Pilot Survey of Electrical Conductivity and Temperature in the South Nation River, Eastern Ontario

Final Report

Prepared for:

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ABSTRACT

This pilot survey was initiated to provide information on small-scale (order of tens of meters) variability of groundwater–surface water interactions (GSWI's) in the South Nation River (SNR) in Eastern Ontario. These interactions are an important part of understanding the hydrological cycle, groundwater and river systems, and in providing estimates of groundwater contributions to rivers (baseflow). Seepage / leakage of groundwater into surface waters can be measured directly, but this is very labour-intensive, and therefore not feasible at the scale of a basin. An alternative method, which was used in this study, infers groundwater seepage from the Electrical Conductivity and Temperature (EC&T) of water at the bottom of the river, based on the assumption that there is a contrast between the incoming groundwater and the river water (which is almost always the case). These measurements are very fast: They are carried out by dragging an EC&T probe from a boat at walking speed.

Using this method, a pilot survey of EC&T of the main branch of the South Nation River was conducted. The mean EC values of the SNR are very high, indicating relatively poor water quality. The mean EC values were relatively constant from the headwaters downstream to the Castor River confluence where they increased sharply. They remained high down stream from Casselman until the confluence with the Ottawa River, where they decreased due to mixing with the lower-EC Ottawa River waters. The sharp increase at the Castor R. is indicative of (1) a much lower water quality in the Castor R., perhaps due to land use practices; or (2) a major zone of deep-system (of high EC) groundwater discharge in the Castor R; or (3) a combination of both. Both scenarios are possible because of the intensive use of the land on the Castor R. and because of the major fault systems around and along the Castor R. The report recommends that additional measurements be made along the Castor R. to attempt to sort out the source of water.

Several anomalies were detected along the river as sharp peaks above or below the mean EC values. Some of the peaks were confirmed zones of seepage near Cass Bridge; the other peaks will have to be confirmed and explained. A very important finding from this data is that areas of groundwater seepage in the SNR are very localized in areas of less than a few tens of meters, indicating that the deep recharge patterns may be the result of fracture flow in the bedrock. A very large anomaly was detected near the crossing of Highway 417, which could be the result of road salting or of septic effluent input from the nearby residences. Differences in EC between the banks of the river and along the banks were the result of differences in land use. Measurements of drainage pipe effluent, when and where they were found flowing, showed that they are major contributors to the high EC values (and therefore the low quality) of the SNR. Several of the recommendations in the report will be carried out as part of a University of Ottawa MSc student work in the Summer of 2003.

The methodology in this study proved useful in detecting groundwater seepage, but it was spectacularly successful at pinpointing sources of local high EC loading in the river. This can therefore be an extremely valuable tool in the watershed management. The level of detail provided by this method is extremely useful in many GIS-based applications, including the assessment of susceptibility of an aquifer to contamination, the understanding of a river ecosystem, flood protection and control and groundwater modeling exercises such as capture zone calculations.

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1. Preamble

1.1 Introduction

This study was initiated to respond to some of the recommendations from the Eastern Ontario Water Resources Management Study (EOWRMS). In particular, the study aims at improving our understanding of groundwater/surface water interactions. The study was mandated by the Eastern Ontario Water Resources Management Committee (EOWRMC), within the Healthy Future for Ontario's Agriculture Program.

1.2 Project objectives

The main objective of this demonstration project was to determine if electrical conductivity and temperature (ECT) of the river water at the sediment interface can be used as indicators of groundwater seepage in the South Nation River. This report presents the results of a pilot survey that covered the main trunk of the South Nation River from the Ottawa River upstream to an area near Cass Bridge (a distance of over 70 km). The survey took place during the summer of 2002, and was complemented with additional direct seepage measurements at ECT anomalies near Cass Bridge. The purpose of the direct seepage measurements was to demonstrate that ECT anomalies could be used to identify areas of groundwater discharge. Unexplained ECT anomalies in other area will have to be verified in subsequent studies with direct seepage measurements.

1.3 Project scope

During the Fall 2001 the field instruments were assembled and modified for this particular application, in a first, preliminary phase of the project. This report presents the results of a second phase, which took place during the Summer 2002, and in which the instrument system was used to map the EC&T of a large portion the main trunk of the South Nation (approximately 70 km) and to verify that EC&T anomalies could be associated with zones of groundwater seepage. The scope of work presented in this report is limited to the results of the pilot survey; an analysis and interpretation of these results; and a list of conclusions and recommendations.

A third phase was originally planned, that would have: (1) verified the results of the first field season with a second round of measurements, (2) covered a more extensive territory, and (3) compared the results to hydrograph analyses. Unfortunately, this phase was preempted due to lack of funding. Notwithstanding, M.Sc. Student Janet Kingsley will be completing a small portion of the third phase work during the summer 2003 for her M.Sc. thesis (expected completion, end of 2003). The additional work to be completed will include a small amount of field work to quantify seepage estimates from the first field season, and a water budget comparing seepage estimates to base flow calculations. A copy of the thesis will be given to the EOWRC when it becomes available (expected early in 2004).

1.4 Report limitations

The results reported here were obtained using an innovative technology that produces numbers that give qualitative estimates of groundwater seepage in the South Nation River. The results were interpreted and analyzed with the best available technology and information; however, they remain somewhat qualitative in nature and should be used with caution to indicate areas of possible further investigation, possibly with direct seepage measurements.

The authors of this report have exercised professional judgment in collecting and analyzing the field data and in presenting recommendations based on the results of the study. The conclusions contained in the report are based on the conditions prevailing at the time of the field work and on information gathered from other sources. Accordingly, the authors of the report cannot accept responsibility for any deficiency, misstatement or inaccuracy in this report that is the result of misstatements, omissions, or misrepresentations contained in the sources of information.

The tasks reported here were executed with scientific integrity and with the quality and due diligence expected in the scientific community. The authors hereby disclaim any responsibility for the use (or misuse) of the information and recommendations contained in this report for any loss, damage, expense, fines or penalties which may arise from the information contained in this report. The use of any part of this report constitutes acceptance of the limits of the authors' liability.

1.5 Acknowledgements

The field measurement reported in this report were gathered by several students at the University of Ottawa, many of whom volunteered their time. During Phase One, the system was tested in the late Fall 2001 as part of B.Sc. Student Guillaume Girouard's Honour's Thesis. The field work for Phase Two was conducted in the Summer 2002 by M.Sc. Student Janet Kingsley, with the assistance of B.Sc.(Eng) Student Stéphane Bouchard; additional testing was conducted by B.Sc. Student Laura Beauchamp, with the assistance of Ph.D. Student Hossein Mohammadzadeh. Post-Doctoral Fellow Bahram Daneshfar assisted greatly in the GIS work and the final report preparation. All were under the supervision of Dr. M.J.L. Robin at the University of Ottawa.

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2. Background and relation to Healthy Future's Program objectives

One of the major gaps in our knowledge identified by the EOWRMS concerns groundwater-surface water interactions (GSWIs). Little is known of GSWIs at the spatial scales necessary for aquifer and surface water vulnerability mapping. But there is mounting evidence to show that GSWIs can be extremely variable, showing zones of aquifer recharge and zones of discharge within a few tens of meters of each other. Time is also a factor: in certain locations GSWI's can also change depending on the seasons and on specific precipitation events.

One of the principal objectives of the Healthy Future for Ontario Agriculture Program is: Healthy Waters, which means healthy surface waters and healthy groundwater; surface waters because they sustain a huge portion of the ecosystems that surround us, and groundwater because it is the source of drinking water for the overwhelming majority of people in Eastern Ontario. It is crucial to know more about the interaction between surface and groundwater for several reasons. From the surface water point of view, groundwater discharge zones (into rivers) are typically sensitive areas that can be pristine, where fish tend to spawn; or that can increase nutrient loading to the river, thereby decreasing the water quality. Water quantity can also be an issue: surface water flow can be deceased if it is fed by an over-pumped aquifer. From the groundwater point of view, zones of groundwater discharge into surface waters means low groundwater vulnerability; conversely, areas where groundwater is recharged by surface waters (either naturally or because of the proximity of a pumping well) pose a risk of contaminating the groundwater with bacteria and other contaminants.

The work reported here helps us identify zones of groundwater discharge, and therefore zones of high surface water vulnerability. It will help us focus future efforts in determining where more detailed measurements are desirable (direct seepage, stream gauge stations, etc); where we should be more careful in our agricultural land management practices; where we should be protecting pristine sites. If we are to promote healthy water management practices, then it stands to reason that we should understand better how, where (the focus of this project), and when these practices are most likely to have an impact.

Groundwater-surface water interactions are an important part of understanding the hydrological cycle, groundwater systems and river ecosystems. However, groundwater-surface water studies that use near shore piezometers and/or seepage meters are often impractical and expensive in larger, more extensive areas. For these reasons, an electrical conductivity and temperature mapping method has proven useful in mapping groundwater discharge zones. The technique identifies groundwater discharge by measuring variations in sediment pore water electrical conductivity and temperature and reduces the number of instruments necessary to quantify inflow. Results from the electrical conductivity-temperature (ECT) method can then guide the installation of piezometers and seepage meters to discharge zones. This system was developed by D. Lee at Atomic Energy of Canada Ltd., Chalk River and has been used to identify groundwater discharge zones in Laholm Bay, Sweden (Vanek and Lee, 1991) Columbia River (Lee et al, 1997) and Hamilton Harbor (Harvey et al, 1997). Using this technique, small-scale variability that occurs on the order of meters to tens of meters can be discovered in a relatively inexpensive way. The level of this variability and the factors that control it may have important implications including the assessment of susceptibility of an aquifer to contamination, the understanding of a river ecosystem, flood protection and control and groundwater modeling exercises such as capture zone calculations.

3. Study Area

3.1 Location

The South Nation Watershed is located in southeastern Ontario between longitudes 74° 41' and 75° 44'W and latitudes 44° 38' and 45°34'N (Fig. 1). The basin covers 3915 km^2, between Ottawa, Brockville, and Cornwall. From its source, a few kilometers north of Brockville, to its confluence with the Ottawa River, the South Nation River flows for 177 km in a northeasterly direction and descends about 84m (Singer et al., 2001). Major sub-basins are the Castor River (733 km^2), the Bear Brook (487 km^2), and the Scotch (272 km^2).

The territory covered in this study is shown in Figure 1. It extended from Oak Valley in the south to the Ottawa River in the north. As a pilot study, measurements were limited to the main trunk of the South Nation River with a few hiati where the river was not navigable. Short segments of two tributaries at the confluence with the South Nation were also included in the study: the Castor and the Scotch.

The area has flat to gently rolling relief and practically no strongly broken relief. Elevations range from 45 meters above sea level to 120 meters and generally increase from east to west (Singer et al., 2001). The South Nation River valley has bank heights of about 23 to 30 meters and a valley width of about 400 meters (Gadd, 1976).

Approximately 60% of the land within the South Nation River basin is used for agricultural purposes. The main agricultural products are corn, grain and hay (Singer, S.N. et al., 2001). Woodlands cover approximately 23% of the land; 9% of the land in the area is idle; and the remaining 8% consists of urban areas, forest plantations and wetlands. The main urban centers in the basin are Casselman, Chesterville, Plantagenet, and Winchester.

3.2 Geological Setting

Bedrock and its Structure

The bedrock elevation within the South Nation River basin ranges from 40 to 120 meters, but most of the basin is between 40 and 80 m (Singer et al., 1997). Areas with higher elevations are located along the eastern, southern and western boundaries. Bedrock is exposed at surface at less than 2% of the study area. It is covered with an overburden thickness up to 30 meters.

Much of the southwestern part of the basin is underlain by rocks of the March and Oxford Formations of Lower Ordovician age. They were laid in a shallow sea transgressing from the east. The March Formation consists of sandstones, dolomitic sandstones, sandy dolostones and dolostones. It ranges in thickness from 6 to 64 m. The Oxford Formation consists of dolostones with a maximum thickness of 200 m (Singer et al., 2001).

The Rockcliffe Formation and Ottawa Group make up the sediments of Middle Ordovician age. They were first deposited in this region when the Chazy Sea spilled over into the basin from the Montreal area, not long before it, too, retreated again to the east. The Rockcliffe Formation occurs in a number of small areas in the central and northern parts of the basin and consists of sandstones and shales and has a thickness up to 125 m (Thurston et al. 1992).

The Gull River, Bobcaygeon, Verulam, and Lindsay Formations occur over large areas in the eastern and northern parts of the basin. Along with the Shadow Lake Formation, these units comprise the Ottawa Group in Eastern Ontario.

The Gull River Formation has a thickness range of 7.5 to 136 m and consists of limestones and silty dolostones. The Bobcaygeon Formation consists of 7 to 87 m of limestones and some shales. The Verulam Formation consists of limestones with interbeds of shales and has a thickness range of 32 to 65 m. The youngest unit in the sequence is the Lindsay Formation. It has a thickness of up to 67 m and consists of limestones and calcareous shales (Thurston et al., 1992).

The Upper Ordovician sediments of the Ottawa-St. Lawrence basin consist of the Billings, Carlsbad, and Queenston Formations. The Billings Formation has a thickness of up to 62 m and consists of shales. The Carlsbad Formation is comprised of interbedded shales, siltstones, and limestones and has a maximum thickness of 186 m. The Queenston Formation consists of shales with interbeds of limestones and calcareous shales (Thurston et al., 1992).

The original uniform configuration of the Paleozoic deposits of the Ottawa-St. Lawrence Lowland has been modified greatly by two major sets of faults. Of these, the principal set of faults, or in some places fault zones, has a general east-southeast trend. The bedrock is tilted and faulted so that a major downfaulted block, or graben, exists between the north shore of the Ottawa River and a fault in the vicinity of Russell, Ontario. The fault is assumed to extend northeasterly, passing between the village of Lemieux and the town of Casselman. The block is further disjointed by faults trending southeasterly.

Glacial History

Pleistocene and recent deposits overlie the Paleozoic bedrock. These deposits are referred to as overburden or unconsolidated deposits and include glacial, glacio-marine, marine and fluvial deposits of Pleistocene age with minor amounts of alluvial and swamp deposits of Recent age. The bedrock outcrops at the surface at several locations within the basin, namely, in the southernmost and northwestern parts of the basin. Elsewhere, the overburden thickness ranges from less than 10 m over most of the southern areas to more than 50 m in the northeastern and central areas.

Throughout most of Eastern Ontario, clays of the Champlain Sea overlie the bedrock and glacial till deposits. In some areas, sand and gravel deposits are essentially continuous from the soil horizon to the bedrock providing direct access for meteoric water to reach deeper aquifer systems.

Till and reworked glacial debris probably derived from till by wave action in the Champlain Sea and/or by other younger weathering processes, are exposed at Casselman and St. Albert. In these places, thin sheets of calcareous sandy grey till are present, but generally they are masked by poorly sorted gravelly glacial debris grading downwards into the typical gravelly to sandy silt till. The best exposure occurs on the west bank of the South Nation River near the Casselman dam where it is only about 1 meter thick (Gadd, 1976). It is overlain by 10 to 20 cm of thin-bedded, red and grey silts that grade upwards into typical banded marine clay. Extensive swamp deposits consisting of peat and muck are found in topographically low areas mainly within Alfred and Winchester.

Of particular importance to the distribution of groundwater resources is the distribution of the eskers with their associated subdued landforms and of drumlins. Esker deposits are recognized as long sinuous and semi-continuous ridges of sand and gravel, oriented north-south. The distribution of the esker complexes is shown in Figure 2. Drumlins are elongated hills with a core of till material, also shown in Figure 2.

Hydrogeology Implications

Chin et al. (1980) indicated that the groundwater supplies from bedrock aquifers in the basin provide adequate quantities of water for domestic uses but are generally inadequate for uses requiring higher yields. Based on lithologic composition, Chin et al. (1980) identified three major bedrock aquifers in the basin, a limestone/shale aquifer (Ottawa Formation), a limestone/dolomite aquifer (Oxford Formation), and a sandstone aquifer (March Formation). Together, the limestone/shale and limestone/dolomite aquifers cover about four-fifths of the basin.

According to Chin et al. (1980), the sandstone aquifer is the most productive bedrock aquifer in the basin. The limestone/dolomite aquifer has the potential for higher yields and it usually contains fresh water. The limestone/shale aquifer, on the other hand, often contains saline and highly mineralized waters.

Faulting and fracturing within the March, Ottawa and Oxford Formations control's the amount of water that can be extracted and conducted through them. Where fracturing is intensive, large quantities of water suitable to supply communal systems may be extracted. The primary aquifer in Eastern Ontario consists of the upper portion of the fractured Paleozoic bedrock and sand and gravel deposits, which directly overlie the bedrock in the lower portion of the overburden. This aquifer system is referred to as the Contact Zone Aquifer (EOWRMS, 2001). The clay and fine-grained deposits in the region act as a confining layer for the Contact Zone Aquifer. The low conductivity of the confining layer is instrumental in preserving the quality of water in the fractured bedrock and sand and gravel aquifer as it significantly decreases the downward migration of recharge from the surface to the aquifer. In regions where the glacial till is absent, the aquifer is more exposed to contamination due to the fact that the attenuation ability of the overlying soil provides a degree of protection to an aquifer (EOWRMS, 2001). In addition, the geologic protection afforded to an aquifer is primarily a function of the thickness, vertical hydraulic conductivity of geologic material overlying the aquifer as well as the direction and magnitude of the hydraulic gradient. The vertical hydraulic conductivity and the gradient determine the recharge to the aquifer.

