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The effect of past land use on Groundwater Nutrient Concentrations, Point Pelee National Park, Ontario, Canada

By:
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MANAGEMENT PERSPECTIVE

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EC Priority/Issue: This work was conducted as part of a larger study on the hydrogeology of the Point Pelee coastal barrier bar/wetland complex funded by Parks Canada, and by the GL2000 program. The work supports the ESD issue "Conserving Canada's Ecosystems" (nutrients and wetlands). It supports the business plan deliverable Thrust #1 under Conserving Canada's Ecosystems (nutrient loading, great Lakes coastal wetlands). Under EC Action Plan, the work supports the action item "Conserving Canada's Ecosystems" with the focus "Understand the impacts of human activities on ecosystems; develop and implement strategies to conserve ecosystems".

Current Status: In the mid 1900's private lands held within Point Pelee National Park were purchased and the buildings removed. The land was revegetated or converted to picnic areas, parking lots, rest facilities, and tile beds. Geochemical sampling of groundwater below one restored area indicates elevated nutrient concentrations are present close to locations where on-site wastewater disposal occurred in the 1970's or earlier. The results suggest that nutrients, in particular phosphate, bound to the aquifer solids are continuing to be released into the flowing groundwater and are potentially being released to the marsh. The study began in late 1995 and is expected to be completed in 1998. An interim report was provided to Parks Canada.

Next Steps: Solid-phase analyses will be conducted to determine the masses and spatial variability of phosphorous bound to aquifer materials. More detailed geochemical sampling will be conducted to determine the mechanisms controlling phosphate release and transport in the shallow aquifer at Point Pelee. Seasonal monitoring of seepage of nutrient-rich groundwater into an eutrophic open-water marsh pond will continue. The results will assist in evaluating the influence of past land-use practices on groundwater quality, and in understanding the role of groundwater in nutrient cycling in wetlands. The results can be applied to evaluating the use of constructed wetlands as a method of wastewater treatment. Final report targeted for 1998.

Abstract

The Blue Heron/Marsh Boardwalk site at Point Pelee National Park has a long history of anthropogenic use including wastewater discharge to the groundwater zone via tile beds and vault toilets. Two active tile beds are present at the site. Elevated concentrations of PO_4 and NH_3, however, are distributed outside the extent of the contaminant plumes from these tile beds. Historical wastewater disposal throughout the site from homes and cottages and a reversing groundwater flow regime account for the ubiquitous nature of the elevated nutrient concentrations beyond that from the existing tile beds. Zones of low nutrient concentrations, <0.2 mg/L PO_4-P and < 1.0 mg/L NH_3-N, are present, however, relatively high concentrations of PO_4-P, ranging between 0.2 and 2.0 mg/L, and NH_3-N, ranging between 1.0 and 10.0 mg/L, are common throughout the study area. The highest concentrations of PO_4 and NH_3 in the groundwater occur at the marsh interface just north of the entrance to the marsh boardwalk. Maximum values of 7.4 mg/L PO_4-P and 75.4 mg/L NH_3-N are present 1.8 m below ground surface. The concentrations of nutrients in this zone are consistent with those observed for untreated wastewater. Alternatively, these elevated concentrations along the marsh interface may be derived from the natural degradation of organic matter. Due to the limited extent of the high concentrations surrounded by much lower concentrations of dissolved PO_4 and NH_3, a combination of these processes is probable.

Keywords: wastewater, groundwater, nutrients, past-land use

The Effect of Past Land Use on Groundwater Nutrient Concentrations, Point Pelee National Park, Ontario, Canada

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Abstract

The Blue Heron/Marsh Boardwalk site at Point Pelee National Park has a long history of anthropogenic use including wastewater discharge to the groundwater zone via tile beds and vault style toilets. Two active tile beds are present at the site. Elevated concentrations of PO_4 and NH_3, however, are distributed outside the extent of the contaminant plumes from these tile beds. Historical wastewater disposal throughout the site from homes and cottages and a reversing groundwater flow regime account for the ubiquitous nature of the elevated nutrient concentrations beyond that from the existing tile beds. Zones of low nutrient concentration, <0.2 mg/L PO_4-P and <1.0 mg/L NH_3-N, are present, however, relatively high concentrations of PO_4-P, ranging between 0.2 and 2.0 mg/L, and NH_3-N, ranging between 1.0 and 10.0 mg/L, are common throughout the study area. The highest concentrations of PO_4 and NH_3 in the groundwater occur at the marsh interface just north of the entrance to the marsh boardwalk. Maximum values of 7.4 mg/L PO_4-P and 75.4 mg/L NH_3-N are present 1.8 m below ground surface. The concentrations of nutrients in this zone are consistent with those observed for untreated wastewater. Alternatively, these elevated concentrations along the marsh interface may be derived from the natural degradation of organic matter. Due to the limited extent of the high concentrations surrounded by much lower concentrations of dissolved PO_4 and NH_3, a combination of these processes is probable.

