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Using Electrical Conductivity and Temperature Mapping To Locate Zones of Groundwater Discharge in the South Nation River, Eastern Ontario

Janet Elizabeth Kingsley

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partial fulfillment of the requirements for the M.Sc.
degree in Earth Sciences

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ABSTRACT

Groundwater-surface water interactions (GSWI's) interactions are an important part of understanding the hydrological cycle, groundwater and river systems, and in providing estimates of groundwater contributions to rivers (base flow). Seepage / leakage of groundwater into surface waters can be measured directly, but this is very labor-intensive, and therefore not feasible at the scale of a basin. An alternative method, which was used in this study, infers groundwater seepage from 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).

Zones of groundwater seepage were confirmed and quantified using open-top seepage meters. The results were then used to obtain an integrated baseflow and compared to baseflow found from graphical hydrograph separation techniques. Baseflow estimates, using the two methods, were similar.

The methodology in this study proved useful in detecting groundwater seepage, but it was also efficient 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 proved 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.

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1. INTRODUCTION

1.1 BACKGROUND INFORMATION

Groundwater/surface water interactions (GSWIs) are an important part of understanding the hydrological cycle, groundwater systems and river ecosystems. Little is known of GSWIs at the spatial scale necessary for aquifer and surface water vulnerability mapping. However, 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 (Porter, 1996; Di lorio, 2001). This study was initiated to respond to some of the recommendations from the Eastern Ontario Water Resources Management Study (EOWRMS, 2001). In particular, the study aims at improving our understanding of GSWIs.

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 was used in this study to try to identify groundwater discharge zones. The technique identifies groundwater discharge by measuring variations in sediment pore water electrical conductivity and temperature and consequently reducing the number of instruments necessary to quantify inflow. Results from the electrical conductivity-temperature (ECT) method can guide the installation of piezometers and seepage meters to discharge zones. The results can then be compared to traditional hydrograph separation techniques.

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.

1.2 PREVIOUS WORK

The electrical conductivity probe designed by D. Lee at Atomic Energy of Canada Ltd. identifies groundwater discharge by measuring variations in sediment pore water electrical conductivity. This method has been used successfully in several previous studies. Lee (1980) first used the method to detect a salt tracer in an artificially created seepage area of a small, shallow lake. Lee et al. (1993) later applied the technique in shallow rivers. Vanek and Lee (1991) used the method for locating fresh water inputs in a small section of a marine bay. Lee and Dal Bianco (1994) applied the technique to detect acid mine drainage in groundwater discharging into shallow surface waters. Harvey et. al. (1997) discovered discharge areas of tens of meters in the Hamilton Harbor, Ontario. They found systematic variations between near shore and offshore sediments and identified anomalous zones that were verified to be zones of groundwater discharge by installing piezometers. Conant (2002) used a simple method to relate fluxes obtained from piezometer data to streambed temperatures. The relationship allowed flux to be calculated at locations where only streambed temperature measurements were made. This is similar to the method used in this study with the exception being that streambed temperature was used in conjunction with electrical conductivity. As it turns out, temperature was a rather poor indicator of groundwater discharge along the South Nation River. The electrical conductivity and temperature probe measurements were compared to the discharge measurements determined through the use of seepage meters.

In this study, seepage meters that also act as mini-piezometers were used to verify electrical conductivity anomalies. The use of hand-driven mini-piezometers to measure vertical gradients is described by Lee and Cherry(1979). Seepage meters are commonly used in groundwater studies since they were made popular by Lee (1977) and Lee and Cherry (1978). The seepage meter allows the direct measurement of seepage flux. Many studies including Woessener and Sullivan (1984), Shaw and Prepas (1990), Porter (1996), and Logan and Rudolpe (1997) have documented the usefulness of seepage meters in quantifying groundwater-surface water interactions. However, modifications to the seepage meter were made to the original design in order to suit the environment of this study.

1.3 OBJECTIVE

The main objective of this project was to determine if electrical conductivity and temperature (ECT) of the river water at the sediment interface could be used as indicators of groundwater seepage in the South Nation River. This pilot survey covered the main trunk of the South Nation River from the Ottawa River upstream to Oak Valley (a distance of over 100 km). The survey took place during the summers of 2002 and 2003, and was complemented with additional direct seepage measurements at unexplained ECT anomalies during the fall of 2003. The purpose of the direct seepage measurements was to determine whether ECT anomalies could be used to identify areas of groundwater discharge. The seepage measurements were then spatially integrated to estimate baseflow and compared to baseflow from graphical hydrograph separation techniques.

2. STUDY AREA AND SITE DESCRIPTION

2.1 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 84 m (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 extends 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.

2.2 PHYSIOGRAPHY

According to Chapman and Putnam (1984), there are five physiographic regions found within the South Nation River basin; the Edwardsburg Sand Plain, the Glengarry Till Plain, the Winchester Clay Plain, the Russell and Prescott Sand Plains, and the Ottawa Valley Clay Plains. 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). In some reaches, particularly in the Casselman region, the South Nation River valley has bank heights of about 23 to 30 meters and a valley width of about 40 meters (Gadd, 1976), while in the upstream reaches the river bank heights are a few meters or less.

The Edwardsburg Sand Plain physiographic region lies almost completely within the southwestern part of the basin. The topography of the sand plain is mostly level or gently undulating, although hummocks and ridges appear in places. According to Chapman and Putnam (1984), the sand was deposited by the melting glacier in the form of kames and subsequently spread about by the waves of the Champlain Sea. The main urban centers within this region are Maynard, Domville, and Spencerville.

