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STUDIES OF THE AGRICULTURAL CONTRIBUTION TO NITRATE ENRICHMENT OF GROUNDWATER AND THE SUBSEQUENT NITRATE LOADING TO SURFACE WATERS

PART II: RECONNAISSANCE SURVEY OF NITRATE CONCENTRATIONS IN SHALLOW GROUNDWATER

FINAL REPORT
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SUMMARY

The objective of this study was to obtain data concerning the distribution of nitrate in the groundwater of several PLUARG watersheds. By relating the observed nitrate concentrations to geologic, soil and land use factors, one would hope to be able to extrapolate, at least in a qualitative sense, to other watersheds.

In addition to the detailed investigations in the Hillman Creek Watershed (AG-13) discussed in Part I of this study, and the detailed studies conducted in the Blue Springs Watershed (under separate funding), monitoring networks were installed in seven other watersheds or sub-basins. These included Hillman Creek (outside the detailed study area, AG-13), Big Creek (AG-1), Venison Creek (AG-2), North Creek (AG-10), Upper Canagagigue Creek - West Branch (AG-4), Upper Canagagigue Creek - East Branch, and Holliday Creek (AG-5). The monitoring networks were not intensive, generally consisting of ten to twenty observation wells arranged in three to four nests in each watershed. The wells were generally located near the streams in order to assess the quality of the groundwater discharging to the streams.

AG-1 (Big Creek), AG-10 (North Creek), AG-4 (Upper Canagagigue - West branch) and AG-5 (Holiday Creek) are similar in that the geologic materials are predominantly fine-textured. With only occasional exceptions, the concentration of nitrate in the groundwater of these regions was near zero. The exceptions generally occurred in the shallowest sampling points or in lenses of coarser textured materials. The shallow samples containing nitrate could be the result of relatively rapid groundwater circulation through fractures in the upper part of the till or clay units. The reason for the low nitrate concentration in fine-grained materials is not clear. It can be shown however, that the rate of groundwater movement through such materials is on the order of fractions of a

centimetre to a few centimetres per year. As a result, there may not have been sufficient time since intensive agricultural practices were adopted for nitrate to have moved a significant distance through the low permeability materials. The low nitrate concentrations may also be the result of denitrification, as discussed in Part I of this report. As a result of the combined effects of low nitrate concentrations and low migration rates, it is quite safe to say that in watersheds where the geologic materials are predominantly fine-textured, significant quantities of nitrate will not be discharged to surface waters by the groundwater.

The strong geologic control on the nitrate distribution is also reflected in the fact that there was no apparent relationship between land use and nitrate in the groundwaters. It should be noted that there was considerable tile drainage in AG-1 and AG-4. These drains may have prevented water from moving to greater depths in these watersheds and therefore could have influenced our observations. Nitrate discharged to the streams from the tile drains was not monitored in this study.

The areas which contained coarse to medium grained geologic materials had significant groundwater nitrate concentrations, although generally less than 10 mg/L -N. These areas include AG-13 (Hillman Creek) AG-2 (Venison Creek), AG-4 (Canagagigue - East branch) and the Blue Springs watershed discussed by Stiebel (1977). Although there is undoubtedly some relationship between land use and nitrate concentration, it appears to be considerably more complicated than a direct relationship between concentration and rate of fertilizer application. For example, considering the high degree of variability in the data, it cannot be said that the nitrate concentration in the groundwater of the east branch of the Canagagigue is significantly different from the concentration in the groundwater of Hillman Creek. However, agricultural production is much more intensive in the Hillman Creek watershed.

Hillman Creek and Venison Creek present an interesting comparison in that they are both under intensive cultivation and both have sandy soils and sandy near-surface geologic materials. In the Hillman Creek watershed the nitrate is located in the upper one to two metres of the saturated zone while in Venison Creek the nitrate is carried several metres below the water table. One difference between the two areas is the depth of the water table below ground surface. At Hillman Creek the water table is generally within 2 m of ground surface while at Venison Creek it is generally at a depth greater than 10 m below ground surface.

In Venison Creek, as a result of the greater unsaturated zone thickness, soluble organic matter may be oxidized aerobically prior to reaching the water table. As a result, there may not be a sufficient energy source for denitrification to proceed in this area. On the other hand, with the shallow water table of the Hillman Creek Watershed, significant soluble organic matter may be transported to depths below the water table. Continued oxidation of the organic matter could remove dissolved oxygen and reduce the Eh of the water until anaerobic oxidation processes predominate. Under these conditions denitrification could proceed.

The detailed studies in the Hillman Creek Watershed (Part I of this report) and in the Blue Springs Watershed (Stiebel, 1977) showed wide variations in nitrate concentration within areas which were geologically similar and had similar land use. As a result, there is considerable uncertainty regarding the extent to which the sparse instrumentation of this study can be considered representative of a particular watershed. In addition, should it be shown that denitrification is a significant process in groundwaters, the problem becomes considerably more complex. Although nitrate may be monitored in the groundwater, the amount discharged to surface waters could be a function of the factors controlling the rate of denitrification. The quantification of these factors is quite problematic at the present time. In view of these uncertainties, quantitative extrapolations to other watersheds is highly speculative.

It should be noted that this report considers only the discharge of nitrate in groundwater and does not consider surface runoff or tile drainage. As a result, it does not address the problem of the total nitrogen discharge to surface waters under different land use and geologic conditions. Some preliminary studies into this problem are reported in Part III of this report.

1. INTRODUCTION

As discussed in Part I of this report, the upper portion of the Hillman Creek watershed was studied in considerable detail in order to evaluate the processes by which nitrate enters and passes through the groundwater flow system of that area. One of the objectives of that aspect of our studies was to gain sufficient information regarding the transport processes to enable one to extrapolate, at least in a semi-quantitative manner, the results to other watersheds.

At an early stage in the investigation, it became apparent that the complexities of the transport processes in the saturated zone were such that extrapolations based solely on the data for Hillman Creek would be extremely unreliable. Consequently, in the second and third years of the study, a portion of our efforts were directed towards a reconnaissance survey of nitrate concentrations in the groundwater of other PLUARG watersheds. The intention was to obtain groundwater nitrate data under a variety of land use and soil type conditions and thus to provide a broader base upon which to extrapolate.

As a result of this effort, piezometers were installed in portions of the Hillman Creek watershed not included in the detailed study area, in five additional PLUARG watersheds and in one area not designated as a PLUARG watershed. In most cases, the instruments were installed during the late summer and fall of 1976 and monitored during the late winter and spring of 1977.

2. METHODS

The installation of piezometers and water sampling procedures were identical to those used in the Hillman Creek watershed, as described in PART I of this report. The piezometers were generally installed in nests in order to determine the vertical distribution of nitrate in the groundwater. In addition, the nests were generally located near the stream in order to determine the concentration of nitrate in the groundwater entering the stream. The stratigraphy at each site was determined from an examination of samples collected during the drilling process.

The elevation of each piezometer was determined relative to a local and arbitrary bench mark, and water level measurements were made at the time water samples were collected. From these measurements it could be determined whether groundwater was discharging to the stream or being recharged from the stream. This is obviously essential information if one is attempting to relate the nitrate concentration in the groundwater to land use activities. In view of the sparse network of piezometers installed at each site, it was not possible to calculate the groundwater and nitrate fluxes into the streams.

All the water samples were analyzed for nitrate and ammonium at the Soils Research Institute. 0ne complete set of samples was analyzed for major cations in the Department of Earth Sciences.

3. WATERSHED STUDIES

3.1 AG #13 Hillman Creek Watershed Outside the Detailed Study Area

3.1.1 Geology

The surficial geology of the Hillman Creek watershed southeast (downstream) of the detailed study area generally shows glacio-lacustrine material with a clayey-silt till exposed along the creek embankment (Vagners, 1972). Figure 1 shows the location of the watershed and the areas of study.

There is an exposure of clayey silt till immediately west of study area #1. This clayey silt till is exposed in a narrow band for a considerable distance along the downstream section of the stream. Throughout the remainder of much of the watershed this clayey silt till is overlain by 1.5 m to 6.0 m of glaciolacustrine material. The texture of this material varies considerably over the watershed ranging from a medium sand to silts and clays. Scattered throughout the watershed are eolian deposits consisting of medium sand dunes developed on glacio-lacustrine sand.

Figure 2 shows the location of the test holes. Examination of the drill samples indicated that the three study areas are underlain by a grey pebbly clay silt till to the termination of each borehole. The deepest borehole was located at study area #1 and was terminated at a depth of 16 m. Glaciolacustrine sands were found to overlie the clay silt till to a depth of 3 m at study area #2 and 2.5 m at study area #3. Study area #1 had 2 m of medium sand at test hole H72 but no glacio-lacustrine material in the other two test holes. Complete borehole logs recorded from test drilling are shown in Appendix A.

3.1.2 Observation Well Network

Four to six observation wells were installed at each of the seven sites located within the areas of study. Nests H70, H71 and H72 were located at study area #1, H68 and H69 at area #2 and H73 and H74 at area #3. Wells located in study area #1 and study area #2 have 0.6 m intake zones while wells located in study area #3 have 0.3 m and 0.45 m intake zones. The observation wells were installed at 1.5 m intervals beginning immediately below the water table and at 3 m intervals beginning 5 m below the water table. A more detailed description of the installations is given in the borehole logs shown in Appendix A.

3.1.3 Land Use

In all three areas of study the predominant crop grown was corn. Some horticultural crops such as beans and asparagus were located near study area #1, however all sites are located in a grassy area between Hillman Creek and a corn field. Study area #2 has some soybeans and a vegetable garden near H68 but the main crop is corn. Corn is the only crop near study area #3.

3.1.4 Results and Discussion

Hydraulic Head - Hydraulic head values measured on March 28, April 15 and May 5, 1977 are given in Table 1. H68 shows generally downward hydraulic gradients while at H69 the shallow gradients are upward towards the stream and at greater depths the gradients are downward. H68 and H69 comprise study area #2, with H69 being located closest to the stream (within approximately 8 m). The data indicates that H68 is in a recharge zone and that H69 is in a discharge zone. The lateral variation in hydraulic head indicates flow from H68 towards H69 i.e. towards the stream.

The results for area 1 and 3 are indentical to area 2 in that the piezometer nests closest to the stream show upward hydraulic gradients in the shallow groundwater while at all other locations the gradients are downward. The lateral gradients at areas 1 and 3 also show flow towards the stream.

There is no indication that the stream discharges water to the groundwater at any of the three study areas. As a result, the groundwater at all sampling points probably had its origin as infiltration through the surrounding agricultural land. In view of the relatively large horizontal gradients, the shallow groundwater was probably recharged very locally while the deeper water may have originated at considerable distances away.

Nitrate and Ammonia - The results of nitrate and ammonia analyses of water samples collected on Sept. 25, 1976 and Mar. 30, April 15 and May 15, 1977 are given in Table 2. At study area #2 (H68 and H69), all samples collected in September, contained no detectable ammonium, while in March, most samples contained a small amount (generally less than 1 mg/L NH_4^+-N). As spring progressed, the number of samples containing ammonium decreased and the maximum observed concentration in May was 0.07 mg/L. In view of the very low concentrations, there appears to be little to gain from a further consideration of the ammonium distribution.

Significant nitrate values at study area #2 occurred only in the shallowest piezometers (H68-P7, H69-P7) with values generally ranging between 10 and 34 mg/L NO_3^- -N. At H68, the shallow nitrate concentration changed from 9.5 mg/L in September to 0.0 in March, 31.5 in April and 34.0 in May, while the shallow concentration at H69 remained quite constant at approximately 10 mg/L, NO_3^- -N. In view of the small amount of data, no attempt was made to explain the temporal variability **in** the nitrate values. It is of particular note, however, that all the high nitrate values are restricted to the very shallow groundwater zone.

At study area #1 (H70, 71 and 72), the maximum observed ammonium concentration was 0.9 mg/L. Most values were considerably lower, and there was no distinct trend in either time or space. The nitrate concentrations were similarly very low, with the only values exceeding 1 mg/L being recorded for H72-P6 (14.7 - March, 6.0 - April, 4.0 - May).

The ammonium concentrations at study area #3 were quite low and showed no trends. The nitrate concentrations at H74-P7 were 3.24 on March 30, 2.67 on April 15 and 0.7 on May 15 and at H73-P8 a concentration of 1.2 mg/L was recorded for March 30. All other nitrate concentrations for this area were less than 0.2 mg/L.

In considering the data of all three study areas, the most obvious feature is that significant nitrate concentrations occur only in the glacio-lacustrine sands overlying the silt clay till. It is not clear if this distribution is the result of physical or chemical factors. The hydraulic conductivity of the till is probably three to four orders of magnitude less than that of the sand. As a result, there may not have been sufficient time for nitrate to have moved into the till. On the other hand, at H68 and H69, the shallow groundwater in the sand contained appreciable nitrate, while at the sampling locations just above the surface of the silty clay, the nitrate concentrations approached zero. This suggests that the nitrate distribution could be the result of nitrate removal processes such as denitrification.

The highest nitrate concentrations were found at sites located at a distance from the stream. These sites tended to be surrounded by cultivated areas while those near the stream were located in grassy areas along the stream. The lower concentrations near the stream suggest a mass balance difficulty which could be explained by nitrate removal.

Major Cations - The major cation analyses are shown in Table 3. At most sites, the upper two or three analyses tend to differ from the lower analyses. This is probably a stratigraphic effect in that the upper samples were from the lacustrine deposits while the lower water samples were representative of the till. This general trend is particularly evident in the calcium data.

A particularly high potassium value (67.0 mg/L) was found at H68-P7. This value may be anomalous, however H68-P7 also showed the highest nitrate concentration (34 mg/L) suggesting that fertilizer may have been the source of both the nitrate and potassium.

3.2 AG #1 Big Creek Tributary of the Thames River - Essex County

3.2.1 Geology

Big Creek Tributary of the Thames River (AGO.) is located in Essex County approximately 8-10 km northeast of Leamington, Ontario. Figure 3 shows the location of the watershed and the study area. The study area is located in the physiographic region of Southern Ontario, known as the Essex clay plain (Chapman and Putnam, 1966). The surficial till plain overlies the Cincinnati arch, which is a low swell in the bedrock of the area.

The Essex clay plain is characterized by a clayey silt till ranging from 30-60 m thick. Deposits of glaciofluvial gravel or gravelly sand are found thinly scattered over the silt till.

The main soil type is the Brookston clay loam. It is a dark-surfaced gleisolic soil developed under a swamp forest. There are also numerous undrained areas where peat and muck have accumulated. Most of the Essex clay plain has such imperfect drainage that dredged ditches and tile drains are installed to provide satisfactory conditions for crop cultivation.

Figure 4 shows the location of the test holes. Results of the drilling indicate a clayey pebbly silt till with the silt becoming a fine sand in places. This was found to the termination of both boreholes at 10.5 m. Complete borehole logs recorded from test drilling are shown in Appendix A.

3.2.2 Observation Well Network

Four observation wells were installed at each site. All wells have a 0.3 m intake zone. The shallow well was installed immediately below the water table and the other wells at each site were installed at vertical intervals of 1.5 to 3.0 m. A more detailed description can be found in the borehole logs shown in Appendix A.

3.2.3 Land Use

The predominant crop within the Big Creek watershed is soybeans. Small grains and corn are also grown in much of the watershed. Site H75 is located near a pig pen with both corn and soybeans grown near the site. Site H76 is located between the creek and a field which had been planted in soybeans in 1976.

3.2.4 Results and Discussion

Hydraulic Head - Hydraulic head values for Mar 28, April 15 and May 18 are shown in Table 4. The gradients at H75 are very low but generally indicate recharge. The head values at H76 indicate both downward and upward gradients towards the creek elevation, indicating that groundwater is discharging to the creek.

Nitrate and Ammonium - The results of the nitrate and ammonium analyses are shown in Table 5. The ammonium values tended to be high in samples collected on March 30 (maximum of 0.48 mg/L) with the concentrations decreasing to zero by May 15. This trend could prompt one to suggest that as the temperatures became warmer, nitrification proceeded at a faster rate reducing the amount of ammonium present. It does not seem reasonable that the temperature at depth would have changed significantly by May 15. Thus, considering the very low groundwater velocities in silt or clay materials, it is difficult to explain the observed changes (H75-P35; 0.31 on April 15 to 0.00 on May 15).