Introduction

Water quality analyses of the marsh ponds at Point Pelee National Park have revealed high nutrient concentrations in open waters adjacent to the western edge of the marsh (McCrea, 1993). Excessive input of phosphorous and nitrogen to marsh waters can lead to an accelerated growth of algae and aquatic vegetation. Due to the proximity of the most contaminated ponds to areas of higher human activity, it was suspected that anthropogenic input of nutrients contributed to the high nutrient concentrations. In an effort to protect the marsh from further anthropogenic nutrient inputs, studies were undertaken to determine the source of the nutrients and potential groundwater discharge zones to the marsh.

One known source of anthropogenic nutrients is septic systems. A study was initiated at the Blue Heron/Marsh Boardwalk area (Fig. 1) where two active tile beds are located. One tile bed is used heavily throughout the year by the Blue Heron washroom facilities and the other is used intermittently by the concession stand at the Marsh Boardwalk. A detailed network of multi-level piezometer bundles and water table wells was installed at the higher use Blue Heron tile bed to determine the extent of wastewater contamination and to evaluate groundwater flow (Fig. 2b) (Ptacek and Crowe, 1997). In addition, a transect was instrumented with multi-level piezometer bundles and water table wells from the marsh westward to Lake Erie to provide background information on the hydrogeological regime at Point Pelee (Crowe and Ptacek, 1997).

Analysis of groundwater samples reported by Ptacek et al. (1997) indicated elevated concentrations of nutrients along the marsh interface (>0.2 mg/L PO_4-P and >10.0 mg/L NH_3-N) and very high concentrations (3.1 mg/L PO_4-P and 51.3 mg/L NH_3-N) just north of the walkway leading to the observation tower and boardwalk (Fig. 2b). The high values were found in an area with no apparent active source of nutrients. A more detailed examination of the historical land use at the site was initiated. This paper summarizes the results of the investigation into the history of the Blue Heron/Marsh Boardwalk site and identifies possible reasons for the distribution of PO_4 and NH_3 within the groundwater system.

Historical Land Use

Human activity at the study site is broadly based and can be traced to the 1800's when Europeans first settled on the peninsula. In the late 1800's, the lot now occupied by the Marsh Boardwalk site and a large portion of the marsh were leased to a gun club. An 1889 land survey indicates that the club erected a club house, boat house and another building which is assumed to be a vault style toilet (Fig. 2a) (McPhillips, 1889). The same survey shows that the Blue Heron site was unoccupied at this time.

For several decades following the establishment of Point Pelee as a National Park in 1918, many private land holdings remained within its boundaries. Summer cottaging was popular in the early 1900's and with time more permanent homes were constructed. Cottages, homes, a store, a barn, boathouses and a variety of other buildings were located within the study site (Fig. 2a). Many small buildings along the marsh edge, detected on aerial photographs, are potential boathouses or vault toilets used during hunting and fishing activities within the marsh. It is assumed that the cottages would have had vault toilets and the more permanent structures, tile beds. None of these facilities, however, have been located. The efficiency of either of these waste disposal systems for the attenuation of PO_4 and oxidation of NH_3 is questionable due to the position of the water table between 0.6 and 2 m below ground surface and due to the tile bed construction practices of the time.

To facilitate access to the open water ponds of the marsh by boat and canoe, channels were cut through the thick cattail mats and a ditch was dredged parallel to the marsh along its western edge (Fig. 2a). This drainage ditch also lessened the flooding of the low lying lands adjacent to the marsh. The excavated organic material was deposited on the adjacent land. The open water at the Marsh Boardwalk was connected to Lake Pond (Fig. 1) for accessibility and to increase the water flow within the marsh. The marsh edge at the Boardwalk site was altered more recently by the infilling of a portion of the dredged channel with gravel to form a walkway connecting the land to the stationary and floating boardwalks and the observation tower (Fig. 2b). This barrier has decreased water flow over the length of the channel.

A park program of land acquisition began in the mid-1900's whereby private lands held within the park were purchased and the buildings removed. By the mid-1970's the study site was virtually clear of most buildings. In 1970 a 4,500 L holding tank had been installed for washroom facilities in the Marsh Boardwalk area (Fig. 2a). This facility was in use for approximately 6 years until the Blue Heron Washroom facilities were installed in 1976. The holding tank was pumped out on a regular basis and, therefore, is not considered to have contributed to groundwater contamination. The original tile bed for the washroom facilities was located in a low lying area between the washroom and the marsh (Fig. 2b). Services were switched to the active tile bed in 1981. A concession stand and picnic shelter were also constructed in the study site (Fig. 2b).

During installation of monitoring wells in the Marsh Boardwalk area pieces of red clay tile were brought to surface at three locations indicated on Figure 2a. The pieces were taken from a depth of <0.6 m. It is unknown if this tile was used for drainage, to carry waste down-gradient to the marsh or was part of a tile bed.

The Subsurface and Groundwater Flow

The subsurface at the Blue Heron/Marsh Boardwalk site consists of an unconfined aquifer composed of two sand units overlying lacustrine clay. A well sorted sand overlies a poorly sorted sand unit and a gravel layer (Fig. 3). The field hydraulic conductivities of both sand units near the marsh were measured at approximately 10^{-2} cm/s (Crowe & Ptacek, 1995). The total sand thickness increases westward from 3 to 6 m. During the installation of wells near the marsh interface an organic rich layer was found at various depths. The organic matter is thought to be the spoils from the channel dredging operations.