The Glengarry Till Plain physiographic region is located in the southeastern portion of the basin and it is a part of a larger region of low relief forming the drainage divide between the international sections of the St. Lawrence River and the Ottawa River basin. The surface of the plain is undulating to rolling, consisting of long morainic ridges and a few well-formed drumlins together with the intervening clay flats and swamps (Chapman and Putnam, 1984). A number of tributaries to the South Nation River arise within this physiographic region, including the South Branch, the Black Creek, Payne River, and Scotch River. The main urban centers are Avonmore, Finch, Newington and Williamsburg.

The Winchester Clay Plain lies between the Glengarry Till Plain and the sand plains of United Counties of Prescott and Russell. It is an area of low relief, lying almost entirely within the drainage basin of the South Nation River. In many places within the clay plain, the underlying till protrudes and there are a few low drumlins. The main urban centers include Winchester, Chesterville, Casselman and Maxville (Chapman and Putnam, 1984).

The Russell and Prescott Sand Plains physiographic region is located in the United Counties of Prescott and Russell. The region consists of a belt of large sand plains separated by the clays of the lower Ottawa valley. Most of the plains are within the drainage basin of the South Nation River, but smaller parts drain to the Rideau and Ottawa rivers. The South Nation River cuts a canyon 22 m deep across the plains from Casselman to Lemieux (Singer et al., 2001).

The Russell and Prescott Sand Plains have a level surface whose elevation is approximately 75 m above sea-level, while the bottoms of the intervening clay-floored valleys lie below 60 m. According to Chapman and Putnam (1984), the plains, excepting the higher sands south of Ottawa, were at first a continuous delta built by the Ottawa River when it rose above sea level.

The Ottawa River Clay Plains physiographic region extends between Pembroke and Hawkesbury and occurs within the basin in Plantagenet, Clarence and Cumberland

Townships where the valley is occupied by the South Nation River and its tributary the Bear Brook. The region consists of clay plains interrupted by ridges of rock or sand. Drainage is generally poor and the Nation River above Plantagenet periodically overflows its banks, flooding the adjacent flats and depositing a little alluvium in the process (Singer et al., 2001).

2.3 GEOLOGICAL SETTING

2.3.1 OVERBURDEN GEOLOGY

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 (Fig. 2). Unconsolidated deposits in the South Nation River area consist of glacial and related sediments from the last (Wisconsinan) glaciation, marine sediments related to the Champlain Sea, and the reworking of these same sediments by modern geomorphic processes. Continental glaciers eroded all surficial materials predating the Wisconsinan glaciation during the last glaciation (Thurston, 1992).

The bedrock outcrops 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 poorly sorted gravelly glacial debris grading downwards into the typical gravelly to sandy silt till masks them. The best exposure occurs on the west bank of the South Nation River near the Casselman dam where it is only about 1 m 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, with a general north –south orientation. 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.

2.3.2 BEDROCK GEOLOGY

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 (Singer et al., 1997).

During the Late Cambrian to early Ordovician Periods a marine transgression occurred and deposited the Nepean, March and Oxford Formations. During the Middle to Late Ordovician, fluctuating sea levels deposited the Rockcliffe Formation and Ottawa Group. Deep-water sedimentation and deposition formed the Billings, Carlsbad and Queenston Formations during the Late Ordovician (Thurston, 1992).

A small area in the northwest has been identified as part of the Nepean Formation of Upper Cambrian Age. It consists of sandstones with conglomerate interbeds and has a thickness of up to 300m (Singer et al, 2001). Rocks of the March and Oxford Formations of Lower Ordovician age underlie much of the southwestern part of the basin. They were laid in a shallow sea transgressing from the east. The March Formation consists of interbedded sandstones and dolostones, with boulder and cobble-sized interclasts of quartzite where the unit is in contact with Precambrian rocks. It ranges in thickness from 6 to 64 m. As the depth of water was increased, the sediments became finer-grained, slowly grading into clay-size sediments and carbonate precipitates (CaMg) of the Oxford Formation (dolostone), characteristic of a hypersaline environment. The last occurrence of sand corresponds to the transition between the March Formation and the Oxford Formation. 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. The rocks of the Rockcliffe Formation grade from sandstone, with quartz-pebble conglomerate locally present, to shale and limestone with silty dolostone interbeds, indicating a gradual deepening of the water, with deeper water conditions to the east. The Formation has a thickness up to 125 m (Thurston, 1992).

The overlying succession of shales, dolostones and limestones, of the Gull River, Bobcaygeon, Verulam and Lindsay formations represent a near-continuous deposition on a deepening shelf. Along with the Shadow Lake Formation, these units comprise the Ottawa Group in Eastern Ontario (Singer et al., 2001). The Ottawa Group occurs over large areas in the eastern and northern parts of the basin.

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, 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 with thin interbeds of dark grey limestone, and is distinguished from the underlying Eastview Formation by its noncalcareous nature indicating deposition in a deep shelf environment (Thurston, 1992). The Billings Formation grades into the Carlsbad Formation which consists of interbedded shale, fossiliferous calcareous siltstone, and silty bioclastic limestone, indicating that the conditions were evolving from deep sea to shallow sea. The Carlsbad Formation has a maximum thickness of 186 m (Thurston, 1992). The depositional sequence indicates marine regression that continued during deposition of the Queenston Formation. The Queenston Formation consists of shales with interbeds of limestones and calcareous shales and is the youngest preserved Paleozoic Unit (Thurston, 1992).

Faulting is extensive throughout the bedrock and in many cases the faults serve as geologic boundaries. 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 (Fig. 3). The fault is assumed to extend northeasterly, passing between the villages of Lemieux and the town of Casselman. The block is further disjointed by faults trending southeasterly.