The only significant nitrate concentrations were recorded at H76-P8 (maximum of 3.6 mg/L NO_3 -N on March 30). The concentration tended to decrease with time. The nitrate value at all other sampling points was less than 1.0 mg/L. Again it should be noted that the only significant nitrate concentration occurred in the very shallow groundwater.

Major Cations - The results of the major cation analyses are given in Table 6. There are no apparent correlations between trends in cation concentrations and trends in the nitrate concentrations. A possible exception is H76-P8 which shows a potassium concentration of 32.0 mg/L, approximately three times greater than the concentration in the other samples at H76. H76-P8 also had the highest nitrate concentration.

3.3 AG #2 Venison Creek Norfolk County

3.3.1 Geology

Venison Creek watershed (AG #2) is located in Norfolk County approximately 9 to 12 km southwest of Delhi, Ontario. Figure 5 shows the location of the watershed and area of study. The watershed is located in the physiographic region of Southern Ontario known as the Norfolk Send Plain (Chapman and Putnam, 1966). Shallow surficial lacustrine and fluvial deposits extend throughout the area. These deposits consist mainly of fine to medium sand with local coarser phases at depth. They occur in broad flat areas between morainic ridges.

The Norfolk Sand Plain is characterized by deltaic sands and silts deposited in glacial lakes Whittlesey and Warren. It is also characterized by deposits of fine to medium grained glacio-lacustrine sand. Sand beds up to 23 metres thick have been recorded. Usually silt or clay strata, or beds of boulder clay occur within 9 meters of the surface. Much of the Venison Creek watershed has overburden in excess of 70 metres thick.

The dominant soil type of well-drained areas is the Plainfield sand, consisting of coarse material with free drainage. This results in a featureless profile and a thin surface horizon with no organic matter. Elsewhere, a finer sand is present. This is the grey-brown sand of the Fox series.

Figure 6 shows the location of the test holes. Test drilling indicates a well-sorted medium grained sand within the area of study. Test hole V1, located in the valley,shows 9.1 metres of well-sorted medium grained sand. Between 9.1 - 9.7 metres, material ranging from fine-grained to coarse grained sand was encountered. Two test holes were drilled along the edge of the valley. Test hole V2, located above test hole V1, shows a well-sorted medium grained sand to the termination of the drill hole at 18.9 metres. Test hole V3, approximately 200 metres to the north of V2 shows a well sorted medium to fine grained sand to the termination of the drill hole at 18.9 metres. Complete borehole logs are shown in Appendix A.

3.3.2 Observation Well Network

Fifteen observation wells were installed at the three sites shown in Figure 6 during late November 1976. All wells have a 0.3 m intake zone. The wells were installed at approximately 1.5 m intervals beginning immediately below the water table. The observation well depths range from 2.7 m to 9.1 m in the valley and 11.9 m to 18.3 m along the edge of the valley. A more detailed description can be found in the borehole logs shown in Appendix A.

3.3.3 Land Use

The general land use pattern in the area of study is mainly cropland with tobacco being the most common crop. There is some productive woodland situated between test hole V2 and test hole V3. The fields in which test holes V2 and V3 are located are generally planted in tobacco. Winter wheat is also planted within the study area.

3.3.4 Results and Discussion

Hydraulic Head - The hydraulic head values for Mar 16, April 13 and May 17 are shown in Table 7. The vertical hydraulic gradients are very small and are generally within the limits of uncertainty of the measurements. All hydraulic head values measured in the groundwater are greater than the stream elevation and the lateral gradients appear to be towards the stream. Thus the water samples collected from the piezometers should be representative of groundwater having originated as infiltration through the soil zone.

Nitrate and Ammonium - The results of nitrate and ammonia analyses of water samples collected on three dates, Mar 16, April 13 and May 17, are given in Table 8. The highest ammonium concentration observed was 1.98 mg/L. NH_4^+-N at V3-P50, on April 13. The ammonium concentration at this piezometer was consistantly high however there is no apparent explanation.

Nitrate concentrations ranged from 0.0 to 6.5 mg/L NO_3^--N. At all three sites, significant nitrate occurred at the maximum depth of measurement, 18 m below ground surface at V2 and V3 and 9 m below ground surface at V1. The concentrations tended to be highest at shallow depths below the water table and decreased at greater depths. There was considerable variability in the nitrate data, with an apparent trend towards lower concentrations as time progressed. This trend is most evident at V2 and V3 which are furthest from the stream and have the deepest water table (12 m below ground surface). At V1, at a depth of 9 m below ground surface (6 m below the water table), the concentration changed from 1.0 to 5.5 mg/L between April 13 and May 17. During the same period, the concentration changed from 2.7 to 0.1 mg/L at V3.

Major Cations - The results of the major cation analysis are given in Table 9. There is relatively little variation in the concentrations either in the vertical or horizontal direction. There is no evidence of increased potassium concentrations associated with high nitrate values. This may be the result of the relative immobility of potassium coupled with the deep water table.

3.4 AG #10 North Creek, Lincoln County

3.4.1 Geology

North Creek, part of the Twenty Mile Creek Drainage System, is located in Lincoln County, just west of Smithville, Ontario. Figure 7 shows the location of the watershed and study area.

The watershed is located in the physiographic region known as the Haldimand Clay Plain, situated between the Niagara escarpment and Lake Erie. (Chapman and Putnam, 1973). The entire area was submerged in glacial Lake Warren, resulting in an intermixture of stratified clay and till. The underlying rocks consist of a succession of Palaeozoic beds dipping slightly southward under Lake Erie. Glacial deposits are generally less than 15 m thick throughout the area.

Results of test drilling show 2.0 - 4.5 m of pebbly clay till overlying a grey dolomite bedrock. Boreholes N1 and N3 have 4.0- 4.5 m of brown and blue-gray clay till, with some medium sand layers or lenses found within the till. Borehole N2, the most easterly borehole has 2 m of silty clay till with some gravel seams within the till. Borehole N3 has approximately 4.0 m of stratified clay deposits above bedrock. Complete borehole logs are shown in Appendix A.

3.4.2 Observation Well Network

Seven observation wells were installed at three sites within the study area. Water table wells were installed with 0.6 m intakes zones. Other wells were installed with 0.3 m intake zones. One well was installed in bedrock at each site. A more detailed description of the location of observation wells can be found in the borehole logs in Appendix A.

3.4.3 Land Use

The main land use within the area of study is pastureland for livestock with only a minor amount of corn and small grains being produced. All sites are located in pastureland with some corn being grown near sites N1 and N3. No sites are near barnyards or other point sources of nitrogen.

3.4.4 Results and Discussion

Hydraulic Head - The results of the hydraulic head measurements are given in Table 10. From the distribution of wells, no estimate could be made of the lateral hydraulic gradients. The vertical gradients were generally upward, and all head values in the groundwater were greater than the elevation of the stream adjacent to the study sites. As a result, it appears reasonably certain that the groundwater was discharging to the stream.

Nitrate and Ammonium - The wells were sampled on April 4 and May 11, and the results of the nitrate and annonium analyses are given in Table 11. All samples collected in May showed undetectable concentrations of both nitrate and ammonium. The maximum nitrate concentration observed in April was 0.1 mg/L and the maximum ammonium concentration was 0.4 mg/L. The data is notable in that the nitrate concentrations are extremely low. This may very well be related to the low level of agricultural activity as well as the fine-textured nature of the soils.

Major Cations - The results of the cation analyses are shown in Table 12. With the exception of N1, the concentrations are reasonably consistent. At N1, the concentrations at P14 and P19 are considerably higher than P5. The variation may be related to the different geochemical regimes of the bedrock and surficial materials.

3.5 AG #4 Upper Canagagigue Creek

3.5.1 Geology

Both east and west branches of upper Canagagigue Creek are located five to eight kilometres north of Elmira, Ontario. Figure 9 shows the location of the watershed. The geology of the area is quite complex and appears to have originated during events preceding the last ice advance in the area (Karrow, 1971). Because of its location the area has been subjected to glaciation by four different ice lobes at various times.

The area of study can be divided into two major sections. The first is a major spillway along much of the east branch of Canagagigue Creek consisting of recent and modern stream alluvium as well as kame and/or outwash sands and gravels. The second section along the west branch of Canagagigue Creek is a major till plain consisting of sandy and silty tills deposited during one or more ice advances.

Results of the test drilling correlate well with previous work done by Karrow, 1971. Four boreholes located in study area #1 have highly variable microstratigraphy. This stratigraphy ranges from 3-10 cm thick gravel layers to 2-6 cm thick silty clay deposited in an intermixture of sand, silt and clay strata. Clayey till was encountered before termination of three boreholes at depths ranging from 6-8 m. Six boreholes in study areas #2 and #3 have both silty and sandy tills with few gravel and sand seams found in the till. Drilling was terminated between 6 m and 8 m at all sites. Complete borehole descriptions are shown in Appendix A.

3.5.2 Observation Well Network

Twenty-nine observation wells were installed at ten sites located within the study areas. The locations of the sites are shown in Figure 10. Observation wells installed have either 0.3 m or 0.6 m intake zones depending on the material in which they are located. Wells placed in fine sands and tills have 0.6 m intake zones while wells placed in coarser material have 0.3 m intake zones. Two to four observation wells were placed at each site at depths ranging from 1 m to 9 m. A more detailed description can be found in the borehole logs shown in Appendix A.

3.5.3 Land Use

Land use activity in this watershed is mainly involved with livestock or feed for livestock such as corn and small grains. Study area #1 is almost entirely pastureland with no barnyards within the vicinity. Study area #2 produces mainly corn with manure being used as the principal fertilizer. Study area #3 is mainly corn and small grains with corn being the main crop during the study period. It should be noted that site C7 is located between the creek and a barnyard. Also, a thin strip of pastureland is found along Canagagigue Creek.

3.5.4 Results and Discussion

Hydraulic Head - Hydraulic head measurements were made on March 10, April 12 and May 10. The results are given in Table 13. The measurements generally indicate groundwater discharge, and in situations where a stream elevation measurement was available, the direction of flow was towards the stream.

Nitrate and Ammonium - The results of the nitrate and ammonium analyses for samples collected on three dates (March 10, April 12 and May 10) are given in Table 14. Sites Cl through C6 are located in the east branch of Canagagigue Creek and generally show appreciable nitrate concentrations. C5 is an exception in that the highest nitrate concentration observed at this site was 0.1 mg/L. The shallow groundwater at C6, which is in the vicinity of C5, had a nitrate concentration of 7.7 mg/L in March, decreasing to 3.0 mg/L in May. The deeper groundwater at this site had very low nitrate concentrations.

C1 through C4 are located in the same area, and all show significant nitrate concentrations. The maximum concentration observed was 10.4 mg/L which occurred at C3-P5 on April 12. The concentrations appear to increase slightly from March to May and significant nitrate concentrations are found throughout the measurement zone. All wells (C1 through C4) show similar trends in space and time. In March the concentrations tended to increase with depth while in April the highest concentrations tended to be near the watertable with the concentration decreasing with depth. In May the lowest concentrations were found at the shallow depths with the concentrations generally increasing with depth.

C7 through C10 are located in the west branch of the watershed (Figure 10) and with the exception of C9 and C10-P14, all wells show very low nitrate concentrations (generally less than 1 mg/L-N). C9-P12 contained the highest concentration observed in the Canagagigue watershed (19.8 mg/L NO_3 -N). From the short period of record available and the small amount of data available concerning the local hydrogeologic conditions, there is no apparent reason for the high concentration. Within the west branch, the high nitrate concentrations were generally restricted to the shallow groundwater.

Considering both the east and west branches of the stream, the ammonium concentrations were quite low, generally less than 0.5 mg/L NH_4^+ -N. Two values were observed to exceed 1.0 mg/L. These values did not persist at a particular sampling point and although they did occur at sites which also had a significant nitrate concentration, they did not appear to show any trends in space or in time.

A comparison of the east and west branches of the Canagagigue Creek is particularly interesting since they are located adjacent to each other and show similar land use, but are hydrogeologically very different. The east branch consists of relatively coarse textured geologic materials which would tend to give rise to high infiltration rates and rapid groundwater circulation. On the other hand, the near-surface geology of the west branch generally shows fine textured till materials. These materials would give rise to low infiltration rates and very sluggish groundwater circulation. It is interesting and perhaps significant that the rapidly circulating system contains nitrate throughout the zones which were sampled while the sluggish system generally showed very low nitrate concentrations throughout the regions sampled.

Major Cations - The results of the major cation analyses are given in Table 15. The concentrations are quite variable but are generally typical of a calcite-dolomite dissolution system. No distinction can be made between the groundwaters of the east and west branch on the basis of the major cations. The most irregular value was a sodium concentration of 280 mg/L at C4-P8. All other sodium concentrations were less than 100 mg/L and most were less than 30 mg/L. Although C4-P8 had a concentration of 280 mg/L, C4-P11, which was located adjacent to but approximately one meter deeper than C4-P8 had a concentration of only 5 mg/L. C4 was located near the highway and thus road salt may be the source of sodium. (Chloride analyses were not performed).

3.6 AG#5 Holiday Creek Watershed

3.6.1 Geology

The location of the Holiday Creek Watershed is shown in Figure 11. The bedrock of the region is the Detroit River Formation of the Devonian Period and is overlain by relatively thick Quaternary sediments deposited during the Wisconsinan stage of the Pleistocene Epoch. The regional thickness of the glacial drift varies from approximately 15 to 75 m.

The general study area is located in an interlobate zone between glaciers moving from both the Huron basin and Erie-Ontario basin. As a result of its position, the area was probably influenced by the advance and retreat of several ice lobes of differing origin resulting in an overall mixing of sediments and thus a complex lithology.

According to Cowan (1975), the oldest known till sheet is the Canning Till overlying the bedrock. This is overlain by the Catfish Till which is in turn overlain by the Port Stanley Till and the Tavistock Till. The tills are generally fine-textured but may contain stringers or lenses of sand.

Many glacio-lacustrine and glacio-fluvial sediments were deposited in the Holiday Creek basin. The only sediments of this type encountered during the installation of the observation wells were glacio-fluvial outwash sands. Generally, the sediments were fine-textured tills (silty sand to silty clay) with minor sand and gravel layers.

3.6.2 Observation Well Networks

Twenty observation wells were installed at the three sites shown in Figure 11. The observation wells range in depth from 1 to 28.3 m below ground surface with the majority located in the upper 6 m. Water table wells and wells located deep in the till have 1.5 m intake zones while observation wells located in the upper 6 m have 0.6 m intake zones.

3.6.3 Land Use

The primary crop grown in the Holiday Creek Watershed is corn. There are also significant acreages of forage crops, cereal grains and pasture. Within the area of detailed study, the principal crops are forages and cereal grains.

3.6.4 Results and Discussion

The results of the nitrate and ammonium analyses are shown in Table 16. Site E3 showed concentrations of 5.5 and 7.0 mg/L of NO_3^- -N in the shallowest piezometers. All other sampling points showed zero or near-zero concentrations of both ammonium and nitrate. The wells containing nitrate were in the shallow groundwater, and were located in coarse textured zones. The other wells, all of which contained no nitrate, were located in fine textured till materials. The data at this site appears to be consistent with that of the other watersheds.

4. RELATED STUDIES

Hillman Creek - Very detailed investigations of the nitrate distribution in the "Detailed Study Area" of the Hillman Creek Watershed (Figure 2) were conducted. A discussion of the results of those investigations is presented in Part I of this report. For the purpose of comparing with the results of the other watersheds, the results obtained in the Detailed Study Area will be summarized here.

The study area was approximately 3.9 km^2 in area and consisted of sand, varying in thickness from 1.0 to 8 m, overlying an impermeable silty clay till unit. The area was under intensive agricultural production with tobacco, potatoes and orchards being the primary crops. Tomatoes, peppers, other horticultural crops and a small amount of cereal grains are also grown.

The nitrate concentration in cultivated areas tended to be high at shallow depths below the water table then decreased to near zero at greater depths within the sand aquifer. The concentration of nitrate in groundwater below uncultivated areas was near zero. Although significant concentrations were generally encountered in the groundwater beneath cultivated areas, there did not appear to be a direct relationship between the nitrate concentration and the rate of fertilizer application. Within the study area the nitrate concentration varied from 0.0 to 45 mg/L NO_3^- -N and within the vicinity of the stream the concentration was about 5 mg/L.