The groundwater flow at Point Pelee National Park was studied by Crowe and Ptacek (1995). This study focused on delineating the contaminant plume emanating from the Blue Heron tile bed and observing the temporal changes in piezometric head along an east-west transect installed across the barrier bar. It was determined that the relative surface elevation of the marsh to that of Lake Erie, infiltration and evapotranspiration affect the groundwater flow at the study site. A reversal in direction of flow occurs over an interval of a few weeks at approximately April and October of each year as depicted in Figure 4. During the winter, when the surface elevation of the marsh is higher than that of the lake, the groundwater flow is from the marsh toward Lake Erie. In the summer, the surface elevation of the lake rises above that of the marsh and the groundwater flow reverses. Stable isotope characterization of the marsh water and groundwater along the transect indicated that marsh water infiltrates during the winter months but does not penetrate to a well located 15 m inland (Crowe et al., 1996). The reversal of the direction of flow resulted in the development of multiple plumes of contaminants to the west and east of the Blue Heron tile bed (Crowe and Ptacek, 1995; Ptacek and Crowe, 1997).

Tritium analyses were used to age date the groundwater along the transect. The results indicate that the deeper groundwater within the sands most likely originated in the early 1970's and, therefore, is flushing out of the system very slowly.

Effects of Historical Land Use

To assist in the location of source areas and discharge zones of anthropogenically-derived nutrient contamination, a series of multi-level bundle piezometers and water table wells were installed at the Marsh Boardwalk site. The bundle piezometers were installed to clay at a spacing of 0.5 m except for 3 bundles installed near the marsh interface with a 0.25 m spacing.

Electrical conductivity and Na concentrations are typically higher in sewage contaminated groundwater and can usually be used to trace septic effluent plumes in the subsurface (Robertson et al., 1991; Walter et al., 1995). Field measurements made in the spring of 1996 found electrical conductivity values >3000 μS/cm and Na concentrations as high as 420 mg/L in the vicinity of the parking lot at the Marsh Boardwalk. Point Pelee National Park has a program to control road dust on the dirt roads and parking lots. Powdered calcium chloride was applied each summer until the late 1980's. From this time until 1995 the park continued to control dust using a brine solution. The brine varied in composition generally containing high concentrations of Na, K, Ca, Mg, NH_3, and Cl. Infiltration of this brine to the subsurface would be responsible for the high values recorded and as such limited the use of electrical conductivity or Na as a tracer of septic effluent migration.

Studies have shown that phosphorous can be attenuated in the subsurface by adsorption and precipitation processes (e.g. Robertson et al., 1991; Shawhney and Starr, 1972; Wilhelm et al., 1994). Despite the potential for attenuation, plumes of groundwater containing low to moderate concentrations of PO_4 (0.1 - 3 mg/L as P) are common. Extensive studies by Walter et al. (1995) indicate that PO_4 readily sorbs onto mineral surfaces such as iron and aluminum oxide coatings until all sorption sites are occupied. In a sewage contaminated aquifer they observed a large reservoir of sorbed solid phase PO_4 at concentrations much higher than those found in the dissolved phase. Desorption experiments concluded that with the addition of PO_4 free groundwater, a slow constant desorption of PO_4 occurred.

NH_3 in septic effluent is oxidized to NO_3^- during transport through the unsaturated zone below tile beds. If, however, this oxidation is incomplete, NH_3 can enter the groundwater directly. In reducing environments N occurs as NH_4^+ which can be attenuated by cation exchange reactions (Wilhelm et al., 1994).

Results of the current monitoring program at the Marsh Boardwalk site are consistent with the initial study showing that elevated concentrations of PO_4 and NH_3 are essentially ubiquitous in the groundwater with the highest concentrations found close to the marsh interface (Fig. 5). PO_4 concentrations ranged from 0.02 to 0.2 mg/L around the Marsh Boardwalk parking lot, to its north, and to the east and west of the Blue Heron tile bed. The area to the north of the parking lot contains dissolved NH_3-N concentrations that ranged between 0.5 and 1.0 mg/L. Concentrations of PO_4 between 0.2 and 1.0 mg/L P were observed at the marsh interface, to the east of the Blue Heron washroom in the vicinity of the abandoned tile bed. This suggests that the elevated levels could be relic nutrients released prior to the abandonment of the tile bed in 1981. PO_4 concentrations >2.0 mg/L P and NH_3 concentrations >5.0 mg/L N were observed in an area close to the previous location of small buildings assumed to be vault toilets (Fig. 2a, assumed vault toilet). The elevated NH_3 concentrations extend northeastward to the marsh edge, however, the PO_4 plume is isolated. This is consistent with the stable isotope determination that the marsh water is not penetrating far into the study site and, therefore, is not causing the release of solid phase PO_4 and expanding the PO_4 plume to the marsh.

Elevated levels of PO_4 and NH_3 found in the area between the concession stand and the walkway could possibly be from a former tile bed servicing the concession stand, although one has not been located. This area probably does not receive fresh water directly from infiltration due to a clay cap emplaced there. The brine applied to the parking lot could also have influenced this area with the addition of NH_3 and high concentrations of cations which could react with dissolved PO_4 present. PO_4 concentrations range between 1.0 and 2.0 mg/L from this area to the northeast.