Faults in the area are usually described as post-Ordovician (probably Cretaceous) age, although some researchers have suggested faulting may have also occurred during the Cambrian and Ordovician (EOWRMS, 2001). Vertical displacements of up to 1000 m are reported for some faults in eastern Ontario. Faults and fractures acted as conduits for fluids responsible for dolomitizing carbonate strata and dissolving salt-bearing strata.

Water may be obtained from fractures in the bedded Paleozoic deposits. Faulting and fracturing within these units controls the amount of water that can be extracted and conducted through these units. Where fracturing is extensive, large quantities of water suitable to supply communal systems may be extracted. Generally, aeas with large thickness of overburden are more likely to hzve large quantites of sand and gravel that can act as aquifers. EOWRMS (2001) suggests that the first few meters of the bedrock is generally fractured from weathering and can provide a source of groundwater to a well at least from domestic use. Additional porous or fractured zones may exist within the bedrock and provide adequate amounts of groundwater.

2.4 REGIONAL HYDROGEOLOGY

The quantity of water available to potentially replenish surface and groundwater resources in Eastern Ontario is called the "Net Available Water", given by the average total annual precipitation minus evapotranspiration. In Eastern Ontario the Average Annual precipitation is 930 mm and the Net Available Water is 510 mm (EOWRMS, 2001). 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 the 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. However, most of the available water contributes to the surface water resources and only an average of 31.2 mm/year actually infiltrates compared to an average of 478.8 mm/year of runoff (EOWRMS, 2001). 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 the 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 (the hydrostratigraphy is discussed in the following section). 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 2m are considered to be possible aquifers that could supply groundwater to a well. Based on the EOWRMS conceptual model, the lower overburden aquifers have the greatest potential for the development when combined with the upper portion of the bedrock.

The degree of geologic potential from contamination varies throughout the study area. It is 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. 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 on the 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 southwest Stormont, Dundas, and Glengarry (SD&G) and near Maxville (EOWRMS, 2001)

2.4.1 HYDROSTRATIGRAPHY OF THE SOUTH NATION RIVER WATERSHED

2.4.1.1 Bedrock Aquifers

Chin et al. (1980) indicated that the groundwater supplies from bedrock aquifers in the South Nation River 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 sandy dolostone 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 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.

2.4.1.2 Overburden Aquifers

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 and semi-confining layer for the Contact Zone Aquifer. The low hydraulic 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 or clay 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.

2.5 LAND USE

Figure 4 illustrates land use in the South Nation River basin. Approximately 60% of the land is used for agricultural purposes in 2001. The main agricultural products are corn, grain and hay (Singer, et al., 2001). Woodlands cover approximately 23% of the land; 9% of the land 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.

2.6 GROUNDWATER USE

There are 10,562 records on file with the Ministry of the Environment for water wells constructed in the South Nation River Basin. Of these, 83.42% are bedrock wells, 10.77% are overburden wells, and the remaining 5.81% are of unknown type (Singer et al., 2001).

Although groundwater in the basin is available in adequate quantities for private domestic supplies and municipal supply for many small communities, it is not readily available to meet the needs of large municipalities or industries. Of the aquifers in the basin, only the Rideau Front aquifer along the western edge of the basin appears to have the potential for large-capacity municipal and industrial wells. The Rideau Front Aquifer has an area of 105 km^2 and is composed of surficial sand and gravel of glaciofluvial origin. It is the most important overburden aquifer within the basin.

Because groundwater is used by thousands of homeowners and by many small communities in the basin, it represents an important asset. As communities grow, surface waters will have to play an increasingly important role in augmenting the available groundwater supplies.

The most common groundwater concerns in the basin relate to inadequate supply and poor quality. Wells with inadequate supplies are located predominantly in the clay plain areas in the central and northern parts of the basin where there are no dependable overburden aquifers and where groundwater in bedrock is highly mineralized. Groundwater quality problems consist of saltiness, high mineralization, and the presence of sulfur. Salty and highly mineralized waters are derived predominantly from bedrock wells in the northern part of the basin, notably in the Bear Brook Valley and the South Nation Valley. Sulphurous waters occur mainly in the central part of the basin.

3. 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 coordinates 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 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 labor intensive (seepage meters and piezometers). An alternative method for identifying zones of groundwater discharge is to use an electrical conductivity (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 levels 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 ambient summer air temperatures warm up surface waters. This is the case in many, if not most gaining rivers, such as the South Nation River.

Each waterway or water body tends to have a relatively consistent range of electrical conductivity values that, once known, can be used as a baseline against which to compare regular measurements of conductivity. Significant changes in conductivity may then indicate that a discharge or some other source of contamination has entered the waterway. 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 drawback is that they are extremely labor 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 at unexplained ECT anomalies. The direct methods are illustrated in Figures 5 and 6 and the ECT method in Figures 7 and 8.

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 this study.

3.1 SURFACE WATER GROUNDWATER INTERACTION

Groundwater and surface water are fundamentally interconnected. 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. Groundwater discharge and surface water exchange in streambeds can affect the distribution and health of benthic and hyporheic-zone aquatic life within streambeds (Conant, 2003). Water quantity can also be an issue: surface water flow can be decreased 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.

3.2 DARCY'S LAW

Darcy's Law is a generalized relationship for flow in porous media. It shows the volumetric flow rate as a function of the flow area, elevation, fluid pressure and proportionality constant. It may be stated in several different forms depending on the flow conditions. Since its discovery, it has been found valid for any Newtonian fluid. Likewise, while it was established under saturated flow conditions, it may be adjusted to account for unsaturated and multiphase flow.