3.3 Regional Hydrology

The quantity of water available to replenish surface and groundwater resources in Eastern Ontario is quite large. However, a major constraint on the quantities of water available for use and development relate to the fact that much of the precipitation falls in the spring, early summer, and late fall and much of it is lost to runoff; while most of the evapotranspiration occurs in summer. This time lag between the supply and demand for water is problematic: Excess supply of water in the early spring can runoff before the groundwater system can fully recharge, and excess demand in the summer takes a further toll on the groundwater system. Most of the available water contributes to the surface water resources: the EOWRMS estimates that an average of 31.2mm/year actually infiltrates compared to an average of 930mm/year of precipitation. The net result is that groundwater resources are generally vulnerable in the region. Therefore, particular care should be taken to ensure the conservation and sustainability of groundwater resources and the protection of significant recharge areas.

The EOWRMS (2001) gives maps of the bedrock surface elevations and the calculated overburden thickness, which show the variation in overburden thickness and the bedrock surface within Eastern Ontario. Generally, areas with a large thickness of overburden are more likely to have large quantities of sand and gravel that can act as aquifers. Figure 2 shows the location of sand and gravel in the upper portion of the overburden. Areas with a sand and gravel thickness of greater than 2 m are considered to be possible aquifers that could supply groundwater to a well. Generally, larger areas have greater potential for the aquifer to supply water. Based on the EOWRMS conceptual model, the lower overburden aquifers have the greatest potential for development when combined with the upper portion of the bedrock. The degree of geologic protection from contamination varies throughout the study area. In general, the lower overburden aquifers have a lesser potential for contamination than the upper overburden. However, in many cases, the two aquifers may be connected such that the lower overburden aquifer may be as vulnerable as the upper overburden aquifer. The EOWRMS presented maps of aquifer vulnerability based mostly on thickness of overlying material, which show several areas within the study area where there is little protection from the overlying geologic material.

The Champlain Sea deposits in Prescott & Russell and the City of Ottawa have the least amount of recharge to the Contact Zone Aquifer, while more permeable deposits throughout Eastern Ontario have moderate to high values of recharge. The highest values of recharge occur on topographic highs where the largest downward gradients exist and in areas of thinner and/or permeable overburden such as in southwest Stormont, Dundas, and Glengarry (SD&G) and near Maxville (EOWRMS, 2001).

4. Methodology

Groundwater seepage flux into or out of a surface water body is a measure of the volumetric flow rate crossing a unit area of sediment bed. For vertical co-ordinates increasing upward, groundwater discharge areas have a positive seepage flux and groundwater will enter the surface water body from the ground. Conversely, recharge areas have a negative groundwater seepage flux (also called leakage), and water will enter the groundwater from the surface water.

There are several methods that can be used to measure groundwater-surface water interactions; however, they are based on large scales (hydrograph separation) or are point estimates that are difficult and/or labour-intensive (seepage meters and piezometers). An alternative method for identifying zones of groundwater discharge is to use an electrical conductivity and temperature (ECT) probe in conjunction with a Global Positioning System (GPS) to map ECT anomalies in the river. The method depends on the presence of a contrast in electrical conductivity and/or temperature between the groundwater seeping into the river and the river water. At the point of discharge, the water from the flow system is likely to have higher level of dissolved minerals because of mineral dissolution as it travels through the ground. The water is also likely to have a lower temperature than river water because surface waters are warmed up by ambient summer air temperatures. This is the case in many if not most gaining rivers, such as the South-Nation.

This study seeks to provide information on small-scale variability of groundwater seepage in the South Nation River. The electrical conductivity method was used because a large territory can be covered in a relatively short time. On the down side the measurements obtained are semi-quantitative, giving only areas of possible groundwater discharge. Generally, seepage measurement methods fall into two broad categories: Direct measurements and indirect measurements. Direct methods give accurate punctual measurements of discharge or recharge (as the case may be); their draw-back is that they are extremely labour-intensive and are thereby impractical at the scale of a basin. Indirect methods infer groundwater seepage from hydrographs or from other measurements, such as

ECT. Hydrograph separation methods give estimates that are integrated at the scale of the basin, which is too coarse for modeling applications. The ECT method, on the other hand, gives small-scale measurements at a reasonably fast rate; but it can only be used to detect zones of possible seepage; it does not give a numerical value, nor can it be used to measure groundwater recharge.

In this study, as mentioned earlier, we used the ECT method over a large portion of the South Nation River and made direct measurements over a small segment near Cass Bridge, to verify the method. The direct methods are illustrated in Figures 3-4 and the ECT method in Figures 5-7. The following is a brief review of the different methods and indicators that can be used to identify zones of groundwater seepage (and possibly measure seepage fluxes). Where appropriate the discussion was expanded to describe the particular methods used in this study. More emphasis was placed on the ECT method since it is the principal method used in the study.

4.1 Closed Top Seepage Meters

Small-scale measurements of groundwater seepage flux are traditionally made with a closed-top seepage meter, originally described by Lee (1977). A schematic diagram is given on the left hand side of Figure 3. The closed-top seepage meter consists of the end section of a $0.203m^3$ steel drum installed into sediment with its open end facing down. The installation procedure is described in detail by Lee and Cherry (1978). The drum is positioned deep enough that it is sealed against the sediments along its circumference but the top of the drum lid is not touching the sediments. The drum is placed into the sediments at an angle with the hole on the top of the drum at the highest point in order to allow the escape of entrapped gases. Once installed into the sediment, all of the water that enters or exits the sediment interface passes through the small hole on top of the drum. A rubber stopper, holding a 10-15cm long polyethylene tube is inserted in the hole at the top of the drum. A plastic collection bag with a know volume of water is attached with a rubber band to the tube. The collection bag is used to measure the volume of water entering or exiting in a given time; this is the volumetric flow rate. The groundwater seepage flux is determined by dividing the volumetric flow rate by the cross sectional area covered by the drum.

Closed-top seepage meters were not used in this study because of difficult access: the sediments were too soft or the river was too deep. Indeed there are very few areas along the South Nation River with a riparian zone amenable to the installation of traditional closed-top seepage meters.

4.2 Open Top Seepage Meters

The open-top seepage meter measures the same volumetric flow rate as the closed-top model, but its physical setup and installation are somewhat different. The open-top seepage meter is made of a thin-walled pipe of any desired length and reasonably large diameter. The pipe is inserted into the sediments at the needed depth and remains open to the atmosphere at the top. A piece of tubing is used to create a hydraulic bridge between the inside of the pipe and the water in the river, this hydraulic bridge acts as a siphon and ensures that the water level inside the seepage meter remain the same as the water level in the river. A plastic collection bag is attached to the end of the hydraulic bridge on the outside of the pipe. The volumetric flow rate is the volume of water that enters or exits the bag at a given time. The groundwater seepage flux is the volumetric flow rate divided by the cross-sectional area of the pipe. Figure 3 gives an illustration of an open-top seepage meter on the right-hand side.

In this study, several open-top seepage meters were installed near Cass Bridge, along a 2-km stretch of the river. The particular stretch of the river was selected because of the presence of EC anomalies and because of the easy access at Cass Bridge. Inexpensive, thin-walled, two-inch PVC pipe was used for the riser pipes (this kind of piping is normally used to for domestic, build-in vacuum systems); and 3/8-inch polyethylene tubing was used for the siphon. The piping was measured and installed to a depth of approximately 1m in the sediments using a hammer consisting of a solid mass of aluminum welded to a 3-inch aluminum pipe. The process is illustrated in Figure 4. Installation was somewhat difficult because of the rocky bottom, and often had to be repeated several times. The seepage meters were allowed to equilibrate for one week without the siphons installed. Water levels were then measured inside and outside of the meters to obtain piezometric measurements. A siphon and 2-L collection bag was then installed on each meter and the seepage meters were allowed to seep for approximately one week. Seepage fluxes were then measured and corrected for changes in the water level of the river.

4.3 Mini-Piezometers

Hydraulic head is defined as the energy possessed by a unit weight of water at a particular point (Freeze and Cherry, 1979). In practical terms, it is measured as the elevation of water in a piezometer above a specific reference point or datum. A piezometer is the device used in the field to measure hydraulic head; it is a tube or pipe in which the water level can be determined. A piezometer is sealed along its length, it is open to water flow at the bottom and open to the atmosphere at the top. The intake at the base of the piezometer is a slotted or screened section that allows water to enter, but preventing sediments from entering the piezometer. The point of measurement in a piezometer is at its open base. A diagram of a piezometer is given in Figure 3, at center.

If a piezometer is installed in the sediments of an open body of water, then the piezometer can be used to measure the vertical component of hydraulic gradient (dh/dl). The vertical component of the gradient is the difference between the water level in the piezometer and the water level in the river (dh), divided by the distance between the screened tip of the piezometer in the sediments and the river bed (dl). Figure 3, at center, illustrates the installation of a mini-piezometer in an open body of water, and the dh/dl measurements.

4.4 Electrical Conductivity and Temperature Measurements

Electrical Conductivity

The specific electrical conductance or conductivity (EC) of water is the ability of a cube of water, with sides measuring 1 cm, to conduct electrical current. It is numerically equal to the reciprocal of the resistance and it has units of Siemens per cm and is most often measured in microSiemens per centimeter (μS/cm = 10^{-6} S/cm) or milliSiemens per centimeter (mS/cm = 10^{-3} S/cm). EC is dependent on temperature and on the type and concentration of the dissolved ions. It is usually defined at 25°C, so that differences in conductance are a function of the concentration and type of dissolved ions only. The specific electrical conductance permits a rapid evaluation of the chemical quality of the water sample (i.e. its total dissolved electrolyte content).

The EC sensor simply consists of metal electrodes that are exactly 1.0 cm apart and are submersed in water. An electrical potential difference between the electrodes produces a current that flows through the water. The resulting current is proportional to the concentration of dissolved ions in the water - the more ions, the more conductive the water resulting in a higher electrical current, which is measured electronically. Distilled or de-ionized water has very few dissolved ions and so there is almost no current flow across the gap (low EC). In fact the specific electrical conductance of water in its purest state is 4.2×10^{-2} μS/cm (Matthess, 1982). However, this degree of purity cannot be maintained. Trace impurities raise the conductance so that the specific electrical conductance of the purest water obtainable in practice is 7×10^{-1} μS/cm, and that of common distilled water is 0.5 - 5 μS/cm (Matthess, 1982). For reference, the following table gives typical EC ranges for different types of water:

Type of water	Total Dissolved Solids (mg/L)	Electrical conductance (μS/cm)
Fresh water	0 - 1000	0 - 1500
Brackish water	1000 - 10000	1500 - 15000
Saline water	10000 - 100000	15000 - 150000
Brine	>100000	>150000
Potable water	< (2000 - 3000)	<(3000 - 4500)
Sea water	≈ 35000	≈ 52500
Rain water		<10's
River water		100's
Groundwater		10's - 10000's
Distilled water		<10's
Reverse-osmosis water		<100's

Electrical conductivity (EC) can be used to estimate the amount of total dissolved solids (TDS), or the total amount of dissolved ions in the water. There is a linear relationship between TDS and EC:

TDS (in mg/L) = A * EC (in $\mu S/cm^{-1}$)

with A = 0.55 – 0.75 depending on the species dissolved (Freeze and Cherry, 1979); a good rule of thumb is to use A = 2/3.

EC is controlled by:

1. Geology (rock types) - The rock composition determines the chemistry of the watershed soil and ultimately the lake or river. For example, limestone leads to higher EC because of the dissolution of carbonate minerals in the basin.
2. The size of the watershed relative to the area of the lake or river - A bigger watershed to river surface area means relatively more water draining into the river because of a bigger catchment area, and more contact with soil before reaching the river.
3. Other sources of ions to river or lakes - there are a number of sources of pollutants, which may be signaled by increased EC:
   -Wastewater from sewage treatment plants (point source pollutants).
   -Wastewater from septic systems and drain field on-site wastewater treatment and disposal systems (non-point source pollutants).
   -Urban runoff from roads (especially road salt). This source has a particularly episodic nature with pulsed inputs when it rains or during more prolonged snowmelt periods. It may "shock" organisms with intermittent extreme concentrations of pollutants, which seem low when averaged over a week or month. Agricultural runoff of water draining agricultural fields typically has extremely high levels of dissolved salts (non-point source of pollutants).
   -A fraction of the total dissolved solids, nutrients (ammonium-nitrogen, nitrate-nitrogen and phosphate from fertilizers) and pesticides (insecticides and herbicides mostly) typically have significant negative impacts on streams or lakes receiving agricultural drainage water. If soils are also washed into receiving waters, the organic matter in the soil is decomposed by natural aquatic bacteria, which can severely deplete dissolved oxygen concentrations.
   -Atmospheric inputs of ions are typically relatively minor except in ocean coastal zones where ocean water increases the salt load of dry aerosols and wet deposition. This oceanic effect can extend inland about 50-100 kilometers and can be predicted with reasonable accuracy. It is not expected to have any impact in this study area.
4. Evaporation of water from the surface of a lake concentrates the dissolved solids in the remaining water - and so it has a higher EC.

During the summer of 2002, zones of groundwater discharge were identified along the South Nation River using an electrical conductivity and temperature (ECT) probe in conjunction to a Global Positioning System (GPS). The ECT was dragged along the bottom sediment and measured electrical conductivity and temperature while the GPS was kept in a motorboat and measured position. The boat traveled at approximately 4 -7 km/hr while the ECT and GPS took measurements every 30 seconds. Surveying involved two persons; one piloting the boat and the other attending to the towing cable, manning the equipment and taking notes on important features such as tributaries and agricultural drainage pipes flowing into the river. Measurements were taken on the two banks and in the center of the river in order to get a cross-sectional analysis. River depths at the center ranged from 2 meters to 15 meters.

The Global Positioning System used was a MEMTRAK™, a mobile unit that stores position reports to its internal RAM memory storage for later download to a PC. The MEMTRAK™ unit was placed in the boat and connected to an external battery. The small GPS antenna is connected to the unit and placed in the boat so that it can "see the sky". The MEMTRAK™ unit can be user programmed to automatically calculate GPS position reports and time tags at user defined intervals. In this case it was programmed to calculate position every 30 seconds.

The ECT probe used was manufactured by Solinst Canada and is shown in Figure 7. It is a 25-cm-long, 8-cm-diameter, stainless-steel cylinder that weighs approximately 1 kg. A 2-cm hole in the side of the probe allows water to flow through and come in contact with a set of electro-conductive pins that are precisely spaced. The probe is calibrated in a 0.01M solution of KCl, to produce an electrical conductivity of 1470 μS/cm at 25°C. All EC readings are corrected to 25°C.

The probe is attached to a 20 meter long tow cable which contains a series of weights in a tygon casing that help keep the electrodes (pins) in contact with the bottom sediments. The cable extends from the probe to a data acquisition system (Reelogger™ system) on board the boat.

As mentioned earlier, this technique requires a contrast between electrical conductivity and temperature between the groundwater and river water. Groundwater commonly has a higher electrical conductivity then surface water because it picks up dissolved ions as it travels through the ground. The electrical conductivity mapping technique identifies groundwater discharge by measuring variation in sediment pore water electrical conductivity; normally areas of higher electrical conductivity correspond to groundwater discharge into the river.

4.5 Reconciliation of Electrical Conductivity and Temperature Measurements

Due to the fact that groundwater-surface water interactions can change depending on day-to-day occurrences such as precipitation events and evaporation, reconciliation between days had to be performed. On June7, 2002 the electrical conductivity of several sections of the river was measured. An average EC of this day was calculated (507.2 μS/cm) and weighed against each individual day. All measurements were reconciled to the June 7, 2002 date. The calculation used was;

Value corrected to June 7 = Uncorrected Value + (Average EC of June 7 – Average of Uncorrected Values)

For example, electrical conductivity values for May 23 were corrected using the equation;

Value corrected to June 7 = Uncorrected Value + (Average of July 7 (507.2mS) - Average of May 23 (456.7))

This calculation was also performed on a day-to-day basis. Each day, a section of the river that was measured the previous day was measured again. Any inconsistencies between the measurements were taken into consideration. For instance, if measurements were 500μS/cm in one location on one day and were measured to be 520μS/cm the next day then each measurement taken the next day would be deducted 20μS/cm.

To rule out any other possibility than groundwater discharge zones, other factors were taken into consideration. Drainage pipes from farmlands flow into the river during certain times of the year and can affect the electrical conductivity in that particular area. The electrical conductivity of the water running out of the drainage pipes was measured using a hand-held electrical conductivity probe. In order to compare the EC of the river and the EC of the drainage water, a calibration between the two probes was performed. It was found that the hand-held probe was approximately 100μS/cm above the ECT probe, which was adjusted for. ECT measurements of tributaries were also taken in order to rule out the possibility that high ECT values were caused by inflowing surface water.