High concentrations of nutrients (7.4 mg/L PO_4-P and 75.4 mg/L NH_3-N) are found in an area containing considerable organic matter derived from dredging and infilling of the channel (Figs. 2 and 5). This area does not coincide with the location of former buildings observed on aerial photographs or location maps, however, the concentrations are typical of untreated septic effluent. Raw domestic wastewater inorganic P concentrations typically range between 7 and 15 mg/L (Wilhelm et al., 1994) and inorganic N concentrations range between 30 and 111 mg/L (Robertson et al., 1991). The use of a vault toilet in this area in the past or wastewater drainage to this area via clay tile (Fig. 2a), therefore, cannot be dismissed. The release of NH_3 and PO_4 from the organic matter found in the subsurface could also be contributing to the high concentrations found in this zone.

The Blue Heron tile bed was shown to efficiently oxidize NH_3 in the septic tank effluent to NO_3^- before the effluent reaches the groundwater below the bed. Denitrification of NO_3^- to $N_{2(g)}$ near the Blue Heron tile bed is occurring above the clay base (Ptacek, 1996). At the Marsh Boardwalk site no NO_3^- is present, but high NH_3 concentrations are found. This suggests that incompletely oxidized wastewater entered the groundwater zone, leading to the elevated NH_3 concentrations observed. Removal of NO_3^- by denitrification reactions may have occurred in the past accounting for the absence of NO_3^-.

Conclusions

Elevated concentrations of nutrients in the groundwater at the Blue Heron/Marsh Boardwalk site are widespread. The location of former residences, cottages and wastewater disposal systems and the complex groundwater flow system suggest that except for the plumes emanating from the active Blue Heron tile bed, the nutrients in the groundwater are derived from relic anthropogenic sources. Relatively high concentrations of PO_4 and NH_3 (>2.0 mg/L PO_4-P and >5.0 mg/L NH_3-N) were shown to coincide with areas of expected contamination due to prior on-site wastewater disposal. The desorption or dissolution of PO_4 from an accumulated solid phase could account for the elevated concentrations found. High concentrations observed at the marsh interface (7.4 mg/L PO_4-P and 75.4 mg/L NH_3-N) are typical of untreated wastewater. This may suggest a source of contaminants in the immediate vicinity, or alternatively, these elevated concentrations may be derived from the natural degradation of organic-rich sediments present at the marsh interface. The zone that contains high concentrations is small and is surrounded by a zone containing much lower concentrations of dissolved PO_4 and NH_3. It is possible that a combination of untreated wastewater and naturally degrading organic matter is contributing to the elevated concentrations at the marsh interface.

References

Crowe, A.S., and Ptacek, C.J., 1995. Groundwater Flow at a Large Freshwater Coastal Wetland: The Point Pelee Marsh, Ontario, Canada. *In: Solutions '95 - Proceedings of the XXVI International Congress of the International Association of Hydrogeologists,* Edmonton, Alberta.

Crowe, A.S., Ptacek, C.J., Huddart, P., Longstaffe, F.J., 1996. *Investigations of Groundwater Flow Within Point Pelee National Park and the Impact of the Septic Systems on the Water Quality of the Marsh, Progress Report to January 1996.* National Water Research Institute, Environment Canada and Department of Earth Sciences, University of Western Ontario. Report to Parks Canada.

McCrea, R., 1993. *An Assessment of the Trophic Status of the Point Pelee Marsh.* Environmental Quality Branch, Inland Waters Directorate, Ontario Region, Environment Canada, Burlington, Ontario. Report to Parks Canada, 16 pp.

McPhillips, G., 1889. *Plan of the Squatters' Holdings on the Naval Reserve at Point Pelee in the Township of Mersea, County of Essex, Ont.* Canada Lands Surveys Records 50730.

Ptacek, C.J., 1996. *Characterization of Groundwater Chemistry in the Vicinity of Septic System Tile-Beds, Point Pelee National Park, Ontario. Report of Progress for the Period April, 1995 - January 31, 1996.* National Water Research Institute, Environment Canada. Submitted to Point Pelee National Park.

Ptacek, C.J., 1997. Geochemistry of a septic-system plume in a coastal barrier bar, Point Pelee, Ontario, Canada. Submitted to *Journal of Contaminant Hydrology.*

Ptacek, C.J. and Crowe, A.S., 1997. Groundwater-surface water interaction at Point Pelee, Ontario, Canada: III. Transport of septic-system derived nutrients. For submission to *Journal of Hydrology.*

Ptacek, C.J., Crowe, A.S., Durham, L., 1997. Groundwater transport of wastewater nutrients at a coastal barrier bar, marsh complex, Point Pelee, Ontario, Canada. This issue.

Robertson, W.D., Cherry, J.A., Sudicky, E.A., 1991. Ground-water contamination from two small septic systems on sand aquifers. *Ground Water,* **29**, 82-92.

Sawhney, B.L. and Starr, J.L., 1977. Movement of phosphorus from a septic system drainfield. *Journal WPCF*, **49**, 2238-2242.