For a 1-D flow, it may be stated as

$$Q=AK(\Delta h/L) \qquad [1]$$

where,

Q = volumetric flow rate (m^3/s),

A = flow area perpendicular to L (m^2),

K = hydraulic conductivity (m/s),

L = flow path length (m),

h = hydraulic head (m),

and

Δ denotes the change in h over the path L.

3.3 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 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 opened 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 at center, Figure 5.

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 (usually the mid-point of the tip is used) and the river bed (dl). Figure 5 at center, illustrates the installation of a mini-piezometer in an open body of water, and the dh/dl measurements.

3.4 SEEPAGE METERS

3.4.1 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 of the left hand side of Figure 5. The closed-top seepage meter consists of the end section of a 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 on the top of the drum. A plastic collection bag with a known 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 period; 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.

3.4.2 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 remains 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 5 gives an illustration of an open-top seepage meter on the right hand side.

In this study, several open-top seepage meters were installed in places of unexplained anomalies. The method is similar to that described by Lee (1977). Inexpensive, thin-walled, 1 ¾-inch PVC pipe was used for the riser pipes 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 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 piezometeric measurements. A siphon and 2-L collection bag was then installed on each meter and the seepage meters were allowed to seep for approximately 1 week. The volume of water collected in the bag and the difference in river water levels was measured 3 times with approximately 1 week between measurements. Seepage volumes were corrected for water level fluctuations in the river. If there was an increase in water level that volume would be subtracted from the volume in the collection bag and if there was a decrease in water level that volume was added to the volume in the collection bag.

3.5 ELECTRICAL CONDUCTIVITY AND TEMPERATURE MEASUREMENTS

3.5.1 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 centimeter but 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 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, 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 x 10^{-2} μS/cm at 25°C (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 x 10^{-1} μS/cm at 25°C, and that of common distilled water is 0.5-5 μS/cm at 25°C (Matthess, 1982). For reference, the following table gives typical EC ranges for different types of water (Robin, 2003):

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	~ 3500	~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:

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

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 (Michaud, 1991):

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 rivers 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 seems low when averaged over a week or a month. Agricultural runoff of water draining agricultural fields typically has extremely high level of dissolved salts (non-point source 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 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 summers of 2002 and 2003, zones of groundwater discharge were identified along the South Nation River using an electrical conductivity and temperature (ECT) probe in conjunction with 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 (Fig. 7, 8). The boat traveled at approximately 3-5 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 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 Memtrak^{TM}, a mobile unit that stores position reports to its internal RAM memory storage for later download to a PC. The Memtrak^{TM} 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^{TM} unit can be user programmed to automatically calculate GPS position reports and time lags 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 9. 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 into 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 that 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 higher electrical conductivity than 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.

3.5.2 RECONCILIATION OF ELECTRICAL CONDUCTIVITY AND TEMPERATURE MEASUREMENTS

Electrical Conductivity at a given location can change from day to day depending on day-to-day occurrences such as precipitation events and evaporation and upstream occurrences. Since the EC survey was conducted over many days (the entire summer season), an attempt was made to remove this temporal variation by "standardizing" all measurements to a single date: June 7, 2002. On June7, 2002 the electrical conductivity of several sections of the river was measured covering the entire territory, and an average EC of this day was calculated (507.2 μS/cm). All measurements made on other days were corrected to the June 7, 2002 date. The calculation used was;

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

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

May 23rd value corrected to June 7 = Uncorrected Value + (Average of June 7 (507.2 μS/cm) – Average of May 23 (456.7))

In addition, short-term temporal variations were corrected: each day, a section of the river that was measured the previous day was measured again. Any inconsistencies between the measurements were corrected. For instance, if uncorrected measurements were 500 μS/cm in one location on one day and were measured to be 520 μS/cm the next day then each measurement taken the next day would be deducted 20 μS/cm.

To rule out any other possibility than groundwater discharge zones, other factors were examined. 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. ECT measurements of tributaries were also taken into consideration in order to rule out the possibility that anomalous ECT values were caused by inflowing surface water.

3.5.3 CALIBRATION OF PROBE

During the field season, the ECT meter was calibrated with a standard before each sampling run. In order to calibrate the ECT meter, a 0.01 molar KCl solution with a conductivity of 1470µS/cm was used. To prepare a 0.01 molar KCl solution, 0.7456 g of KCl was dissolved in 1L of deionized water. Calibration was performed using the software that is attached to the probe.

3.6 OTHER INDICATORS OF GROUNDWATER SEEPAGE

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

Topography can also be an indicator of groundwater seepage. Topographic highs often correspond to high potential areas and recharge areas where groundwater flow is generally downwards into an aquifer. Areas of low potential are often discharge zones where groundwater flow is generally upwards towards surface water features such as streams. Aquifers lose water by discharge to surface water features. Groundwater discharge can contribute a significant portion to the flow of rivers, known as baseflow. 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. The amount and intensity of precipitation in a watershed can vary considerably over the course of the year, and consequently, 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, 1979). Saturation and high pore-water pressures in clays are principal factors in the landslide mechanism.

These groundwater indicators were used only as first glance indicators in this study and were not quantitative.

3.7 HYDROGRAPHIC SEPARATION

A stream hydrograph shows the discharge of a river at a single location as a function of time. While the total streamflow shown on the hydrograph gives no indication of its origin, it is possible to break down the hydrograph into components such as overland flow, baseflow, interflow, and direct precipitation (Fetter, 1997).