4.6 Other indicators

The interaction between groundwater and surface water has an influence on nutrient fluxes in rivers and streams (Fiebig et al., (1990), Triska et. Al (1993)). Di Iorio (2002) showed that there is a good correlation between groundwater seepage and the Pickerelweed distribution. Groundwater has significantly higher electrical conductivity, therefore it contains more ions. It is possible that discharge areas provide more nutrients for the Pickerelweed, which causes their distribution to be centered on areas of groundwater discharge.

Groundwater flow can be summarized as a process whereby water flows from areas of high potential (elevation) to areas of low potential (elevation) therefore topography can be an indicator of groundwater seepage. The high potential areas represent recharge areas where groundwater flow is generally downwards into an aquifer, such as topographic highs. Areas of low potential are discharge zones where groundwater flow is generally upwards towards surface water features such as streams. Aquifers lose water by discharge to surface water features. The discharge groundwater can contribute a significant portion to the flow of rivers. The degree of the groundwater contribution to a stream flow can fluctuate temporally since it depends on net infiltration inputs, which themselves depend principally on precipitation, evaporation and surface runoff. Therefore, the amount and intensity of precipitation in a watershed can vary considerably over the course of a year, thus the groundwater component of stream flow can also be quite variable in time. Porter (1996) concluded that seepage could be positive or negative depending on the time of year, which suggests that a few measurements in time cannot be used to produce a conclusive flow regime of the watershed.

Landslides are also indicative of groundwater seepage. High landslide potential is correlated with a high level of saturation of the clay, which may be related to the presence of sand cover over the marine clay (Gadd, 1976). Saturation and high pore-water pressures in clays are principal factors in the landslide mechanism.

5. Results and Discussion

5.1 Correlation between EC and temperature

The EC values in the south Nation River ranged from around 70 μS/cm near the confluence with the Ottawa River to around 660 μS/cm where Highway 417 crosses the South Nation River. The temperature range was from 18 to 28 °C.

As mentioned earlier, zones of groundwater discharge are often associated with areas of high EC and low temperature. One would therefore expect a negative correlation between the two parameters (a decrease in one variable as the other increases). However, the temperature and EC did not correlate very well in the South Nation River. Figure 8 gives temperature as a function of EC for all data points on the South Nation River. Although there is no clear trend, it is possible to determine areas of waters of differing EC-T signatures, which appear as clusters on the graph. The clusters were circled and numbered on Figure 8 and the corresponding geographical areas of origin are indicated on the map given in Figure 9(a) and 9(b).

Clusters 1,2,5, and 6 all have similar EC values but progressively warmer temperatures. A clear association of temperature values could not be identified and may simply be related to the air temp temperature and sunshine level the day of measurement.

Clusters 3 and 4 have a midrange temperature but high EC values. They correspond to waters in the Castor River and immediately downstream of the confluence of the Castor River with the South Nation River; as well as the waters between Lemieux and Plantagenet.

Undoubtedly, cluster 7 stands out the most, with its low EC values and mid-range temperatures. This cluster corresponds to the confluence of the South Nation River and the Ottawa River and therefore reflects the mixing of the two waters. The EC of the Ottawa River is much lower than that of the South Nation, but it is unlikely that it would be as low as around 100 μS/cm. It is therefore possible that an additional source of lower EC water can be seeping into the system at this location. The preponderance of geological faults and high relief topography in the area supports the hypothesis that there could be a short-residence time pathway for relatively unaltered rainwater in the area.

It is recommended that additional EC measurements be made in the Ottawa River, both up- and downstream from the confluence with the South Nation River, as well as at the mouth of the South Nation River. This will determine the baseline EC value of the Ottawa River and help assess the impact of the South Nation River on the Ottawa River. If low EC waters are found to be seeping into the South Nation (and possibly the Ottawa) River then an attempt should be made to locate the area(s) of recharge for these waters (which should be fairly close by) so that the area(s) can be protected.

5.2 Correlation between EC and seepage at Cass Bridge

Laura Beauchamp, a 4th year Environmental Studies student at the University of Ottawa, used the information gathered to determine locations for the installation of piezometers. She found that peaks of electrical conductivity corresponded to seepage, and areas where no peaks were found showed no significant seepage. Seepage values were on the order of 25.4 mm/year; hydraulic gradients averaged 0.654 m, and the resulting hydraulic conductivity of the sediments was around 23.3 m/day.

5.3 Effect of turbidity on EC

The effect of turbidity on EC was examined by BSc Student Laura Beauchamp (2003) using Time Domain Reflectrometry (TDR). TDR is a commonly used method for measuring water content of soils in agricultural research applications; but it was shown in this study to be effective at measuring the soil content of water (turbidity). TDR can also be used to measure EC simultaneously (Topp et al., 2002). The technique was used to show that the effect of turbidity on EC was not significant in the South Nation River ($p<0.05$). Another interesting outcome of this study is that TDR appears to be a very promising method for large-scale EC surveys such as the one reported here.

5.4 Electrical conductivity profile of the South Nation River

The survey was conducted from May 23, 2002 to August 19, 2002. Because of the large scale of the study, small-scale details of the ECT survey do not show very well on a map of the full study area. A profile of the EC along the river proved to be far more instructive, particularly when complemented with blow-up maps of the areas of interest. Figure 10 presents the EC profile, giving EC as a function of downstream distance from the most upstream location of the survey (approximately 5 km upstream of Cass Bridge). Because of GIS limitations the distance was measured in a straight line from the reference point to the measurement point rather than from point to point along the river. The data plotted on Figure 10 also includes measurements made along a short distance in the Castor River, near its confluence with the South Nation River. Gaps in the data record correspond to locations in the river that were not navigable safely. The gray area on the figure corresponds to actual measurements and the dark line is a moving average. Figure 10 also identifies landmark locations along the river (towns, villages, etc), geological faults, tile drainage sampling points, and EC anomalies, which will be discussed shortly. A map view of the study area is given in Figure 11, in which portion of the South Nation that was surveyed is shown as a bold line. The locations of the anomalies and of major geological fault lines in the area are also shown in Figure 11.

General EC levels

As shown in Figure 10 the EC values in the South Nation River are in the 500 - 600 μS/cm range, which is quite high relative to other rivers in the area (the Ottawa River for instance has EC values in the 200 μS/cm range). This indicates that the level of dissolved electrolytes in the river is quite high, which is likely the result of non-point source contamination. The EC levels in the river remained near 500 μS/cm from the headwaters to the confluence with the Castor River, where they rose sharply to around 560 μS/cm. The EC values remained at this level downstream to the Ottawa River where mixing with the Ottawa River (and possibly other sources of low-EC waters) reduced the EC values.

There was an obvious contribution of the Castor River to the higher EC values in South Nation but if this were the only high EC contribution we would have expected the EC levels to eventually drop back down to the 500 μS/cm levels because of dilution with additional incoming waters. The fact that the EC levels remained high indicates that the waters contributed to the South Nation from groundwater or from other streams have a higher EC value downstream from the confluence with the Castor River than upstream. This may be the result of different land usage (agricultural practices and population density) and/or groundwater discharge from deep-circulation systems in the entire area. The latter hypothesis is supported by the regional groundwater discharge patterns given in the EOWRMS for this particular area. It is recommended that these issues be resolved with additional EC measurements in the Castor River and in the tributaries of the South Nation River downstream of the Castor. If specific sources of high EC waters cannot be identified then it is recommended that piezometers be installed in areas of high EC contributions.

Transverse EC profiles

During the survey EC values were measured near each bank of the river and at the center. There was no consistent trend but one bank was often much more conductive than the other, depending on the land use adjacent to the river. In some locations the center of the river was more conductive than the two banks, which may indicate groundwater discharge from a deeper circulation pattern.

These observations can be supported by examining the variability of the measurements (gray area) around the moving average (dark line) shown in Figure 10. As can be seen, some areas showed more variability than others; for instance, the area between Cass Bridge and Chesterville shows much more variability than the area downstream from Chesterville. Upon close examination of the detailed maps (Appendix 1), it becomes apparent that the variability is caused by EC differences from one bank to the other or between the two banks and the center of the river: since all points on a transverse section of the river plot at nearly the same longitudinal distance, variability in the transverse direction will appear as variability around the moving average in the longitudinal distance.

A noteworthy area of extreme variability in the EC readings is the area between the confluence of the Castor River and Casselman (c.f. Figure 10). The variability here is caused largely by the fact that the Castor River has a significantly higher EC than the South Nation River (more on this shortly). Since both rivers plot at the same distance from the headwaters, the differences translate into high variability in the profile.

Examining the variability around the moving average in Figure 10 is therefore an extremely valuable exercise. It enables the water resources manager to pinpoint areas where electrolyte loading may be a problem.

Unexplained anomalies

The EC profile of the South Nation River in Figure 10 shows numerous positive anomalies, as spikes above the average, and negative anomalies, below the average. The more pronounced anomalies are labeled. The anomalies are shown in blown up maps in Appendix 1 along with the locations of geological fault lines, where appropriate. The following table summarizes the anomalies labeled in Figure 10.

Anomaly (from Figure F)	Reason
A	Possible groundwater discharge. To be verified.
B	Possible groundwater discharge. To be verified.
C	Possible groundwater discharge. To be verified.
D	Unknown source of low EC water. To be verified.
E	Groundwater discharge. Verified, L. Beauchamp (2003)
F	Unknown source of low EC water. To be verified.
G	Unknown source of low EC water. To be verified.
H	Possible groundwater discharge. To be verified
I	Possible groundwater discharge. To be verified
J	Possible groundwater discharge. To be verified
K	Area is not navigable.
L	Mixing of high EC Castor River waters with South Nation River waters. Source of high EC in Castor should be identified.
M	Unknown source of low EC water. To be verified
N	Area is not navigable.
O	Unknown source of low EC water. To be verified.
P	Unknown source of low EC water. To be verified.
Q	Mixing of high EC South Nation River waters with low EC Ottawa River waters. Source of low EC should be identified.

As can be seen from Figure 10 there are numerous positive anomalies along the river. The ones near Cass Bridge were shown to correspond to zones of groundwater discharge. Several other anomalies are discussed in some detail in the paragraphs that follow, but the majority many remain unconfirmed and unexplained. It is therefore recommended that the unexplained positive anomalies be confirmed (with EC measurements) and explained, possibly with additional instrumentation.

A very interesting result of this survey is the presence of "negative" anomalies: EC values that are below average. These may also correspond to local discharge areas but with water that is less conductive than the South Nation River water. The EC values of the negative anomalies are in the range of "normal" streams in the area, which suggests that the anomalies more likely correspond to inflows of "normal", less conductive creeks and ditches and surface runoff, into a river that is of "abnormally" high EC values. It is recommended that the negative anomalies be investigated to confirm their presence and to determine their cause(s).

Road salt and/or septic system influence near Highway 417 crossing.

Figure 10 shows a rather extensive, low amplitude, positive anomaly between the Castor River and Casselman. This anomaly is located along a 2-km stretch of the river (approximately), near the point where the river is over-passed by Highway 417. It is believed road salt may be to blame in large part for the high EC values. The area also coincides with a number of residences that are located in relatively close proximity to the riverbank. The septic systems of these residences may also be contribution to the salt loading of the river in the area. It is recommended that additional measurements be made in the area in an attempt to identify the exact cause for the anomaly.

Confluence with the Castor River

The confluence with of the Castor River with the South Nation River is marked by a sharp increase in EC values. The high EC values originate from the Castor River. The Castor River runs through agricultural land and several villages (e.g. Russell and Embrun) and it is very possible that the high EC values of the Castor River arise from land usage. However, deep-circulation sources of groundwater cannot be ruled out, because the Castor River intersects numerous geological faults in the area. It is highly recommended that the sources of high EC be identified in the Castor River: Additional EC measurements should be made in the Castor along with piezometric and direct seepage measurements where warranted. If the sources of high EC waters are found to be anthropogenic then immediate corrective action should be taken.

Confluence with the Ottawa River

The area between Plantagenet and the Ottawa River shows marked decreases in EC values. This is shown as Anomaly Q in Figure 10, which is also indicated on the map of Figure 11. These low EC values are the result of mixing with Ottawa River waters, which have much lower EC values. The lowest EC values were in the 70 μS/cm range, which is extremely low, and which may indicate the influence of other sources of low EC waters. This hypothesis is supported by the preponderance of faults in the area, which could provide a short path between nearby areas of recharge and the river. Other supporting evidence for short pathways is the presence of sharp topographical contrasts in the area. It is recommended that these issues be resolved with additional measurements in the South Nation River and in particular in the Ottawa up- and downstream from its confluence with the South Nation. This will also provide additional information on the impact of the South Nation on the Ottawa.

Effects of geological faults

Major geological faults can, in some cases, play an important hydrogeological role. Some faults become hydrogeologically inactive in time because of mineral infilling whereas others remain open and active; they then act as conduits for groundwater. If a hydrogeologically active fault is connected with a deep circulation pattern then the water it carries can have a high EC, which can discharge to surface waters in some locations. Conversely, faults could also conceivably produce discharges of low EC if they are connected to shallow circulation system originating in low EC recharge (such as a surface water body). The impact of a fault system is expected to be most pronounced when the overburden is thin, a situation that is encountered mostly at, and upstream of Casselman.

The fault zones in the study area were mapped in Figure 11 and the intersection of the faults with the South Nation River are indicated on Figure 10. As can be seen from these two figures there is no apparent correspondence between the locations of faults and EC anomalies. Possible exceptions are at the Castor River and at the Ottawa River. However, the anomalies a both of these locations can also be explained by other factors. The main conclusion here is that the location of faults is not a reliable indicator of groundwater discharge areas.

Effects of surficial geology

Contacts between hydrogeologically different materials can sometimes correspond to areas of discharge (or occasionally recharge), particularly if there is a large contrast in hydraulic conductivity between materials at the contact zone. Figure 2 is a map of the surficial geology of the study area. It shows several areas where there are large contrasts between surface materials. Comparing the location of the contacts in Figure 2 with the anomalies in Figure 10 shows that there was no clear correspondence between them in the South Nation River.

Tile drain effluent measurements

The EC of several tile drain effluents was measured at locations and times when they were flowing. No measurements could be made downstream of Casselman because of the time of year (the survey took place in August downstream from Casselman). The EC values are plotted in Figure 10 and mapped in Figure 12. The numbers given in Figure 12 are the difference between the EC reading at the drainpipe and the EC value of the river, averaged in the vicinity of the drainpipe. EC values were corrected to account for calibration differences

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between the different probes used. In all cases the EC values of the drainpipes exceeded the river values, by approximately 100 to 200 μS/cm, and sometimes by up to 300 to 400 μS/cm. There was a cluster of particularly high EC values a few km upstream from Crysler.

It is clear from these measurements that the tile drains are contributing significantly to the high EC of the South Nation River, which indicates that changes to land management practices could have a significant impact on the river water quality. While this result is not unexpected, a very important unforeseen benefit of this methodology is that it was particularly effective at identifying specific sources of loading in the river. The implication is that the method could be used to monitor the river in general and most importantly to help focus efforts to change land management practices at the individual field level. It is recommended that the EC of drainpipe effluent be measured regularly, as part of the monitoring program.

6. Summary and conclusions

The primary objective of this study was to identify zones of groundwater discharge in a portion of the South Nation River by taking advantage of differences between surface water and groundwater ionic strengths and temperatures. It was hypothesized that low temperatures would correspond with high electrical conductivity, as they do in many river systems. However, in the South Nation River, it was found that there was no relationship between the two and that temperature is not a good indicator of groundwater discharge. In addition, the level of turbidity did not affect the EC reading significantly.

Electrical conductivity at the water-sediment interface was measured along the river. In general, it was found that the EC of the South Nation River is much higher than other rivers in the region, and as a result EC contrasts were more difficult to identify. The EC increased downstream in one step at the confluence with the Castor River. Many anomalies were found of both higher and lower EC than the average.

It was originally thought that large aerial extents of high EC measurements would be found, due to regional groundwater discharge; but instead, anomalies were extremely restricted in aerial extent, showing up as sharp peaks. This is an extremely important find as it indicates that groundwater seeps may be extremely localized (on the order of a few meters in extent). This could be due to local groundwater discharge through fault and fracture zones, in particular in areas where the riverbed is in contact with bedrock. The possible areas of groundwater discharge that were identified with this method should be verified in later work.

As an added benefit, the EC&T method was extremely useful at determining areas of electrolyte loading along the river, including point sources or semi-diffuse sources. For this reason alone, we believe that this tool should be part of the arsenal of tools utilized by the conservation authorities to monitor the state of the river. Another very important conclusion is that it is not sufficient to make EC readings near the surface of the water because mixing will blur the picture considerably; EC measurements should be made at the sediment-water interface.

Low electrical conductivity anomalies were also observed. While this issue should be further explored, it is hypothesized that they are the result of "normal" surface waters entering an "abnormally" high-EC river system.

Water from agricultural drainage pipes was tested and was found to have a much higher EC than the river water. This is further evidence that indicates that land use practices may be root cause for the poor quality of the South Nation River. An extremely important conclusion is that the tool used in this study can be used to pin-point the sources of electrolyte loading in the river.