Walter, D.A., Rea, B.A., Stollenwerk, K.G., Savoie, J., 1995. *Geochemical and hydrogeological controls on phosphorus transport in a sewage-contaminated sand and gravel aquifer near Ashumet Pond, Cape Cod, Massachusetts.* U.S. Geological Survey, Massachusetts. Open-File Report 95-381.

Wilhelm, S.R., Schiff, S.L., Robertson, W.D., 1994. Chemical fate and transport in a domestic septic system: Unsaturated and saturated zone geochemistry. *Environmental Toxicology and Chemistry*, **13**, 193-203.

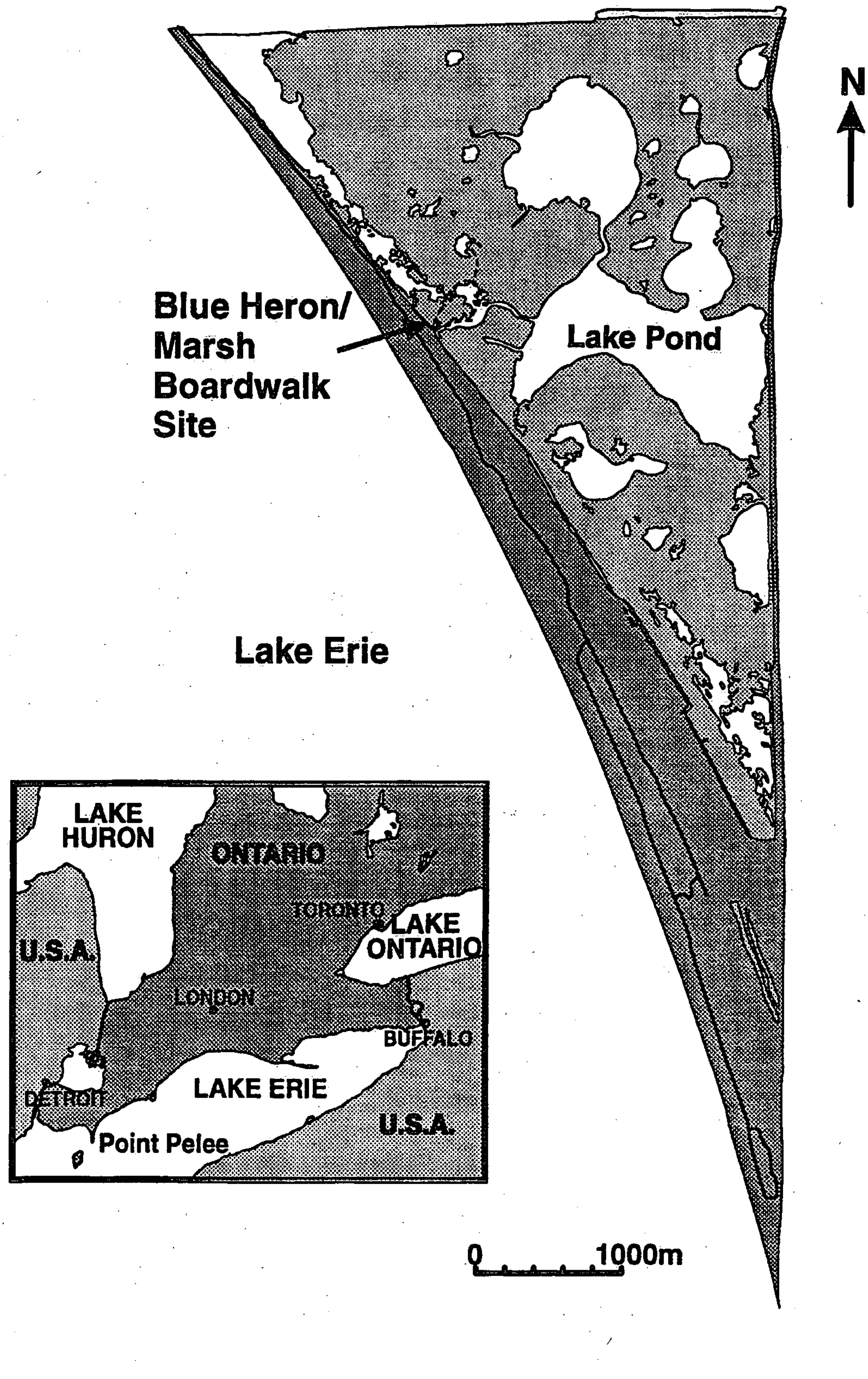

Figure 1: Location of Point Pelee National Park and the Blue Heron/Marsh Boardwalk study site.