Blue Springs Watershed - Detailed studies of the occurrence and migration of nitrate in the groundwater of a portion of the Blue Springs Watershed have been conducted by the University of Waterloo. A complete description of the study is given by Stiebel (1977).

The study area is located about 15 km east of Guelph near Rockwood. The stratigraphy of the area is very complex with inter-bedded coarse and fine textured units. The surface materials are generally sandy to silty in texture and appear to have high infiltration capacities. The principal crops grown in the area are corn, cereal grains and forage crops. Significant nitrate concentrations, generally ranging between 2.0 and 10.0 mg/L-N were observed in the coarse textured geologic materials. The concentrations were significantly greater beneath cultivated areas than beneath uncultivated areas.

Denitrification Studies - The observation wells discussed in this report are continuing to be monitored under Department of Supply and Services and Department of the Environment and Fisheries contract No. ISU77-00153. The objective of this monitoring programme is to obtain additional information concerning the possible occurrence of denitrification in groundwater. The nitrate data obtained in this study is similar to that included in the tables of this report. As part of the study, dissolved oxygen measurements are also being made. With very few exceptions, there were no nitrate concentrations in excess of 1.0 mg/L in water with a DO concentration less than 1.5 mg/L. Also, with few exceptions, there was little or no nitrate in water containing methane.

The data suggests that there is little or no nitrate present under reducing conditions, suggesting that denitrification may be a significant process in groundwaters.

6. SUMMARY AND CONCLUSIONS

The objective of this phase of the study was to obtain some qualitative information regarding the distribution of nitrate in the groundwater of agricultural watersheds and to provide a data base from which it might be reasonable to extrapolate to other watersheds. Although we believe significant progress has been made in this direction, some words of caution are appropriate at this time.

The detailed study in the Hillman Creek Watershed indicated that wide variations in nitrate concentration could occur in a region which is geologically uniform and reasonably uniform with respect to land use. The nitrate concentration was equally variable in the Blue Springs Watershed as reported by Stiebel (1977). In the watersheds instrumented specifically for this study, there were generally only a few piezometers installed at three to four sites in each watershed.

As a result, there is some uncertainty regarding the extent to which the measurements made in a watershed represent the conditions of that water-shed. In addition, the possibility of denitrification in the groundwater makes interpretation of the data difficult. In the absence of denitrification, the concentration of nitrate in the groundwater can be considered as an indication of the environmental impact of the nitrate source an the groundwater quality, and ultimately on the surface water which receives the groundwater.

If denitrification is found to be a factor, then the nitrate observed at a given time may be reduced to gaseous forms of nitrogen before it is discharged to surface waters and thus it would not become an environmental factor. The discharge of nitrate from such systems would then become a function of the factors controlling the rate of denitrification in the groundwater.

The quantification of these factors is an extremely difficult problem requiring considerably more research. As a consequence of the reservations discussed above, we believe that any conclusions based on the data of this report must be of a qualitative nature. Although areas of very intensive agricultural production with high rates of fertilizer application were investigated, few measurements exceeded the drinking water standard of 10 mg/L NO_3 -N. Occasional values well in excess of drinking water standard were observed, particularly in the Hillman Creek Watershed; however, no extensive zones of groundwater pollution were observed.

AG #1 (Big Creek) , AG #10 (North Creek) , AG #4 (Upper Canagagigue - West branch) and AG #5 (Holiday Creek) are similar in that the geologic materials are predominantly fine-textured. With only occasional exceptions, the concentration of nitrate in the groundwater of these regions was near zero. The exceptions generally occurred in the shallowest sampling points or in lenses of coarser textured materials. The shallow samples containing nitrate could be the result of relatively rapid groundwater circulation through fractures in the upper part of the till or clay units.

The reason for the low nitrate concentration in fine-grained materials is not clear. It can be shown however, that the rate of groundwater movement through such materials is on the order of fractions of a centimetre to a few centimetres per year. As a result, if agricultural practices are the source of the nitrate, there may not have been sufficient time for the nitrate to have moved a significant distance through low permeability materials. The low nitrate concentrations may also be the result of geochemical processes. In addition to the low nitrate concentrations, the rate of groundwater movement through the fine-textured materials would be such that insignificant amounts of nitrate would be discharged to surface waters through these materials.

The areas which contained coarse to medium grained geologic materials had significant groundwater nitrate concentrations. These areas include AG #13 (Hillman Creek) AG #2 (Venison Creek), AG #4 (Canagagigue - east branch) and the Blue Springs watershed discussed by Stiebel (1977). Although there is undoubtedly some relationship between land use and nitrate concentration, it appears to be considerably more complicated than a direct relationship between concentration and rate of fertilizer application. For example, considering the high degree of variability in the data, it cannot be said that the nitrate concentration in the groundwater of the east branch of the Canagagigue is significantly different from the concentration in the groundwater of Hillman Creek.

Hillman Creek and Venison Creek present an interesting comparison in that they are both under intensive cultivation and both have sandy soils and sandy near-surface geologic materials. In the Hillman Creek watershed the nitrate is located within one to two metres of the water table while in Venison Creek the nitrate is carried several metres below the water table. One difference between the two areas is the depth of the water table below ground surface. At Hillman Creek the water table is generally within 2 m of ground surface while at Venison Creek it is generally at a depth greater than 10 m below ground surface. In Venison Creek, as a result of the greater unsaturated zone thickness, soluble organic matter may be oxidized aerobically prior to reaching the water table. As a result, there may not be a sufficient energy source for denitrification to proceed in this area. On the other hand, with the shallow water table of the Hillman Creek Watershed, significant soluble organic matter may be transported to depths below the water table. Continued oxidation of the organic matter could remove dissolved oxygen and reduce the Eh of the water until anaerobic oxidation processes predominate. Under these conditions denitrification could proceed. We hope to evaluate this hypothesis under the DSS project discussed briefly in Chapter 5 of this report.

From the available data it can be concluded that groundwater passing through fine-textured geologic materials will not contribute appreciable amounts of nitrate to surface waters. The major groundwater contributions of nitrate to surface water will be through coarse textured geologic materials. The apparent lack of correlation between the land use and nitrate concentration in the groundwater, and the evidence in favour of denitrification as a significant process in groundwater makes it extremely difficult to predict rates of nitrate discharge from groundwater regimes which have not been instrumented.

It should be noted that this report considers only the discharge of nitrate in groundwater and does not consider surface runoff or tile drainage. As a result, it does not address the problem of the total nitrogen discharge to surface waters under different land use and geologic conditions. Some preliminary studies into this problem are reported in Part III of this report.

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TABLE 1 Hydraulic head values: Hillman Creek (AG #13) outside the detailed study area*

SITE No.	WELL No.	DEPTH WELL POINT (metres)	Hydraulic Head (m) 28/03/77	15/04/77	18/05/77
H68	P7	1.5-2.1	50.27	49.69	49.49
H68	P12	3.0-3.6	50.17	49.59	49.47
H68	P17	4.5-5.1	50.19	49.64	49.47
H68	P25	6.9-7.5	49.91	49.57	49.46
H68	P35	9.9-10.3	49.02	47.56	48.28
H68	P45	12.9-13.5	48.90	46.75	48.64
H69	P7	1.5-2.1	48.69	47.75	47.65
H69	P12	3.0-3.6	48.63	47.75	47.64
H69	P17	4.5-5.1	48.57	47.79	47.68
H69	P24	6.7-7.3	48.63	47.79	47.67
H69	P34	9.7-10.3	47.25	45.17	46.16
H69	P45	12.9-13.5	47.22	44.93	46.04
CREEK NEAR H69					47.21
H70	P12	3.0-3.6	48.86	48.19	48.05
H70	P17	4.5-5.1	48.84	48.18	48.02
H70	P22	6.0-6.6	48.76	47.99	47.81
H70	P32	9.0-9.6	48.79	47.13	46.73
H70	P42	12.0-12.6	48.69	47.59	47.29
H70	P52	15.0-15.6	48.66	47.73	47.43
H71	P12	3.0-3.6	46.57	46.19	46.04
H71	P18	4.8-5.4	46.47	46.01	45.90
H71	P24	6.6-7.2	46.47	45.26	45.53
H71	P34	9.6-10.2	46.61	46.14	45.85
CREEK NEAR H71					45.29
H72	P6	1.2-1.6	48.78	48.04	47.89
H72	P11	2.7-3.3	48.70	47.91	47.75
H72	P16	4.2-4.8	48.48	47.86	47.72
H72	P23	6.3-6.9	47.94	47.51	47.49
H72	P33	9.3-9.9	46.30	45.73	46.02
H73	P8	2.1-2.4	48.98	48.03	47.86
H73	P14	3.9-4.2	48.80	48.15	47.92
H73	P24	6.9-7.2	48.55	47.42	48.01
H73	P34	9.9-10.2	48.16	plugged	47.79
CREEK NEAR H73					47.73
H74	P7	1.8-2.3	51.29	51.05	50.97
H74	P15	4.0-4.5	51.18	51.02	50.95
H74	P25	7.0-7.5	50.94	50.60	50.70
H74	P35	10.0-10.5	51.14	50.54	50.61

* The table is subdivided according to elevations taken from different arbitrary datum points

TABLE 2 NO_3 and NH_4^+ data (mg/L - N) Hillman Creek (AG #13) outside the detailed study area

SITE NO	WELL NO	DEPTH OF WELL POINT	25/09/76		30/03/77		15/04/77		15/05/71	
			NO_3	NH_4	NO_3	NH_4	NO_3	NH_4	NO_3	NH_4
H68	P 7	1.5-2.1	9.5	0.00	0.0	0.04	31.53	0.13	34.0	0.05
H68	P12	3.0 -3.6	0.0	0.00	0.3	0.04	0.0	0.00	0.0	0.0
H68	P17	4.5- 5.1	0.0	0.00	0.1	0.02	0.1	0.00	0.0	0.00
H68	P25	89 - 7.5	0.0	0.00	0.1	0.02	0.0	0.00	0.0	0.00
H68	P35	9.9 -10.5	0.0	0.00	0.1	0.02	0.0	0.00	0.0	0.00
H68	P45	12.9 -13.5	0.0	0.00	0.6	0.05	0.0	0.00	0.0	0.00
H69	P 7	1.1 -2.1	10.25	0.00	9.1	0.00	10.3	0.00	9.6	0.0
H69	P12	3.0 -3.6	0.0	0.00	0.7	0.16	0.22	0.13	0.1	0.07
H69	P17	4.5 - 5.1	0.0	0.00	0.2	0.09	0.36	0.09	0.0	0.00
H69	P24	6.7-7.3	0.0	0.00	0.1	0.05	0.0	0.00	0.0	0.00
H69	P34	9.7 -10.3	0.0	0.00	0.0	0.00	0.2	0.09	0.0	0.00
H69	P45	12.0 - 13.5	0.0	0.00	0.1	0.00	0.0	0.00	0.0	0.0
H70	P12	3.0 -3.6	0.0	0.00	0.3	0.02	0.4	0.09	0.0	0.00
H70	P17	4.5 - 5.1	0.0	0.00	0.0	0.31	0.2	0.00	0.0	0.00
H70	P22	6.0 -6.6			0.0	0.55	0.2	0.0	0.0	0.00
H70	P32	9.0-9.6			0.2	0.14	0.3	0.28	0.0	0.00
H70	P42	12.0 - 12.6			0.0	0.04	0.1	0.00	0.3	0.00
H70	P52	15.0 - 15.6			0.0	0.02	0.0	0.00	0.0	0.00
H71	P12	3.0 -3.6			0.2	0.24	0.1	0.03	0.0	0.00
H71	P18	4.8 - 5.4			0.1	0.00	0.1	0.09	0.1	0.07
H71	P24	6.6 -7.2	0.2	0.90	0.2		0.5	0.00	0.1	0.22
H71	P34	9.6 -10.2	0.0	0.20	0.2		0.3	0.17	0.3	0.34
H72	P 6	1.2 -1.6			14.7		6.0	0.00	4.0	0.03
H72	P11	2.7 -3.3	0.0	0.00	0.1	0.00	0.1	0.00	0.0	0.0
H72	P16	4.2 -4.8	0.0	0.40	0.1		0.3	0.04	0.1	0.07
H72	P23	6.3 -6.9	0.2	0.20	0.1	0.00	0.1	0.08	0.0	0.00
H72	P33	9.3 -9.9	0.8	0.00	0.1	0.12	0.1	0.00	0.0	0.00

TABLE 2 (continued)

SITE No.	WELL No.	DEPTH OF WELL POINT	25/09/76		30/03/77		15/04/77		15/05/71	
			NO_3	NH_4	NO_3	NH_4	NO_3	NH_4	NO_3	NH_4
H73	P 8	2.1 -2.4	0.0	0.00	1.2	0.00	0.0	0.00	0.0	0.0
H73	P14	3.9-4.2	0.0	0.00	0.1	0.00	0.0	0.00	0.0	0.0
H73	P24	6.9-7.2			0.1	0.14				
H74	P 7	1.8 -2.3			3.24	0.00	2.67	0.13	0.7	0.0
H74	P15	4.0-4.5	0.0	0.00	0.0	0.00	0.1	0.12	0.1	0.0
H74	P25	7.0-7.5	0.0	0.00	0.0	0.00	0.0	0.09	0.2	0.0
H74	P35	10.0 - 10.5	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.0
CREEK NEAR H69					15.8		7.3		4.5	
CREEK NEAR H71					17.0		5.3		1.5	
CREEK NEAR H73					17.2		7.4		3.2	

TABLE 3. Major cation analyses for Hillman Creek (AG #13) outside the Detailed study area

SITE No.	WELL No.	DEPTH OF WELL POINT	K^+ mg/L	Mg^{2+} mg/L	Ca^{2+} mg/L	Na^+ mg/L
H68	P7	1.5-2.1	67.00	23.6	94.0	4.5
H68	P12	3.0-3.6	2.15	47.9	142.0	11.5
H68	P17	4.5-5.1	1.51	26.2	89.0	13.5
H68	P25	6.9-7.5	1.66	14.3	52.0	30.0
H68	P35	9.9-10.5	3.00	10.4	55.0	43.5
H68	P45	12.9-13.5	1.90	14.3	48.0	40.5
H69	P7	1.5-2.1	0.87	37.8	161	11.0
H69	P12	3.0-3.6	1.38	41.1	128	20.0
H69	P17	4.5-5.1	1.74	22.4	72	25.5
H69	P24	6.7-7.3	1.97	22.8	66	36.0
H69	P34	9.7-10.3	1.90	10.4	33	53.5
H69	P45	12.9-13.5	2.10	7.3	25	55.0
H70	P12	3.0-3.6	5.30	71.0	222	21.0
H70	P17	4.5-5.1	5.20	120.0	372	40.5
H70	P22	6.0-6.6	7.20	126.0	347	60.0
H70	P32	9.0-9.6	4.90	5.5	16	80.0
H70	P42	12.0-12.6	3.80	31.2	102	78.0
H70	P52	15.0-15.6	2.80	24.6	69	89.0
H71	P12	3.0-3.6	5.10	106.0	339	55.5
H71	P18	4.8-5.4	5.10	138.0	477	39.5
H71	P24	6.6-7.2				
H71	P34	9.6-10.2	4.30	61.0	160	65.0
H72	P6	1.2-1.6	1.57	21.8	126	6.5
H72	P11	2.7-3.3	0.87	23.7	87	6.0
H72	P16	4.2-4.8	1.42	17.1	81	13.0
H72	P23	6.3-6.9	1.66	13.4	53	26.0
H72	P33	9.3-9.9	2.20	14.3	58	38.0

TABLE 3 continued

SITE No.	WELL No.	DEPTH OF WELL POINT	K^+ mg/L	Mg^{2+} mg/L	Ca^{2+} mg/L	Na^+ mg/L
H73	P8	2.1-2.4	2.07	31.9	113	10.0
H73	P14	3.9-4.2				
H73	P24	6.9-7.2	2.20	13.6	47	51.0
H74	P7	1.8-2.3	2.80	46.9	220	11.0
H74	P15	4.0-4.5	2.40	19.2	66	30.0
H74	P25	7.0-7.5	1.48	9.7	61	47.5
H74	P35	10.0-10.5	1.46	5.8	33	56.0
STREAM NEAR H69			7.40	17.1	100	18.5
STREAM NEAR H71			8.00	17.5	92	26.5

TABLE 4 Hydraulic head values - Big Creek (AG #1) *

SITE NO	WELL NO	DEPTH OF WELL POINT (metres)	Hydraulic Head		
			28/03/77	15/04/77	18/05/77
H75	P12	3.3 -3.6	48.94	48.22	48.16
	P17	4.8 - 5.1	48.96	48.23	48.14
	P25	7.2 - 7.5	48.96	48.19	48.09
	P35	10.2 - 10.5	48.93	48.14	48.05
H76	P 8	2.1 - 2.4	48.76	48.36	48.18
	P15	4.2 - 4.5	48.77	48.30	48.17
	P24	6.9 -7.2	48.77	48.24	48.12
	P34	9.9 - 10.2	48.43	47.39	47.39
CREEK NEAR H76					47.43

* The table is subdivided into elevations taken from different arbitrary datum points.

