, of which approximately 70% consists of a marsh comprised of cat-tails and numerous open-water ponds (Fig. 2). The marsh is completely separated from Lake Erie by two barrier bars running along the eastern and western sides of the marsh. These barrier bars converge at the south, giving Point Pelee its distinctive triangular shape. Although the northern half of the marsh was drained for agricultural purposes, it remains one of the largest surviving marshes on the lower Great Lakes (Herdendorf 1992).

Point Pelee National Park is internationally known as a migratory bird stop-over site. It has attained an international reputation as a world-class bird watching site, where annually about 100,000 birders and photographers from around the world observe over 360 species of birds which have been seen within the Park. In addition to its diverse bird population, the Point Pelee marsh is a highly productive ecosystem supporting many species of fish, mammals, reptiles and amphibians, including many unique to Canada. Point Pelee has been declared a RAMSAR Site, which is a

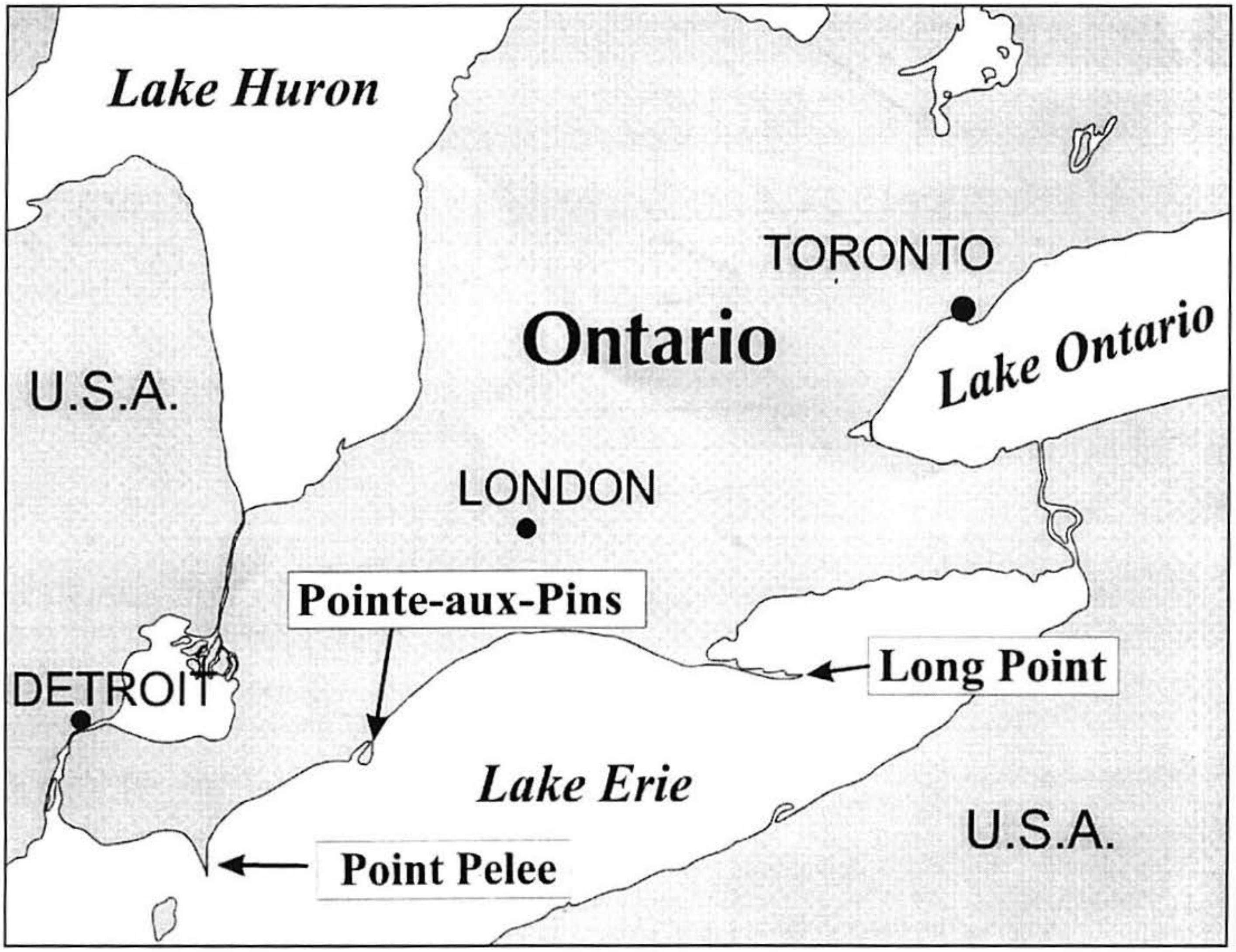


Figure 1: Location of Point Pelee, Long Point & Pointe-aux-Pins.

wetland of international importance. Point Pelee National Park has also received international fame as a resting site for Monarch butterfly migration. During the early fall, hundreds of thousands of Monarch butterflies descend on the Park.

European settlement within the Park began in the early 1800's. Land was cleared for farming and orchards; hunting, fishing and trapping took place within the marsh; most of the cedar forest was harvested for lumber; large sections of the cattails were extensively burned, and a commercial fishery was established. By the late 1800's, naturalists and local residents recognized Point Pelee's importance as a stopover for migratory bird and were instrumental in having Point Pelee designated a National Park. On May 29, 1918, Point Pelee National Park was established; it was the first National Park in Canada created on the basis of its biological value.

Even after Point Pelee National Park was created, the commercial land uses and activities within the Park continued. Agriculture, especially apple orchards, occupied a large portion of the Park until the late 1960's. Recreational activities became the major activity during the early 1900's. By the 1950's, numerous cottages and seasonal houses, and even hotels were built in the Park. The number of visitors increased, peaking at over 781,000 in 1963. The tremendous number of visitors on the very small land area of the Park had a severe impact on the natural system and species. During the 1960's steps were taken to reduce the number of visitors by eliminating overnight camping, restricting parking, removing various non-ecological activities and reclaiming private land holdings. By the mid-1970's only a few private dwellings remained in

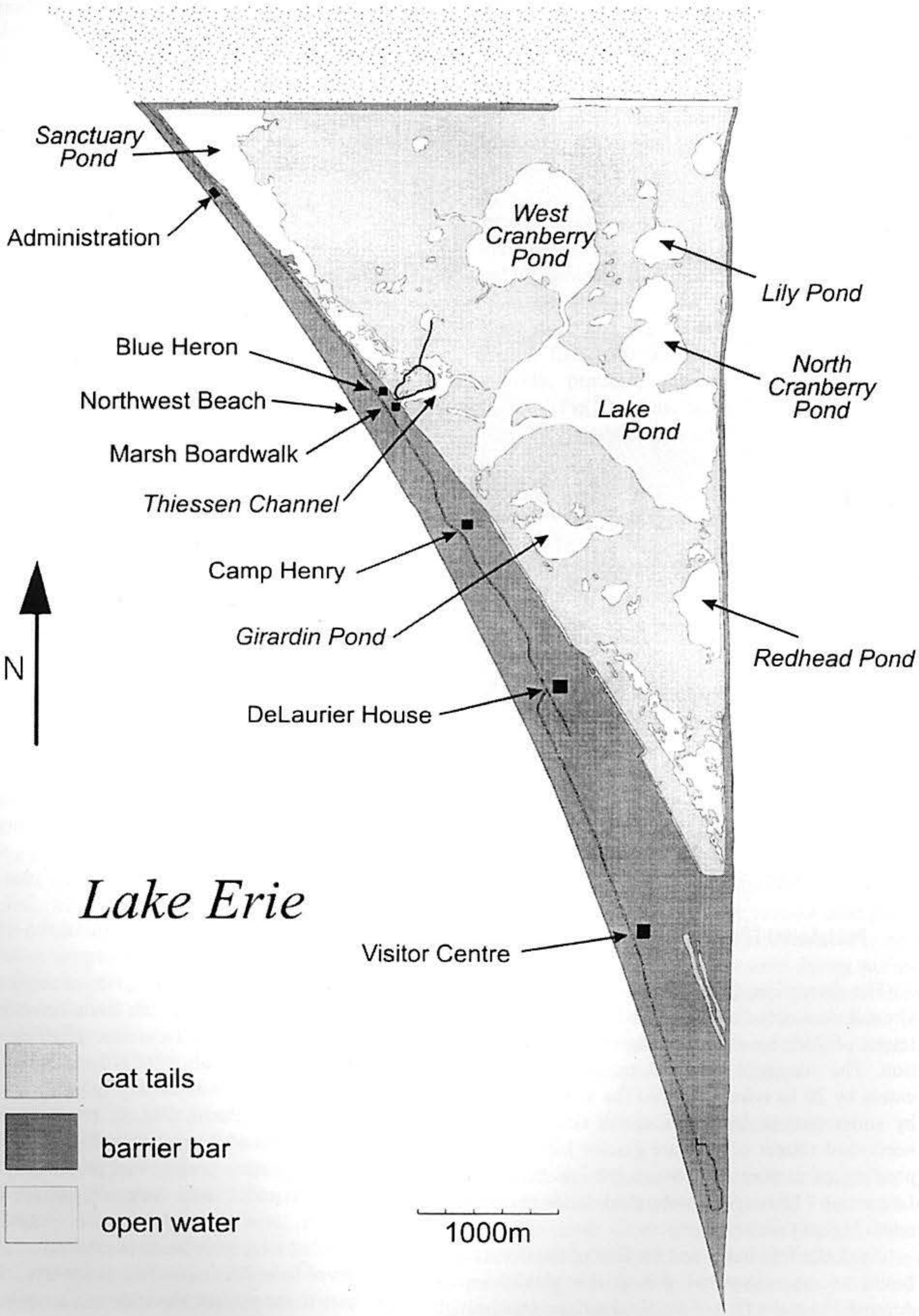


Figure 2: Location map of Point Pelee.