As mentioned earlier, base flow is the groundwater contribution to streamflow. In order to successfully compare the direct seepage values to the base flow found from hydrographs in the South Nation River, two hydrograph separation techniques were utilized and compared; the base flow recession equation and the fixed base method. The provisional mean daily discharges (m^3/s) for 2003 were obtained from 4 different stations in the South Nation River Watershed; station number 02LB005 (South Nation River near Plantagenet Springs), 02LB006 (Castor River at Russell), 02LB007 (South Nation River at Spencerville), and 02LB008 (Bear Brook near Bourget). A map of the location of these stations is shown in Figure 10. The time frame that was studied was from September 5, 2003 to October 14, 2003, which was selected to correspond to the time frame when direct seepage values were being collected. The base flow values that were obtained from hydrograph separation were then added up for this time frame and compared to the base flow obtained from direct seepage measurements and the EC survey.

3.7.1 BASE FLOW RECESSION

In the absence of precipitation the groundwater reservoir will be depleted and stream flow will decrease (Fetter, 1997). The hydrograph will decay following an exponential curve. The discharge is composed entirely of groundwater contributions. The baseflow recession for a drainage basin is a hydromorphic characteristic. It is a function of the overall topography, drainage pattern, soils and geology of the watershed. The point of inflection on the falling side of the hydrograph is commonly assumed to mark the time at which surface inflow to the channel system ceases. Thereafter, the recession curve represents withdrawal of water from storage within the basin.

The base-flow recession equation is (Fetter, 1997);

$$Q = Q_o e^{-at}$$

Where

Q = flow rate at some time after recession begins
Q_o = flow rate at beginning of recession
a = recession constant for the basin
t = time since recession began

The recession constant represents the behaviour of the basin, and it can be estimated from stormflow hydrographs. Once this constant is obtained, it is possible to calculate baseflow, Q, from the above equation. The details of the calculation are given in Appendix 3.

3.7.2 FIXED BASE METHOD

The fixed base method of separation assumes that the time base of direct runoff (i.e. the duration of runoff) remains relatively constant from storm to storm. The overland flow is assumed to end some fixed time after the storm peak. As a general rule of thumb, this can be approximated by the formula (Linsley, Kohler, & Paulhus 1975);

$$D=0.827A^{0.2}$$

Where

D is the number of days between the storm peak and the end of overland flow

A is the drainage basin area in square kilometers

The exponential constant of 0.2 is empirical; thus, the preceding formula should be used with caution. The value will depend upon many drainage basin characteristics, such as mean slope, vegetation, drainage density, geology, etc.

This procedure consists of extending the recession existing before the storm to a point under the peak of the hydrograph. From this point a straight line is drawn to the hydrograph at a point N days after the peak. The reasoning behind this procedure is that as the stream rises, there is flow from the stream into the banks. Hence, baseflow should decrease until stages in the stream begin to drop and bank storage returns to the channel. Figure 11 shows hydrograph separation into overland flow component and baseflow component for a stream. Appendix 3 describes this procedure in more detail.

3.8 BASEFLOW INTEGRATION FROM DIRECT SEEPAGE MEASUREMENTS

During the fall of 2003, seepage meter/ piezometers were used to measure the groundwater flux to the South Nation River. A total of 17 piezometers/seepage meters were installed at 5 different locations (Fig. 12) along the South Nation River. 3 or 4 piezometers were installed at each location in order to get a cross-section of flux along the river. The seepage meter locations were decided based on the electrical conductivity survey; areas with unexplained positive EC anomalies were deemed to be potential groundwater discharge zones.

In order to compare direct seepage measurements to baseflow found from graphical hydrograph separation techniques, an integration of baseflow from the seepage measurements was needed. This was achieved by estimating the entire groundwater discharge zone in the locations where seepage measurements were made. The groundwater discharge area was established by multiplying the width of the river by the estimated length of the river where discharge was taking place. This length was based on the EC survey; if the EC values were above the moving average in the area, then discharge was assumed to be occurring. The estimated groundwater discharge area (m^2) was then multiplied by the average seepage meter flux ($m^3/m^2/s$) found in this area to obtain the integrated baseflow (m^3/s). The results were then compared to the results found from hydrograph separation techniques. An example of this technique is illustrated in Figure 13.

The width of the river was measured in GIS, which causes error in the calculation. GIS does not measure the width of the river by its waterline but by its banks. Therefore, there is an estimated width error of 5 meters, or 10-20%, depending on the location of the measurement. There is also error in the length calculation due to the fact that it is found by a visual estimation. An estimated length error is 10 meters, or 1-3%, again depending on the location. Therefore, the worst scenario would be 25% error. This would reduce the volumetric flow rate by 0.25, or 4 factors. An example of the error calculation is given in Appendix 4.

3.9 "MAIN TRUNK" VALUE

A "main trunk" value was found because direct seepage measurements were made on the main trunk only. Therefore, in order to compare the integrated seepage values to the hydrograph techniques, baseflow contributions from the main trunk only had to be found. The main trunk "contribution" was the flow at the most downstream station (Plantagenet) minus flow at the station upstream from the most upstream seepage measurement (Spencerville), minus the major tributaries (Castor and Bear Brook). This method will actually overestimate the main trunk contribution because it actually ignores the small tributaries. The formula used to get the "main trunk" value was:

"Main Trunk" = Plantagenet – (Spencerville + Castor + Bear Brook)

4. RESULTS AND DISCUSSION

4.1 CORRELATION BETWEEN EC AND TEMPERATURE

The EC values in the South Nation River bottom sediments ranged from around 50μS/cm near the confluence with the Ottawa River to around 660μS/cm where Highway 417 crosses the South Nation River. The temperature range was from 18 to 28°C.