TABLE 5. NO_3 and NH_4^+ data (mg/L - N) Big Creek (AG #1)

SITE NO.	WELL NO.	DEPTH OF WELL POINT (metres)	30/03/77		15/04/77		15/05/77	
			N - NO_3	NH_4	N - NO_3	NH_4	N - NO_3	NH_4
H75	P12	3.3 -3.6	0.1	0.14	0.8	0.00	0.0	0.00
	P17	4.8 -5.1	0.0	0.28	0.1	0.04	0.0	0.00
	P25	7.2-7.5	0.0	0.48	0.2	0.28	0.0	0.00
	P35	10.2 - 10.5	0.0	0.35	0.4	0.31	0.0	0.00
H76	P 8	2.1 -2.4	3.6	0.05	3.0	0.17	1.6	0.0
	P15	4.2 - 4.5	0.6	0.17	0.6	0.33	0.0	0.0
	P24	6.9-7.2	0.2	0.42	0.0	0.55	0.0	0.0
	P34	9.9 -10.2	0.1	0.21	0.0		0.0	0.11
CREEK NEAR H76			11.6		8.1		2.03	

TABLE 6. Major cation analysis - Big Creek (AG #1)

SITE NO	WELL NO	DEPTH OF WELL POINT (metres)	K^+ mg/L	Mg^{2+} mg/L	Ca^{2+} mg/L	Na^+ mg/L
H75	P12	3.3 - 3.6	7.10	135.0	320	48.5
H75	P17	4.8 - 5.1	9.40	118.0	228	56.0
H75	P25	7.2-7.5	6.20	100.0	193	71.0
H75	P35	10.2 - 10.5	4.10	50.0	130	92.0
H76	P 8	2.1 - 2.4	32.00	77.0	269	41.0
H76	P15	4.2 - 4.5	8.70	187.0	440	58.0
H76	P24	6.9-7.2	7.90	122.0	226	75.0
H76	P34	9.9 -7.2	3.20	229.4	96	82.0
STREAM NEAR H76			4.10	37.0	104	17.0

TABLE 7 Hydraulic head values: Venison Creek (AG #2)

Elevation taken from an arbitrary datum point

SITE NO	WELL NO	DEPTH OF WELL POINT (metres)	Hydraulic Head		
			16/03/77	13/04/77	17/05/77
V1	P10	2.7 - 3.0	45.61	46.42	46.35
V1	P15	4.2 - 4.5	45.62	46.42	46.35
V1	P20	5.7 -6.0	45.60	46.51	46.35
V1	P24	6.9 -7.2	45.60	46.51	46.35
V1	P30	8.7 - 9.0	45.60	46.44	46.38
Creek near V1					45.84
V2	P40	11.7 - 12.0	46.68	46.65	46.58
V2	P45	13.2 - 13.3	46.68	46.66	46.58
V2	P50	14.7 - 15.0	46.69	46.66	46.59
V2	P55	16.2 - 16.5	46.69	46.67	46.60
V2	P60	17.7 - 18.0	46.69	46.65	46.59
V3	P41	12.0 - 12.3	47.04	46.89	46.82
V3	P46	13.5 - 13.8	47.04	46.92	46.85
V3	P50	14.7 - 15.0	47.08	46.92	46.85
V3	P55	16.2 - 16.5	47.05	46.91	46.84
V3	P60	17.7 - 18.0	47.06	46.92	46.86

TABLE 8 NO_3^- AND NH_4^+ data (mg/L - N) Venison Creek (AG #2)

SITE NO	WELL NO	DEPTH OF WELL POINT (metres)	16/03/77		13/04/77		17/05/77	
			N - NO_3	NH_4	N - NO_3	NH_4	N - NO_3	NH_4
V1	P10	2.7 -3.0	6.4	0.03	4.3	0.12	2.8	0.00
V1	P15	4.2 - 4.5	3.8	0.01	4.4	0.00	3.7	0.00
V1	P20	5.7- 6.0	2.8	0.00	3.5	0.01	3.1	0.00
V1	P24	6.9-7.2	2.9	0.00	---	----	1.4	0.00
V1	P30	8.7 -9.0	0.1	0.00	1.0	0.0	5.5	0.00
V2	P40	11.7 - 12.0	3.0	0.09	5.6	0.40	0.2	0.61
V2	P45	13.2 - 13.5	---	----	0.2	0.62	0.2	0.42
V2	P50	14.7 - 15.0	2.8	0.13	0.0	0.00	0.0	0.00
V2	P55	16.2 - 16.5	---	----	0.0	0.06	0.0	0.00
V2	P60	17.7 - 18.0	0.1	0.03	0.0	0.00	0.0	0.00
V3	P41	12.0 - 12.3	6.3	0.09	6.5	0.00	0.0	0.00
V3	P46	13.5 - 13.8	---	----	3.23	0.60	2.8	0.41
V3	P50	14.7 - 15.0	5.3	0.83	4.9	1.98	0.3	0.41
V3	P55	16.2 - 16.5	---	----	0.9	0.10	0.1	0.43
V3	P60	17.7 - 18.0	2.5	0.01	2.7	0.05	0.1	0.02

TABLE 9 Major cation analyses - Venison Creek (AG #2)

SITE NO	WELL NO	DEPTH OF WELL POINT	K^+ ppm	Mg^{2+} ppm	Ca^{2+} ppm	Na^+ ppm
V1	P10	2.7 -3.0	0.88	13.1	69	3.0
V1	P15	4.2 -4.5	0.75	16.1	60	3.5
V1	P20	5.7 -6.0	0.71	15.9	77	3.5
V1	P24	6.9-7.2	0.80	15.6	64	4.5
V1	P30	8.7 - 9.0	1.16	17.7	62	3.5
V2	P40	11.7 - 12.0	1.33	13.4	84	3.5
V2	P45	13.2 - 13.5	1.56	16.4	82	4.5
V2	P50	14.7 - 15.0	1.69	17.8	73	4.0
V2	P55	16.2 - 16.5	2.00	15.6	75	4.3
V2	P60	17.7 - 18.0	2.40	17.6	77	4.5
V3	P41	12.0 - 12.3	1.21	16.1	94	4.5
V3	P46	13.5 - 13.8	1.42	18.8	89	6.0
V3	P50	14.7 - 15.0	2.70	18.4	99	8.2
V3	P55	16.2 - 16.5	1.87	14.5	68	12.5
V3	P60	17.7 - 18.0	3.00	13.1	56	38.0

TABLE 10 Hydraulic head values: AG #10, North Creek

All elevations were taken from an arbitrary datum point for each nest of piezometers.

SITE No.	WELL No.	Hydraulic Head 13/04/77	Hydraulic Head 11/05/77
N1	P5	49.18	48.87
N1	P14	49.25	49.26
N1	P19	49.36	49.37
STREAM NEAR N1			47.99
N2	P6	48.07[5]	47.70
N2	P9	48.08[5]	47.71
STREAM NEAR N2			47.30
N3	P16	48.72[5]	48.84
N3	P20	48.92	49.21
STREAM NEAR N3			48.47

TABLE 11 NO_3^- and NH_4^+ data (mg/L - N) NORTH CREEK (AG #10)

SITE NO.	WELL NO.	DEPTH OF WELL POINT (metres)	13/04/77		11/05/77	
			N - NO_3	NH_4	N - NO_3	NH_4
N1	P 5	0.9 - 1.5	0.1	0.40	0.0	0.0
N1	P14	3.7 - 4.0	0.1	0.12	0.0	0.0
N1	P19	5.4 -5.7	0.1	0.40	0.0	0.0
N2	P 6	1.3 -1.9	0.1	0.3	0.0	0.0
N2	P 9	2.4-2.7	0.0	0.0	0.0	0.0
N3	P16	4.0 - 4.6	0.0	0.04	0.0	0.00
N3	P20	5.2 - 6.0	0.0	0.15	0.0	0.00
CREEK NEAR N1					0.0	
CREEK NEAR N2					0.0	
CREEK NEAR N3					0.0	

TABLE 12 Major cation analyses - North Creek (AG #10)

SITE NO.	WELL NO.	DEPTH OF WELL POINT (metres)	K^+	Mg^{2+}	Ca^{2+}	Na^+
			ppm	ppm	ppm	ppm
N1	P 5	0.9 - 1.5	1.55	185.0	174	90.0
N1	P14	3.7 -4.0	6.30	323.0	395	195.0
N1	P19	5.4 - 5.7	6.30	365.0	557	156.0
N2	P 6	1.3 - 1.9	3.10	88.0	153	49.0
N2	P 9	2.4 -2.7	2.80	109.0	140	32.5
N3	P16	4.0 - 4.6	4.00	195.0	230	53.0
N3	P20	5.7 - 6.0	3.50	158.0	178	49.5
STREAM NEAR N1			10.50	20.8	52	12.5
STREAM NEAR N2			10.50	24.3	53	16.5
STREAM NEAR N3			10.50	76.0	89	29.5

TABLE 13 Hydraulic head values - CANAGAGIGUE CREEK

Elevations taken from different arbitrary datum points for C1 - C4, C5 - C6, C7 - C9, and C10 (metres).

SITE No.	WELL No.	Hydraulic Head		
		10/03/77	12/04/77	10/05/77
C1	P5	broken	48.23	48.00
C1	P10	48.54	48.23	48.12
C1	P15	48.54	48.24	48.13
C1	P27	frozen	flowing	49.35
C2	P3	48.79	48.42	48.19
C2	P6	48.81	48.39	48.19
C2	P10	48.82	48.43	48.20
C3	P5	48.96	48.46	48.24
C3	P10	48.62	48.38	48.25
C3	P24	49.76	49.52	49.32
C4	P8	49.57	49.16	48.90
C4	P11	49.59	49.18	48.91
C4	P16	49.75	49.45	49.22
C4	P22	49.78	49.62	49.30
STAFF GAUGE				46.04
C5	P4	frozen	-	48.08
C5	P25	48.79	-	48.08
C6	P4	49.29	-	48.53
C6	P19	49.29	-	48.91
STREAM NEAR C6			-	48.49
C7	P8	45.19	-	44.56
C7	P25	45.20	-	44.93
C8	P7	44.85	-	43.90
C8	P14	43.29	-	43.16
C8	P18	43.19	-	43.08
STREAM NEAR C8				43.81
C9	P12	44.43	-	47.29
C9	P25	44.14	-	44.21
C10	P8	49.12	-	47.82
C10	P14	48.98	-	47.71
C10	P19	48.08	-	47.70
C10	P24	48.94	-	47.68
STREAM NEAR C10				47.48

TABLE 14 NO_3^- and NH_4^+ data (mg/L - N) Canagagigue Creek (AG #4)

SITE NO.	WELL NO.	DEPTH OF WELL POINT (metres)	12/03/77		12/04/77		10/05/77	
			N - NO_3	NH_4	N - NO_3	NH_4	N -NO_3	NH_4
C1	P 5	0.9-1.5	frozen		4.8	0.00		
C1	P10	0.9-3.0	1.9	0.11	7.1	0.00	2.6	0.10
C1	P15	3.9-4.5	4.1	0.03	2.7	0.00	6.0	0.15
C1	P27	7.5 -8.1	frozen		5.2	0.00	1.2	0.05
C2	P 3	0.6 -0.9	0.2	0.03	0.4	0.43	0.4	0.14
C2	P 6	1.5 -1.8	2.9	0.08	0.5	1.4	7.41	0.12
C2	P10	2.4 -3.0	4.2	0.05	3.7	0.0	7.0	0.00
C3	P 5	0.9 - 1.5	0.3	0.09	10.4	0.11	0.2	0.35
C3	P10	2.7 -3.0	6.0	0.14	9.1	0.00	5.6	0.03
C3	P24	6.6-7.2	8.8	0.03	7.7	0.02	10.1	0.09
C4	P 8	1.8 -2.4	0.7	0.11	9.4	0.00	1.3	0.00
C4	P11	2.7-3.3	2.5	0.03	9.1	0.00	9.2	0.02
C4	P16	4.5 - 4.8	7.1	0.01	8.1	0.00	9.61	0.01
C4	P22	6.3 - 6.6	5.1	0.01	1.3	0.00	9.13	0.00
C5	P 4	6.6 -1.2	frozen		0.0	0.00	0.0	0.00
C5	P25	7.2 -7.5	0.1	0.00	0.1	0.00	0.0	0.00
C6	P 4	0.6-1.2	7.7	0.13	6.1	0.10	3.0	0.10
C6	P19	5.5 - 5.9	0.1	0.04	0.1	0.00	0.1	0.00
C7	P 8	1.8 - 2.4	0.6	0.70	0.1	0.50	0.1	0.46
C7	P25	7.2 -7.5	0.1	0.04	0.0	0.00	0.0	0.00
C8	P 7	1.5 - 2.1	0.3	0.15	0.2	0.11	0.2	0.17
C8	P14	4.0 -4.3	0.0	0.12	0.0	0.00	0.0	0.00
C8	P18	5.2 - 5.5	0.0	0.01	0.0	0.00	0.0	0.00

Table 14 (continued)

SITE NO	WELL NO	DEPTH OF WELL POINT (metres)	12/03/77		12/04/77		10/05/77	
			N - NO_3	NH_4	N - NO_3	NH_4	N - NO_3	NH_4
C9	P12	3.1 -3.7	19.8	0.03	17.0	0.00	17.5	0.0
C9	P25	7.2-7.5	13.2	0.26	1.9	0.07	0.17	0.04
C10	P 8	1.8 -2.4	0.2	0.21	0.0	0.00	0.0	0.00
C10	P14	3.6 -4.2	5.1	0.09	4.1	0.07	3.7	1.32
C10	P19	5.4 -5.7	0.1	0.15	0.0	0.00	0.0	0.00
C10	P24	6.9-7.2	0.1	0.03	0.0	0.00	0.0	0.00
CREEK NEAR C1							2.6	
CREEK NEAR C6							0.0	
CREEK NEAR C8							2.7	
CREEK NEAR C10							0.7	

TABLE 15 Major Cation analysis: Canagagigue Creek (AG #4)

SITE NO.	WELL NO.	DEPTH OF WELL POINT	K^+ ppm	Mg^{2+} ppm	Ca^{2+} ppm	Na^+ ppm
C1	P10	2.4 -3.0	1.08	26.2	94	11.5
C1	P15	3.9-4.5	1.22	24.7	72	6.0
C1	P27	7.5 -8.1	1.93	20.8	49	11.0
C2	P 3	0.6 - 0.9	1.91	33.7	149	25.5
C2	P 6	1.5-1.8	0.91	25.7	118	5.5
C2	P10	2.4 -3.0	2.01	29.1	110	8.0
C3	P 5	0.9-1.5	0.92	18.9	121	9.5
C3	P10	2.7 -3.0	1.27	23.9	99	30.0
C3	P24	6.6 -7.2	1.31	22.1	79	5.5
C4	P 8	1.8 - 2.4	2.30	43.3	157	280.0
C4	P11	2.7 -3.3	1.00	22.4	71	5.5
C4	P16	4.5 - 4.8	1.13	22.1	60	5.5
C4	P22	6.3 - 6.6	2.40	23.0	59	6.0
C5	P 4	0.6 -1.2	2.20	34.4	102	8.5
C5	P25	7.2 -7.5				
C6	P 4	0.6 -1.2	1.03	28.3	100	5.0
C6	P19	5.6 - 5.9	5.20	22.4	54	20.5
C7	P 8	1.8 - 2.4	5.80	60.0	144	32.5
C7	P25	7.2-7.5	7.30	30.8	45	29.3
C8	P 7	1.5 - 2.1	2.10	32.5	89	7.0
C8	P14	4.0 - 4.3	2.30	21.4	41	95.0
C8	P18	5.2 - 5.5	2.09	22.3	46	18.0