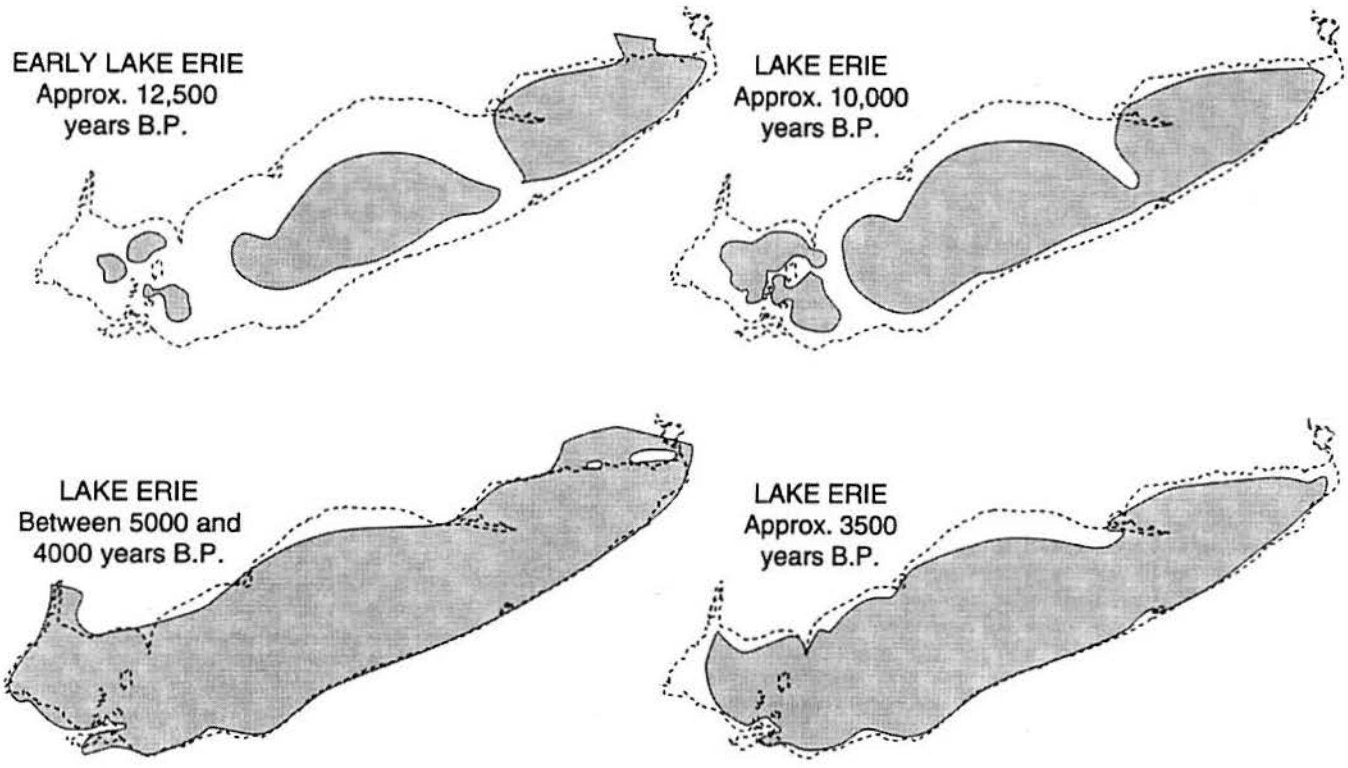


Figure 3 - The post glacial evolution of Lake Erie (from Coakley, 1985).

the Park. Currently, the Park receives about 500,000 visitors each year. The Park is currently undertaking numerous programs to reclaim and restore much of the native habitat.

THE EVOLUTION OF THE THREE MAJOR CUSPATE FORELANDS OF THE NORTH SHORE OF LAKE ERIE

Postglacial History of the Lake Erie Area

The formation and present features of the lower Great Lakes are directly related to the advance and retreat of thick ice-sheets during the Wisconsin glaciation. The ice-sheet reached its maximum southern extent by 20 ka covering all of the area now occupied by south-western Ontario and the Great Lakes. The northward retreat of the last glacier led to a general ponding of meltwater between the ice front and the Laurentian / Mississippi watershed divide at elevations much higher than at present.

The Lake Erie basin was the first of the Great Lakes basins to be uncovered during the glacial retreat. Around 14 ka, the first of the final series of major high-level glacial lakes in the basin, Lake Maumee, formed at the western end of the Erie basin. Further northward and eastward retreat of the ice created larger lakes, Lake Whittlesey at around 13.2 ka, and Lake Warren at about 12.9 ka. Because the Niagara Escarpment was blocked by the ice, drainage was toward the northwest into the Mississippi River system.

The high-level proglacial lake phase ended in the Erie Basin when glacial ice left the Niagara Escarpment and water in the down-tilted Erie basin drained eastward via the Niagara outlet. This brought into being an extreme low-level stage (~ 40 m below present levels) in the Erie Basin between 12.4 and 12.7 ka, dubbed Early Lake Erie (Hartley, 1960; Hough, 1966, Lewis et al., 1966). Early Lake Erie comprised discrete water bodies largely confined to the Central and Eastern Basins (Fig. 3). The Western Basin, where the surface of the glacial sediment was less than 30 m below present levels, was presumably only partially flooded and drained via a river system into the Central Basin.

The long-term isostatic rebound of the Niagara outlet of Lake Erie caused the water levels in Lake Erie to rise to the present elevation and an enlargement of the surface area of the lake to its present state. The initial rise was about 20 mm/year, but declined exponentially to approximately 0.1 mm/year at present. An abrupt, temporary rise in levels is postulated due to the Nipissing "flood" event around 4 ka. It is suggested that at that time, lake levels rose to about 5 m above datum, then fell relatively rapidly back to pre-existing levels within a relatively short time before resuming their slow rise (Coakley and Lewis, 1985; Barnett, 1985).

Because of the rise in lake levels over the past 2.0 ka, all shoreline traces since the Early Lake Erie stage have been eroded or buried below postglacial sediments and dramatic changes have occurred in the shoreline configuration of Lake Erie. The shoreline has undergone considerable erosion and recession in some areas and deposition and accretion in areas such as the three cuspate forelands of the north shore: Long Point, Pointe-aux-Pins, and Point Pelee (Fig. 1). These features will be visited in turn during the field excursion. The sections that follow summarize models of origin and evolution that put these cuspate forelands within the context of the postglacial history of the lake basin.

Long Point (Stop 1)

Long Point covers approximately 100 km^2 and is approximately 35 km in length, with the outer 25 km comprising the Long Point Provincial Park and Nature Reserve. It is located over the cross-lake Norfolk moraine (Lewis, 1969), which extends from the base of the present foreland to just west of Presque Isle, on the Ohio shore. It encloses an extensive marsh, designated a United Nations World Biological Site, which serves as an important stop-over for migrating birds.

Evolution of Long Point

The paleogeographic reconstruction of the eastern Lake Erie shoreline (Fig. 3) suggests that the initial phase in the evolution of Long Point was a broad, north-south-trending morainal ridge or isthmus covered with glaciolacustrine sediments and spanning the lake. Rising levels in the central sub-basin eventually led to the opening of the inter-basin channel near the Presque Isle end of the structure, creating an elongated cuspate foreland. The peninsula was likely the site of massive sand accumulation from littoral drift from sand-rich sources immediately to the west.

Due to its position at the end of a long-fetch distance for the prevailing westerly winds and waves, the foreland migrated eastward as well as northward, up the glacial-sediment surface, as lake levels rose. Longshore-drifted sand would have been carried around the southern end to be eventually deposited as recurved spits on the eastern side. By 6 ka, the foreland had assumed a more rounded form, with recurves extending northeastward and concave southeastward, i.e., toward the dominant wave direction in that part of the eastern sub-basin. Traces of these early Long Point recurve spits are preserved as the low, concave-lakeward beach ridges discernible on aerial photographs and topographic maps of the present Long Point.

The lack of any sign of a transition between the previous stage and that of the present. suggests that the change from one stage to the next occurred fairly abruptly, probably due to the so-called Nipissing "flood" (Fig. 3). This submergence created a broad sandy shoal, which later served as the spit platform for the next Long Point stage that followed.

As lake levels again fell to approximately 3 m below present level about 3.5 ka (Coakley and Lewis, 1985), the sediments making up the spit platform were reworked by shallow-water wave action to initiate the formation of the present eastward-trending "flying" spit (Fig. 1). This change is reflected in the abrupt change in the preserved beach-ridge pattern on the Point from concave- to convex-lakeward. The obvious truncation of the beach ridges indicates that such elements at one time extended as far north as the north shore of the eastern basin, forming an asymmetrical cuspate foreland with present-day Turkey Point.

Over the last 4,000 years, Long Point has been steadily migrating northward and eastward under the effect of slowly rising lake levels and the dominant southwesterly wave climate. The major geomorphologic processes now acting are the transfer inland of materials from the southern shoreface inland either by wind or washover through low-lying areas during storms and high-lake-level periods. Washover processes have at times opened major inlets across narrow parts of the foreland; some of these inlet breaches have been large enough to permit the passage of ships.

Pointe-aux-Pins (Stop 2)

Pointe-aux-Pins, or Rondeau Peninsula, is a rounded cuspate foreland protruding some 7 km southward from the north shore of Lake Erie (Fig. 1). From its junction with the shoreline, the eastern limb of the cuspate foreland widens from approximately 0.5 to 2 km near its southern extremity. The southwestern limb, however, is much narrower (less than 100 m in places), and is occupied by the town of Erieau. The entire foreland covers approximately 50 km^2, 60% of which comprises an enclosed area of pond and marsh, Rondeau Bay, less than 4 m in depth. The eastern limb of the foreland and the enclosed lagoon make up Rondeau Provincial Park.

Evolution of Pointe-aux-Pins

Like Long Point, the Pointe-aux-Pins area was occupied by a broad till-cored promontory at the time of Early Lake Erie representing the surface expression of the Erieau Moraine (Fig. 3). The Erieau Moraine, which determined the location of Pointe-aux-Pins, crosses the lake from Rondeau, Ontario to Fairport, Ohio. It has the least topographic expression of the three cross-lake moraines, a fact that may be related to it marking only a limited stop by the retreating Erie lobe of the Laurentide glacier. The tip of this ancestral foreland probably extended some 20 km further south than at present, and served as the focus for large-scale accumulation of sand, derived from the deltaic deposits to the west, and from local shoreline erosion in general (Coakley, 1989).

During the period of rapid lake level rise (12.0 to 8.0 ka), the dominant evolutionary trend was the reduction in area of the subaerial portion of the foreland and a net shoreward retreat. The more stable levels then prevailing allowed further accumulation of drifted sand along the sides of the foreland, leading to the development of beach ridges and dune fields above lake level. At this time, maximum wave fetches (and greatest wave energy) would probably have been from the east, so the dominant littoral drift was likely from the east, around the tip of the foreland, to the more sheltered southwest-facing side. The result would be the transformation of the early foreland into an asymmetrical cuspate shape, probably with an elongated sand spit at the end.

The Nipissing "flood", approximately 4.0 ka, probably led to the wholesale drowning of much of the low-lying dunes and beach ridges then making up the Pointe-aux-Pins foreland. Depending on the elevation of the foreland, the site would have been occupied by either a shoal or a low island (Fig. 3). Most of the sand submerged by the rise would be dispersed in the area in the form of a sand-covered shelf, or spit platform.

By 3.5 ka, lake levels had returned to close to their pre-"flood" positions. Parts of the spit platform were again exposed to shallow-water wave action, and a new generation of storm-beach barriers gradually developed at the site. This marked the beginning of the modern Point-aux-Pins foreland (Fig. 3), originally consisting of a straight-to-convex-lakeward beach barrier, facing southeast, and facing the shorter fetch to the southwest, a lower, concave-lakeward barrier through which an inlet into the marsh behind was probably located.

From about 2.0 ka, to present, the principal morphological developments at Pointe-aux-Pins were the gradual shift in the orientation of both sides with changes in the direction of maximum fetch distances and wave energy from the east and west. The east-facing barrier grew, by accreting beach ridges, to become aligned more north-south as developments at Long Point and embayment by erosion of bluff shorelines to the east increased the fetch of east, rather than southeast, waves.

Point Pelee (Stop 3)

The section below will summarize evolutionary models of Point Pelee based on previous models of the origin and evolution of the foreland by Coakley (1976) and Trenhaile and Dumala (1978), and revised with recent drilling data. An extensive drilling program was recently undertaken to install wells within the western barrier bar at the Park Gate transect, the Northwest Beach transect, and the Camp Henry site (Fig. 4). Additional drilling, specifically for geological investigations (Coakley et al., 1998), was undertaken at three additional sites: the DeLaurier transect, the Visitor Centre transect and at the southern tip of Point Pelee (Fig. 4).