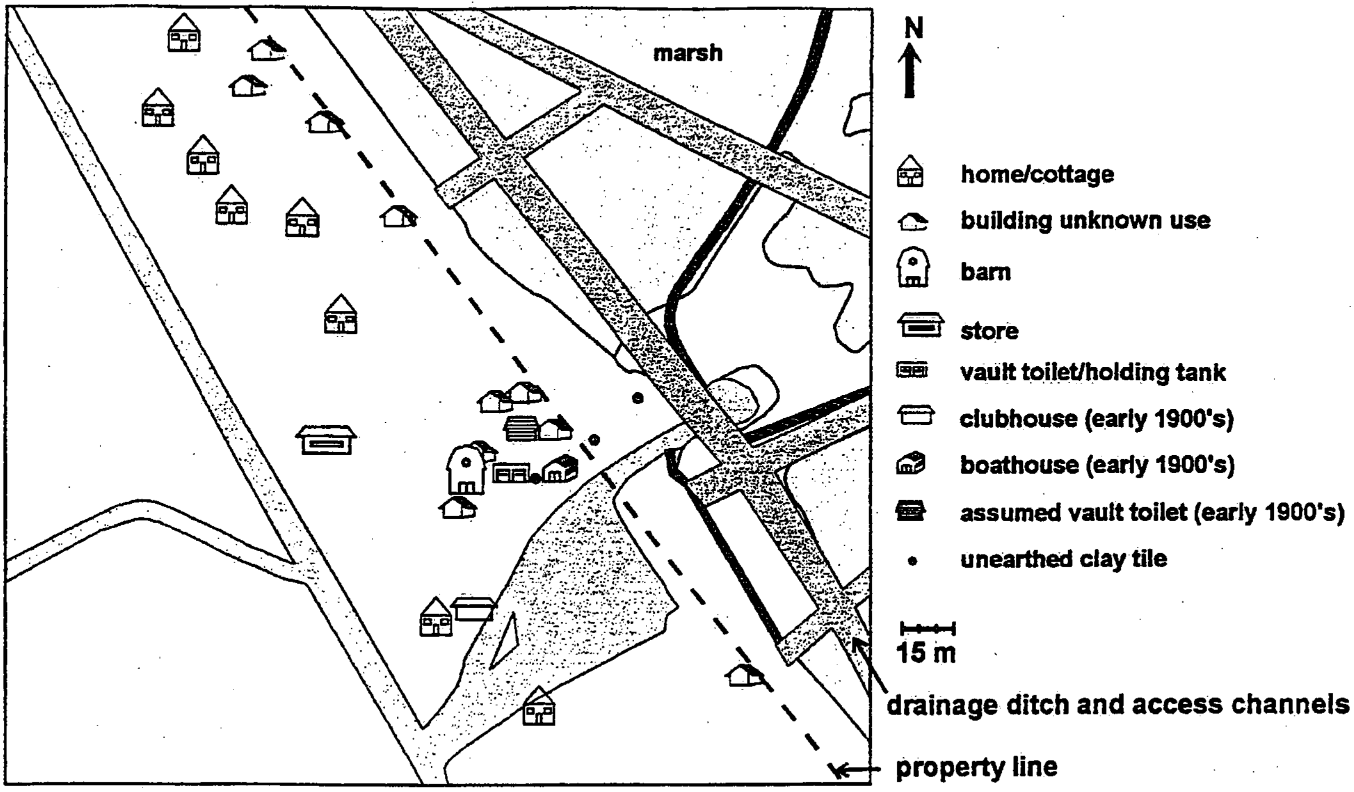

Figure 2a: Aerial view of the Blue Heron/Marsh Boardwalk site showing land use before mid-1970's.

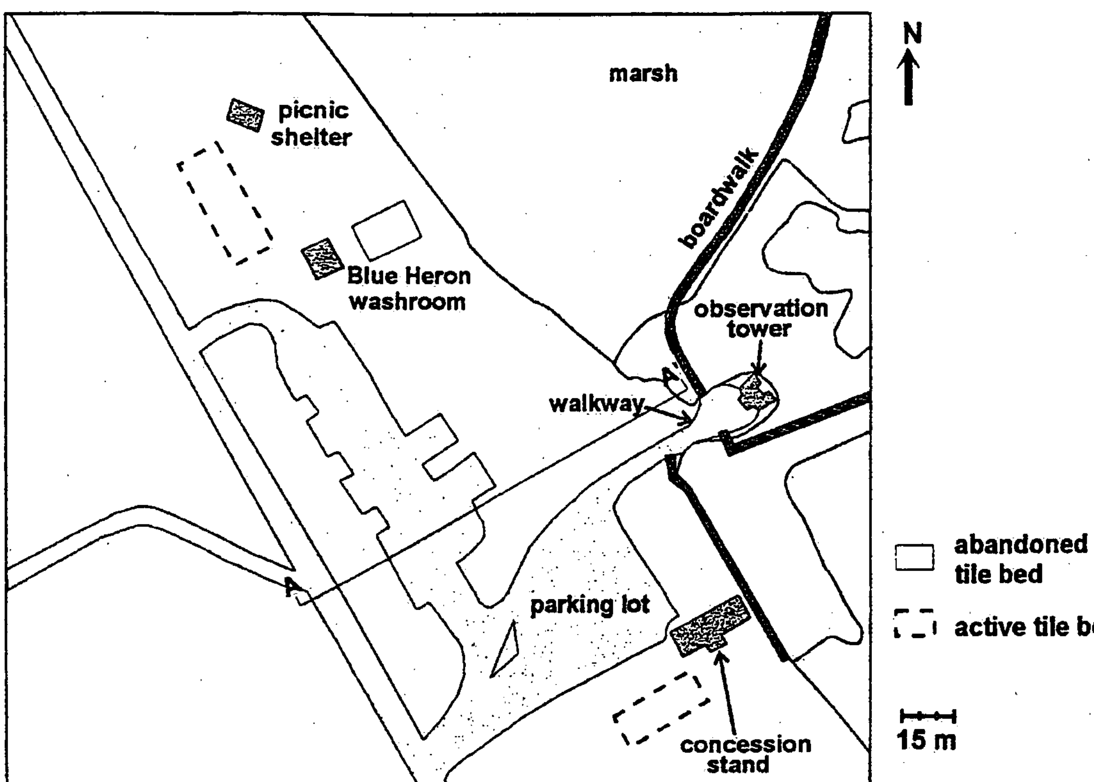

Figure 2b: Aerial view of the Blue Heron/Marsh Boardwalk site showing present day land use.