TABLE 15 (Continued)

SITE NO.	WELL NO.	DEPTH OF WELL POINT	K^+ ppm	Mg^{2+} ppm	Ca^{2+} ppm	Na^+ ppm
C9	P12	3.1 -3.7	2.20	29.4	92	11.0
C9	P25	7.2-7.5	7.70	33.8	48	17.0
C10	P 8	1.8 -2.4	3.00	37.8	106	36.5
C10	P14	3.6 -4.2	1.41	32.5	96	5.5
C10	P19	5.4 -5.7	2.20	32.4	55	25.5
C10	P24	6.9-7.2	3.50	13.8	40	47.5
STREAM NEAR C6			1.71	27.4	69	11.0
STREAM NEAR C8			3.26	24.4	52	6.5
STREAM NEAR C10			2.80	23.4	63	5.5

TABLE 16. NO_3^- and NH_4+ data (mg/L -N) Holiday Creek Watershed

SITE NO	WELL NO	DEPTH OF WELL POINT	22/08/75 NO_3-N	22/08/75 NH_4+
E1	E76	2.1-3.6	0.0	0.5
	E77	3.6-4.2	0.0	0.0
	E78	4.2-4.8	0.0	0.0
	E79	4.8-5.4	0.0	0.0
	E80	5.4-6.0	0.0	0.0
	E81	6.3-7.9	0.0	0.0
	E82	8.4-9.0	0.0	0.0
E2	E85	3.9-4.5	0.0	0.0
	E83	8.3-8.9	0.1	0.3
E3	E71	3.3-4.0	5.5	0.6
	E72	4.0-4.6	7.0	0.1
	E73	6.0-7.5	0.0	0.0

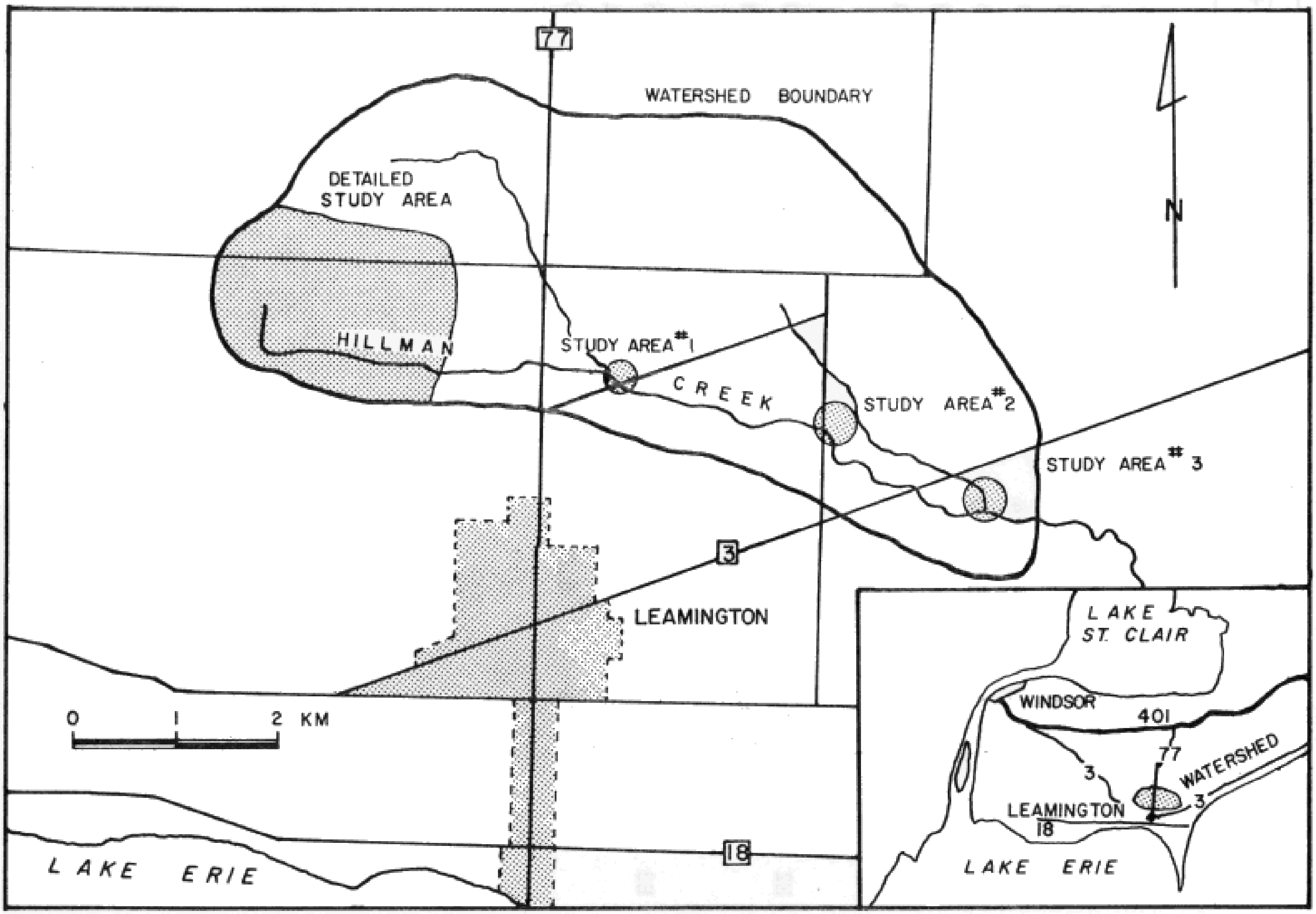

Figure 1. Location of Hillman Creek Watershed (AG#13) and the study areas.

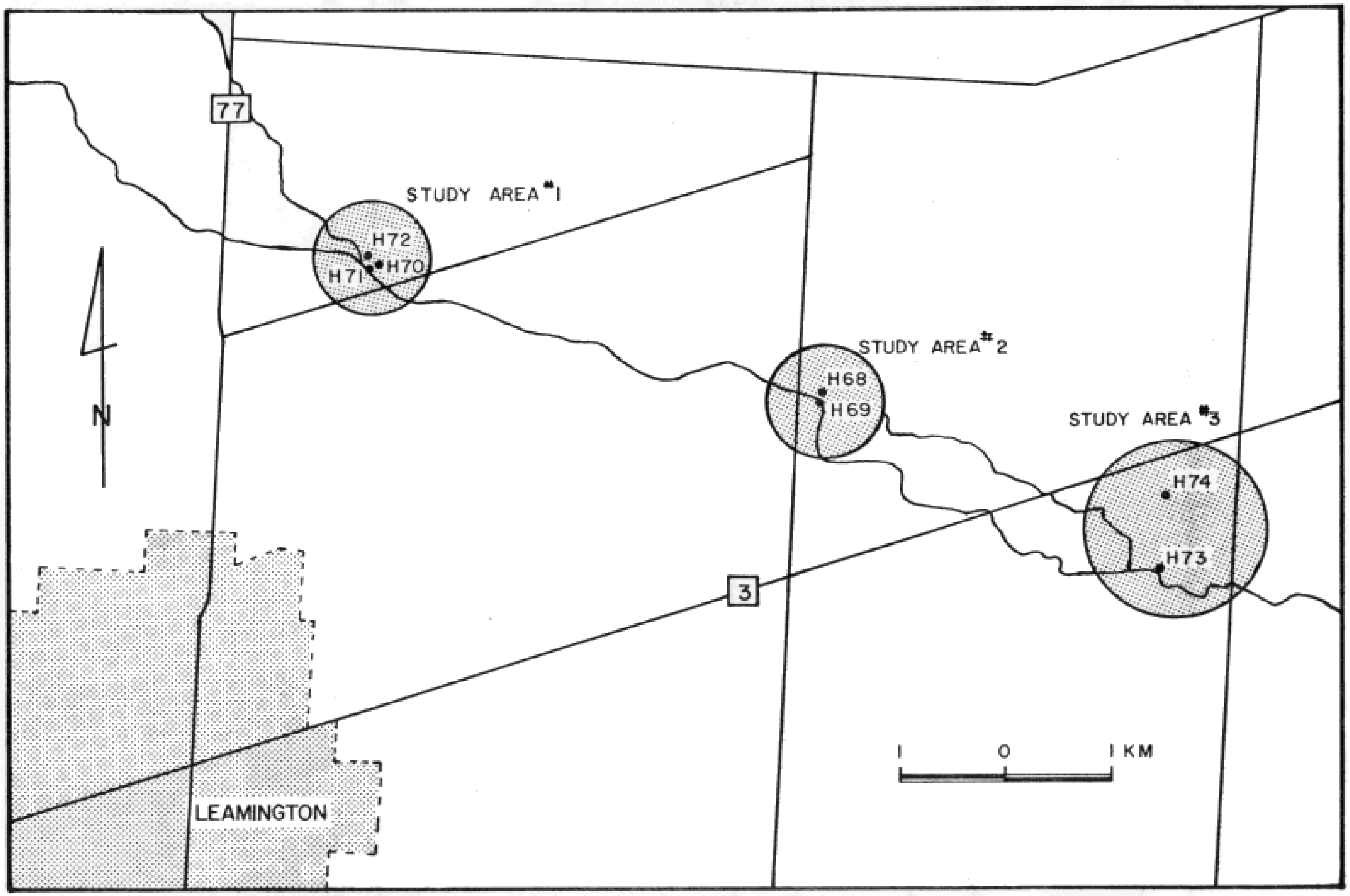

Figure 2. Location of the piezometer nests in the Hillman Creek Watershed.

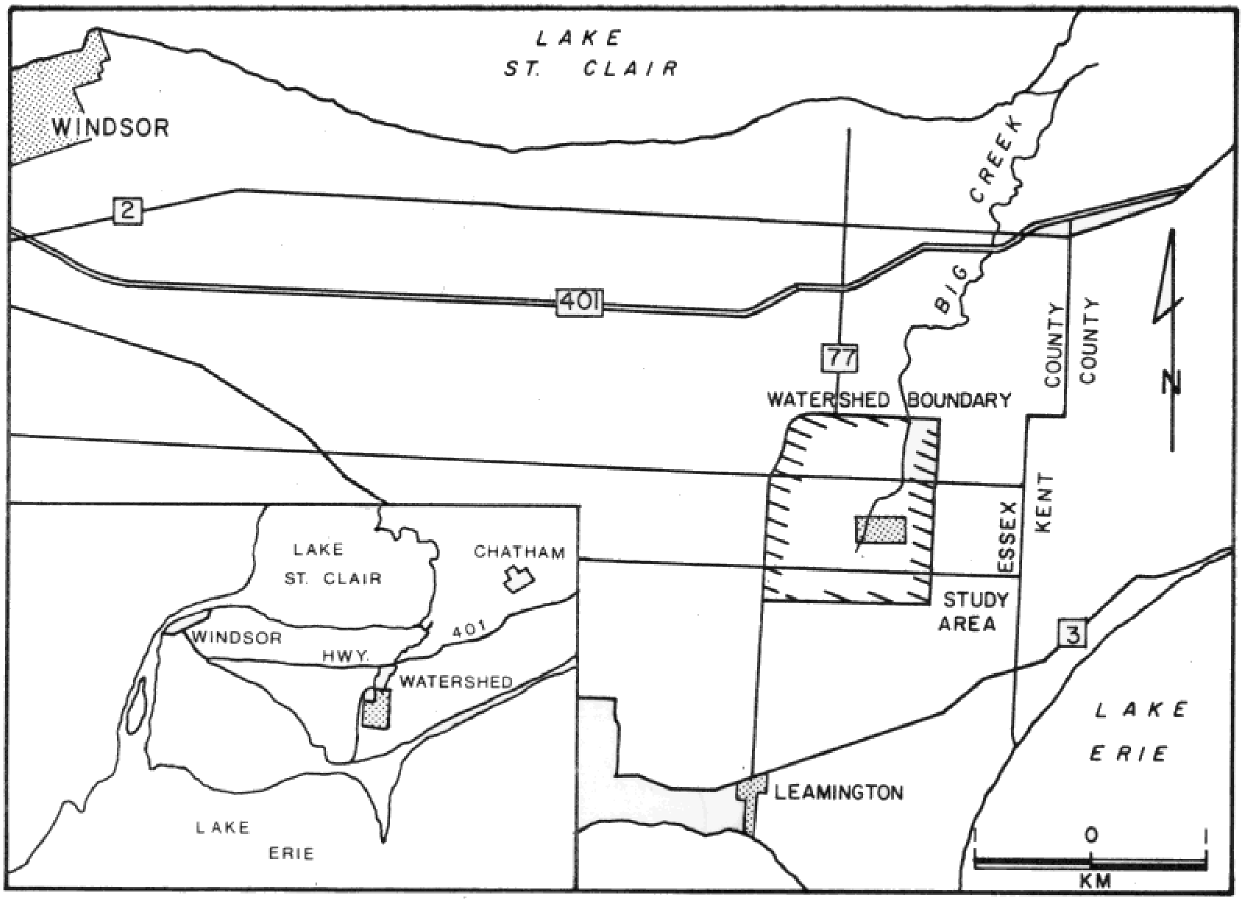

Figure 3. Location of Big Creek Watershed (AG#1) and the study area.

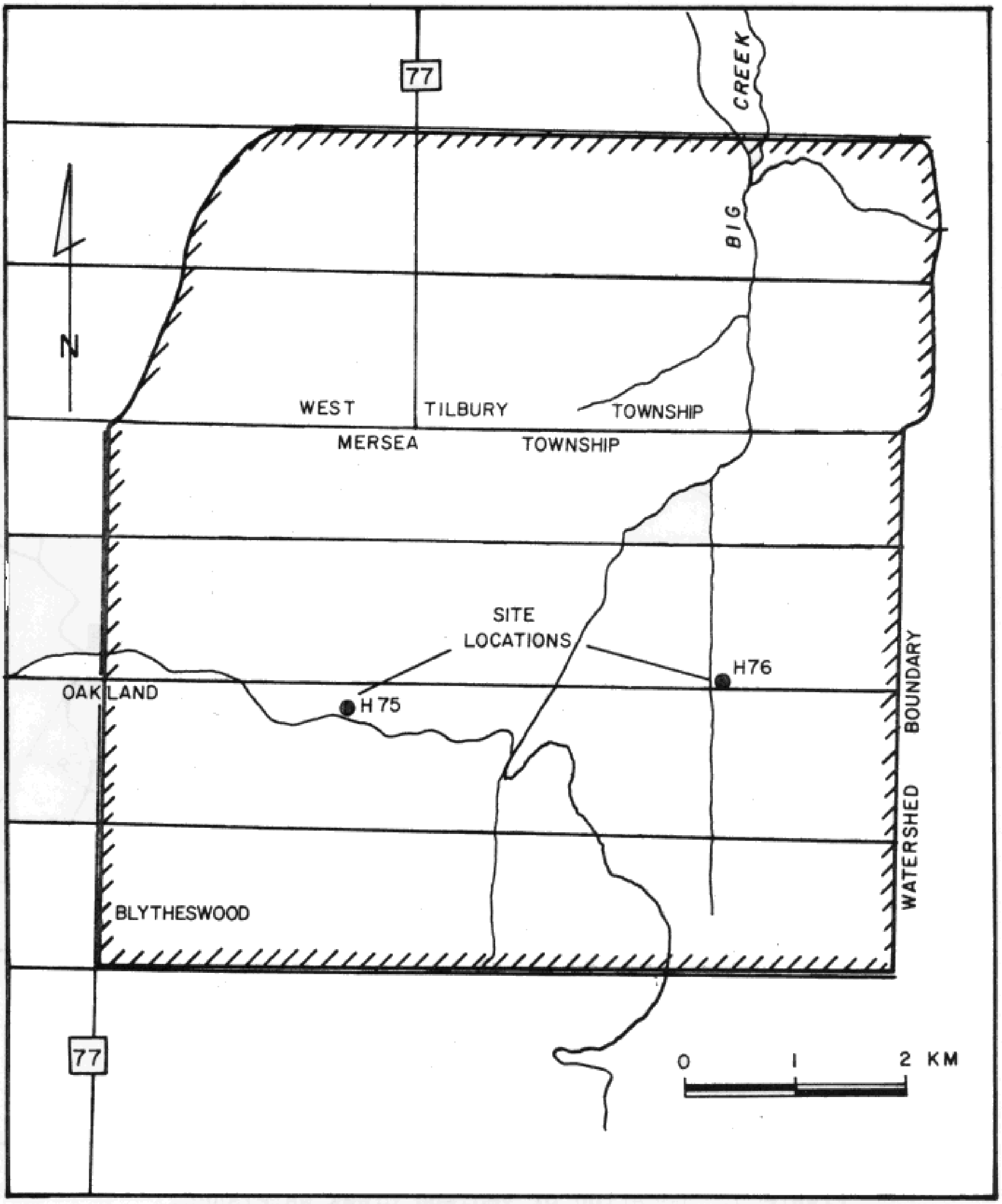

Figure 4. Location of test holes in the Big Creek (AG#1) watershed.