Point Pelee postglacial stratigraphy

Four major sedimentary units were identified, three within the barrier bar and one within the marsh. The lowermost unit encountered was a clay-rich till which forms the main structural feature on which Point Pelee was formed. A fine-grained, grey glaciolacustrine sand was encountered on the clay-till but it is present only south of the Marsh Boardwalk site. The upper-most sediment comprising the barrier bar is a medium-grained sand and gravel unit, and it is subdivided into two sub-units. A poorly sorted shoreface sand, composed of essentially the same material found along the present beach, varies in thickness from 7 m at the beach to 1 m adjacent to the marsh. An aeolian (dune) sand derived from the shoreface sand, varies in thickness from 0 m at the beach to 8 m within the largest dunes, and overlies the shoreface sand. The base of the

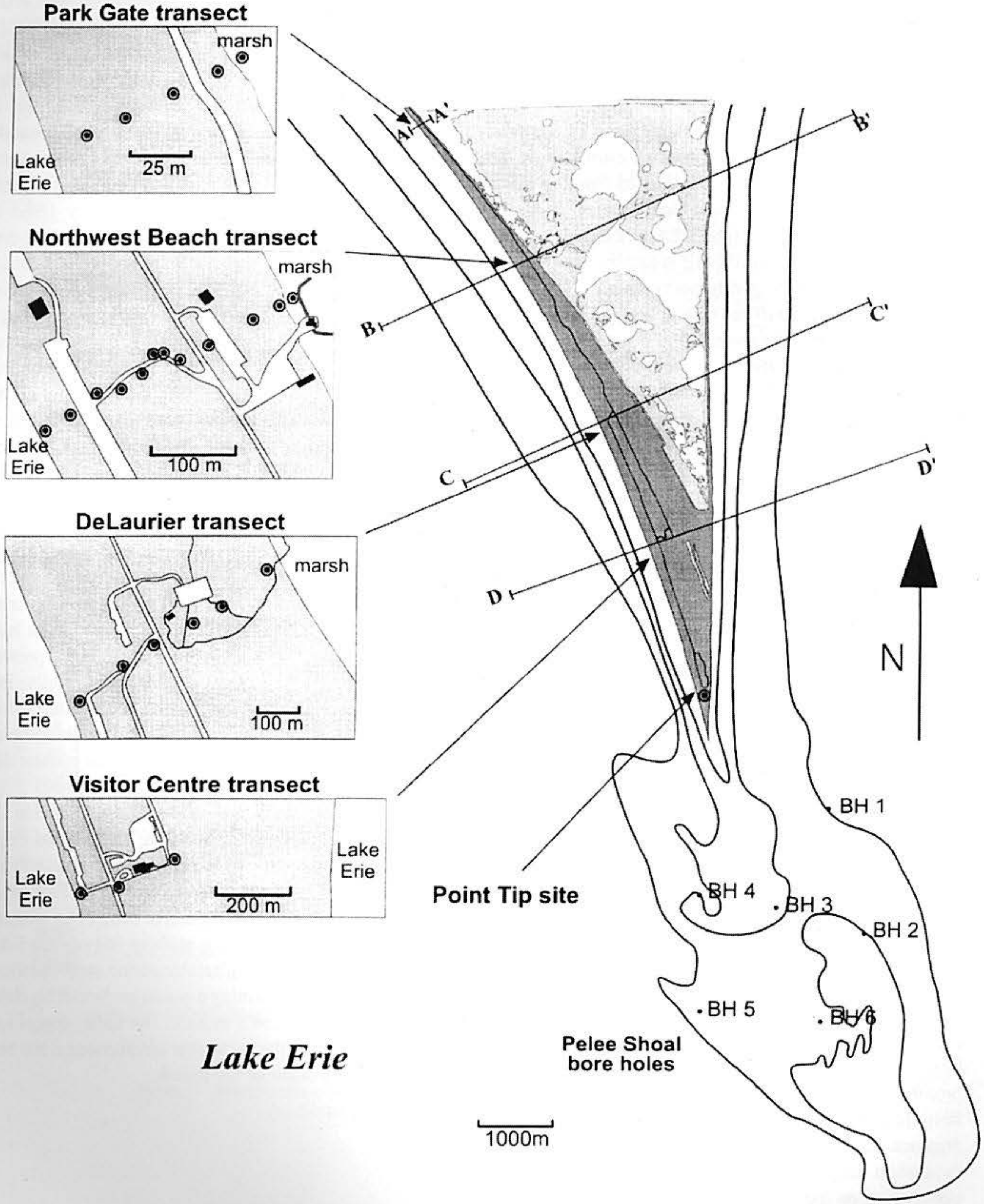


Figure 4: Location of bore holes, cores, geological transects and the Pelee Shoal.

marsh is composed of an organic marsh deposit (gyttja and peat), which sits on top of the clay-till.

Four west-east cross sections show the presence (or absence) of the glacial sediments and their elevation across the entire point (Fig. 5) as well as details across the western barrier bar at Point Pelee (Fig. 6). The north-south cross sections are located along the Lake Erie shoreline and along the central dunes of the western barrier bar (Fig. 7). These cross sections show that the surface of the till slopes southward from an elevation of 172 m a.s.l. at the Park Gate transect to an elevation of 164.5 m a.s.l. at the DeLaurier transect. South from here, the surface of the till is apparently flattened by erosion but slopes gently south to an elevation of 164 m a.s.l. at the tip of the point. The glaciolacustrine sand is absent from the eastern and northern portion of Point Pelee. Its top surface is essentially level at an elevation of 169.5 m a.s.l., and its absence corresponds to where the surface of the till exceeds an elevation of 169.7 m a.s.l.. Its absence from the northern portion of Point Pelee and its level surface suggests that it is an erosional remnant of a once-extensive deposit. The aeolian and shoreface sands are present along the entire length of the western barrier bar, and rest on the glaciolacustrine sand, or directly on the till where the glaciolactustrine sand is absent. The elevation of the base of the aeolian sand rises towards the west to the present day high waterline.

The evolution of the Point Pelee foreland

As is the case with the other Lake Erie cuspate forelands described earlier, the formation and evolution of the marsh and barrier bars comprising Point Pelee are related to local geology and to the postglacial history of lake levels in the basin. Point Pelee developed at the location of the sand-capped Pelee moraine that crossed the lake to the south shore near Lorain, Ohio (Coakley, 1976). The evolution of the Point is summarized in Figure 8. Using interpretations based on the vestiges of earlier storm beach ridges preserved on the Point, the ancestral foreland is believed to have extended much further south and east of its present position. Its present configuration of a central marsh and coalesced barrier beaches to the east and west was initiated around 3.5 ka, presumably soon after the Nipissing "flood" event, judging from the consistency of radiocarbon dates on basal marsh organics. Since then, the Point has retreated primarily on the eastern side, while some evidence of continuing accretion is seen on the west-facing side, namely through the sequence of preserved beach ridges.

The recent drilling (Coakley et al., 1998) confirmed the assumptions implicit in the above interpretation and added information. The presence of the broad, flattened, wave-eroded, and subaerially-exposed platform below Point Pelee extending southward, has been confirmed. However, other new information of importance to Point Pelee evolution has been added. This includes the definition of a fine glaciolacustrine sand unit in association with the more widespread till facies. The surface of this sand unit has been eroded essentially flat, at an elevation of approximately 169.5 m a.s.l., apparently prior to, or concurrent with, the erosion of the till, during a low-water period in the basin.

The presence of the above indicators of the fairly stable low-level period at or below 169.5 m a.s.l. suggests that that period was followed by a relatively abrupt rise in lake levels prior to the building of the modern Point Pelee foreland. Until this time, the till promontory would have been subaerially exposed and most likely normally wooded, with no sign of a marsh. The flattening of the promontory was likely caused by water levels several metres higher than 172 m a.s.l. (the highest till elevation at the Park Gate transect (Fig. 6a). Such a level is close to, or above, present levels, and could have coincided with the so-called Nipissing "flood", of which evidence exists in other parts of the basin. The radiocarbon dates of around 3.2 ka (Terasmae, 1970; Coakley et al., 1998) for the basal gyttja (at around 172 m a.s.l., or almost 2 m below present levels) are evidence that lake levels subsequently fell to initiate the conditions leading to formation of the Point Pelee marsh. The steady rise since then is reflected in the increase in thickness and contact elevation of the surface dune sand sub-unit.

Although there was an overall rising trend in Lake Erie levels from 10,000 years before present, two major intervals in which the lake levels were at a stand-still are documented by the sediments at Point Pelee. First, the surface of the till below the south end of Point Pelee was eroded by waves to a planar surface at about 164 m a.s.l. Second, the upper portion of the glaciolacustrine sand was also eroded by wave action forming a planar surface at an elevation of approximately 169.5 m a.s.l.. The initial deposition of the sands forming the barrier bar commenced at the same time as the formation of the marsh.

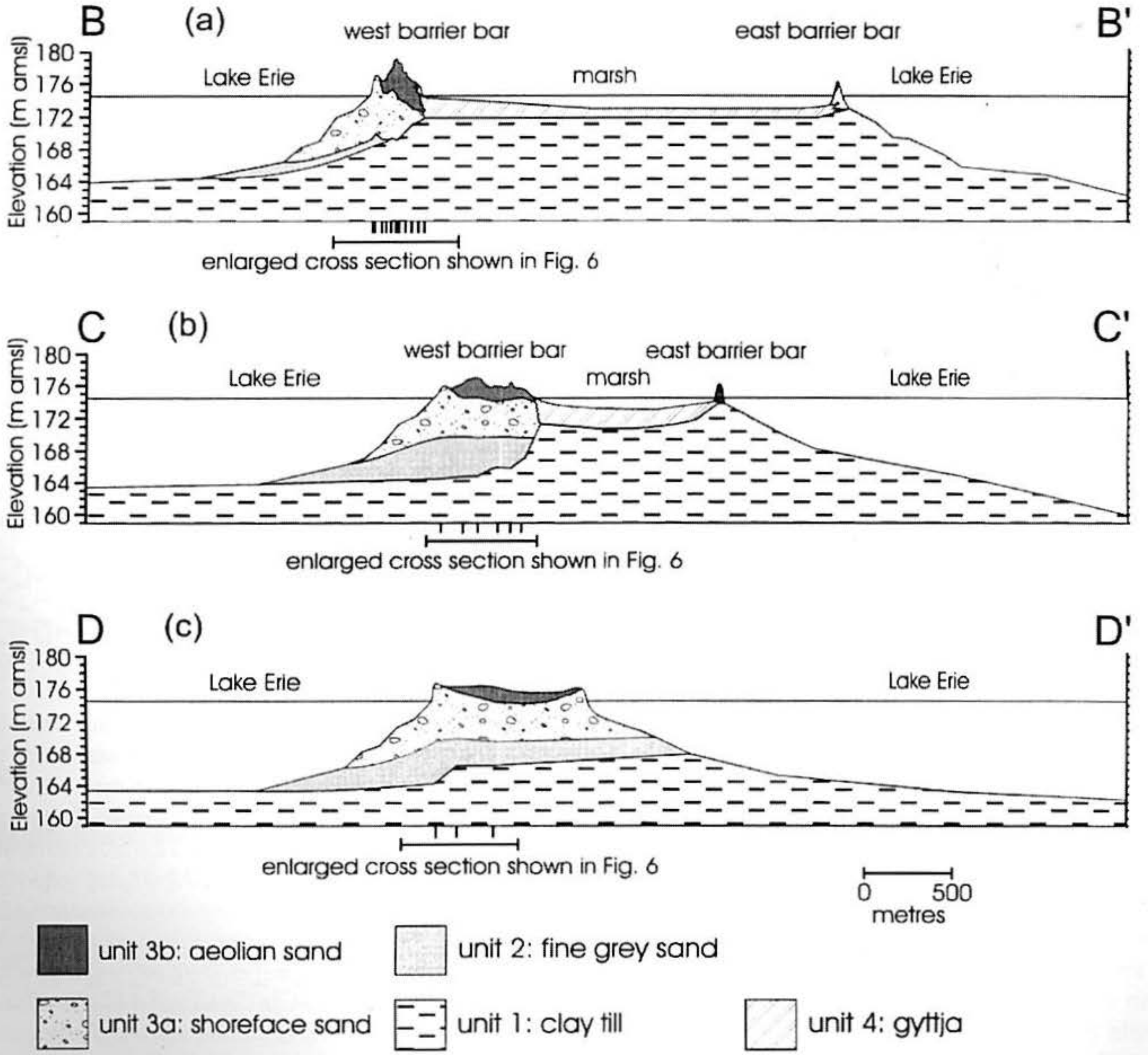


Figure 5: Stratigraphic cross section across Point Pelee through (a) the Northwest Beach transect, (b) the DeLaurier transect, and (c) the Visitor Centre transect.