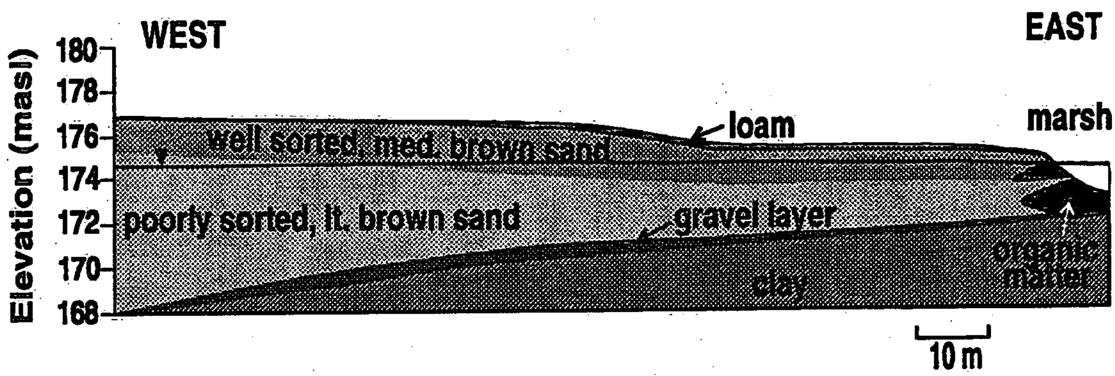

Figure 3: Cross-section A-A' (Fig. 2b) through the Marsh Boardwalk site showing lithology and the position of the water table.

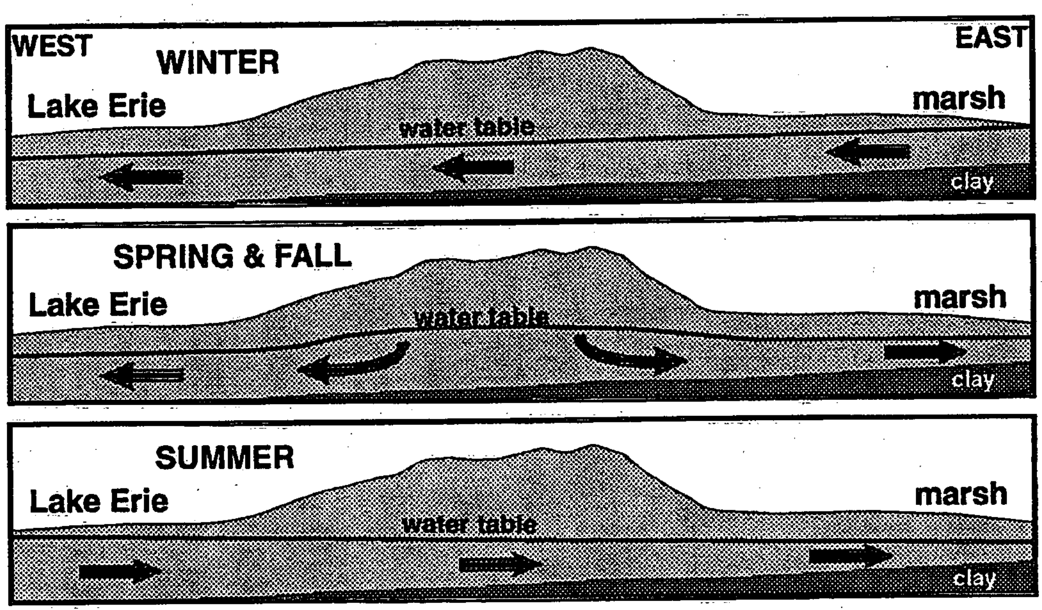

Figure 4: Conceptual model of the seasonal changes in groundwater flow direction across the barrier bar at the Blue Heron/Marsh Boardwalk study site.