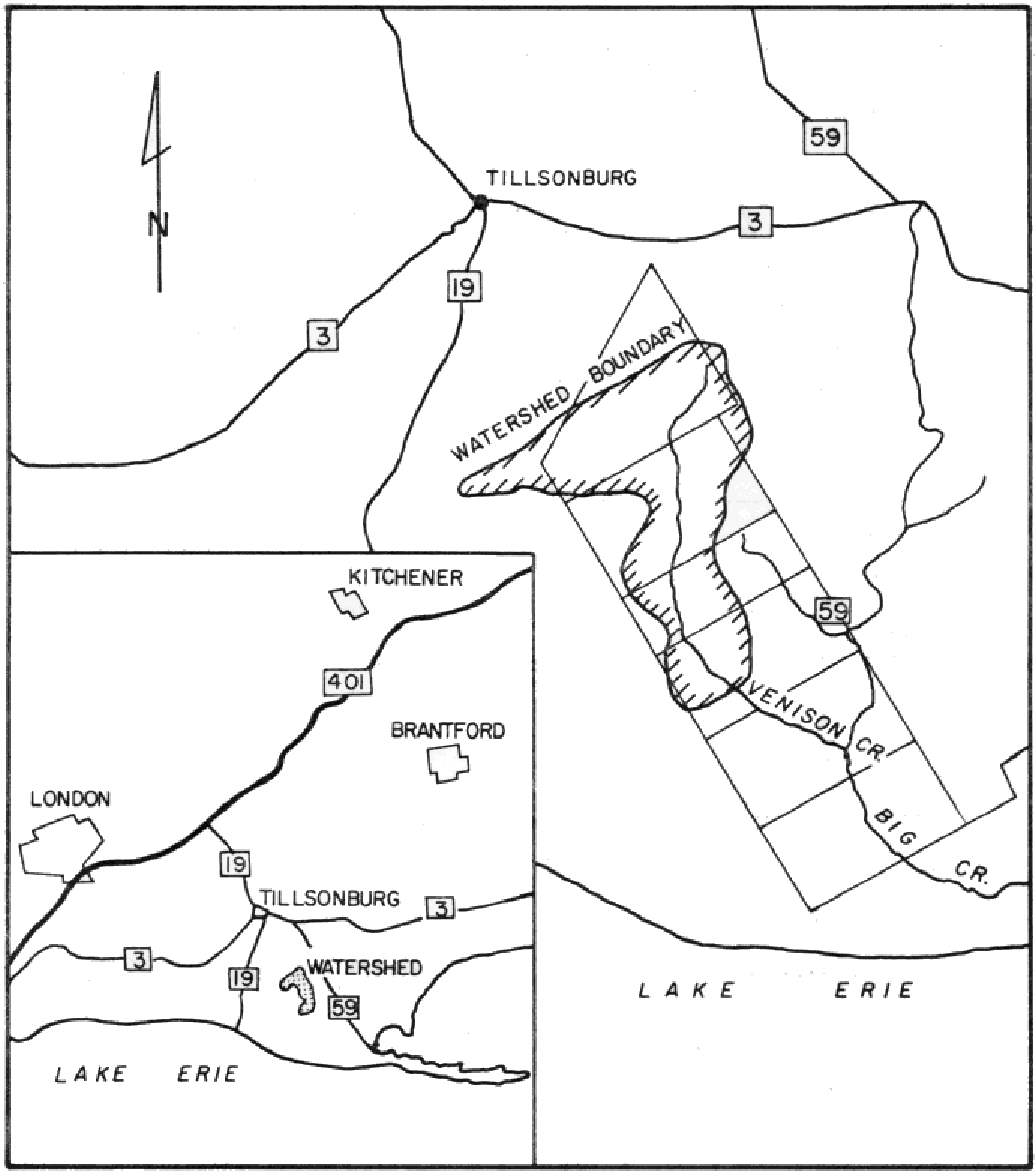

Figure 5. Location of Venison Creek watershed.

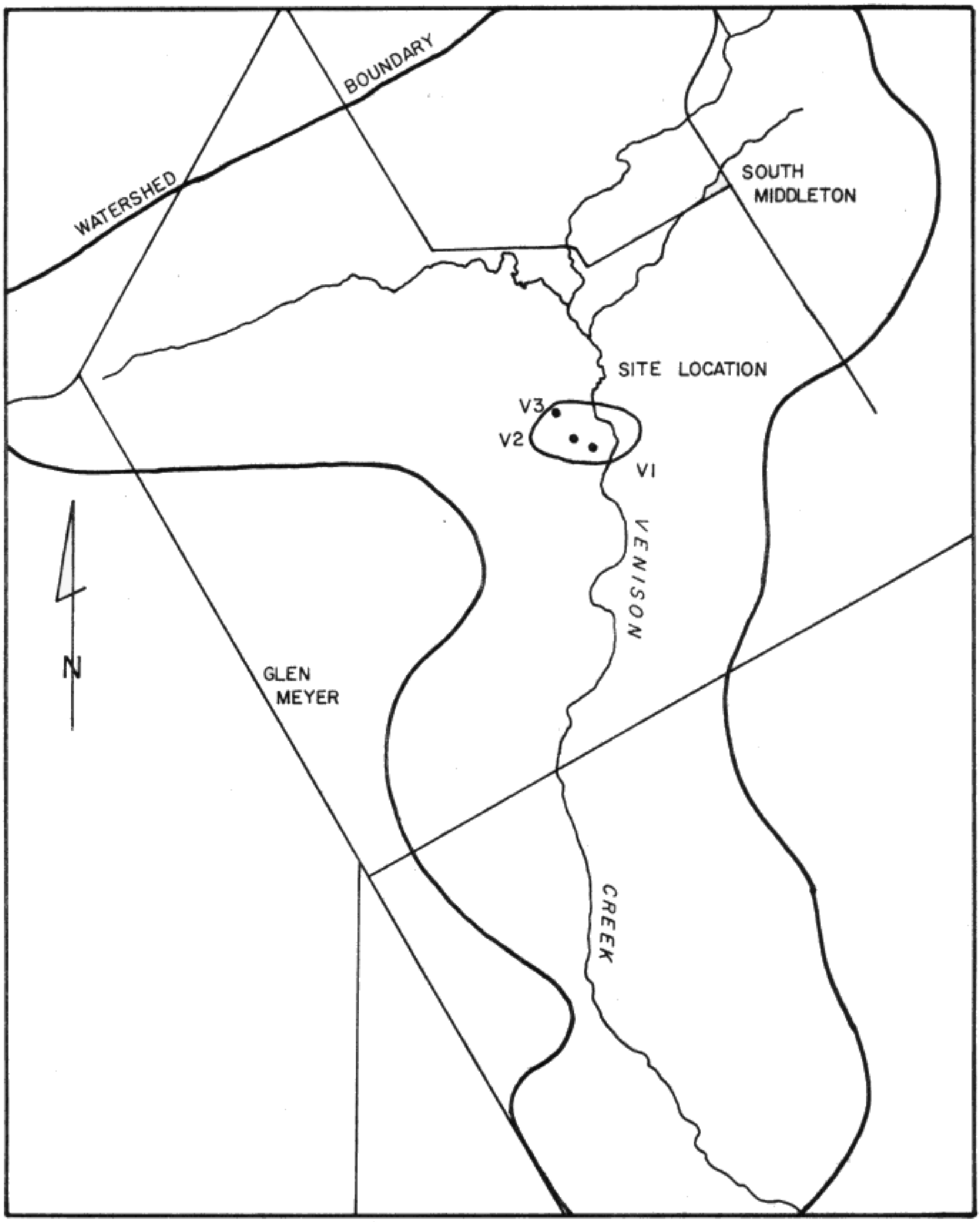

Figure 6. Location of the test holes in the Venison Creek watershed.

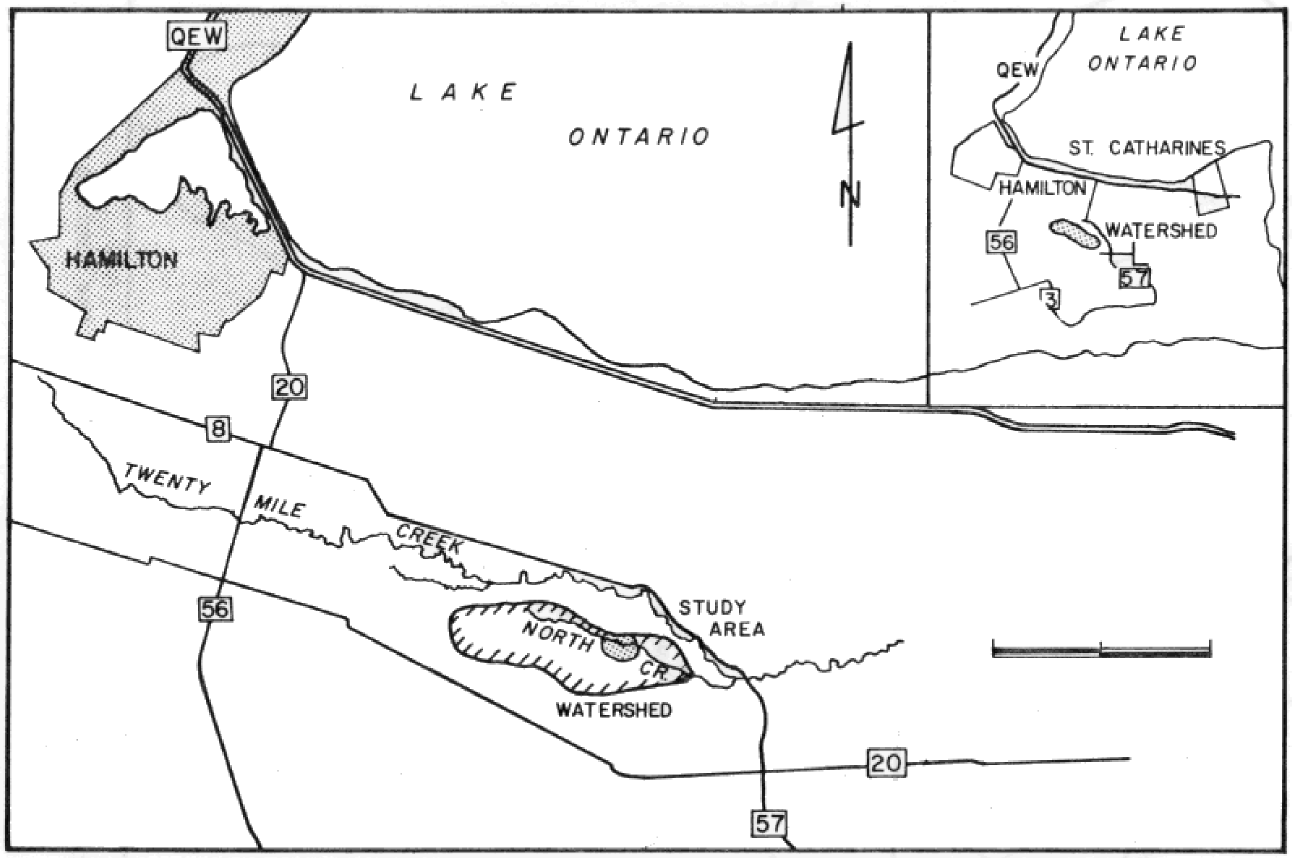

Figure 7. Location of the North Creek watershed (AG#10).

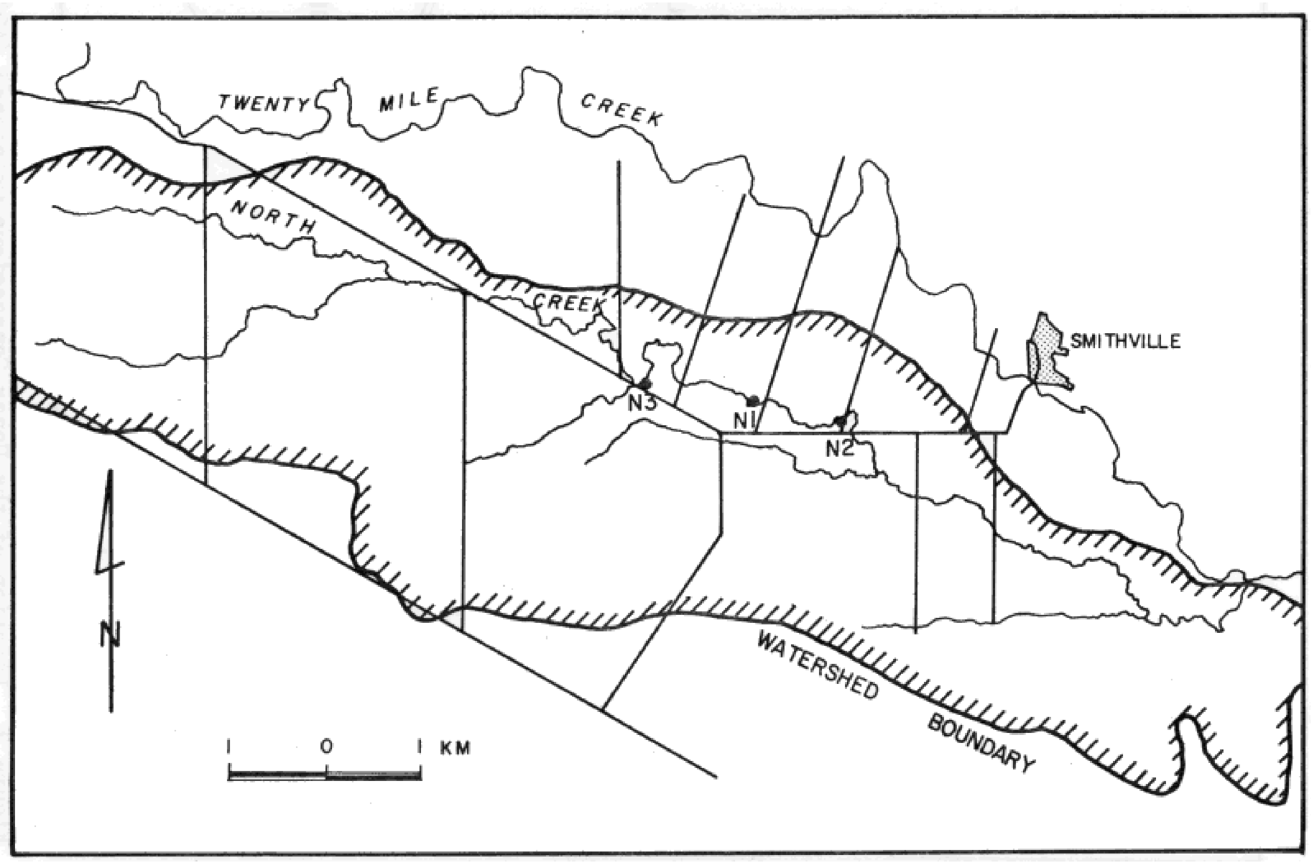

Figure 8. Location of the test holes in the North Creek watershed.