7. Recommendations

Several specific recommendations were made in the discussion of the results; they are summarized here and additional recommendations are made of a more general nature.

1- Additional EC measurements should be made in the Ottawa River, both up-and downstream from the confluence with the South Nation River. This will determine the baseline EC value of the Ottawa River and help assess the impact of the South Nation River on the Ottawa River. If low EC waters are found to be seeping into the South Nation (and possibly the Ottawa) River then an attempt should be made to locate the area(s) of recharge for these waters (which should be fairly close by) so that the area(s) can be protected.

2- Additional EC measurements should also be made in the Castor River and in the tributaries of the South Nation River downstream of the Castor, to identify the source(s) of high EC waters entering the system. If specific sources of high EC waters cannot be identified then it is recommended that piezometers be installed in areas of high EC contributions to establish the deep groundwater discharge patterns.

3- Unexplained positive and negative anomalies should be confirmed with additional EC measurements and explained, possibly with additional instrumentation such as seepage meters and piezometers. For comparison, EC measurements should also be made on groundwater from deep and shallow wells in the vicinity of the river.

4- Additional measurements should be made near Highway 417 to determine if the high EC values in the area are caused by road salt or septic systems.

5- Once the anomalies are confirmed and areas of seepage are identified and measured, a comparison should be made against base-flow calculations from stream hydrograph separation methods.

6- This study was conducted over a very limited segment of the South Nation River. A larger scale study would be extremely beneficial, it would identify areas of groundwater recharge and possibly "hot" spots of high EC contribution to the river. In fact, it is highly recommended that these types of EC surveys be carried out regularly by the Conservation Authority: they are a worthwhile investment, as they are inexpensive and can produce a wealth of information. The technical level of expertise in gathering the data is minimal; however, the analysis of the data requires hydrogeological and hydrological know-how. The Conservation Authority should consider hiring summer students to carry out the surveys and assigning the analysis of the data to their staff hydrogeologist.

7- EC measurements should be made over several seasons to show the time behaviour of groundwater seepage over several field seasons. This could be used to determine the seasonality of seepage flux, and nutrient loading of the river.

8- Confirmed zones of groundwater seepage should be instrumented with seepage meters for the first season and permanently with piezometers.

9- The EC of drainpipe effluent should be measured regularly, as part of the river's monitoring program, and compared to river EC values. These values can help guide landowners in their Best Management Practices.

10- Hot spots of high EC areas that are not of groundwater origin contribute in a major way to the poor water quality of the South Nation River. It is recommended that action be taken to help reduce these areas of loading. Actions can range from public awareness campaigns to political and legal actions.

11- In terms of public awareness, results such as those presented here could be made public (after being confirmed) in a news letter to residents.

Recommendations 1-5 will be carried out by a University of Ottawa M.Sc student during the summer 2003.

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Lee, David R., Geist, David R., Saldi, Kay, Hartwig, Dale and Cooper, Tom (1997). Locating groundwater discharge in the Hanford Reach of the Columbia River. Atomic Energy of Canada Ltd. 38p.

Matthess, Georg. (1982). The properties of groundwater. Wiley. 406p.

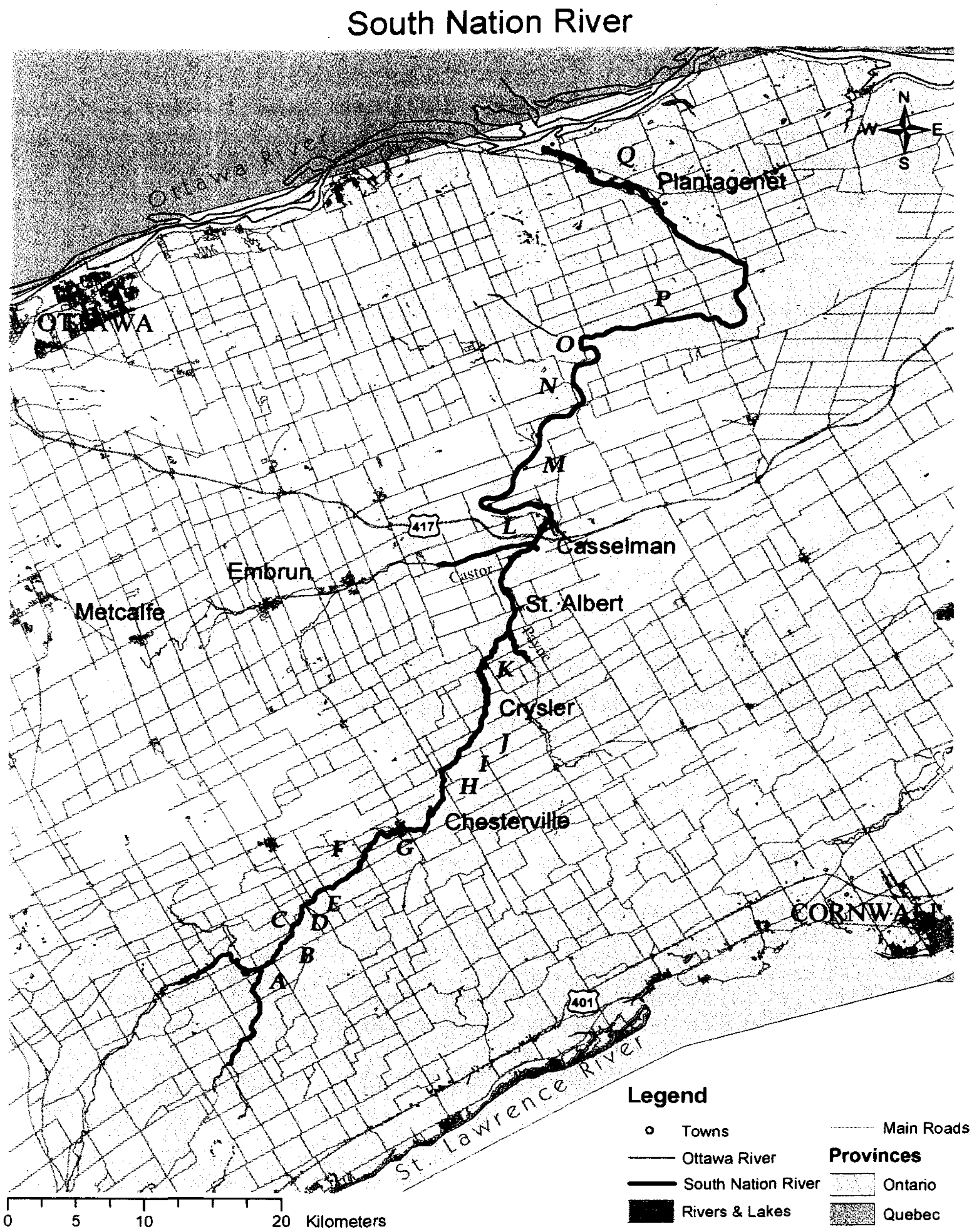


Figure 1 : Map of Eastern Ontario showing the reach of the South Nation River that was surveyed. (EOWRMS, 2001).

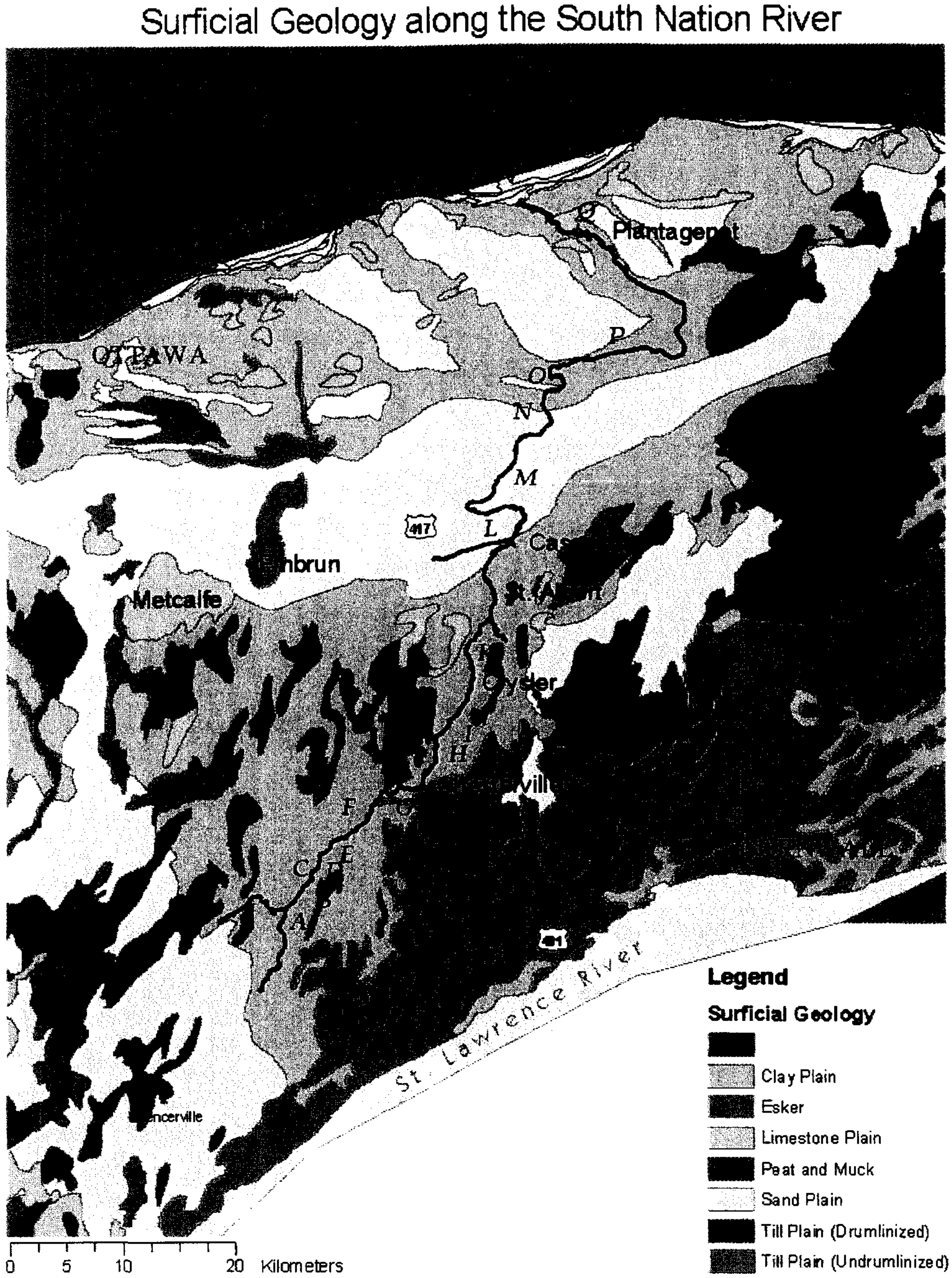


Figure 2 : Surficial geology map of the study area (EOWRMS, 2001).

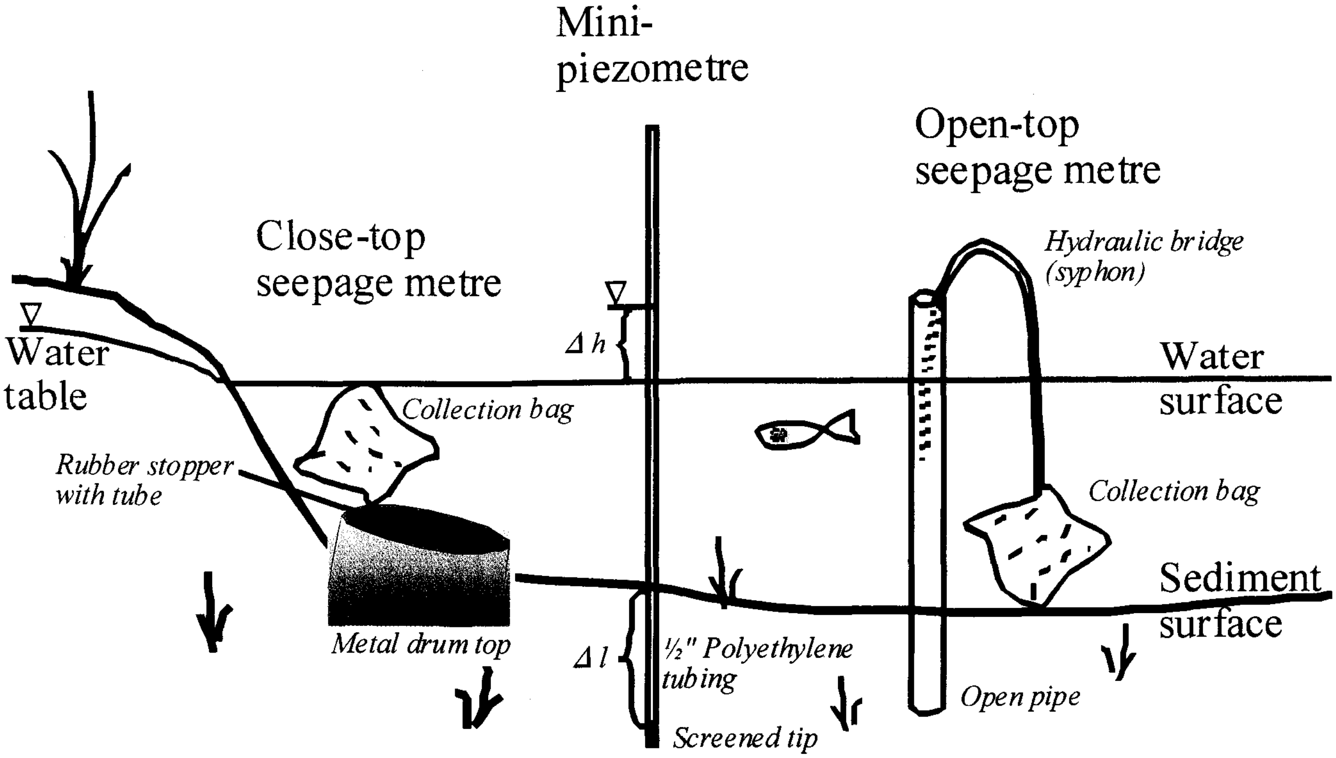


Figure 3 : Diagram depicting a mini-piezometer (center) a closed-top seepage meter (left) and an open-top seepage meter (right). The mini-piezometer is used to measure hydraulic head but when used in an open body of water (as shown in the diagram), it can be used to measure the vertical component of the hydraulic gradient as $\Delta h/\Delta l$. The seepage meters measure groundwater seepage flux (volume of water per unit area per unit time) entering the meter (seepage) or leaving (leakage). The open-top seepage meter can also act as a piezometer.

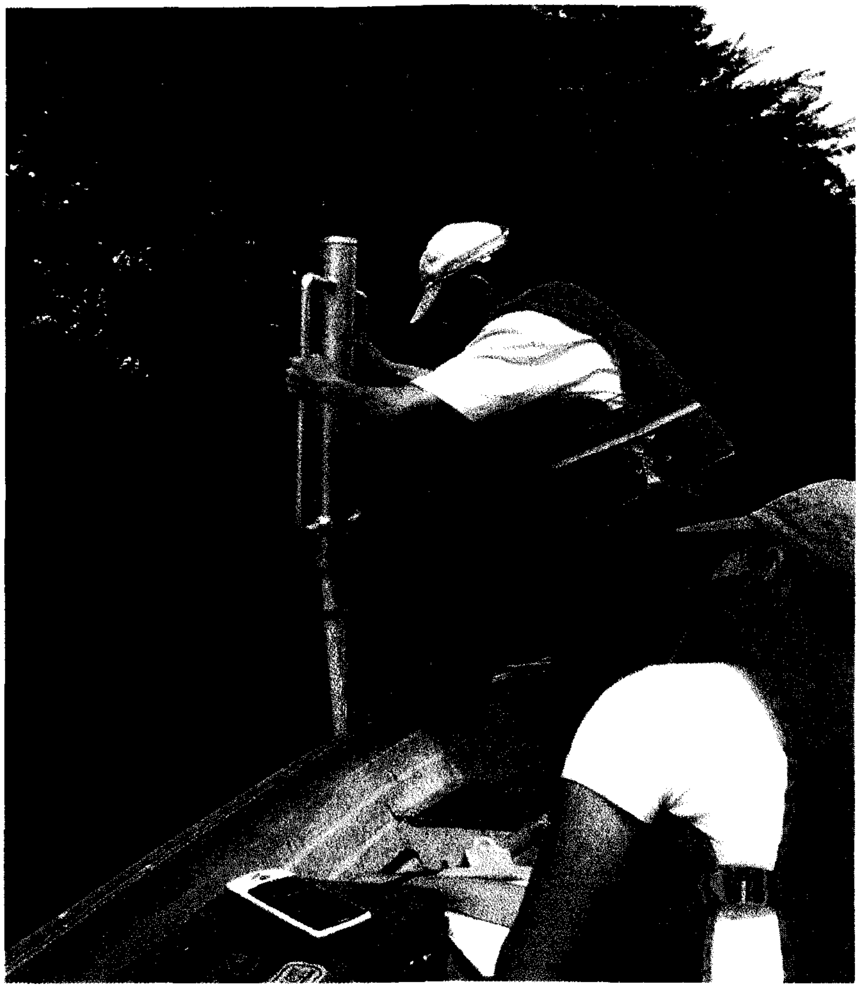


Figure 4 : Photo of Open-top seepage meter installation using a “monkey” hammer.