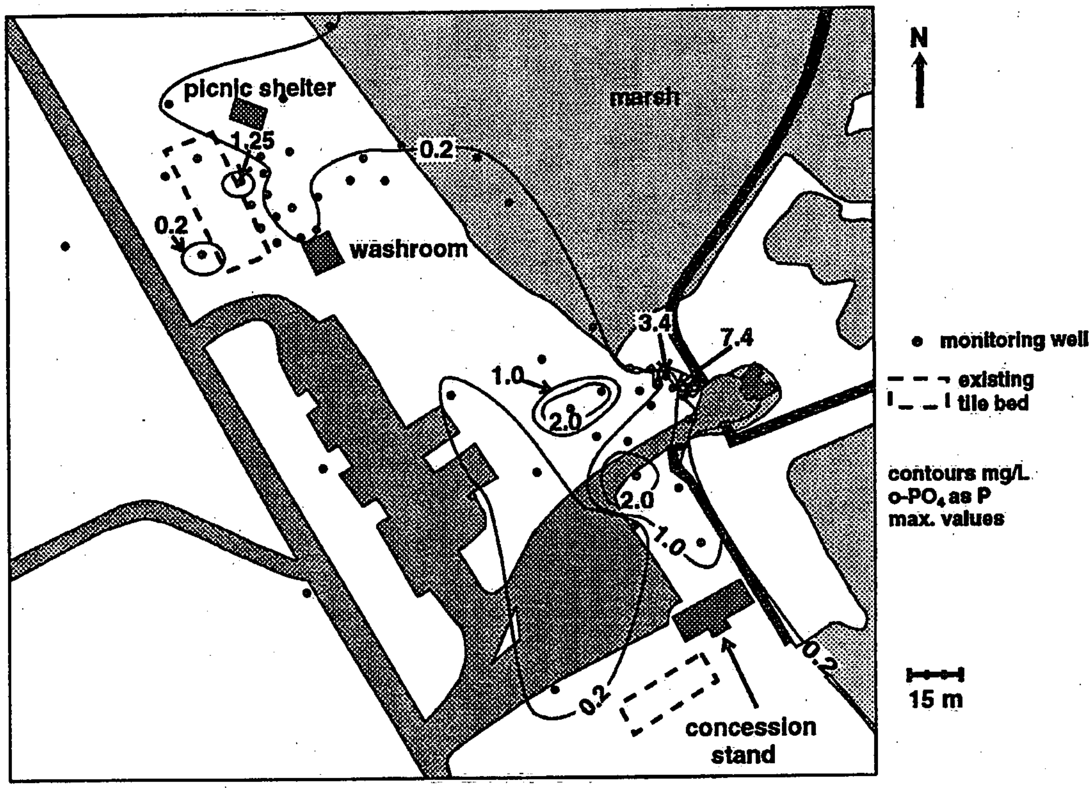

Figure 5a: Areal view of the study site showing maximum concentrations of phosphate obtained in October 1996.

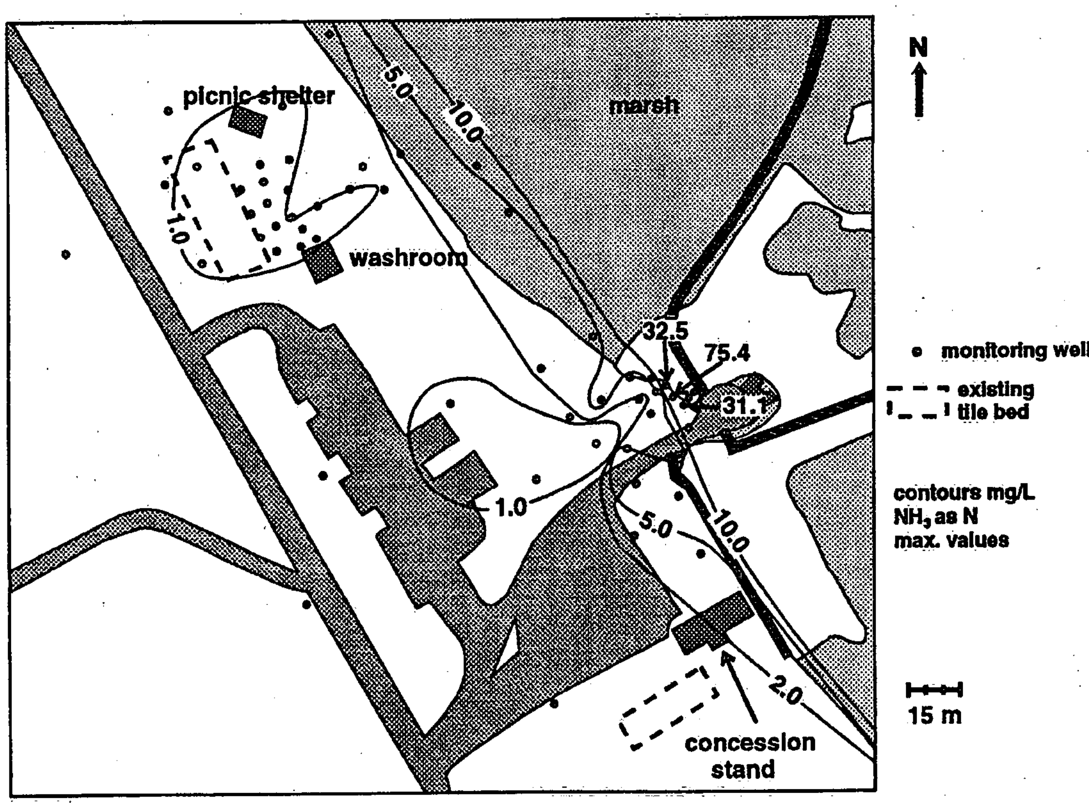

Figure 5b: Areal view of the study site showing maximum concentrations of ammonia obtained in October 1996.

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