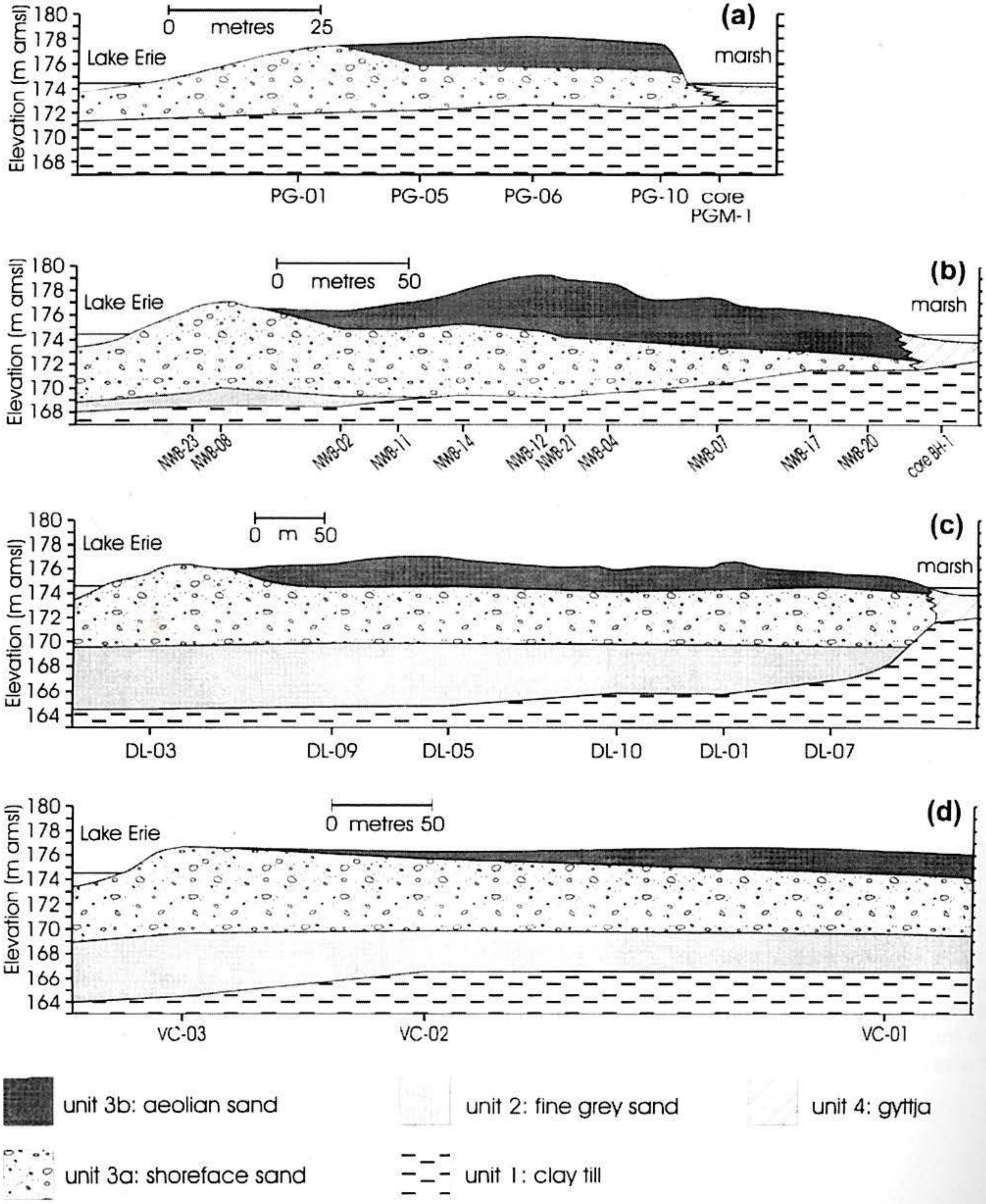


Figure 6: Stratigraphic cross sections across the western barrier bar at (a) the Park gate transect, (b) the Northwest Beach transect, (c) the DeLaurier transect, (d) the Visitor Centre transect.

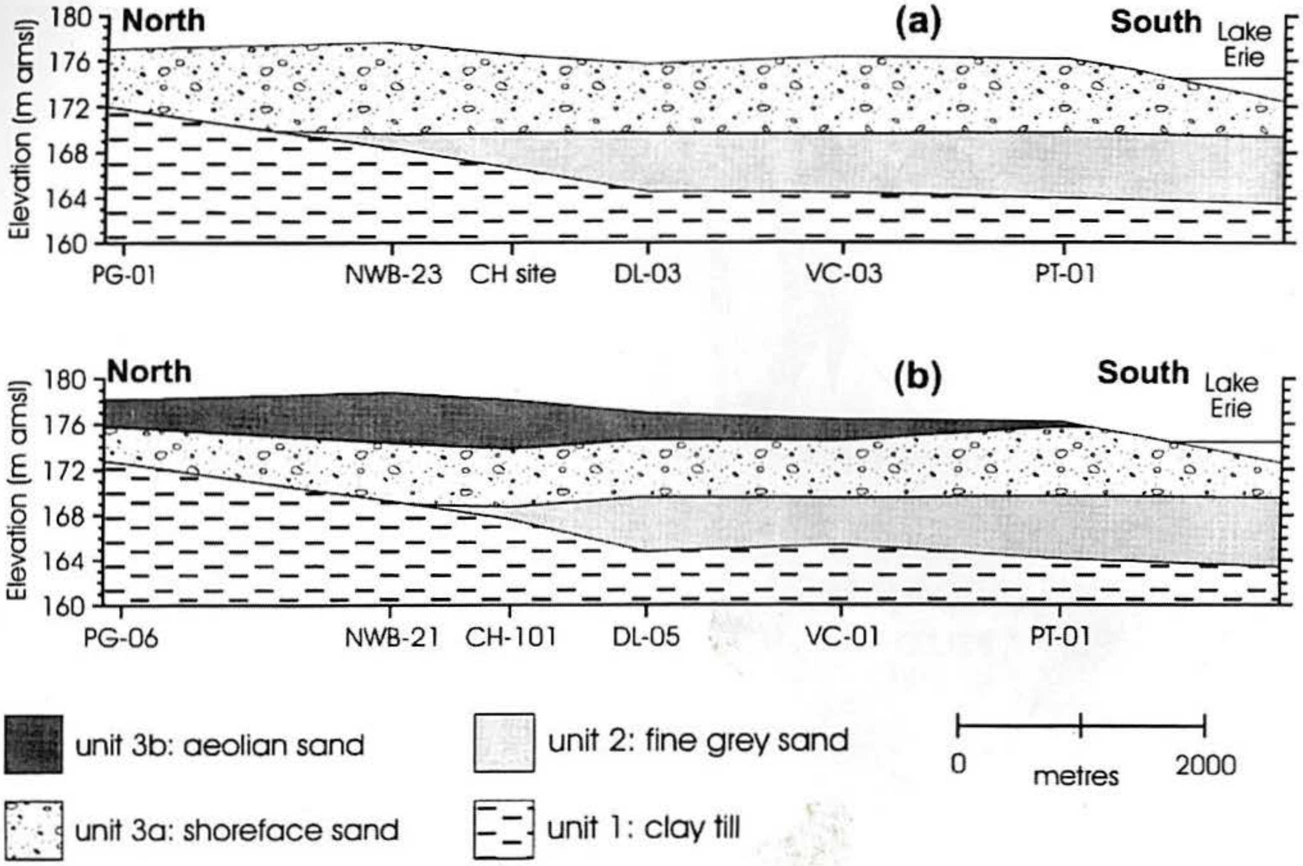


Figure 7: North - south cross sections along the western barrier bar (a) along the beach and (b) through the central sand dunes.

HYDROGEOLOGY OF THE WESTERN BARRIER BAR AT POINT PELEE (Stop 4)

Recent studies (Crowe and Ptacek, 1995, 1998) have shown that the groundwater flow regime within the barrier bars at Point Pelee is complex, with the direction of groundwater flow, groundwater velocities, and primary sources of recharge varying from north to south. The field trip will stop at three sites instrumented for hydrogeological investigations (Fig. 9). The Park Gate transect is representative of a narrow portion of the barrier bar (~ 80 m) with relatively low relief (max. elevation of 176.6 m a.s.l.). The Northwest Beach transect represents a wider portion of the barrier bar (~ 320 m) with considerably higher relief (max. elevation of 182.5 m a.s.l.). The Camp Henry site is located on a wide portion of the barrier bar (~ 420 m) with moderate relief (max. elevation of 180.0 m a.s.l.).

The groundwater flow regime within the western barrier bar at Point Pelee is controlled by three main factors: (1) infiltration and evapotranspiration, (2) the fluctuations in the surface elevations of Lake Erie and the Point Pelee marsh, and (3) the width of the barrier bar. The hydraulic conductivity of the aeolian sand is 1.8×10^{-2} cm/s, the near-shore sand is 2.4×10^{-2} cm/s, and the lacustrine sand is 3.1×10^{-3} cm/s.

Throughout the barrier bar, the water table exhibits a large rise each spring, due to the infiltration of melting snow and early spring rains. Although the water table gradually declines throughout the remainder of the year (Fig. 10), major precipitation events cause a rapid rise in the elevation of the water table followed by a decline over the next few days. Evapotranspiration impacts the groundwater flow regime from April to October. Where the depth to the water table is quite shallow (< 2.5 m), evapotranspiration directly affects the water table causing it to decline daily by 20 mm. Where the water table is deeper, evapotranspiration does not directly affect the water table, but intercepts infiltration before it reaches the water table.