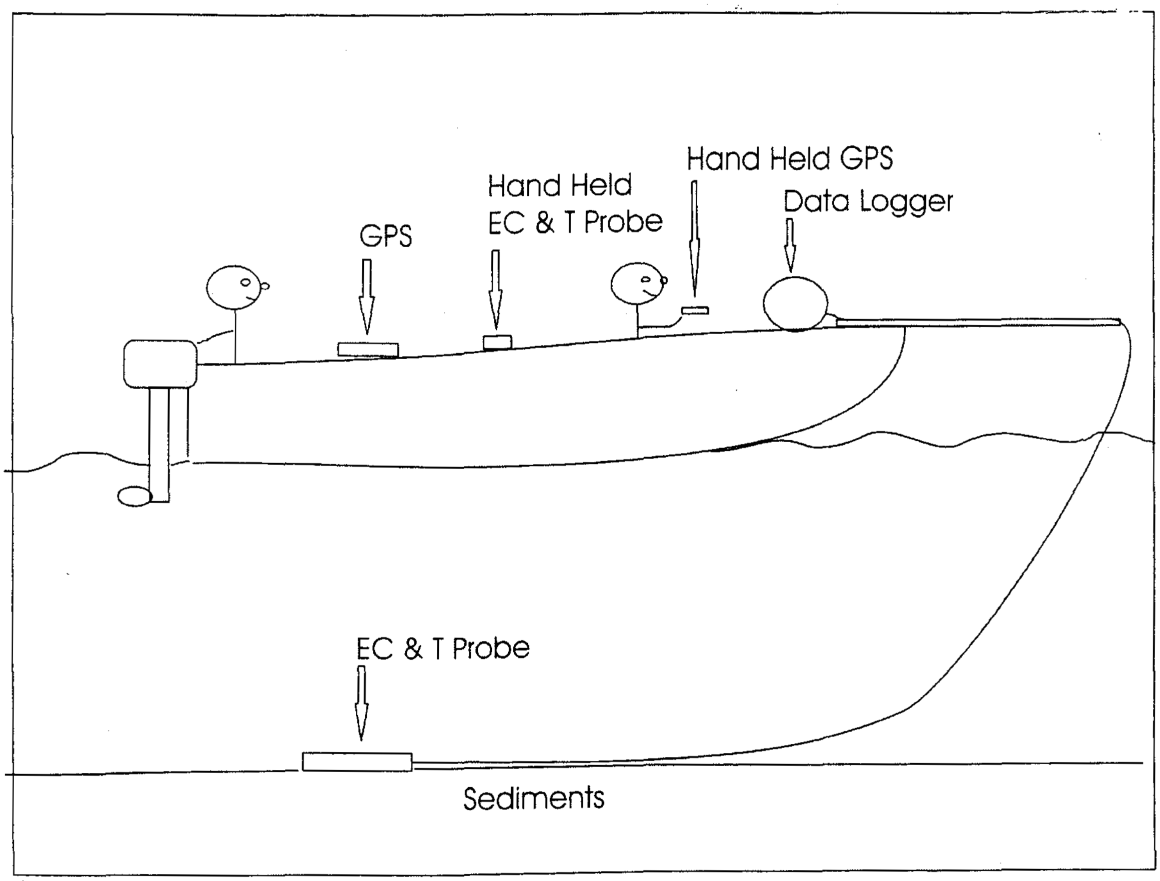


Figure 5 : Field set-up during summer 2002 field season. The ECT was dragged along the bottom sediment and measured electrical conductivity and temperature while the GPS was kept in a motorboat and measured position. The boat traveled at approximately 4 -7 km/hr while the ECT and GPS took measurements every 30 seconds

Figure 6 : Photo of field set-up at Cass Bridge launching site.

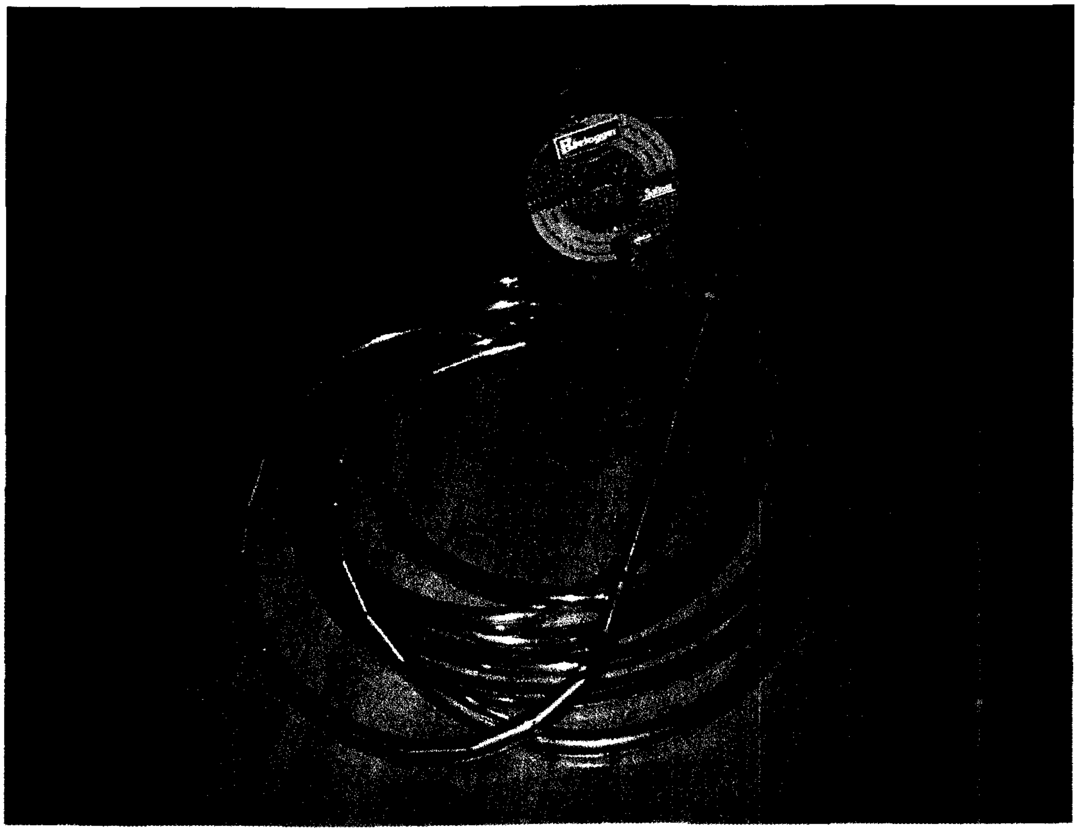


Figure 7 : ECT Probe, tygon casing and data acquisition system that is manufactured by Solinst Canada. The photo actually shows a pressure probe in tandem with the ECT probe. The pressure probe was for this study. The ECT probe is a 25-cm-long, 8-cm-diameter, stainless steel cylinder that weighs approximately 1 kg. A 2-cm hole in the side of the probe allows water to flow through and come in contact with a set of electro-conductive pins that are precisely spaced. The probe is calibrated with a 0.01M solution of KCl, to produce an electrical conductivity of 1470 μS/cm at 25°C. All readings are corrected to 25°C.

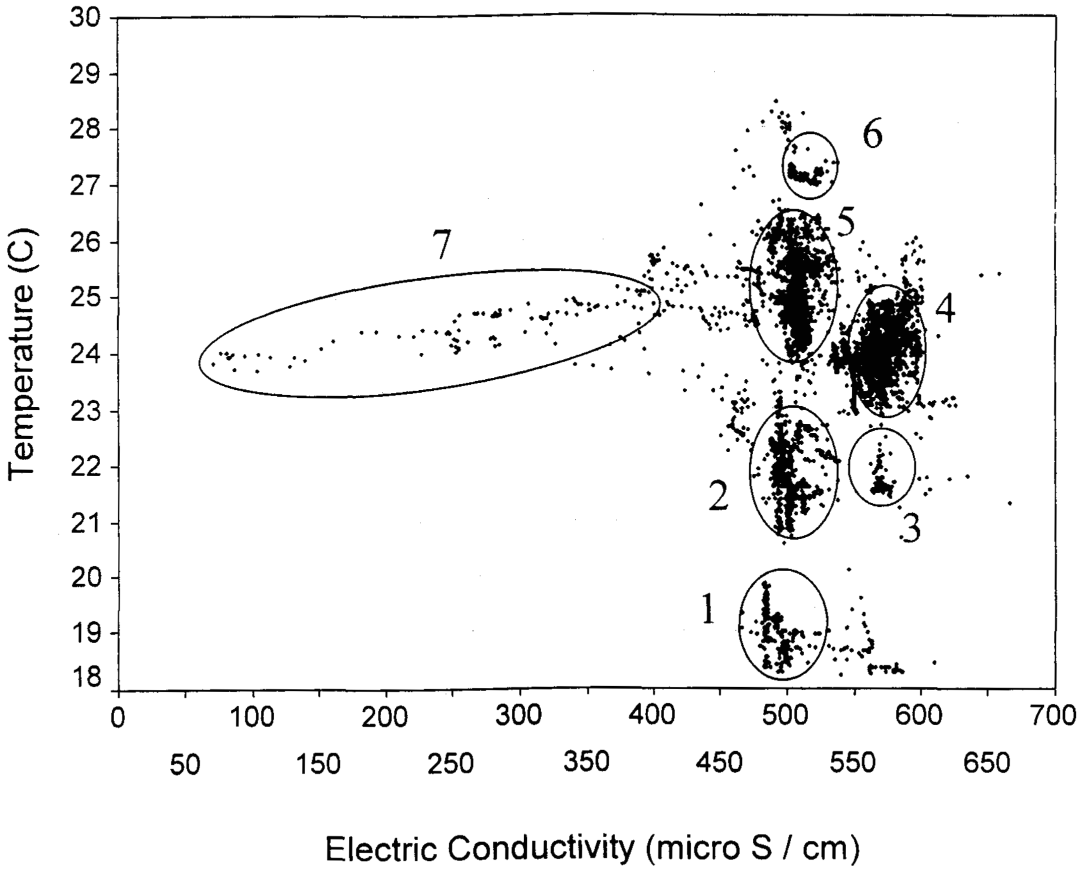


Figure 8 : Graph of Temperature versus Electrical Conductivity. Values are grouped into 7 classes, shown below.

Group Code

1 – Low Temperature, Medium EC
Crysler to confluence of Castor River - Banks
2 – Medium Temperature, Medium EC
Cass Bridge to confluence of Castor River - Center
3 – Medium Temperature, High EC
Just downstream confluence of Castor River
4 – Medium Temperature, High Electric Conductivity
Lemieux to Plantagenet and Castor
5 – Medium Temperature, Medium Electric Conductivity
Riverhead to Crysler banks and after Casselman Dam
6 – High Temperature, Medium Electric Conductivity
Riverhead to Cass Bridge – Center
7 – Medium Temperature, Low Electric Conductivity
Confluence of South Nation with Ottawa River

South Nation River - Group Codes

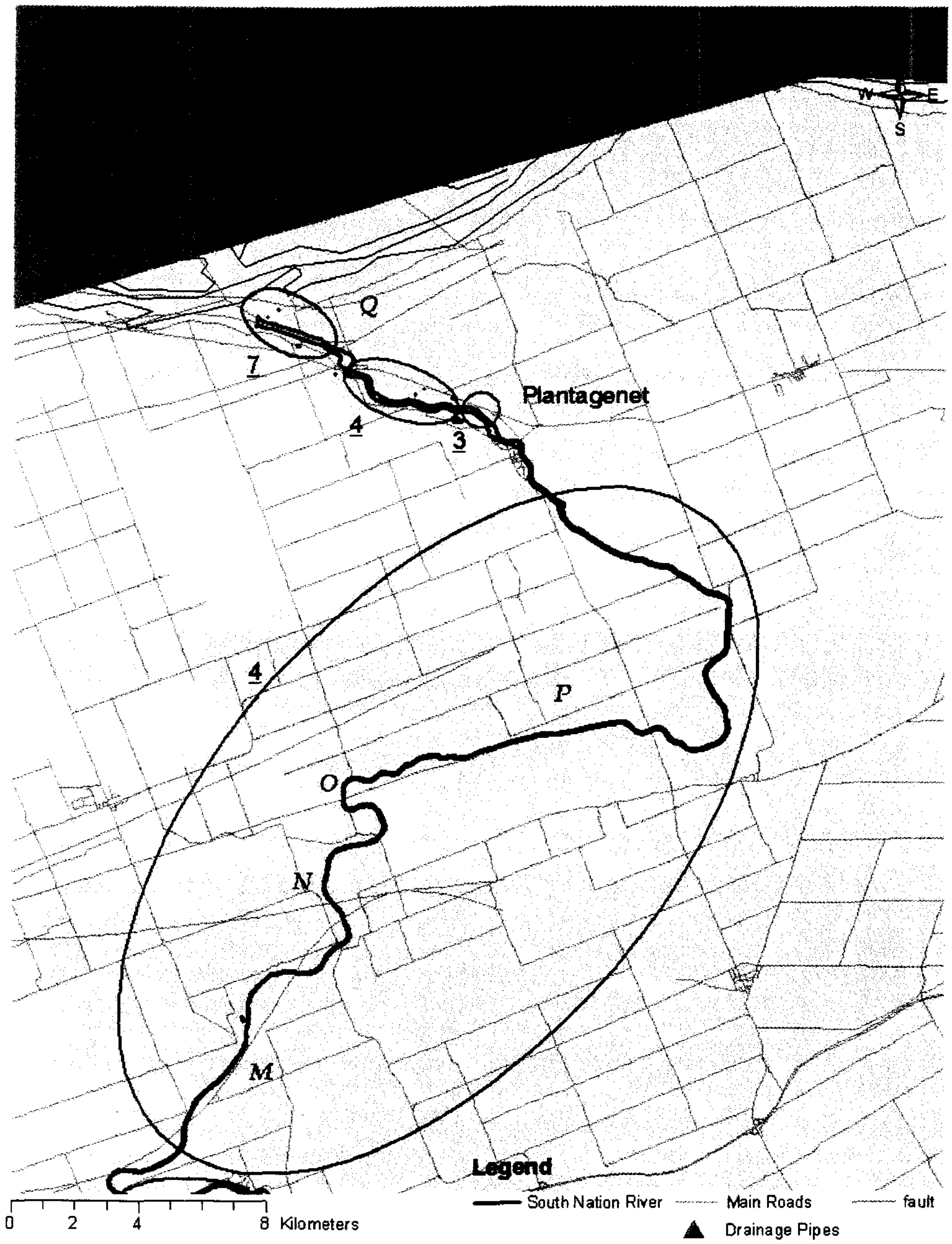


Figure 9(a) : EC & T are grouped into 7 classes (Fig. 8). The locations of these values are shown here and in Figure 9(b). (EOWRMS, 2001).

South Nation River - Group Codes

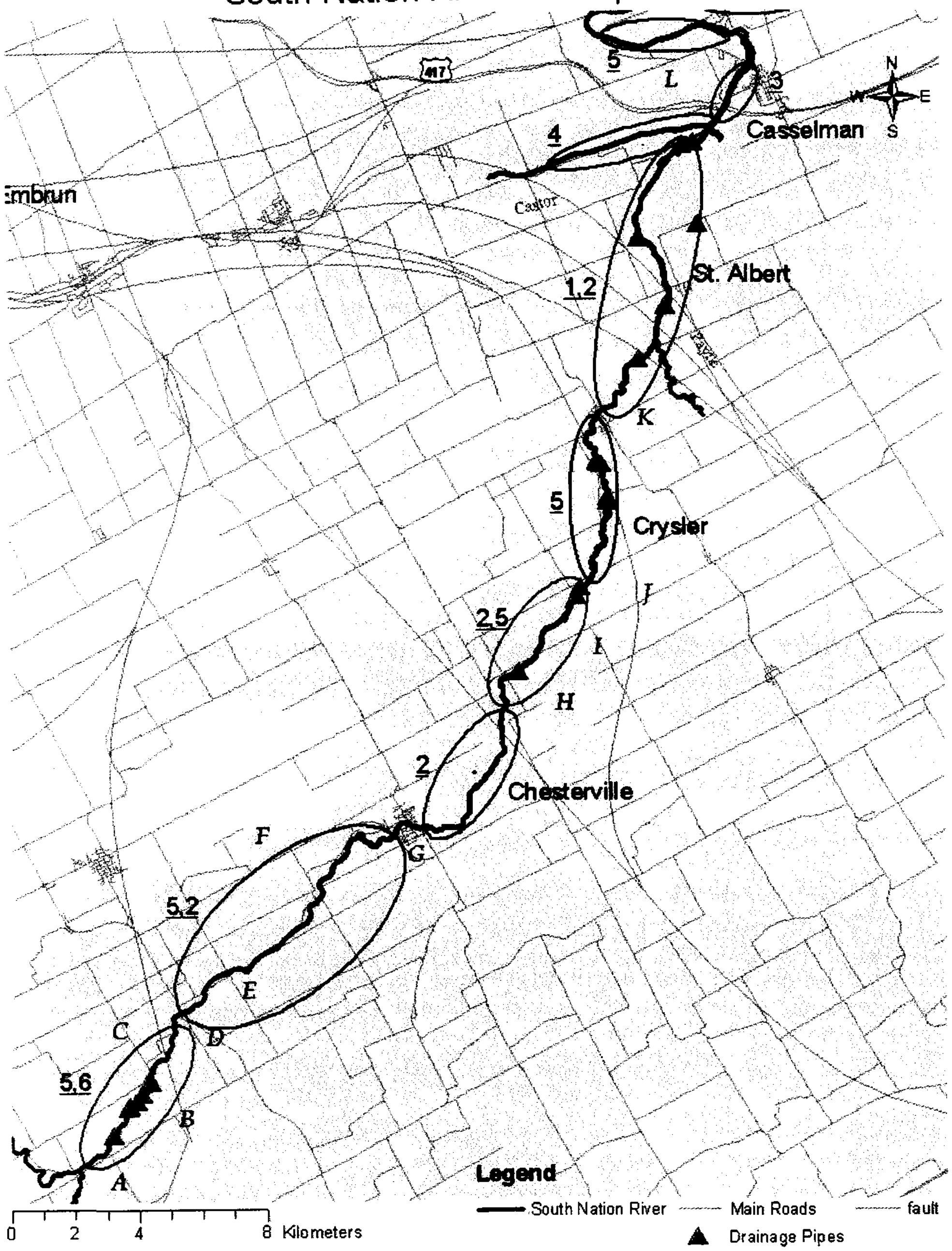


Figure 9(b) : EC & T are grouped into 7 classes (Fig. G.). The locations of these values are shown here and in Figure 9(a). (EOWRMS, 2001).