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. However, the temperature and EC did not correlate very well in the South Nation River. Figure 14 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 14 and the corresponding geographical areas of origin are indicated on the maps given in Figures 15 (a) and (b).

Clusters 1,2,5, and 6 all have similar EC values but progressively warmer temperatures, and therefore, a clear association of temperature values could not be identified. As shown in Figure 15(b) these clusters are all found in the upper reaches of the river, where the river is relatively shallow, and the temperature variations may simply be related to the air temperature and sunshine level on the day of measurement.

Clusters 3 and 4 have 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. Although some measurements were made on the Castor River near its confluence with the South Nation River, major sources of EC loading could not be pinpointed. However, since the Castor River crosses several municipalities, it is easy to speculate that the source(s) of EC loading are anthropogenic. The area between Lemieux and Plantagenet shows high EC values that are at least partly the result of the nature of the soil in the area. The soil, particularly around Lemieux, where a major landslide took place in 1989, is prone to micro landslides, which increase the sediment and electrolyte loading.

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 measuring at about 100μS/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.

4.2 ELECTRICAL CONDUCTIVITY PROFILE OF THE SOUTH NATION RIVER

Due to 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 16 presents the EC profile, giving EC as a function of upstream distance from the confluence with the Ottawa River to the most upstream location of the survey (Oak Valley). Because of the 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. This artefact adds some variability in the data plotted, and so a 20 point moving average is also shown. Gaps in the data record correspond to locations in the river that were not navigable (Fig. 22) In particular; the area around Lemieux was not navigable. A large landslide occurred in this area in 1989 and the South Nation River is full of debris therefore making it non-navigable by boat. The gray area on the figure corresponds to actual measurements and the dark line is a moving average. Figure 16 also identifies landmark locations along the river (towns, villages, etc.), geological faults, tile drain sampling points, and EC anomalies. A map view of the study area is given in Figure 1, in which a 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 17.

4.3 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 more conductive than the other. 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 16. 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 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.

4.4 NEGATIVE ANOMALIES

The survey shows the presence of several "negative" anomalies: EC values that are below average. These may correspond to local groundwater discharge areas but with water that is less conductive than the South Nation River water. However, a more likely explanation is that since the EC values of the negative anomalies are in the range of “normal” streams in the area, 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.

4.5 ROAD SALT INFLUENCE NEAR HIGHWAY 417 CROSSING.

Figure 16 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, a major highway in eastern Ontario. Water from a pipe draining from the road was measured for EC and it was found that the water had an EC value of 1270 µS/cm and is believed to be the result of road salt in the area.

4.6 CONFLUENCE WITH THE CASTOR RIVER

The confluence of the Castor River with the South Nation River is marked by a sharp increase in EC values in the South Nation River. 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. In addition, an area of groundwater discharge was verified only in proximity to the confluence of the Castor River and the South Nation River.

4.7 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 16, which is also indicated on the map of Figure 17. These low EC values are thought to be the result of mixing with the 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.

4.8 GENERAL EC LEVELS

As shown in Figure 16, 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 100 μS/cm range). This indicates that the level of dissolved electrolytes in the SNR 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 the South Nation but if this were the only high EC contribution we would have expected the EC levels to eventually drop back down somewhat due to dilution with additional incoming waters downstream from the Castor. 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 (2001) for this particular area.

4.9 EFFECTS OF GEOLOGICAL FAULTS

Major geological faults can, in some cases, play an important hydrogeological role. Some faults become hydrogeologically inactive 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 Casselman and upstream.

The fault zones in the study area were mapped in Figure 3 and the intersection of the faults with the South Nation River are indicated in Figure 16. 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 at 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 in the South Nation River.

4.10 TILE DRAIN EFFLUENT MEASUREMENTS

The EC of several tile drain effluents were measured at locations and times when they were flowing. The EC values are plotted in Figure 16 and mapped in Figure 18. The numbers given in Figure 18 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 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 up to 400 μS/cm. It is clear from these measurements that the tile drains are contributing significantly to the high EC of the South Nation River.

4.11 DIRECT SEEPAGE MEASUREMENTS

A total of 17 piezometers/seepage meters were installed at 5 different locations (Fig. 19) along the South Nation River. 3 or 4 piezometers were installed at each location in order to get a cross-section of flux of the river. Results of these measurements are shown in

Appendix 2. Hydraulic gradient measurements ranged from 0.09 cm/cm to 0.73 cm/cm while fluxes ranged from 1.84E-07 to 5.67E-07 $m^3/m^2/s$.

Hydraulic conductivity describes the ease with which water can pass through the sediments; it is a function of the geological material and the physical properties of water. One would therefore expect to see differences in hydraulic conductivity along the river. There are two main sediment types along the river; clay and sand (Fig. 2). The hydraulic conductivity values ranged from 1.13E-04 cm/s to 9.72E-05 cm/s, which corresponds to loess and silty sand in Freeze and Cherry (1979).

4.12 HYDROMETRIC STATIONS

Provisional mean daily discharge values were obtained from 4 hydrometric stations within the South Nation River Basin. The locations of the 4 stations are shown in Figure 10 while the details of the different stations are illustrated below in Table 2. Appendix 3 includes their hydrographs.

Station #	Station Name	Latitude	Longitude	Gross Drainage Area (km^2)	Range of Mean Daily Discharge* (m^3/s)
02LB006	Plantagenet	45°31'03"N	74°58'44"W	3810	1.12–4.39
02LB007	Castor River	45°15'43"N	75°20'40"W	433	0.303–0.849
02LB008	Spencerville	44°50'32"N	75°32'38"W	246	0.014-0.223
02LB009	Bear Brook	45°25'35"N	75°09'12"W	440	0.167-0.718

* The range of mean daily discharge (m^3/s) during the studied time frame (Sept.5 – Oct 14)

Table 2: Hydrometric Station Details.