The elevation of both Lake Erie and the Point Pelee marsh exhibits a rise in the spring, followed by a decline throughout the remainder of the year (Fig. 11). However, the rise and fall of Lake Erie (~ 0.5 m) is

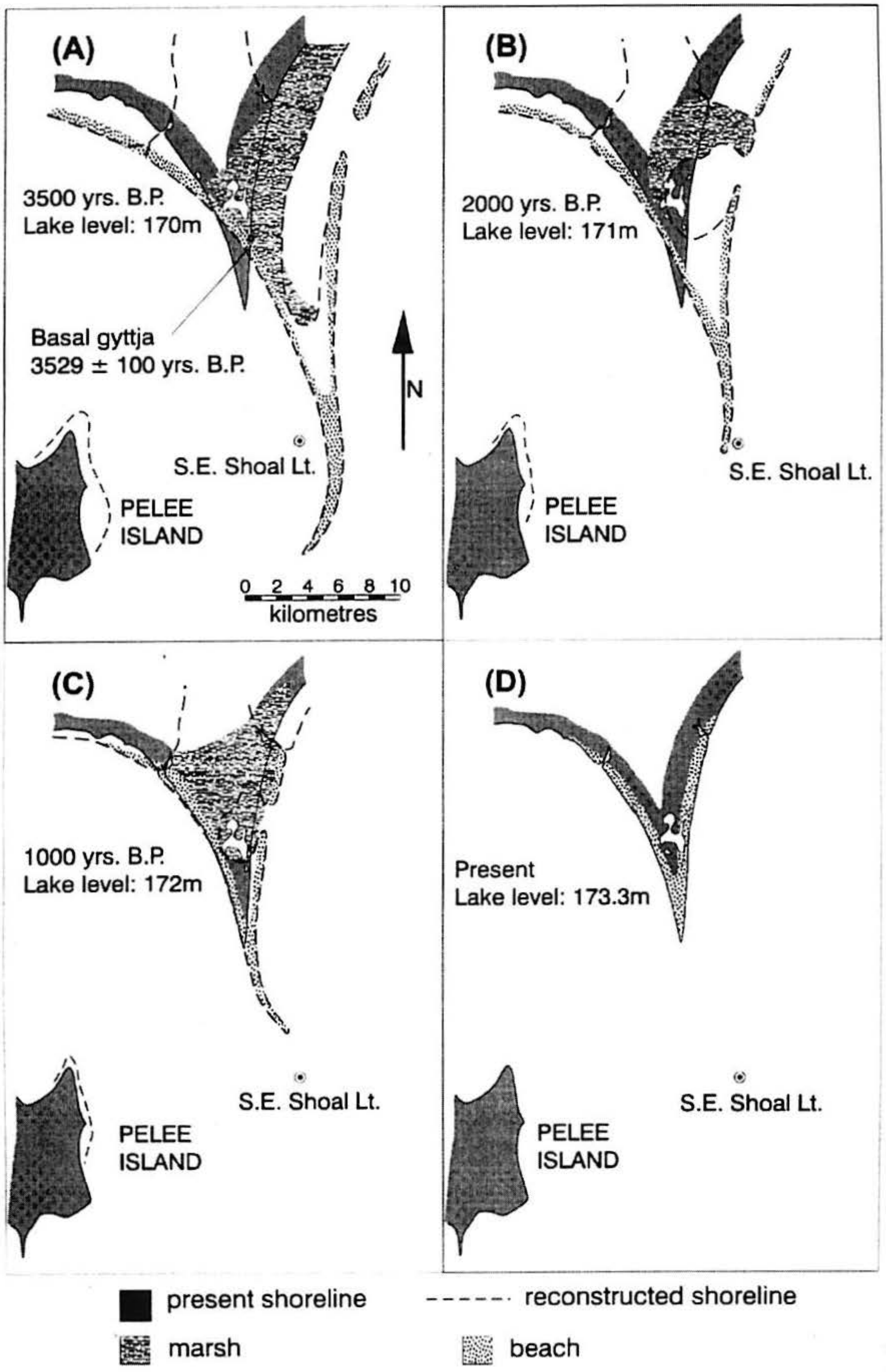


Figure 8: An illustration of the evolution of Point Pelee (from Coakley, 1985).

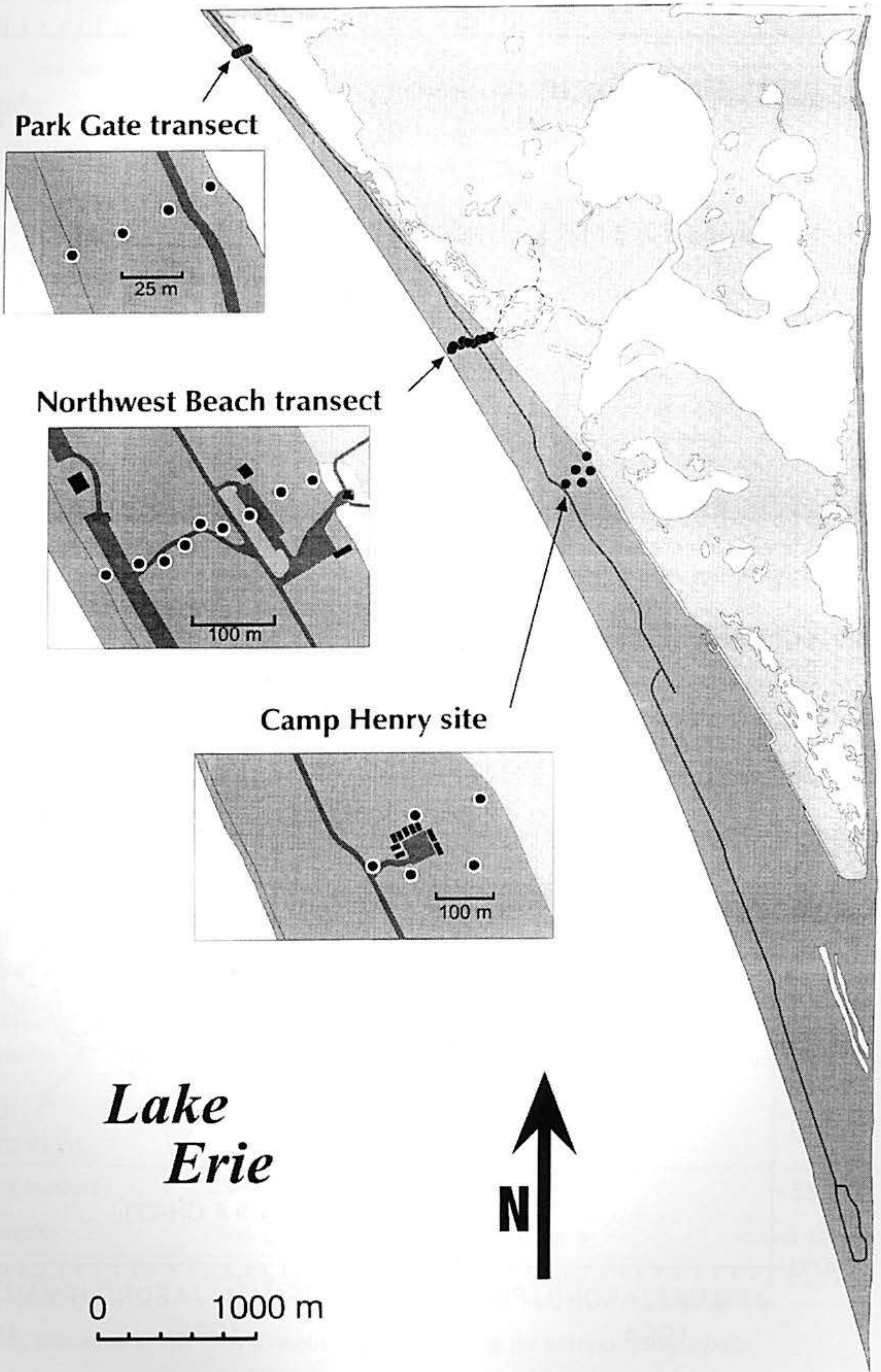


Figure 9: Location of water table wells and multi-level bundle samples at the Park Gate transect, Northwest Beach transect, and the Canp Henry Site

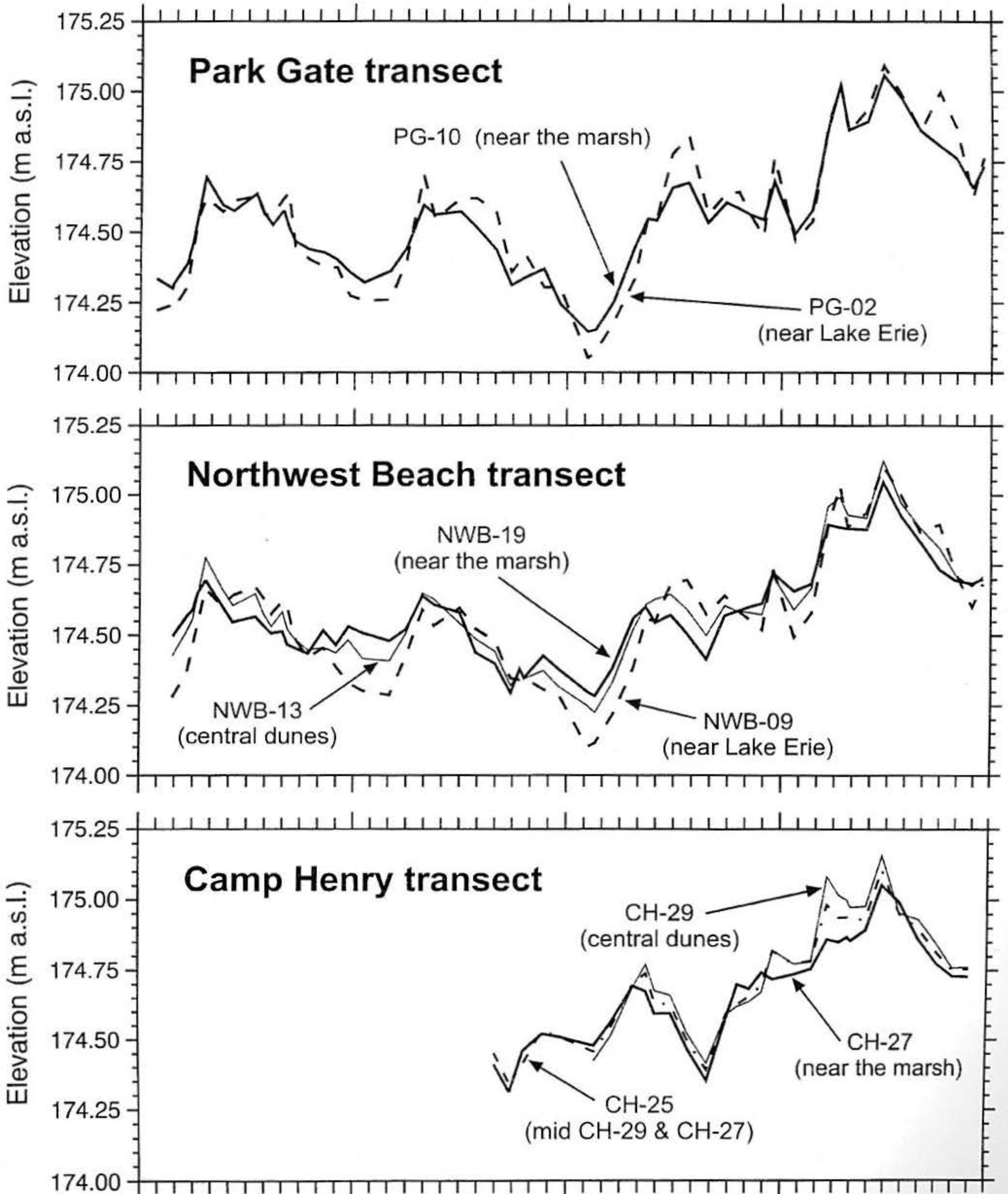


Figure 10: Elevation of the water table from selected wells along the (a) Park Gateway transect, (b) Northern Beach transect, (c) Camp Henry Transect

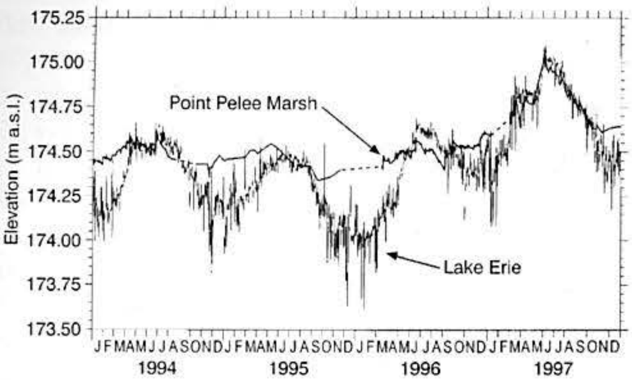


Figure 11: Fluctuations in the surface elevation of Lake Erie and the Point Pelee marsh.

much greater than that of the marsh (~ 0.1 m). Further, the relative elevations of the lake and the marsh change, with the surface of Lake Erie often being above that of the marsh during the summer, and below the marsh during the rest of the year.