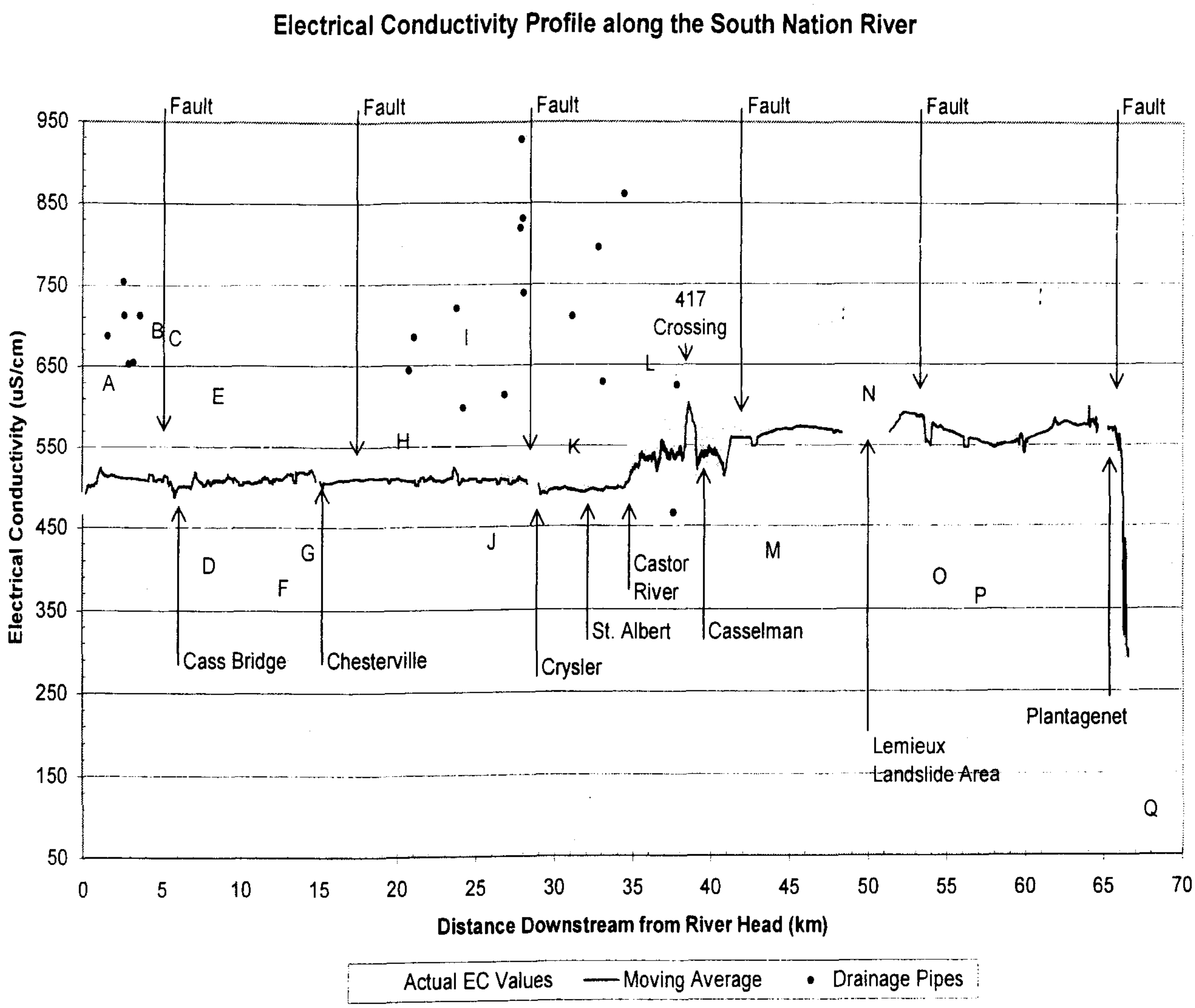


Figure 10 : EC profile along the South Nation River. Distance is measured as a straight line from the "headwaters" (most upstream measurement location), rather than along the river. Blank spaces are where the river is non-navigable. The figure shows the locations of landmarks along the river (for reference), the locations of 17 anomalies that were identified, and the locations of fault zones. Drain-pipe EC values are also plotted at the locations where they were measured.

Location of Fault Zones along the South Nation River

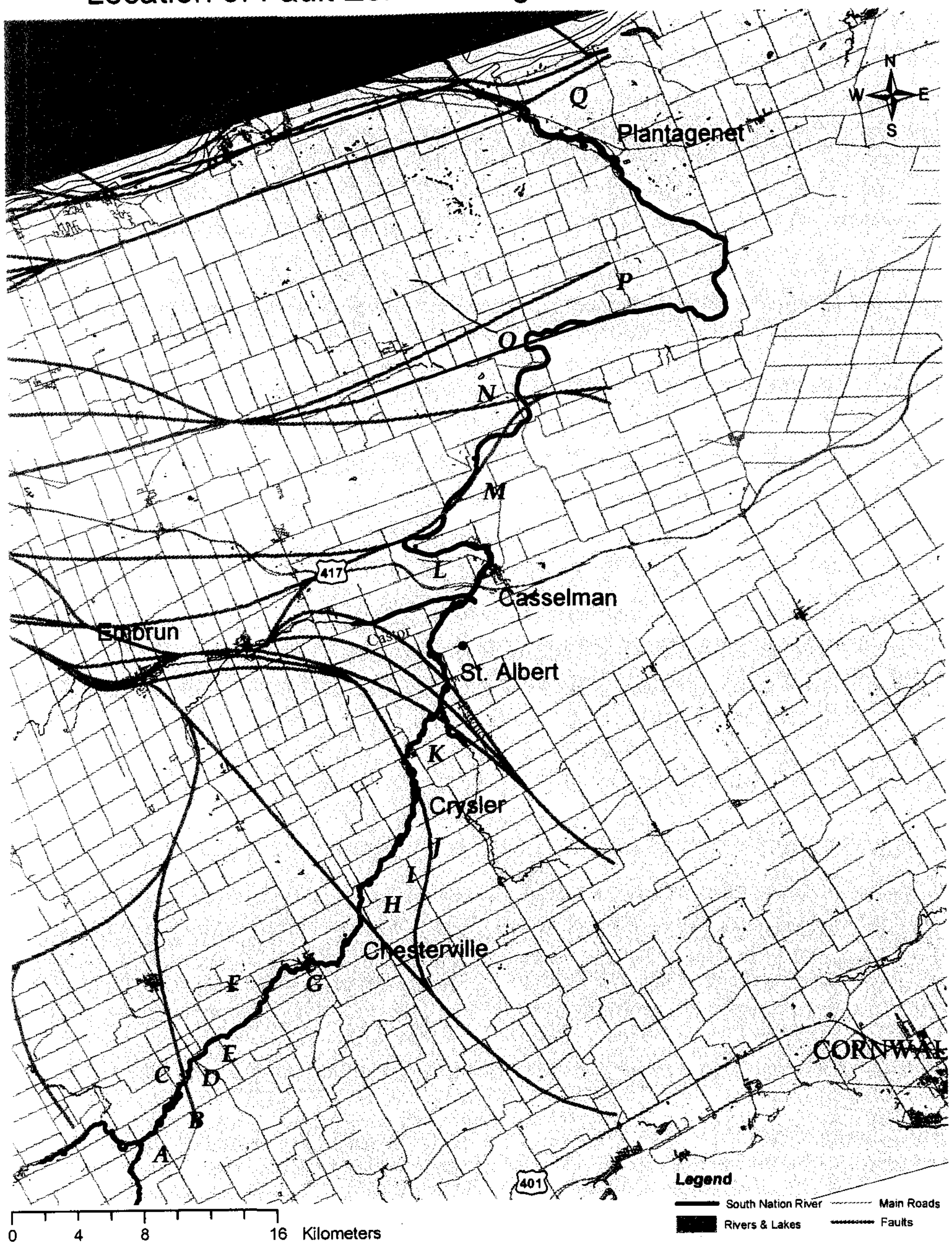


Figure 11 : Several major fault zones are found along the South Nation River. Major geological faults can sometimes act as conduits for deep groundwater circulation systems, and act as recharge or discharge features where they strike. (EOWRMS, 2001).

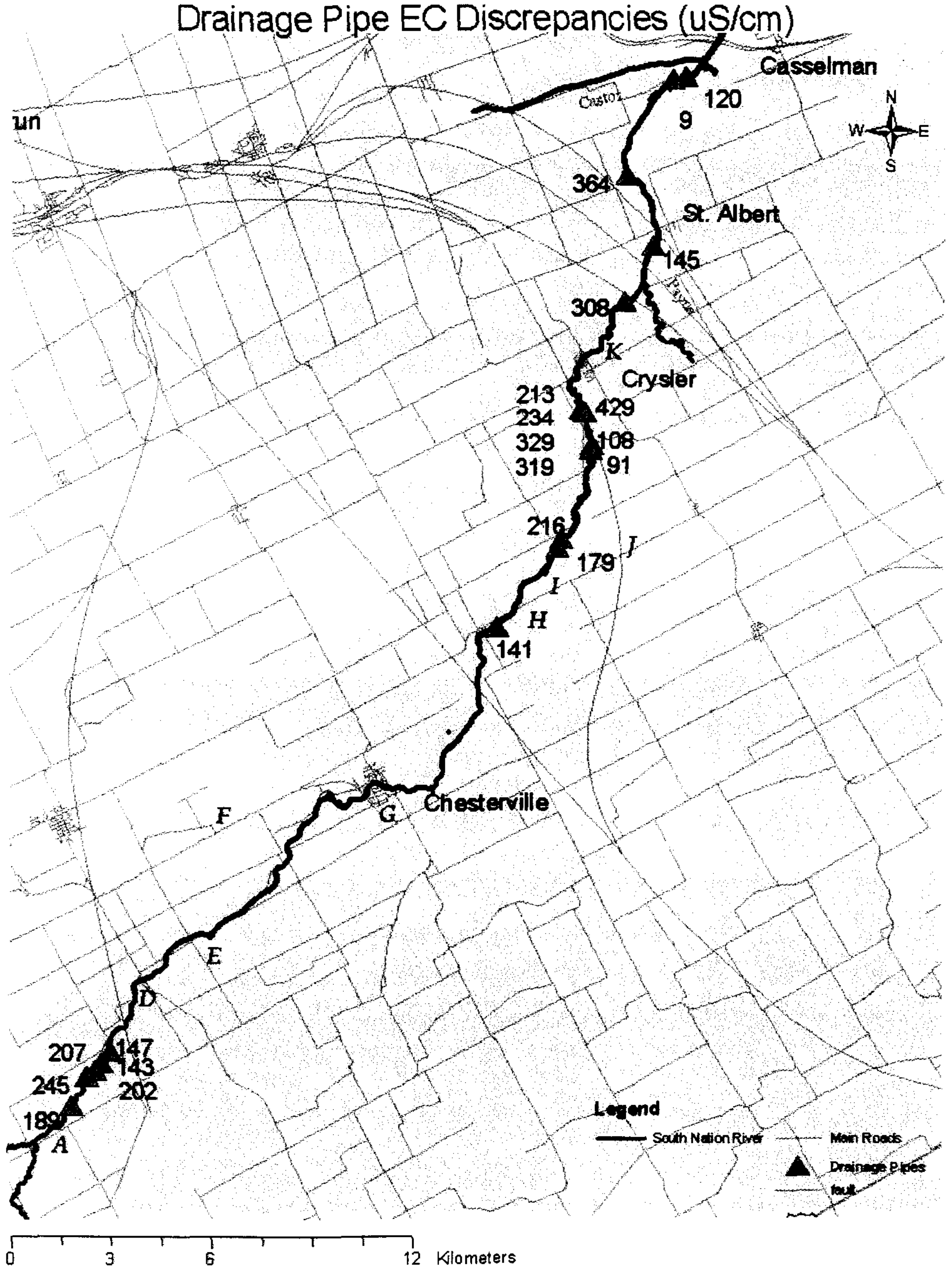
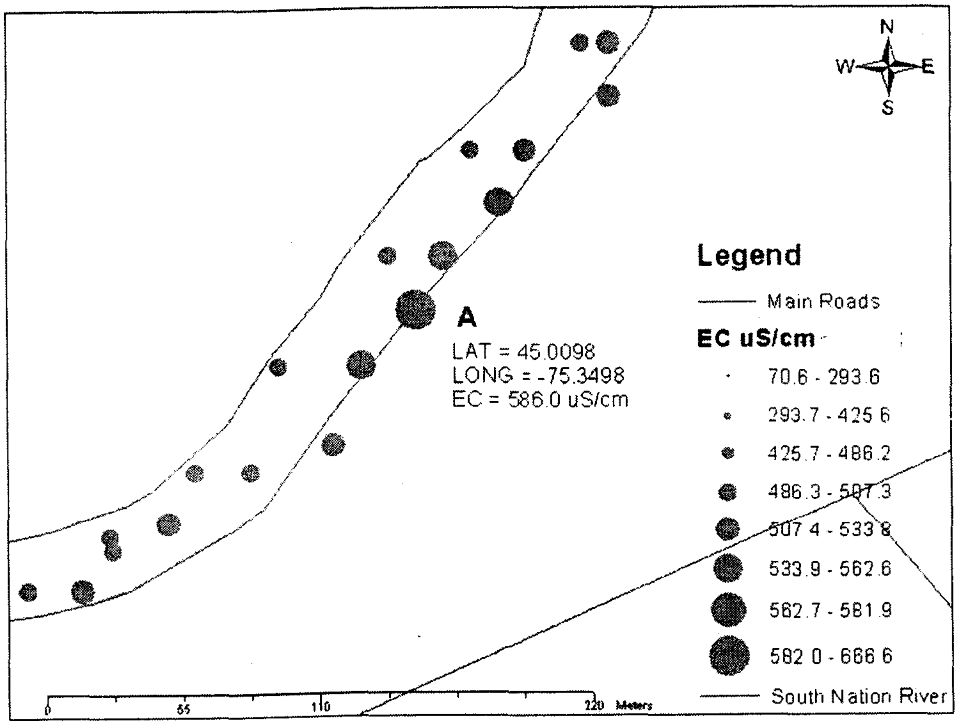
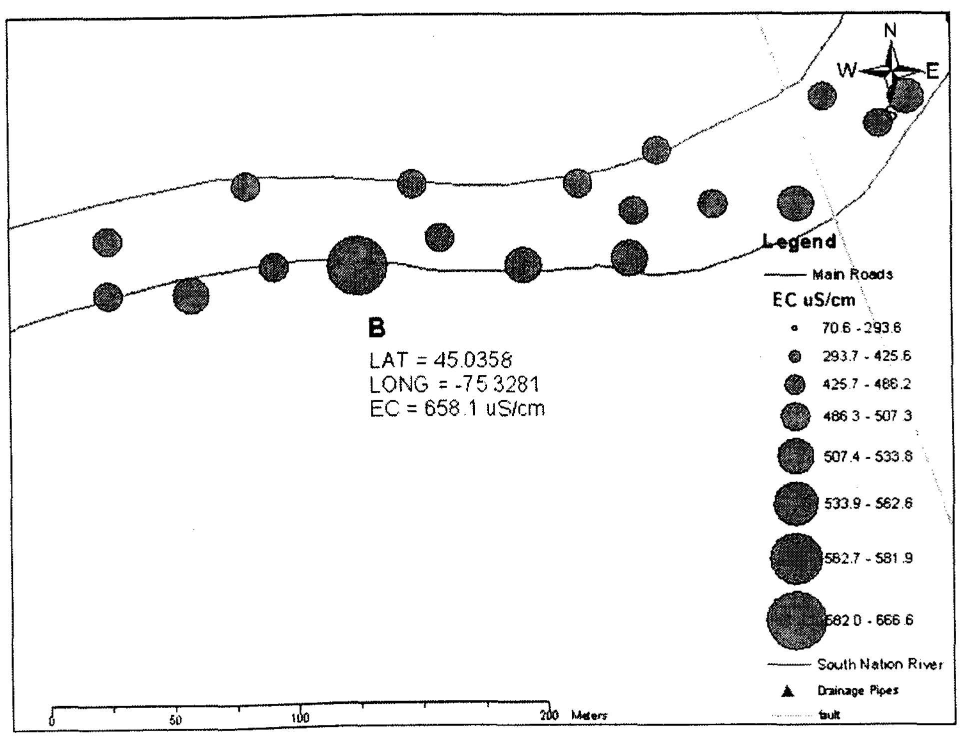