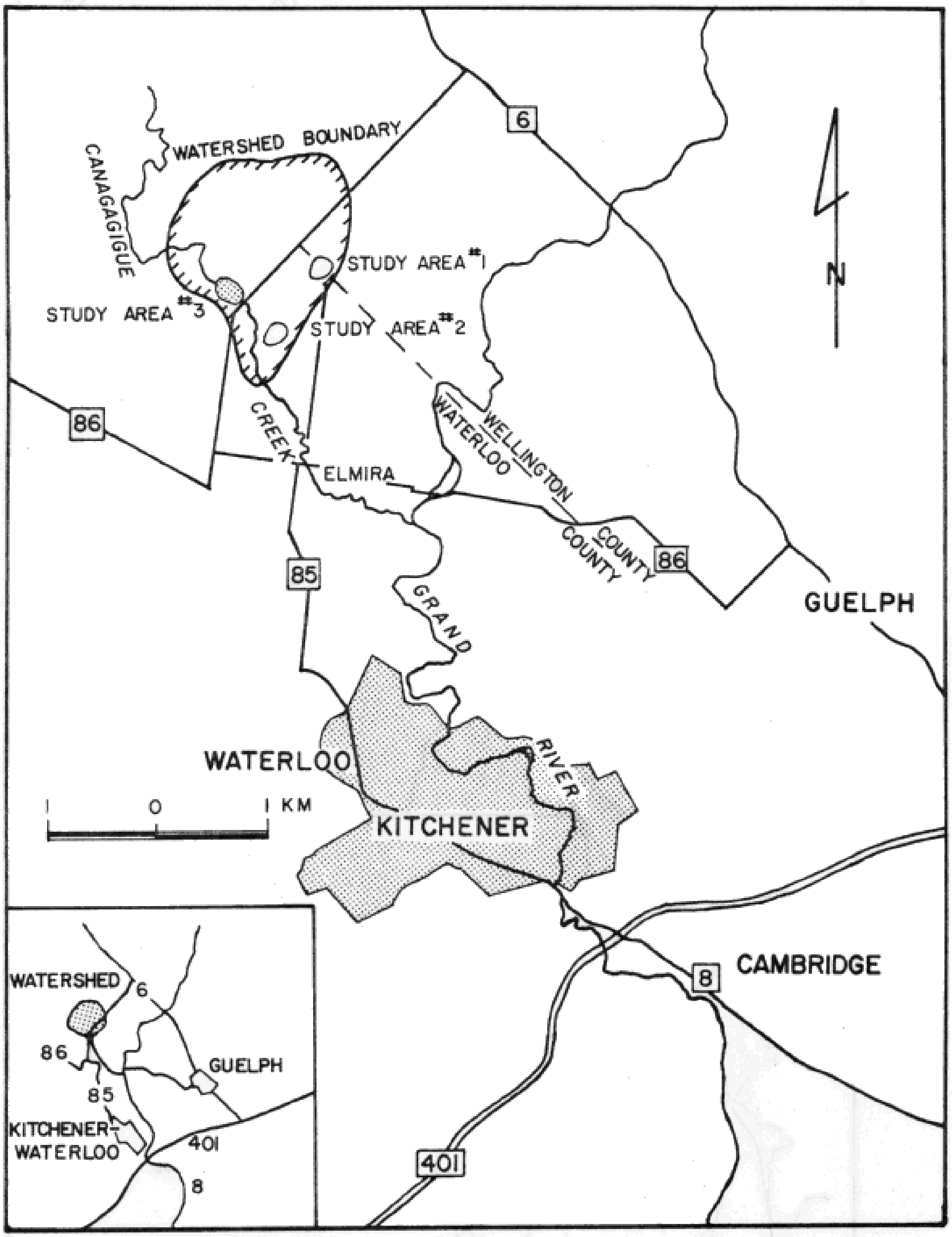

Figure 9. Location of the Upper Canagagigue watershed (AG#4).

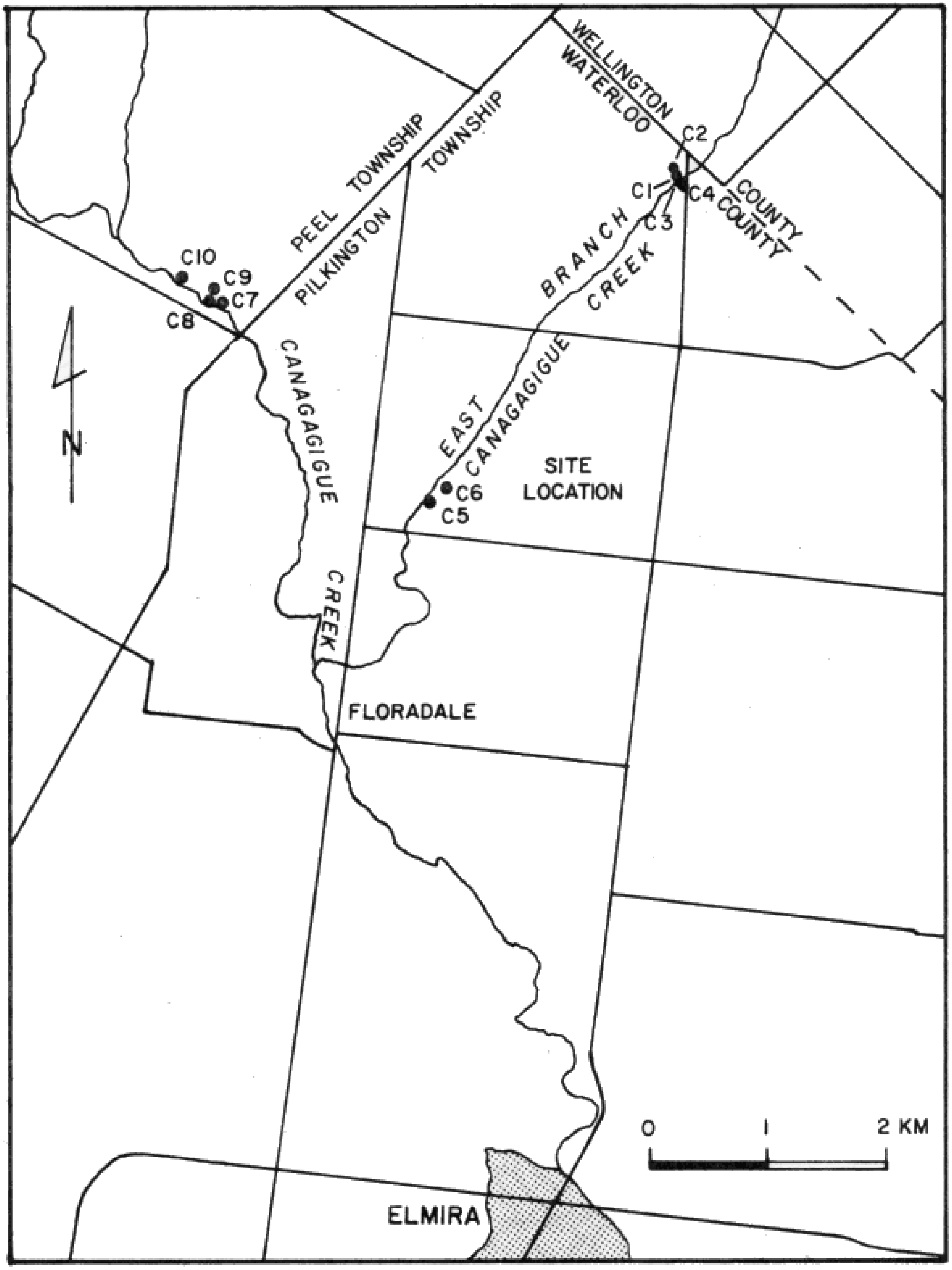

Figure 10. Location of test holes in the Canagagigue watershed.

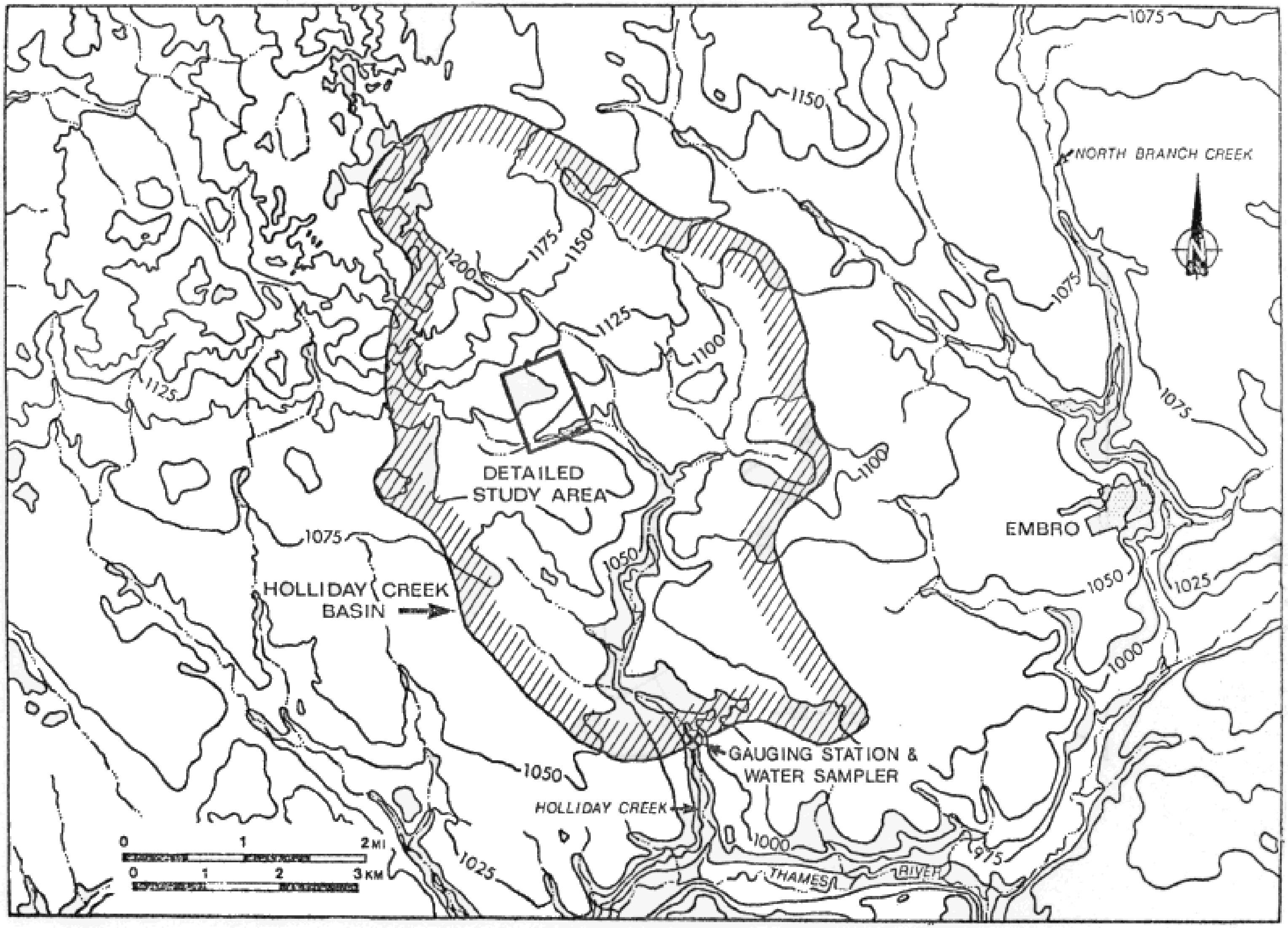

Figure 11. Location of the Holiday Creek watershed.

APPENDIX A

SITE NO. H68

WATERSHED Hillman Creek (AG#13)

DATE DRILLED 12/08/76

LOCATION Leamington, Ontario

DRILLER Sam Vales

GEOLOGIST

DEPTH ELEV METRES	STRATIGRAPHY	DESCRIPTION	SAMPLE NO.	SAMPLE TYPE	SAMPLE BLOWS/FT	SAMPLE METRES	PIEZOMETER LOCATION	REMARKS
		Sand, brown fine-grained sand with some silt and clay fractions found throughout						
		water table						
		changing to grey sand	1	S.S	5		H68-P7	
3.6		increasing silt	2	S.S	10		H 68-P12	
		Till, grey, pebbley, clayey, silt till.						
			3	S.S	5		H68-P17	
		reddish-grey in colour	4	S.S	9			
							H68-P25	
			5	S.S	6			
			6	S.S	4			
							H68-P35	
			7	S.S	6			
							H68-P45	
13.8		Borehole terminated at 13.8 m	8	S.S	7			

SITE NO. H69

WATERSHED Hillman Creek (AG#13)

DATE DRILLED 13/08/76

LOCATION Leamington, Ontario

DRILLER Sam Vales

GEOLOGIST

DEPTH ELEV METRES	STRATIGRAPHY	DESCRIPTION	SAMPLE NO.	SAMPLE TYPE	SAMPLE BLOWS/FT	SAMPLE METRES	PIEZOMETER LOCATION	REMARKS
		Sand brown, silty, clayey, fine-grained sand						
		grey colour (water table)	1	S.S	6		H69-P7	
			2	S.S	6		H69-P12	
3.0								
		Till grey, pebbley, clayey, silt till						
		reddish-grey 4.2 - 4.5 m	3	S.S	2		H69-P17	
			4	S.S	8			
							H69-P24	
			5	S.S	7			
			6	S.S	8			
							H69-P34	
			7	S.S	5			
			8	S.S	5			
							H69-P45	
14.0		Borehole terminated at 14.0 m	9	S.S	3			

SITE NO. H70

WATERSHED Hillman Cr. (AG#13)

DATE DRILLED 14/08/77

LOCATION Leamington, Ontario

DRILLER Sam Vales

GEOLOGIST

DEPTH ELEV. METRES	STRATIGRAPHY	DESCRIPTION	SAMPLE NO.	SAMPLE TYPE	SAMPLE BLOWS/FT	SAMPLE METRES	PIEZOMETER LOCATION	REMARKS
		Till grey, pebbley, clayey silt till						
		brownish and mottled to 2.7 m water table	1	S.S	24			
							H70-P12	
			2	S.S	16			
							H70-P17	
			3	S.S	18			
							H70-P22	
			4	S.S	12			
			5	S.S	15			
							H70-P32	
			6	S.S	7			
		reddish-grey colour from 11.0 - 15.0 m						
			7	S.S	6			
							H70-P42	
			8	S.S	1			

SITE NO. H70

WATERSHED Hillman Cr (AG#13)

DATE DRILLED

LOCATION Leamington, Ontario

DRILLER Sam Vales

GEOLOGIST

DEPTH ELEV METRES	STRATIGRAPHY	DESCRIPTION	SAMPLE NO.	SAMPLE TYPE	SAMPLE BLOWS/FT	SAMPLE METRES	PIEZOMETER LOCATION	REMARKS
			9	S.S	3			
							H70-P52	
			10	S.S	5			
16.3		Borehole terminated at 16.3 m						

SITE NO. H71

WATERSHED Hillman Cr (AG#13)

DATE DRILLED 17/08/76

LOCATION Leamington, Ontario

DRILLER Sam Vales

GEOLOGIST

DEPTH ELEV METRES	STRATIGRAPHY	DESCRIPTION	SAMPLE NO.	SAMPLE TYPE	SAMPLE BLOWS/FT	SAMPLE METRES	PIEZOMETER LOCATION	REMARKS
		Till, grey pebbley, clayey silt till						
		water table	1	S.S	10			
			2	S.S	8		H71-P12	
			3	S.S	6		H71-P18	
			4	S.S	8		H71-P24	
			5	S.S	8			
							H71-P34	
		reddish-grey colour	6	S.S	5			
10.8		Borehole terminated at 10.8 m					note - all piezometers are sand packed	

SITE NO. H72

WATERSHED Hillman Cr. (AG#13)

DATE DRILLED 18/08/76

LOCATION Leamington, Ontario

DRILLER Sam Vales

GEOLOGIST

DEPTH ELEV METRES	STRATIGRAPHY	DESCRIPTION	SAMPLE NO.	SAMPLE TYPE	SAMPLE BLOWS/FT	SAMPLE METRES	PIEZOMETER LOCATION	REMARKS
		Sand brown medium-grained sand grading into a grey fine grained sand below the W.T.						
		water table	1	S.S	4		H72-P6	
		some clay laminations	2	S.S	4		H72-P11	
3.6								
		Till, grey, pebbley, clayey silt till.	3	S.S	9		H72-P16	
			4	S.S	8		H72-P23	
			5	S.S	10			
							H72-P33	
10.6			6	S.S	7			
		Borehole terminated at 10.6 m						

SITE NO. H73

WATERSHED Hillman Cr. (AG#13)

DATE DRILLED 18/08/76

LOCATION Leamington, Ontario

DRILLER Sam Vales

GEOLOGIST

DEPTH ELEV METRES	STRATIGRAPHY	DESCRIPTION	SAMPLE NO.	SAMPLE TYPE	SAMPLE BLOWS/FT	SAMPLE METRES	PIEZOMETER LOCATION	REMARKS
		Sand light brown medium-grained sand						
			1	S.S	8			
6.8		water table						
		Till, grey, pebbley, clayey silt till					H73-P8	
			2	S.S	8			
							H73-P14	
		reddish-grey to 4.8 m	3	S.S	6			
			4	S.S	4			
							H73-P24	
			5	S.S	3			
							H73-P34	
			6	S.S	4			
10.9		Borehole terminated at 10.9 m						