As the width of the barrier bar increases from north to south, the groundwater flow regime changes from being dominated by the lake and the marsh to being dominated by infiltration. The fluctuations in the elevation of Lake Erie and the marsh have a major impact on the hydraulic gradient across the barrier bar (i.e., change in elevation of the lake and the marsh divided by the width of the barrier bar). A relatively large gradient occurs where the barrier bar is narrow. But as the width of the barrier bar increases, not only does the hydraulic gradient across the barrier bar decrease, but the area over which infiltration occurs increases.

Where the barrier bar is narrow (e.g., 80 m wide at the Park Gate transect), a large hydraulic gradient forms in the direction of the lower surface water body (Fig. 10). Hence, a seasonal reversal in the direction of groundwater flow occurs each fall and winter, with groundwater flow towards the lake during the winter and towards the marsh during the summer (Fig. 12a). The large groundwater velocities result in groundwater movement towards the lake and marsh of 10-20 m and 15-25 m, during the winter and summer respectively (Table 1). Thus, not only is much of the infiltration discharged into the lake or the marsh, but there is a considerable inflow of water from the marsh and the lake. However, the gradients are not sufficiently large nor is there a sufficient length of time during which flow is in one direction for water to completely travel from Lake Erie through the western barrier bar to the marsh, or vice versa.

As the barrier bar becomes wider (e.g., 300 m wide at the Northwest Beach transect), the lake and the marsh still exhibit a strong influence on the hydraulic gradients and direction of groundwater flow. But due to a decreased hydraulic gradient, groundwater velocity

TABLE 1. GROUNDWATER VELOCITIES AND TRAVEL DISTANCES

Park Gate transect			
months	flow direction	velocity	travel distance[1]
May - Sep	towards the marsh	13 cm/d	12 - 28 m
Nov - Apr	towards the lake	10 cm/d	10 - 20 m
Northwest Beach transect			
months	flow direction	velocity	travel distance[1]
June - Oct	towards the marsh	3 cm/d	2 - 4 m
Oct - May	towards the lake	4 cm/d	5 - 9 m
Camp Henry transect			
months	flow direction	velocity	travel distance[1]
all year	towards the marsh	1 cm/d	1 - 2 m

[1] distance that groundwater moves by advective transport during the corresponding months.

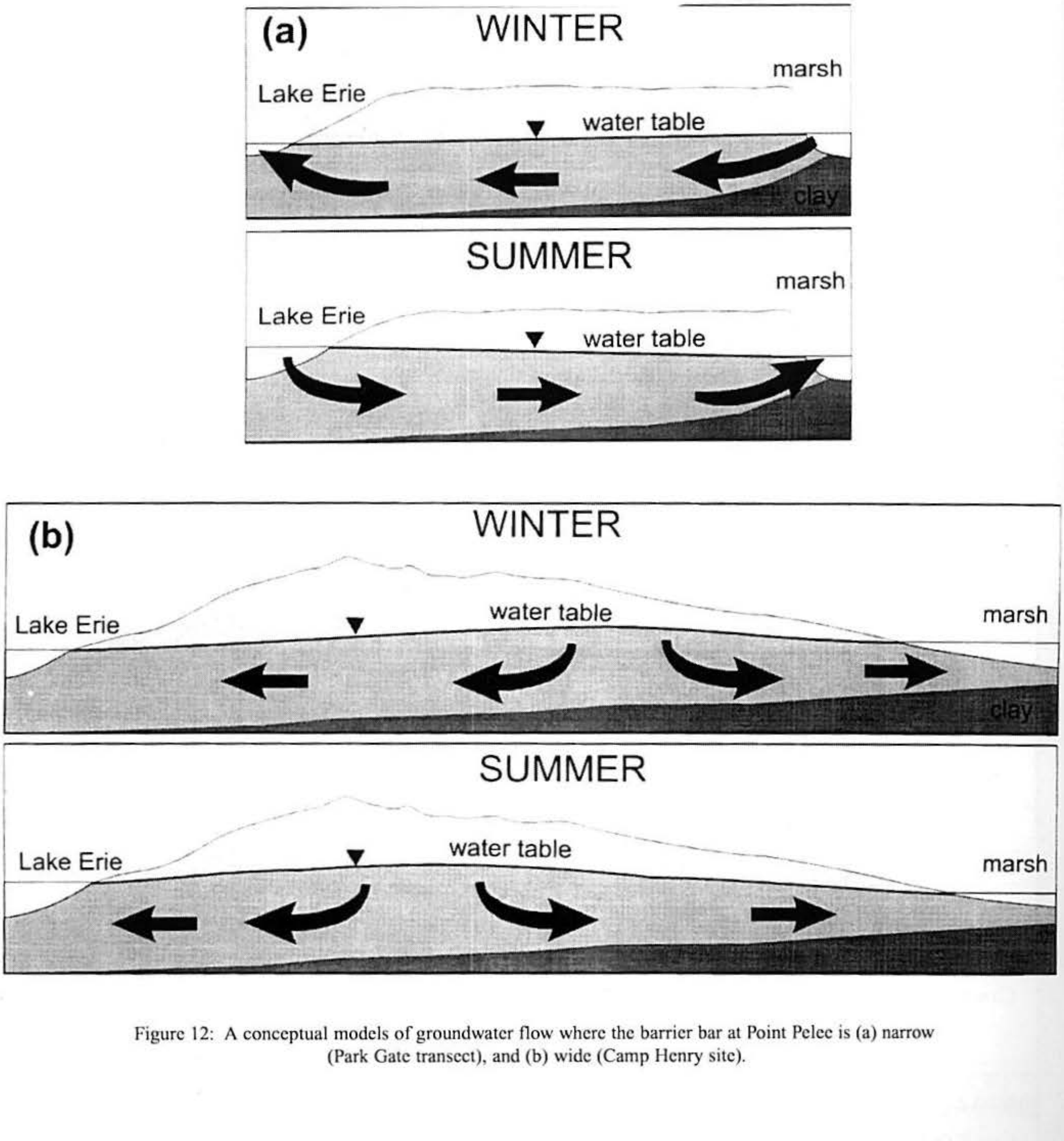


Figure 12: A conceptual models of groundwater flow where the barrier bar at Point Pelee is (a) narrow (Park Gate transect), and (b) wide (Camp Henry site).

and movement are much lower (Table 1). Groundwater flow exhibits a reversal in the direction of flow (Fig. 10) at a rate of 5-9 m per year towards the lake during the winter and 2-4 m per year towards the marsh during the summer, for a net annual travel distance of about 3 m. Hence, there is little movement of groundwater from the barrier bar into the lake and the marsh, and little corresponding movement of marsh and lake water into the barrier bar. Also, much of the infiltration is lost through evapotranspiration. The small net annual movement due to the reversal in flow will result in long residence times at the Northwest Beach transect (Ptacek et al., 1997). Confirmation of the long residence time of groundwater within the sand aquifer was provided by tritium dating, which shows that the deeper groundwater (> 2 m below the water table) originated during the early 1970's (Crowe and Ptacek, 1998)

Once the barrier bar becomes wide (e.g., 450 m wide at the Camp Henry site), the seasonal fluctuations in the lake and marsh have a minor impact on the groundwater flow system, and infiltration becomes the dominant factor. Hence, there is essentially no seasonal reversal in the direction of groundwater flow because of the low hydraulic gradient across the barrier bar and the dominance of infiltration (Fig. 12b). Groundwater flows at a rate of only a couple of metres per year from the central portion of the barrier towards both the lake and the marsh (Table 1).

Stable isotopes (O and H) have been used to confirm the physical hydrogeology (Huddart et al., 1998). Isotopic analyses show water from Lake Erie and the marsh move a considerable distance into the barrier bar at the Park Gate transect, but does not move inland significantly at the Northwest Beach transect. Isotopic analyses show that infiltration is the main source of groundwater recharge, but it does not penetrate deeply into the barrier bar.

Environmental Impact of Sewage Disposal in the Barrier Bar (Stop 5)

Point Pelee National Park, like many parks in North America, relies on the use of septic-tanks and tile-line leach fields to dispose of sewage generated in the park. Sewage released to the subsurface from leach fields usually leads to the development of plumes of groundwater which contain elevated concentrations of nutrients (including NO_3, PO_4, NH_3, and DOC) and other dissolved constituents. If located close to surface water bodies, these plumes have the potential to discharge and modify the nutrient budgets of surface water bodies. At Point Pelee, several marsh ponds located close to areas of known sewage discharge experience prolific algal blooms. There are more than 30 active tile beds at Point Pelee National Park. These beds are installed directly in the shallow sands of the western barrier bar. Wastewater derived from approximately 0.5 million visitors each year is discharged to the subsurface through the tile beds.

Groundwater and surface water investigations are being conducted at four sites to assess whether groundwater input of sewage-derived nutrients is a potential source of the elevated nutrient concentrations observed in the marsh ponds. The Park Administration Building tile bed is located where the barrier bar is relatively narrow (< 100 m wide) and where groundwater flow is strongly influenced by the relative elevations of Lake Erie and the marsh. This study was initiated in 1997 and is in the initial instrumentation stages. The active Blue Heron tile bed receives wastewater from a high-use comfort station. It is located where the barrier bar is intermediate in width (~ 320 m) and where groundwater flow is also strongly influenced by the lake and marsh. The Camp Henry tile bed ceased sewage disposal in 1995. Groundwater monitoring has continued to evaluate the rate at which the aquifer responds after sewage cessation. The Marsh Boardwalk area, where sewage disposal last occurred nearly 20 years ago is monitored to assess long-term impact of sewage disposal on groundwater quality. Stops will be made at the Blue Heron, Camp Henry, and the Marsh Boardwalk aresa (Fig. 2). A variety of groundwater instrumentation will be shown, including conventional standpipe piezometers, multi-level bundle piezometers, individual minipiezometers, and seepage meters. The groundwater seepage zone will be viewed.