Figure 12 : Map showing the location of agricultural drainage pipes where EC was measured. Only flowing drainage pipes could be measured, and none were encountered downstream from Casselman because of the timing of the survey in that reach. All EC values observed were higher in the drainage pipes than in the river in the immediate vicinity. The discrepancy values are shown on the map for each drain pipe location. (EOWRMS,

Appendix 1


N
W
E
S
A
LAT = 45.0098
LONG = -75.3498
EC = 586.0 uS/cm
Legend
Main Roads
EC uS/cm
70.6 - 293.6
293.7 - 425.6
425.7 - 486.2
486.3 - 507.3
507.4 - 533.8
533.9 - 562.6
562.7 - 581.9
582.0 - 666.6
South Nation River
0
65
110
220 Meters


N
W
E
B
LAT = 45.0358
LONG = -75.3281
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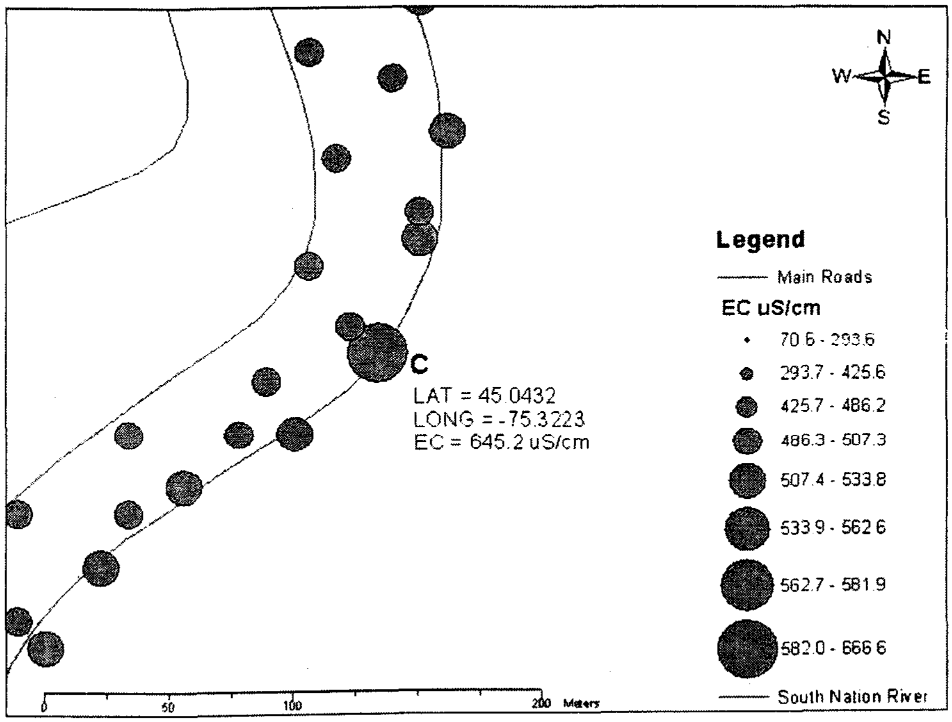
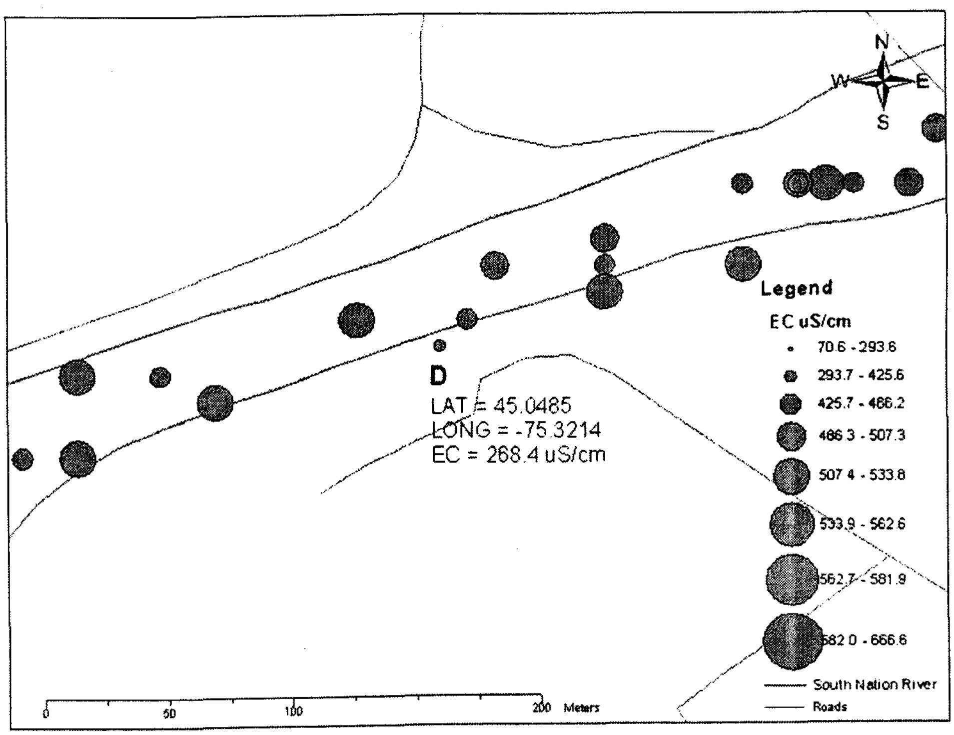
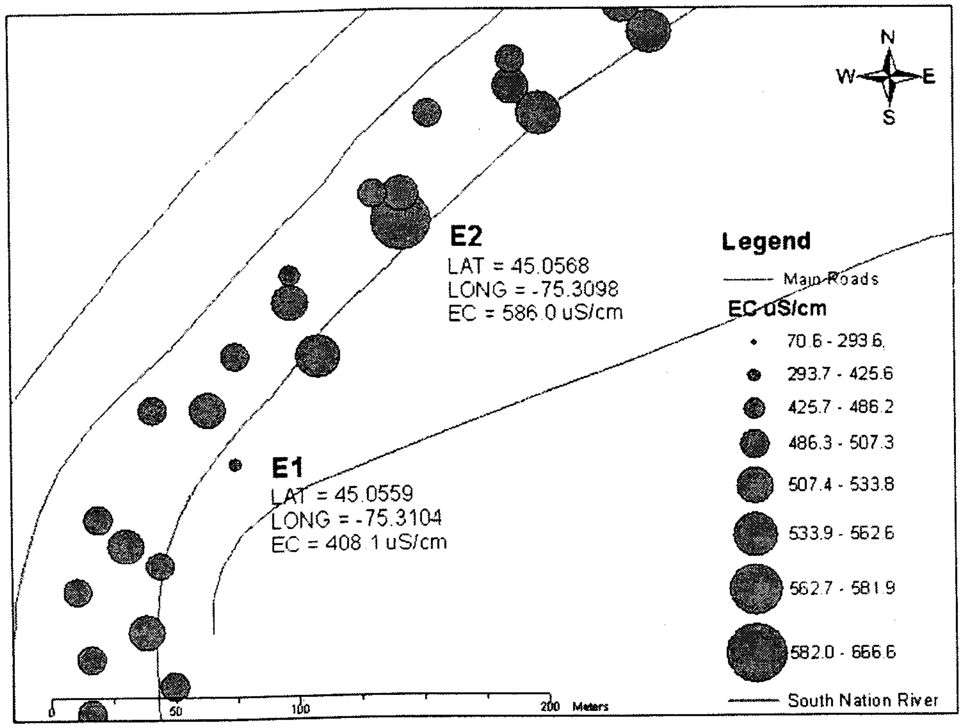
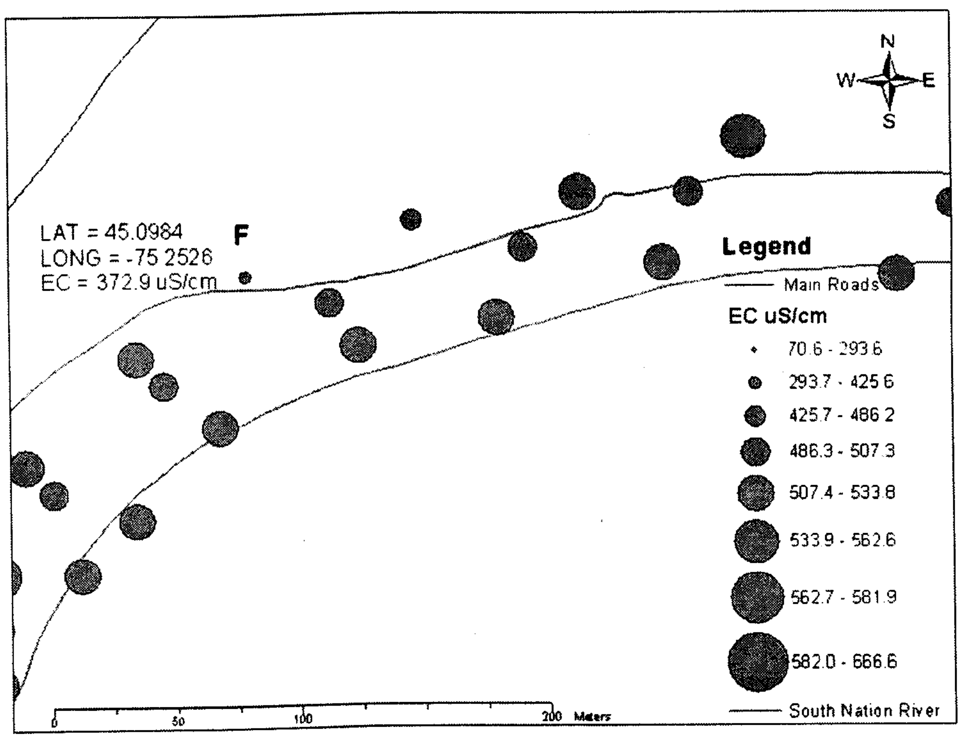
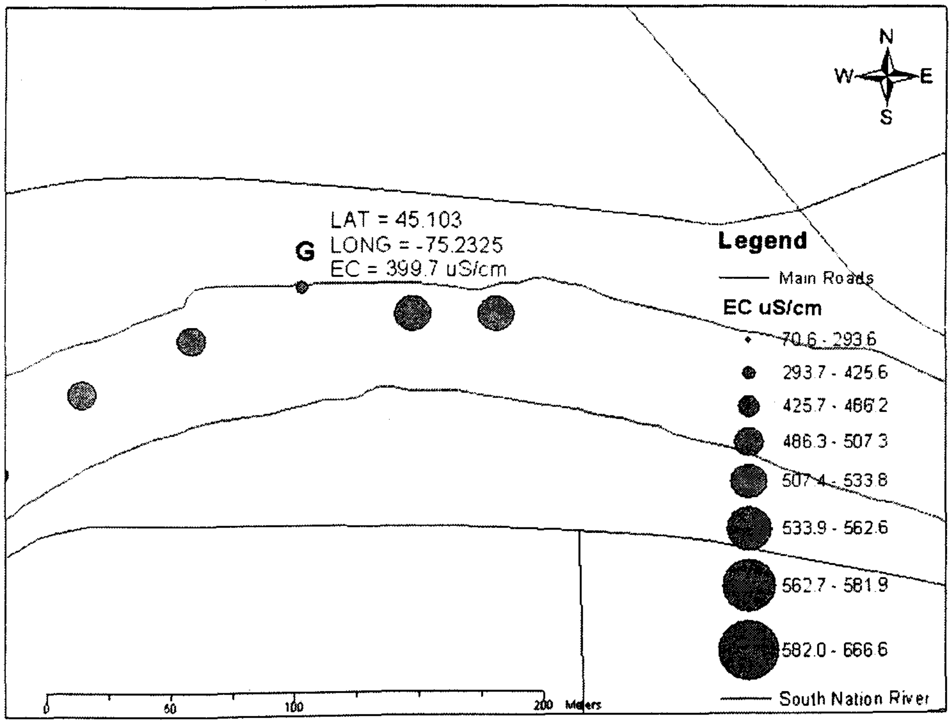
Legend
Main Roads
EC uS/cm
70.6 - 293.6
293.7 - 425.6
425.7 - 486.2
486.3 - 507.3
507.4 - 533.8
533.9 - 562.6
562.7 - 581.9
582.0 - 666.6
South Nation River
Drainage Pipes
fault
0
50
100
200 Meters

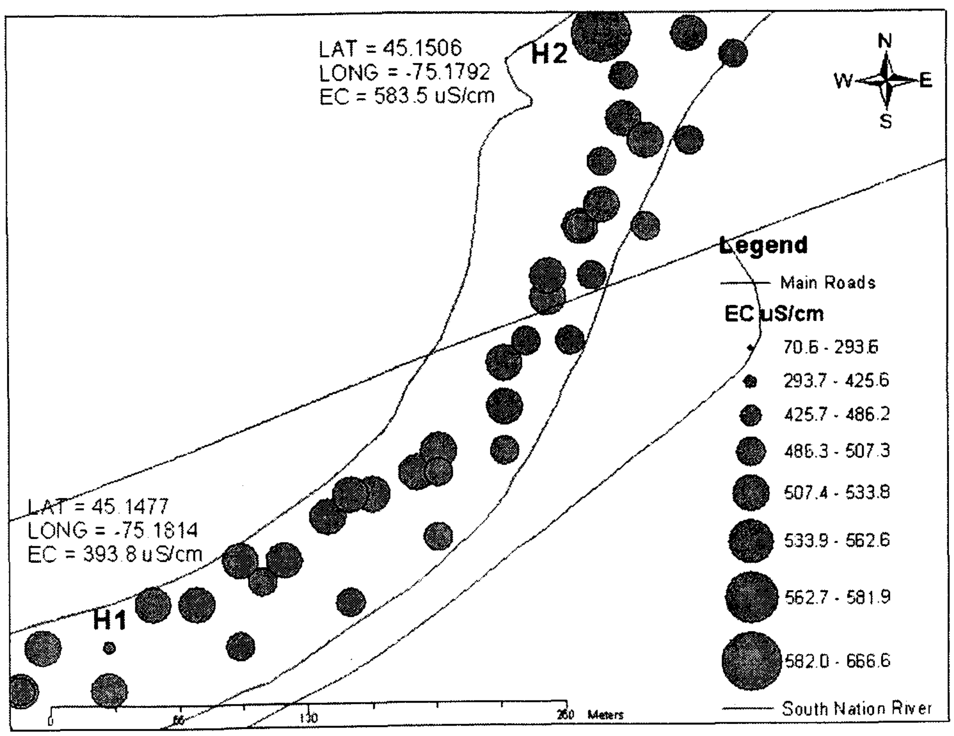

N
W
E
S
Legend
Main Roads
EC uS/cm
70.6 - 293.6
293.7 - 425.6
425.7 - 486.2
486.3 - 507.3
507.4 - 533.8
533.9 - 562.6
562.7 - 581.9
582.0 - 666.6
South Nation River
C
LAT = 45.0432
LONG = -75.3223
EC = 645.2 uS/cm
0
50
100
200 Meters