SITE NO. H74

WATERSHED Hillman Cr (AG#13) | DATE DRILLED 19/08/76

LOCATION Leamington, Ontario | DRILLER Sam Vales

GEOLOGIST

DEPTH ELEV METRES	STRATIGRAPHY	DESCRIPTION	SAMPLE NO.	TYPE	BLOWS/FT	METRES	PIEZOMETER LOCATION	REMARKS
		Sand, yellowish, fine-grained sand with some clay laminations.						
			1	S.S	6		H74-P7	
2.4		Till, grey, pebbley, clayey silt till.						
			2	S.S	14			
							H74-P15	
			3	S.S	11			
							H74-P25	
							H74-P35	
			4	S.S	4			
9.6		Borehole terminated at 9.6 m						

SITE NO. H75

WATERSHED Big Cr. (AG#1)

DATE DRILLED

LOCATION Leamington, Ontario

DRILLER Sam Vales

GEOLOGIST

DEPTH ELEV. METRES	STRATIGRAPHY	DESCRIPTION	SAMPLE NO.	SAMPLE TYPE	SAMPLE BLOWS/FT	SAMPLE METRES	PIEZOMETER LOCATION	REMARKS
		Till, brown-clayey, pebbley silt till						
			1	S.S	12			
		changing to grey (water table)	2	S.S	22		H75-PI2	
			3	S.S	13		H75-PI7	
							H75-P25	
			4	S.S	5			
							H75-P35	
			5	S.S	4			
11.1		Borehole terminated at 11.1 m						

SITE NO. H76

WATERSHED Big Cr. (AG#1)

DATE DRILLED

LOCATION Leamington, Ontario

DRILLER Sam Vales

GEOLOGIST

DEPTH ELEV. METRES	STRATIGRAPHY	DESCRIPTION	SAMPLE NO.	SAMPLE TYPE	SAMPLE BLOWS/FT	SAMPLE METRES	PIEZOMETER LOCATION	REMARKS
		Till, yellow-brown sandy, silty pebbley clay till						
			1	S.S	10			
							H76-P8	
3.0			2	S.S	23			
		Till, grey silty pebbley clay till						
							H76-P15	
			3	S.S	8			
							H76-P24	
			4	S.S	7			
							H76-P34	
10.8			5	S.S	5			
		Borehole terminated at 10.8 m						

SITE NO. V1

WATERSHED Venison Cr. (AG#2) DATE DRILLED 18/11/76

LOCATION Langton, Ontario DRILLER Sam Vales

GEOLOGIST

DEPTH ELEV. METRES	STRATIGRAPHY	DESCRIPTION	SAMPLE NO.	SAMPLE TYPE	SAMPLE BLOWS/FT	SAMPLE METRES	PIEZOMETER LOCATION	REMARKS
		Sand, brown, medium-grained well-sorted						
			1	S.S	10			
		water table						
							VI-P10	
			2	S.S	19			
		some layered, grey sand					VI-P15	
			3	S.S	46			
							VI-P20	
			4	S.S	51			
							VI-P24	
7.5		Sand, grey, medium-grained with some fine sand and silt	5	S.S	33			
8.7		Sand, brown, coarse-grained with some layers of fine-grained sand.					VI-P30	
			6	S.S	31			
9.6		Borehole terminated at 9.6 m						

SITE NO. V2

WATERSHED Venison Cr. (AG#12) DATE DRILLED 23/11/76

LOCATION Langton, Ontario DRILLER Sam Vales

GEOLOGIST

DEPTH ELEV. METRES	STRATIGRAPHY	DESCRIPTION	SAMPLE NO.	TYPE	BLOWS/FT	METRES	PIEZOMETER LOCATION	REMARKS
		sand, brown medium-grained well-sorted						
			1	S.S	7			
			2	S.S	22			
			3	S.S	17			
							V2-P40	
		water table						
			4	S.S	64			
							V2-P45	

SITE NO. V2 (continued)

WATERSHED Venison Cr. (AG#2)

DATE DRILLED 23/11/76

LOCATION Langton, Ontario

DRILLER Sam Vales

GEOLOGIST

DEPTH ELEV. METRES	STRATIGRAPHY	DESCRIPTION	SAMPLE NO.	SAMPLE TYPE	SAMPLE BLOWS/FT	SAMPLE METRES	PIEZOMETER LOCATION	REMARKS
							V2-P50	
			5	S.S	68			
							V2-P55	
							V2-P60	
18.6		some silt on the wall of the split-spoon sampler	6	S.S	56			
		Borehole terminated at 18.6 m.						

SITE NO. V3

WATERSHED Venison Cr (AG#2)

DATE DRILLED 24/11/76

LOCATION Langton, Ontario

DRILLER Sam Vales

GEOLOGIST

DEPTH ELEV METRES	STRATIGRAPHY	DESCRIPTION	SAMPLE NO.	SAMPLE TYPE	SAMPLE BLOWS/FT	SAMPLE METRES	PIEZOMETER LOCATION	REMARKS
		Sand, brown, medium-grained well sorted						
			1	S.S	17			
5.4		Sand, brown, medium to fine-grained, well sorted						
			2	S.S	8			
			3	S.S	55			
		water table						
			4	S.S	77		V3-P41	

SITE NO. V3 (continued)

WATERSHED Venison Cr (AG#2)

DATE DRILLED 24/11/76

LOCATION Langton, Ontario

DRILLER Sam Vales

GEOLOGIST

DEPTH ELEV. METRES	STRATIGRAPHY	DESCRIPTION	SAMPLE NO.	SAMPLE TYPE	SAMPLE BLOWS/FT	SAMPLE METRES	PIEZOMETER LOCATION	REMARKS
							V3-P46	
							V3-P50	
			5	S.S	68			
							V3-P55	
							V3-P60	
			6	S.S	68			
		Borehole terminated at 18.6 m						

SITE NO. N1

WATERSHED North Cr. (AG#10) DATE DRILLED 24/08/76

LOCATION Smithville, Ontario DRILLER Sam Vales

GEOLOGIST

DEPTH ELEV METRES	STRATIGRAPHY	DESCRIPTION	SAMPLE NO.	SAMPLE TYPE	SAMPLE BLOWS/FT	SAMPLE METRES	PIEZOMETER LOCATION	REMARKS
		Till - grey - blue - grey pebbley clay till	1	S.S	10			
		mottled to 1.0 m	2	S.S	11		NI-P5	
		0.2 m of medium grained sand at 1.5 m	3	S.S	15			
			4	S.S	20			
		some silt fraction	5	S.S	17			
			6	S.S	20			
4.0			7	S.S	45		NI-P14	
		Bedrock - grey dolstone	cored					
5.7							NI-P19	
		Borehole terminated at 5.7 m						

SITE NO. N2

WATERSHED North Cr. (AG#10)

DATE DRILLED 30/08/76

LOCATION Smithville, Ontario

DRILLER Sam Vales

GEOLOGIST

DEPTH ELEV. METRES	STRATIGRAPHY	DESCRIPTION	SAMPLE NO.	SAMPLE TYPE	SAMPLE BLOWS/FT	SAMPLE METRES	PIEZOMETER LOCATION	REMARKS
		Till, grey pebbley clay till red mottled	1	S.S	8			
			2	S.S	9			
1.8		water table, some gravel silty fraction	3	S.S	36		N2-P7	
		Bedrock - grey dolostone	4	S.S	-		N2-P9	
2.7		Borehole terminated at 2.7 m						

SITE NO. N3

WATERSHED North Creek (AG#10)

DATE DRILLED 31/08/76

LOCATION Smithville, Ontario

DRILLER Sam Vales

GEOLOGIST

DEPTH ELEV. METRES	STRATIGRAPHY	DESCRIPTION	SAMPLE NO.	SAMPLE TYPE	SAMPLE BLOWS/FT	SAMPLE METRES	PIEZOMETER LOCATION	REMARKS
		Till, grey pebbley clay till reddish brown mottled clay	1	S.S	9			
			2	S.S	34			
			3	S.S	27			
			4	S.S	20			
		blue-grey colour, moist	5	S.S	21			
4.6			6	S.S	21			
		clay - glaciolacustrine finely stratified clay with some silt stratifications	7	S.S	8		N3-P14	
6.0			8	S.S	6			
		Bedrock - grey dolostone					N3-P20	
		Borehole terminated at 6.0 m						

SITE NO. C1

WATERSHED Canagagigue Cr (AG#4)

DATE DRILLED 28/09/76

LOCATION Elmira, Ontario

DRILLER Sam Vales

GEOLOGIST

DEPTH ELEV METRES	STRATIGRAPHY	DESCRIPTION	SAMPLE NO.	SAMPLE TYPE	SAMPLE BLOWS/FT	SAMPLE METRES	PIEZOMETER LOCATION	REMARKS
		Sand and gravels - silty, clayey, medium-to-fine grained sand with some clay stringers and gravel intermixed					CI-P5	
			1	S.S	12			
		medium-grained silty sand					CI-P10	
		coarse sand with some gravel	2	S.S	25			
							CI-P15	
			3	S.S	15			
		silty fine-grained sand with clay stringers						
			4	S.S	7			
		clayey fine-grained sand with a 0.3 m clay layer						
			5	S.S	32		CI-P27	
8.1								
		Till mottled, oxidized, multi-coloured (white, green, blue, red, yellow, black) silty till	6	S.S	12			
9.0		Borehole terminate at 9.0 m						

SITE NO. C2

WATERSHED Canagagigue Cr. (AG#4) DATE DRILLED 29/09/76

LOCATION Elmira, Ontario DRILLER Sam Vales

GEOLOGIST

DEPTH ELEV. METRES	STRATIGRAPHY	DESCRIPTION	SAMPLE NO.	SAMPLE TYPE	SAMPLE BLOWS/FT	SAMPLE METRES	PIEZOMETER LOCATION	REMARKS
		Sands and gravels - silty clayey sands and gravels with layers of silts and clays					C2-P3	
		gravelly sand	1	S.S	13		C2-P6	
							C2-P10	
		fine gravel silty sand	2	S.S	25			
4.8		course sand clay and silt laminations	3	S.S	15			
6.3		Till - clayey silt till with black mottles	4	S.S	27			
		Borehole terminated at 6.3 m						

SITE NO. C3

WATERSHED Canagagigue Cr (AG#4) DATE DRILLED 30/09/76

LOCATION Elmira, Ontario DRILLER Sam Vales

GEOLOGIST

DEPTH ELEV. METRES	STRATIGRAPHY	DESCRIPTION	SAMPLE NO.	SAMPLE TYPE	SAMPLE BLOWS/FT	SAMPLE METRES	PIEZOMETER LOCATION	REMARKS
		Sands and gravels - medium-grained sand with some coarse gravel and some silty fractions						
							C3-P5	
		water table	1	S.S	20			
							C3-P10	
		some gravel	2	S.S	26			
		sandy silt clayey silt	3	S.S	14			
		coarse sand, some gravel	4	S.S	24			
							C3-P24	
7.5								
		Till silty clay till, mottled	5	S.S	148			
7.8								
		Borehole terminated at 7.8 m						

SITE NO. C4

WATERSHED Canagagigue Cr (AG#4) DATE DRILLED 5/10/76

LOCATION Elmira, Ontario DRILLER Sam Vales

GEOLOGIST

DEPTH ELEV METRES	STRATIGRAPHY	DESCRIPTION	SAMPLE NO.	SAMPLE TYPE	SAMPLE BLOWS/FT	SAMPLE METRES	PIEZOMETER LOCATION	REMARKS
		Sands and gravels - fine to coarse-grained sand with gravel and some silty layers						
		silty sand						
		water table	1	S.S	23			
		boulders 1.2 0 2.1 m					C4-P8	
		some silt layers	2	S.S	25		C4-P11	
		silty clay layers						
			3	S.S	16		C4-P16	
		sandy silt						
			4	S.S	21		C4-P22	
		gravel						
			5	S.S	53			
		Borehole terminated at 7.8 m						

SITE NO. C5

WATERSHED Canagagigue (AG#4)

DATE DRILLED 5/10/76

LOCATION Elmira, Ontario

DRILLER Sam Vales

GEOLOGIST

DEPTH ELEV METRES	STRATIGRAPHY	DESCRIPTION	SAMPLE NO.	SAMPLE TYPE	SAMPLE BLOWS/FT	SAMPLE METRES	PIEZOMETER LOCATION	REMARKS
		Till sandy, clay till with some silt and sand stringers					C5-P4	
		water table	1	S.S	6			
		some sand stringers						
			2	S.S	29			
		some silt stringers	3	S.S	97			
			4	S.S	91			
							C5-P25	
7.8			5	S.S	82			
		Borehole terminated at 7.8 m						

SITE NO. C6

WATERSHED Canagagigue (AG#4) DATE DRILLED 7/10/76

LOCATION Elmira, Ontario DRILLER Sam Vales

GEOLOGIST

DEPTH ELEV METRES	STRATIGRAPHY	DESCRIPTION	SAMPLE NO.	SAMPLE TYPE	SAMPLE BLOWS/FT	SAMPLE METRES	PIEZOMETER LOCATION	REMARKS
		Till, pebbley, sand clay till						
		water table					C6-P4	
			1	S.S	10			
			2	S.S	41			
			3	S.S	68			
							C6-P19	
6.1			4	S.S	78			
		Borehole terminated at 6.1						

SITE NO. C7

WATERSHED Canagagigue (AG#4) DATE DRILLED 14/10/76

LOCATION Elmira, Ontario DRILLER Sam Vales

GEOLOGIST

DEPTH ELEV. METRES	STRATIGRAPHY	DESCRIPTION	SAMPLE NO.	SAMPLE TYPE	SAMPLE BLOWS/FT	SAMPLE METRES	PIEZOMETER LOCATION	REMARKS
		Till clayey sandy till						
			1	S.S	8			
		water table					C7-P8	
			2	S.S	52			
			3	S.S	227			
			4	S.S	127			
			5	S.S	167		C7-P25	
7.7		Borehole terminated at 7.7 m						

SITE NO. C8

WATERSHED Canagagigue (AG#4) DATE DRILLED 12/10/76

LOCATION Elmira, Ontario DRILLER Sam Vales

GEOLOGIST

DEPTH ELEV. METRES	STRATIGRAPHY	DESCRIPTION	SAMPLE NO.	TYPE	BLOWS/FT	METRES	PIEZOMETER LOCATION	REMARKS
		Till - clayey sandy till						
		water table	1	S.S	28		C8-P7	
			2	S.S	18			
			3	S.S	44		C8-P14	
5.5		small layer of coarse sand	4	S.S	30		C8-P18	
		Borehole terminated at 5.5 m						

SITE NO. C9

WATERSHED Canagagigue (AG#4)

DATE DRILLED 8/10/76

LOCATION Elmira, Ontario

DRILLER Sam Vales

GEOLOGIST

DEPTH ELEV METRES	STRATIGRAPHY	DESCRIPTION	SAMPLE NO.	SAMPLE TYPE	SAMPLE BLOWS/FT	SAMPLE METRES	PIEZOMETER LOCATION	REMARKS
		Till, sandy, clayey, silt till						
			1	S.S	5			
		-stoney clay layer	2	S.S	71		C9-P12	
			3	S.S	82			
		-clay layer	4	S.S	54			
							C9-P25	
			5	S.S	57			
8.1		Borehole terminated at 8.1 m						

SITE NO. C10

WATERSHED Canagagigue Cr (AG#4) DATE DRILLED 15/10/76

LOCATION Elmira, Ontario DRILLER Sam Vales

GEOLOGIST

DEPTH ELEV METRES	STRATIGRAPHY	DESCRIPTION	SAMPLE NO.	TYPE	BLOWS/FT	METRES	PIEZOMETER LOCATION	REMARKS
		Till, clayey, sandy till with sand layers						
		some gravel	1	S.S	21		C10-P8	
		sand	2	S.S	94		C10-P14	
			3	S.S	38			
		sand layer						
			4	S.S	107		C10-P19	
		sand layer	5	S.S	107			
							C10-P24	
7.9			6	S.S	56			
		Borehole terminated at 7.9 m						