4.13 COMPARISON OF BASEFLOWS BETWEEN HYDROGRAPHS AND DIRECT SEEPAGE MEASUREMENTS

Baseflow estimations are shown in Table 3. Results are given as average values from the "main trunk" during the period of September 5, 2003 until October 14, 2003. Details from hydrographs and their baseflow separation techniques are shown in Appendix 3.

Technique	Baseflow Estimation (m^3/s)
Directly from Hydrograph	1.04
Fixed Base Method	0.71
Baseflow Recession Method	0.84
Direct Seepage Measurements	0.06

Table 3: Baseflow Estimation Values. Results are given as average values from the "main trunk" during the period of September 5, 2003 until October 14, 2003.

This time period did not show much variability in discharge due to the time of year in which direct seepage measurements were made (September 5, 2003 to October 14, 2003). At this time of year, water levels in the river are low and are fed mostly by baseflow. Therefore, values from hydrograph separation techniques proved to be near the values of mean daily discharges taken directly from the hydrographs.

Baseflow integration values and the areas where they were measured are shown in Appendix 4. The average baseflow contribution from the 5 areas where groundwater discharge was quantified is 0.0593 m^3/s. This value is relatively close to the values found from mean daily discharge (1.04 m^3/s), the Fixed Base Method (0.71 m^3/s), and the

Baseflow Recession Method (0.84 m^3/s). When evaluating these results, one must consider the fact that non-navigable areas such as Lemieux were not accounted for.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The primary objective of this study was to identify zones of groundwater discharge in the South Nation River by taking advantage of differences between surface water and groundwater electrolyte concentrations 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 the temperature was not a good indicator of groundwater discharge.

EC at the water-sediment interface was measured along the river. In general, it was found that the EC of the South Nation River was 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 tens of 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. As an added benefit, the EC method was extremely useful at determining areas of electrolyte loading along the river, including point sources and semi-diffuse sources. Another important finding 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. This proved to be the result of "normal" surface waters entering an "abnormally" high EC river system.

Water from agricultural drainage pipes was found to have a much higher EC than the river water. This is further evidence that indicates that land use practices may be one 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 pinpoint the sources of electrolyte loading in the river.

Baseflow values from hydrograph separation techniques compared well, within the margin of error, to the integration from direct seepage measurements, as they were relatively close.

5.2 PRACTICAL RECOMMENDATIONS CONCERNING FUTURE EC WORK.

From this study, many recommendations can be made concerning future work. Most of these recommendations come from the 2 summers of fieldwork that were required for this study.

1. Make sure the boat is traveling at a slow speed (~3-4 km/hr). This is to verify that the probe is dragging along the bottom sediments.

2. Test all tributaries, water coming from roads and drainage pipes flowing into the river. They contribute enormously to the EC of the river water and can easily be mistaken for possible areas of groundwater discharge.

3. Let the PVC pipe that is installed in the sediments equilibrate for at least 1 week. An open top seepage meter that also acts as a piezometer is effective but slow responding.

4. Make sure that there is a minimum of three passes (2 sides and the center) completed when measuring EC. The EC can change significantly from bank to bank.

5. Weights in the tow cable were not needed but are recommended. The weight of the probe itself was sufficient if the boat traveled at a slow speed. However, extra weight in the tow cable confirms that the probe is reaching the bottom sediments.

6. Measure the water level during each check when collecting direct seepage measurements. If the water level is different than the water level during installation, it must be accounted for when calculating flux.

7. Measure the cross-sectional area of the PVC pipe after they are pulled out. When installing the pipes, they can damage if they are installed near rocks. This can affect the area that the water must flow through and must be accounted for when determining flux.

5.3 RECOMMENDATIONS TO THE SOUTH NATION CONSERVATION AUTHORITY

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 temperature. The method used proved valuable in finding groundwater seepage but also proved useful in determining areas of electrolyte loading in the river, including point sources or semi-diffuse sources. For this reason, we offer the following recommendations to the South Nation River Conservation Authority.

1a) <u>It is recommended that this tool be part of the arsenal of tools utilized by the South Nation Conservation Authority to monitor the state of the river.</u> Appendix 1 shows that the tool used in this study helps in finding groundwater discharge zones, as well as help pinpoint the sources of electrolyte loading in the river.

b) It is highly recommended that the Conservation Authority carry out these types of EC surveys regularly: 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.

2a) It is recommended that "hot spots" be re-examined to confirm that electrolyte loading found in this survey are still occurring.

b) 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. In terms of public awareness, results such as those presented here could be made public and accessible via Internet.

c) It is recommended that the Conservation Authority approach the appropriate authorities to reduce the road salt loading as it is damaging to both the surface water and groundwater. EC readings near main roads, especially the 417, were extremely high and were confirmed to be the result of salt loading.

3). It is recommended that the EC of drainpipe effluent be measured regularly, as part of the monitoring program and made public. This will help focus efforts to change land management practices and to help farmers save money and improve the quality of the environment. Figure 18 shows that the difference in EC between the effluent from the drainage pipes and the river ranged from 9 μS/cm to 429 μS/cm. These 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.

4). It is recommended that confirmed zones of groundwater seepage (Fig. 20) be instrumented permanently with piezometers. Piezometers are monitoring wells that are primarily used to report groundwater elevation measurements and determine speed and direction of groundwater flow. The permanent installation of piezometers will help map aquifers and help to determine how water is moving through the ground. Groundwater seepage is an essential component of water budgets, which will likely be necessary in the Source Water Protection Planning.