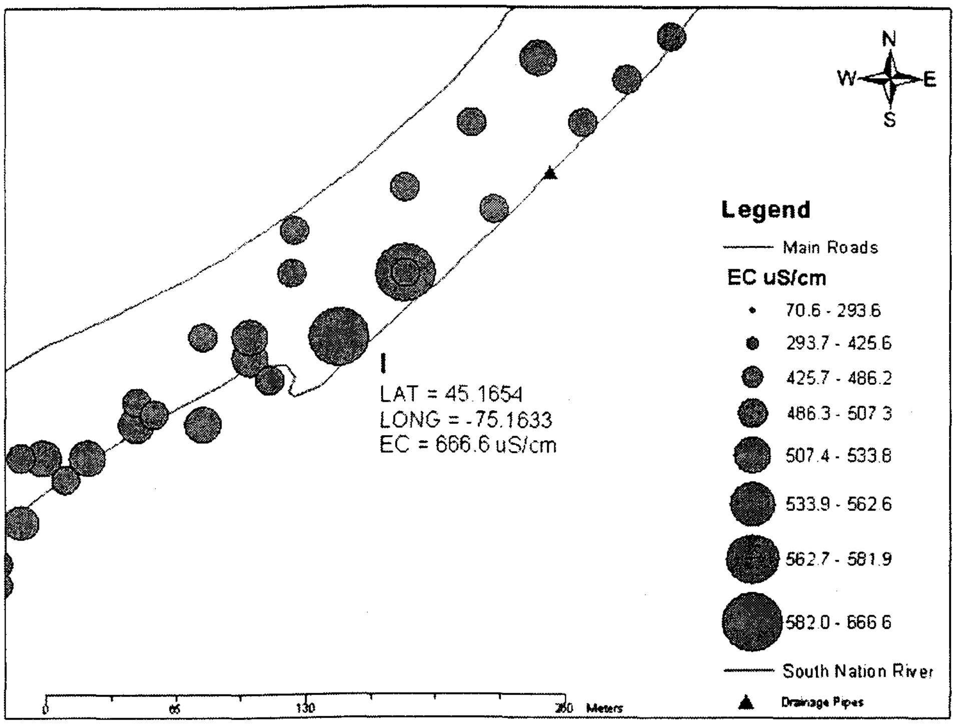

N
W
E
S
Legend
EC uS/cm
70.6 - 293.6
293.7 - 425.6
425.7 - 486.2
486.3 - 507.3
507.4 - 533.8
533.9 - 562.6
562.7 - 581.9
582.0 - 666.6
South Nation River
Roads
D
LAT = 45.0485
LONG = -75.3214
EC = 268.4 uS/cm
0
50
100
200 Meters

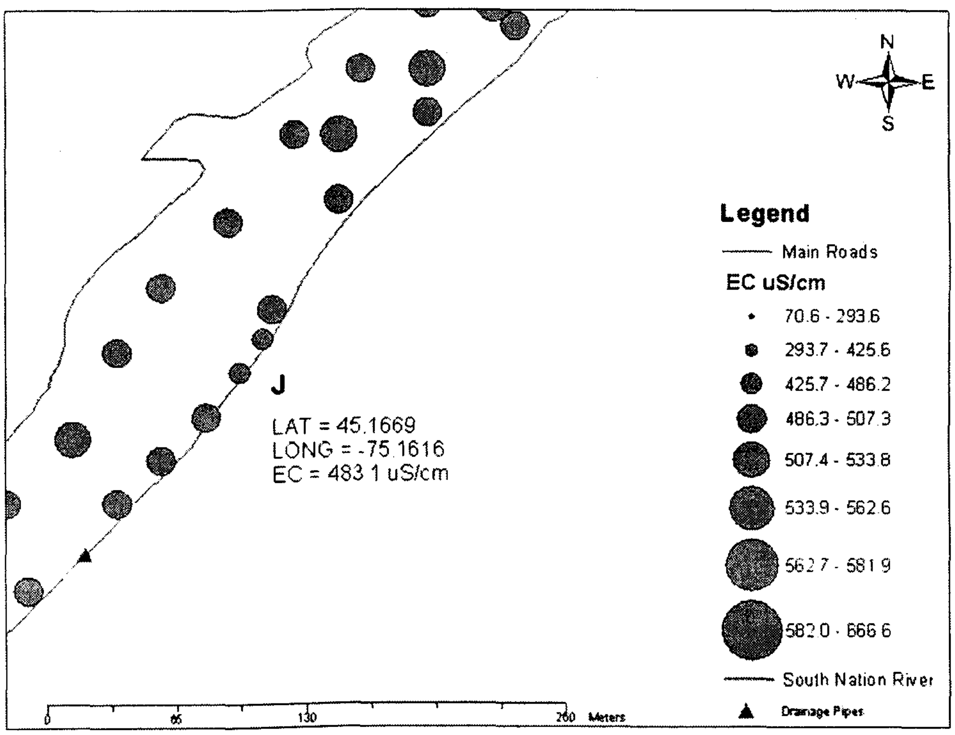

N
W
E
S
E2
LAT = 45.0568
LONG = -75.3098
EC = 586.0 uS/cm
E1
LAT = 45.0559
LONG = -75.3104
EC = 408.1 uS/cm
Legend
Main Roads
EC uS/cm
70.6 - 293.6
293.7 - 425.6
425.7 - 486.2
486.3 - 507.3
507.4 - 533.8
533.9 - 562.6
562.7 - 581.9
582.0 - 666.6
South Nation River
0
50
100
200 Meters

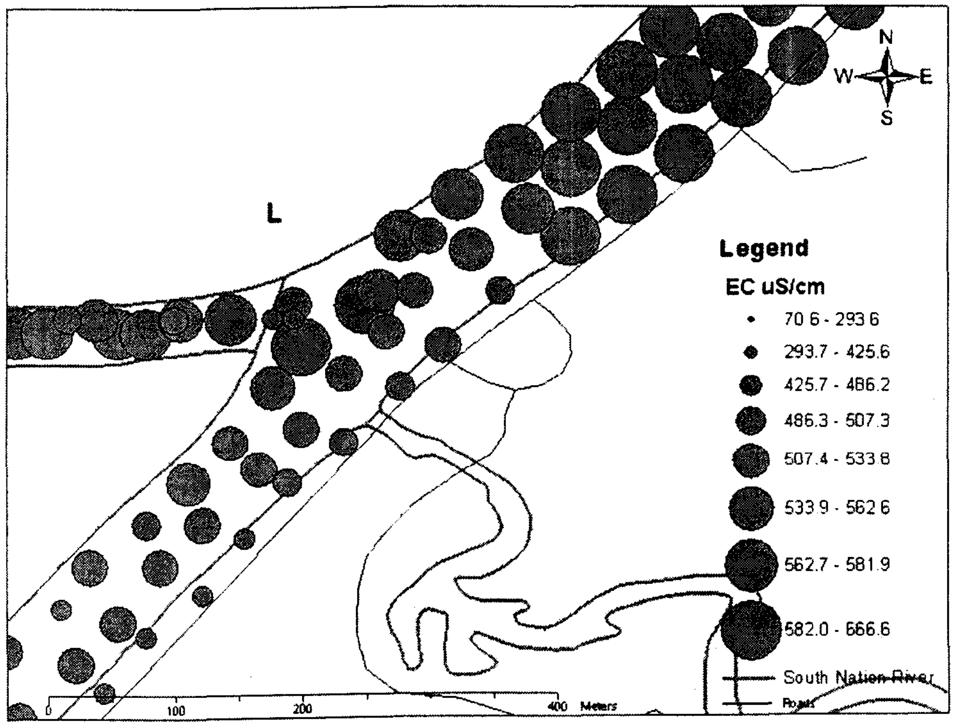

N
W
E
S
LAT = 45.0984
LONG = -75.2526
EC = 372.9 uS/cm
F
Legend
Main Roads
EC uS/cm
70.6 - 293.6
293.7 - 425.6
425.7 - 486.2
486.3 - 507.3
507.4 - 533.8
533.9 - 562.6
562.7 - 581.9
582.0 - 666.6
South Nation River
0
50
100
200 Meters

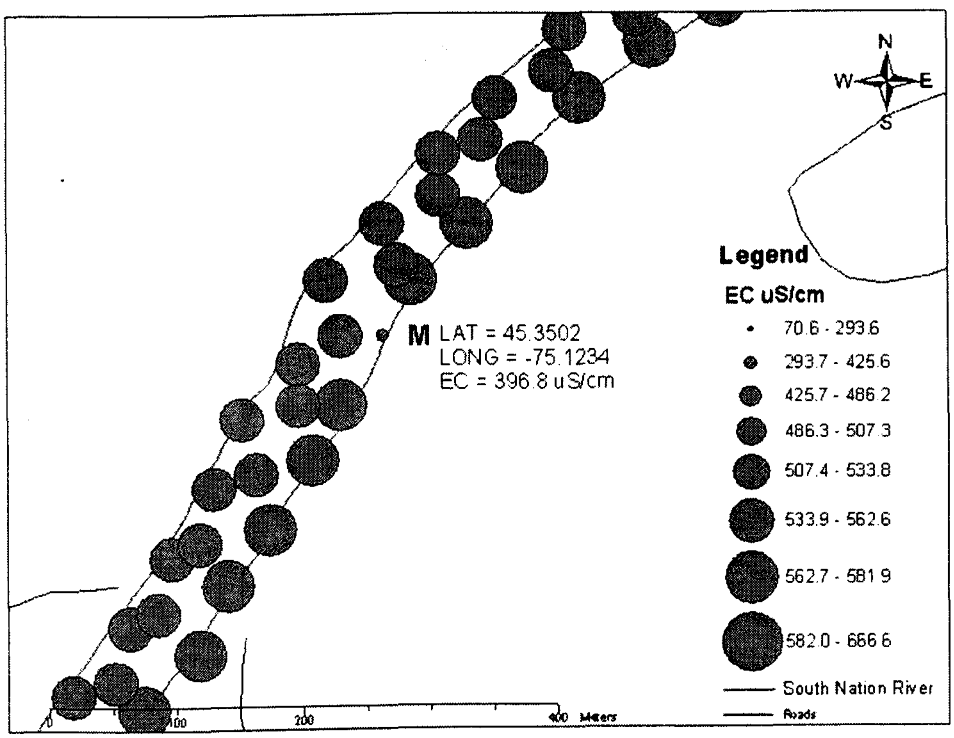

N
W
E
S
LAT = 45.103
G
LONG = -75.2325
EC = 399.7 uS/cm
Legend
Main Roads
EC uS/cm
70.6 - 293.6
293.7 - 425.6
425.7 - 486.2
486.3 - 507.3
507.4 - 533.8
533.9 - 562.6
562.7 - 581.9
582.0 - 666.6
South Nation River
0
50
100
200 Meters

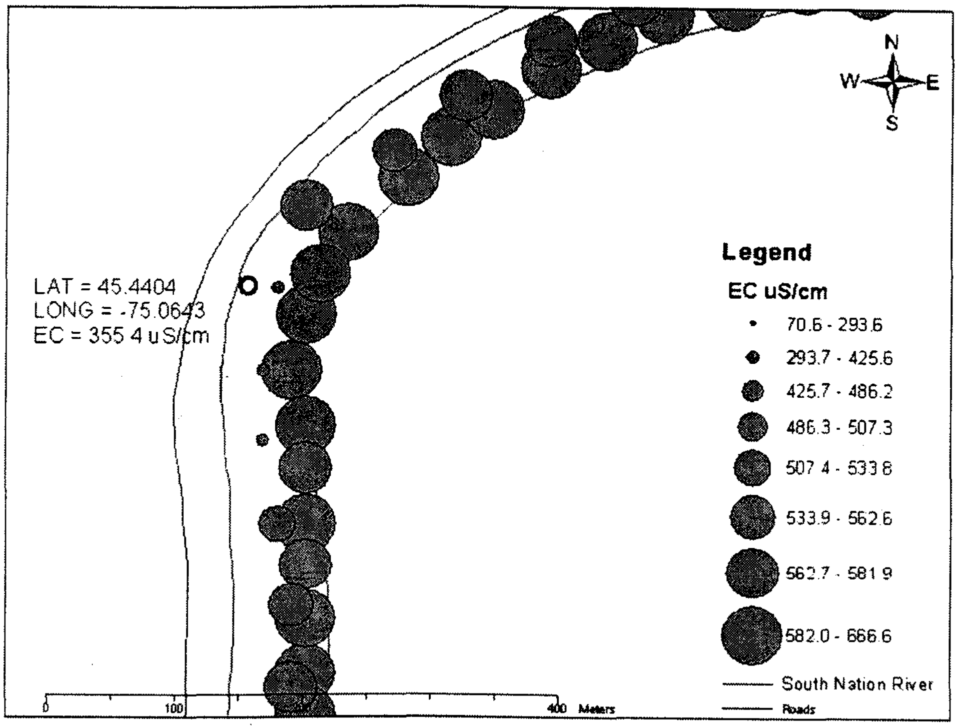

LAT = 45.1506
LONG = -75.1792
EC = 583.5 uS/cm
H2
N
W
E
S
Legend
Main Roads
EC uS/cm
70.6 - 293.6
293.7 - 425.6
425.7 - 486.2
486.3 - 507.3
507.4 - 533.8
533.9 - 562.6
562.7 - 581.9
582.0 - 666.6
South Nation River
LAT = 45.1477
LONG = -75.1814
EC = 393.8 uS/cm
H1
0
130
260 Meters

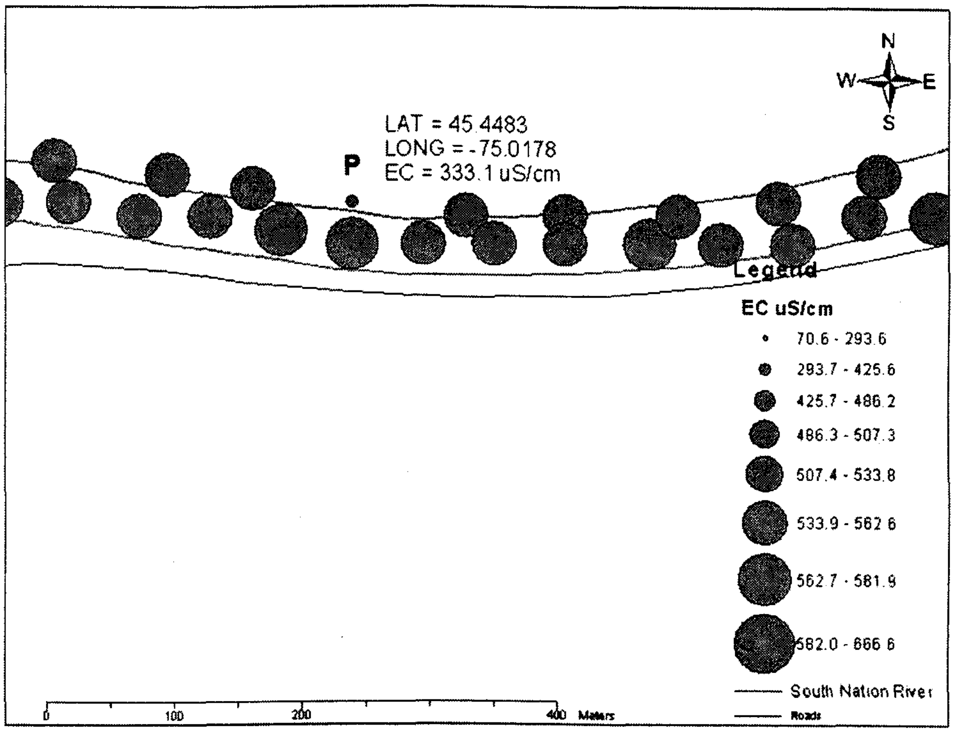

N
W
E
S
Legend
Main Roads
EC uS/cm
70.6 - 293.6
293.7 - 425.6
425.7 - 486.2
486.3 - 507.3
507.4 - 533.8
533.9 - 562.6
562.7 - 581.9
582.0 - 666.6
South Nation River
Drainage Pipes
I
LAT = 45.1654
LONG = -75.1633
EC = 666.6 uS/cm
0
65
130
260 Meters


N
W
E
S
Legend
Main Roads
EC uS/cm
70.6 - 293.6
293.7 - 425.6
425.7 - 486.2
486.3 - 507.3
507.4 - 533.8
533.9 - 562.6
562.7 - 581.9
582.0 - 666.6
South Nation River
Drainage Pipes
J
LAT = 45.1669
LONG = -75.1616
EC = 483.1 uS/cm
0
65
130
260 Meters


N
W
E
S
L
Legend
EC uS/cm
70.6 - 293.6
293.7 - 425.6
425.7 - 486.2
486.3 - 507.3
507.4 - 533.8
533.9 - 562.6
562.7 - 581.9
582.0 - 666.6
South Nation River
Roads
0
100
200
400 Meters


N
W
E
S
Legend
EC uS/cm
M
LAT = 45.3502
LONG = -75.1234
EC = 396.8 uS/cm
70.6 - 293.6
293.7 - 425.6
425.7 - 486.2
486.3 - 507.3
507.4 - 533.8
533.9 - 562.6
562.7 - 581.9
582.0 - 666.6
South Nation River
Roads
0
100
200
400 Meters


LAT = 45.4404
LONG = -75.0643
EC = 355.4 uS/cm
O
N
W
E
S
Legend
EC uS/cm
70.6 - 293.6
293.7 - 425.6
425.7 - 486.2
486.3 - 507.3
507.4 - 533.8
533.9 - 562.6
562.7 - 581.9
582.0 - 666.6
South Nation River
Roads
0
100
400 Meters


N
W
E
S
LAT = 45.4483
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EC = 333.1 uS/cm
P
Legend
EC uS/cm
70.6 - 293.6
293.7 - 425.6
425.7 - 486.2
486.3 - 507.3
507.4 - 533.8
533.9 - 562.6
562.7 - 581.9
582.0 - 666.6
South Nation River
Roads
0
100
200
400 Meters