Blue Heron Active Tile Bed

The Blue Heron active tile bed receives about 10,000 L/day of blackwater year-round from a visitor comfort station. It was installed in 1980, and relies on a dosing pump to distribute wastewater through six perforated tile lines (30 m long, spaced 1.6 m apart). At the site, the water table elevation changes both seasonally and annually and occurs between 1.5 and 3 m below ground surface. Wastewater derived from the comfort station is gravity fed into a holding tank. Anaerobic decomposition of organic solid wastes occurs in the holding tank, releasing dissolved organic carbon, ammonia and phosphate to the wastewater. Liquid

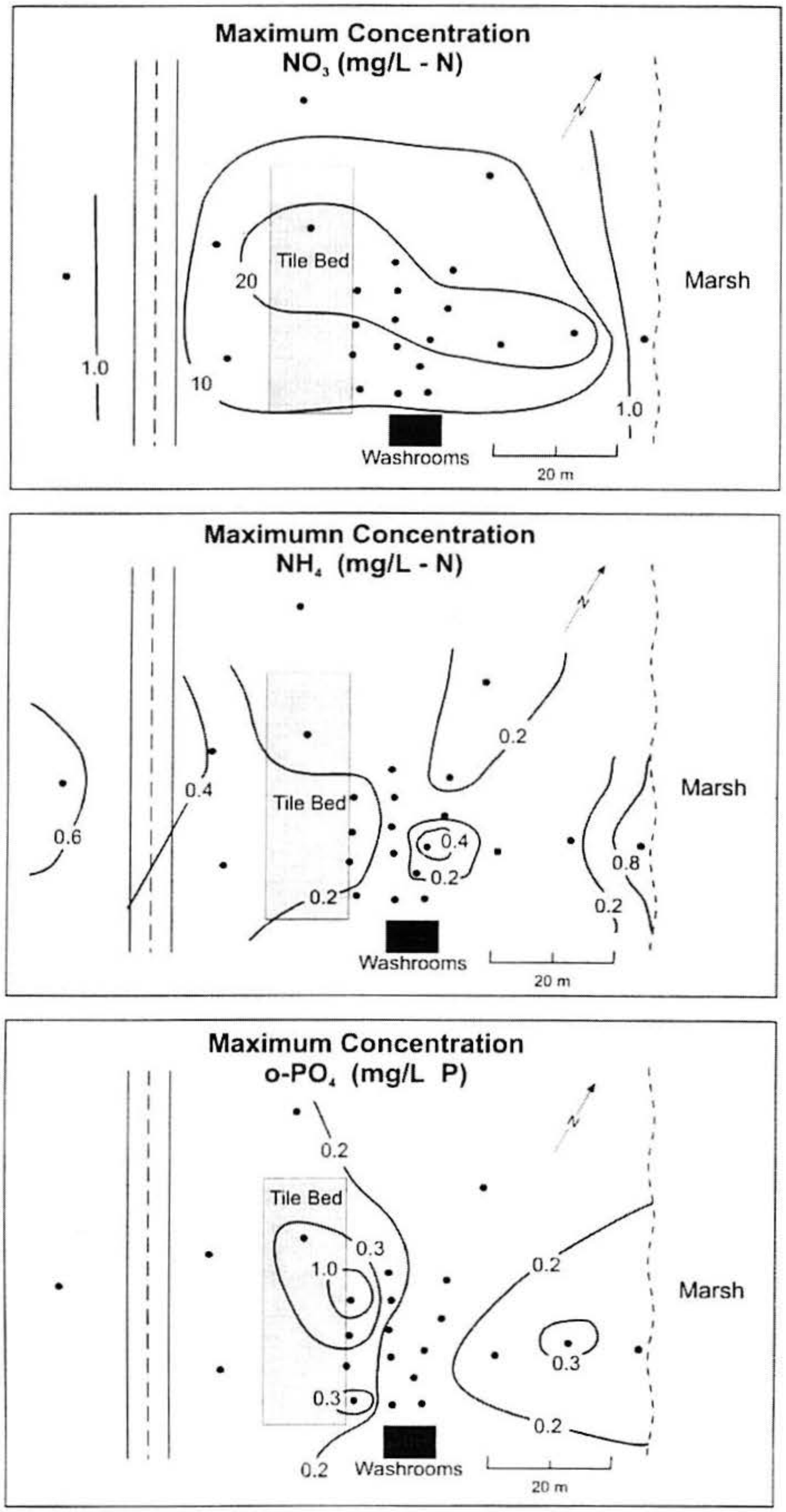


Figure 13: Concentrations of nitrate, ammonia and phosphate in groundwater near the Blue Heron active tile bed. At the time of sampling, the bed had been in operation for 18 years.

Table 2. Composition of septic-system effluent collected from Blue Heron holding tank, May, 1996.

Parameter	Concentration
NO_2+NO_3 (mg/L as N)	< 0.05
NH_3 (mg/L as N)	36.4
P, total (mg/L)	4.12
DOC (mg/L)	34.7

wastewater leaves the holding tank and enters a dosing chamber. A timed dosing pump feeds wastewater into the tile lines to promote distribution of wastewater over the entire bed. The wastewater entering the leach field is reduced and contains elevated concentrations of organic carbon, ammonia, phosphorous and other constituents (Table 2). After entering the perforated tile lines, the sewage infiltrates into the unsaturated zone by gravity. Aerobic oxidation of the wastewater occurs in the unsaturated zone, leading to improvement in water quality. Directly below the tile bed, removal of particulates, bacteria and viruses and > 50% of phosphorous occurs. Dissolved organic carbon and ammonia are oxidized, resulting in increased concentrations of nitrate, carbon dioxide and acid in the infiltrating water.

Concentrations of NO_3, PO_4 and NH_3 are elevated in a plume which extends to the base of the aquifer and in east and west directions of the tile bed (Fig. 13) (Ptacek et al., 1994; 1997; Ptacek, 1998). The plume has developed in a bimodal shape in response to the changing directions of groundwater flow at the site. Concentrations of NO_3 range between 1 and 30 mg/L (as N) to distances more than 40 m from the edge of the bed. These concentrations are well in excess of the WHO drinking water guideline of 10 mg/L NO_3-N. In reducing zones at the marsh edge and at the base of the aquifer, bacterial denitrification processes result in the removal of NO_3 to concentrations < 0.001 mg/L N. Concentrations of NH_3 are elevated to distances more than 60 m from the tile beds. These elevated concentrations of NH_3 suggest oxidation of the septic tank effluent was incomplete during its transport through the unsaturated zone. Phosphate concentrations exceed 1 mg/L P up to 10 m from the bed. At the base of the aquifer, in the reducing zone, concentrations of PO_4-P range between 0.1 - 1 mg/L, up to the marsh edge. These concentrations represent a large decline from approximately 5 - 10 mg/L in the original effluent (Table 2). The large volume of groundwater containing concentrations > 0.1 mg/L P, however, represents sufficient PO_4 to be of concern if discharged to the marsh. Similarly, elevated concentrations of NH_3 represent a potential input of N into the marsh.

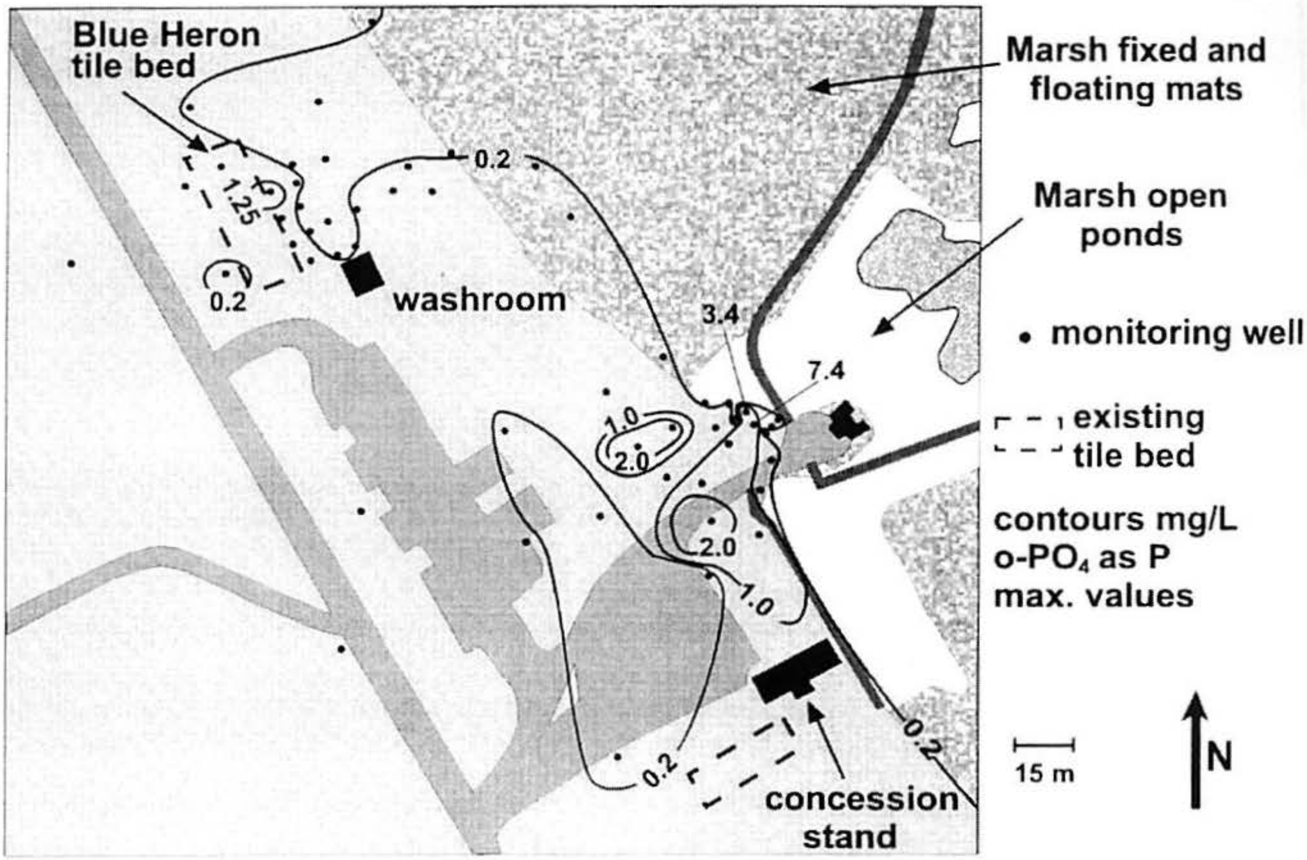
The groundwater monitoring network at the Blue Heron tile bed site includes several stand-pipe piezometers, used for aquifer response tests and head measurements, and multilevel bundle piezometers used to collect samples of groundwater at discrete depth intervals for geochemical analysis. Additional minipiezometers were installed along the marsh edge.

Former Sewage Disposal Area

The Marsh-Boardwalk area was a popular boat launching area for hunting and fishing in the early half of this century, and more recently used for a variety of recreational activities. There were a number of buildings at the site, including cottages, a store, concession stands, and a barn, which were removed through a land acquisition and naturalization program. Wastewater disposal at the site relied on the use of latrines and pit privies, and later vault toilets with holding tanks. The Park constructed a marsh viewing area and boardwalk in this area, and visitor use has continued to be very high. All known wastewater disposal in this area ceased in the late 1970's, with the exception of a leach field which receives wastewater from the current concession stand (Fig. 14).

Elevated concentrations of PO_4 and NH_3 are present in the groundwater zone at this site (Fig. 14, NH_3 not shown). Very high concentrations of PO_4 (1-2 mg PO_4-P) were observed in isolated pockets close to locations of earlier sewage discharges (Thompson et al., 1997). There are also very high concentrations of PO_4 in isolated pockets along the edge of the marsh (> 8 mg/L PO_4-P), close to the former location of a vault toilet. It appears that even after 20 years, there is the potential for sewage-derived PO_4 and NH_3 to persist in the groundwater zone.

Hydraulic head and seepage meter measurements indicate groundwater flow is directed into the marsh for



Maximum Phosphate Concentrations, October 1996

Figure 14: Concentrations of phosphate in area where on-site wastewater disposal last occurred 20 years ago (central area). Also shown are the locations of the active Blue Heron tile bed (top) and the active Concession tile bed (bottom). This area had numerous buildings, a barn, pit privies, and vault toilets, that were removed by the Park (from Thompson et al., 1997)

most of the year. For example, in May 1996 groundwater was observed to be discharging into the marsh at a rate of 0.02 and 0.13 litres/m²/day (Ptacek et al., 1997). Even higher discharge rates are expected to occur during periods of high infiltration (spring melt, autumn rains) or in response to large declines in the elevation of the marsh. This discharge has the potential to release nutrients to the pond. Macrophytes are abundant in the discharge zone and prolific phytoplankton blooms occur each year. Once nutrients are present in the marsh water column and sediments, a portion will be buried, and a portion will be regenerated each year for renewed biomass growth.

Camp Henry Tile Bed

The Camp Henry "old" tile bed received blackwater seasonally from an overnight camp for about 17 years (Fig. 15). The old tile bed was sampled while it was active, and biannually or annually since sewage disposal ceased three years ago. Groundwater flow in the area of Camp Henry is dominated by recharge infiltration processes and as a result the plume of tile-bed derived dissolved constituents is directed primarily toward the marsh (Fig. 15).

Sampling during the active stage of the tile bed indicates concentrations of NO_3 were very high in the groundwater zone, ranging between 1 and 80 mg/L in a plume that extended more than 40 m from the edge of the tile bed. In reducing zones at the marsh edge and base of the aquifer, NO_3 removal by bacterial denitrification lead to a decline in concentrations < 0.01 mg/L N. Concentrations of NH_3 exceeded 10 mg/L N and concentrations of PO_4 exceeded 1.0 mg/L, and remained elevated up to the marsh edge (Fig. 15).

In 1995, wastewater discharge at the Camp Henry site was switched to a new "raised" tile bed to enhance oxidation of wastewater (Fig. 15). Sampling two years after sewage cessation indicated large declines in concentra-

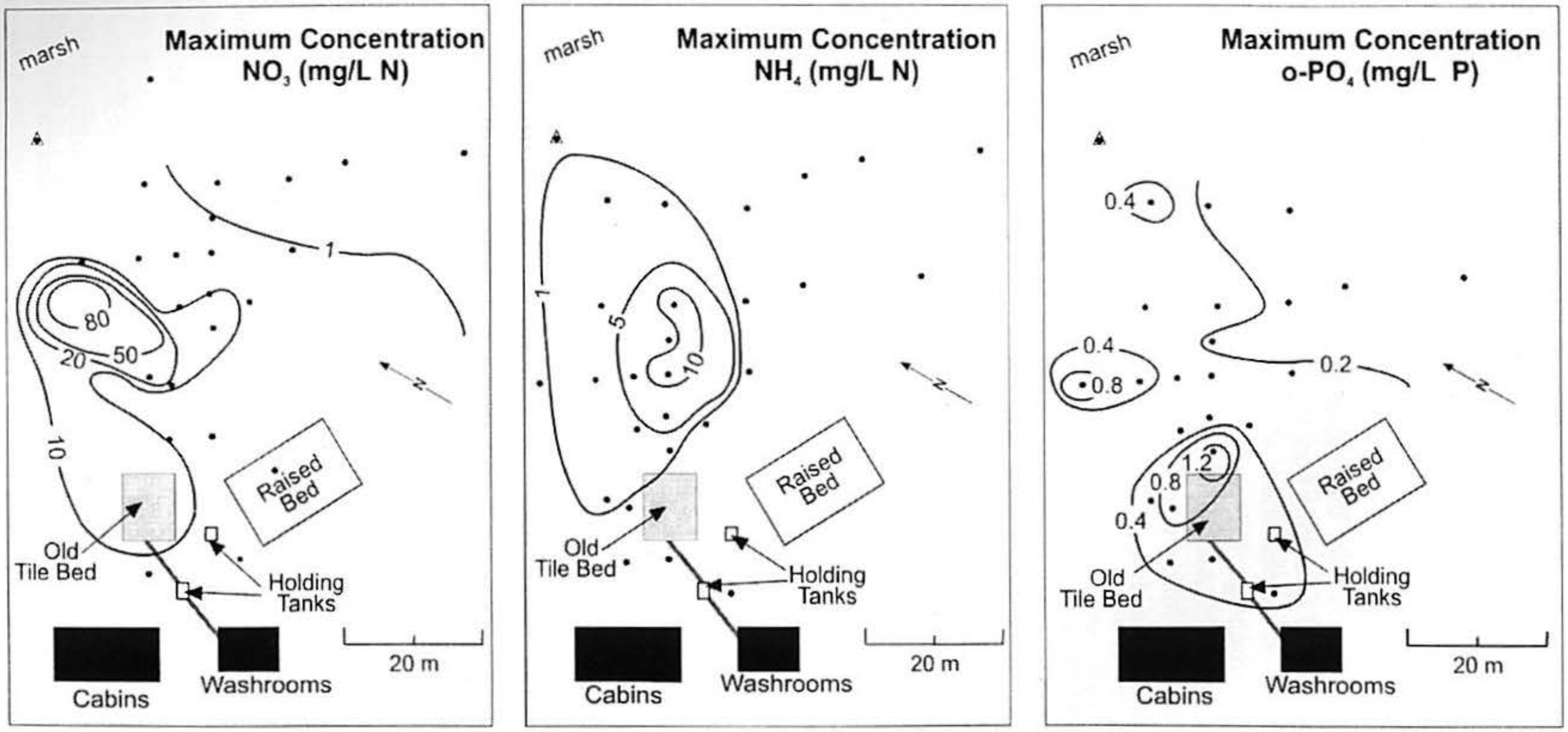


Figure 15: Concentrations of NO_3, NH_3, and PO_4, in groundwater near the Camp Henry tile bed during the active stage of sewage disposal. The bed was in operation for 16 years at the time of sampling.

tions of NO_3 and NH_3 occurred, but virtually no change in PO_4 concentrations over the two year period. The elevated concentrations of PO_4 in the groundwater are attributed to release of PO_4 from earlier accumulations on the aquifer.

IMPLICATIONS

Many Parks rely on subsurface disposal of wastewater. Groundwater plumes emanating from these sites typically contain elevated concentrations of nutrients. These plumes can discharge into surface waters increasing the nutrient pool. After tile bed abandonment, release of phosphate from previously accumulated solid-phases can lead to additional release to surface waters.

Large Park comfort stations commonly discharge 10,000 L/day of sewage containing between 5 and 15 mg/L P to the subsurface. Because, these comfort stations operate for many decades, total phosphorous released can be on the order of 100's to 1000's of kg over the life of a leach field. Even if only a portion of this phosphorous is eventually leached, the loadings can cause a significant increase in the nutrient pool of surface water bodies.

ITINERARY

Day 1

9:00 The field trip will depart from the GSA meeting site in Toronto. The bus will proceed along the Queen Elizabeth Way to Burlington, then along Highway 403 to Brantford, south on Highway 24 through Simcoe and Port Rowan, then along Highway 59 to Long Point. Along the way, there will be commentary on geological history of area, agricultural setting, and postglacial evolution of Lake Erie.

11:30 **Stop 1: Long Point**

Upon arrival at Long Point, there will be an inspection of beach pads (migrating sand waves at the water line), dunes and washover fans, and previous drilling sites. The stratigraphy below Long Point will be discussed and related to its postglacial history.

12:30 After leaving Long Point, the field trip will travel along the north shore of Lake Erie to Rondeau Provincial Park via County Roads 42, 24 and 20, and Highway 3. Commentary will focus on evolution of Lake Erie shoreline (erosion) and its effects on local inhabitants, agriculture (tobacco is the major cash crop here), and introduction to geology of the Pointe-aux-Pins foreland. A box-lunch will be provided enroute.

14:30 **Stop 2: Point-aux-Pins**

At Rondeau Provincial Park there will be a brief tour of the beach and erosion problems, wooded dune-fields at Point-aux-Pins, and discussion of sediments, stratigraphy, and origin.

15:30 After departing from Rondeau Provincial Park, the field trip will continue to travel westward on Highway 3 along north shore of Lake Erie. Again, there will be commentary on geomorphology, agriculture, and social history of Essex county area.

17:00 The field trip will stop over night in Leamington, Ontario, which is located approximately 7 km from Point Pelee National Park. Accommodation will be provided at the Pelee Days Inn, located between Point Pelee and Leamington.

Leamington is the hub of the largest hot-house and field tomato growing area in Canada, as well as a variety of other vegetables, fruit, and flowers. Its main industry is H.J. Heinz tomato processing plant, which for decades has manufactured ketchup and other tomato products. More recently there has been strong growth in wine crafting, with the local Pelee Island winery (main outlet located in Kingsville) garnering considerable recognition for its superb Reislings, and Chardonnays. Pelee Island, less than 15 km offshore, is reachable by ferry from Leamington and Kingsville.

Day 2:

8:00 Breakfast will be available at the Pelee Days Inn. All participants are required to check-out of the hotel and be on the bus by 9:00 am.

9:00 **Stop 3: Point Pelee (Geology)**

Field Trip attendees will be greeted at Point Pelee National Park by a Park warden who will provide a short discussion on the history and natural features of Point Pelee National Park. A brief overview of the coastal problems at Point Pelee and conflicts between agriculture, tourism, and nature conservation, and sediments and coastal evolution trends will be presented. As the bus proceeds through the Park, a series of short stops will be made at the major areas drilled (Park Gate, Northwest Beach, Camp Henry, DeLaurier, Visitor Centre, Point Tip) during 1994-96. The drilling rig from the National Water Research Institute will obtain a fresh log of subsurface sediments.

10:30 **Stop 4: Point Pelee (Hydrogeology)**

The bus will proceed north through the Park stopping at the three sites instrumented for the hydrogeological study; the Park Gate transect, the Northwest Beach transect, and the Camp Henry site. Groundwater flow within the western barrier bar varies considerably from north to south. A discussion of the groundwater flow regime within the western barrier bar will focus on how the width of the barrier, the relative fluctuations of Lake Erie and the Point Pelee marsh, and infiltration and evapotranspiration, control the direction, velocity, and travel distance of groundwater flow.

12:00 Depending upon the weather, lunch will be provided either outside at the Boardwalk site or inside at the Visitor Centre. There will be sufficient time available for participants to walk along the marsh boardwalk or visit the beach.

13:00 **Stop 5: Point Pelee**
(Impact of sewage disposal)

The bus will stop at one of the three septic system research sites (Marsh Boardwalk - Blue Heron). The transport and geochemistry of the septic-system derived nutrients within the groundwater flow regime, and at the marsh-groundwater interface will be described. The participants will observe the impact of the septic-system derived nutrients on the marsh. Demonstrations of the instrumentation used will be presented.

15:30 During the final hour of the trip to Point Pelee, there will be a stop at the Park's Interpretive Centre, where attendees can learn more about the history, natural features, and wildlife of the Park.

16:30 The field trip will leave Point Pelee National Park to return to Toronto via 401. There will be a brief stop in London for dinner, and the field trip will return to the GSA meeting site in Toronto at 22:00.

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