5). It is recommended that piezometers be installed at zones of potential recharge to help identify areas of high groundwater vulnerability. Figure 21 shows a hydrogeological interpretation of where these potential recharge areas may be located. Groundwater recharge zones should be found in order to locate areas of high aquifer vulnerability to contamination from surface water. This is possible by examining the geology of the area as was done in this study (refer to geology maps) because permeable soils, fault and fracture zones and permeable bedrock promote recharge.

6). It is recommended that the Conservation Authority cover the whole basin with this type of survey. 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.

7). It is recommended that un-navigable areas at the time of this pilot survey be surveyed at a time of the year when water levels are higher. This survey had data gaps in non-navigable areas due to low water levels in the river (Fig. 22). In some areas the EC probe could be walked, but other areas are deemed unsafe, in particular near Lemieux. This will help to obtain more accurate estimates of the contribution of baseflow to the South Nation River.

8). It is recommended that EC measurements be made over several seasons and different times of the year to show the time behavior of groundwater seepage over several field seasons. This could be used to determine the seasonality of seepage flux, and nutrient loading of the river and also as an essential component of the water budget.

9). It is recommended that existing gauging stations be used to gather additional information, particularly with respect to groundwater / surface water interactions. At the moment, the only information available at these stations is river discharge. If more information were available, determining the water budget of the watershed would be more accurate and much easier. For example, permanent piezometers should be installed at the stations to find groundwater flow, rain gauges should be installed to find precipitation, and temperature gauges should be installed in order to help determine evapotranspiration.

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FIGURES

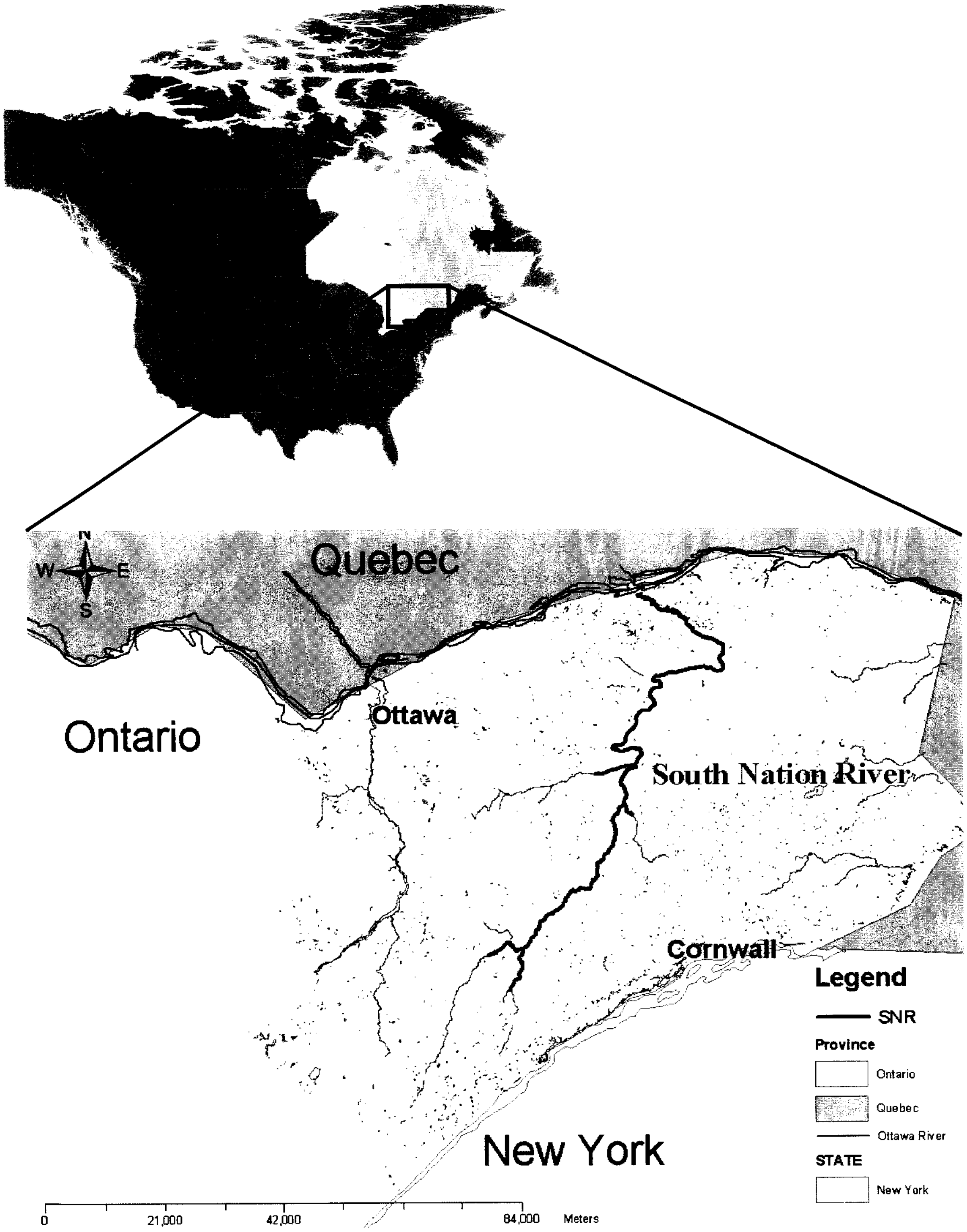


Figure 1: Map of Eastern Ontario showing the reach of the South Nation River.

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

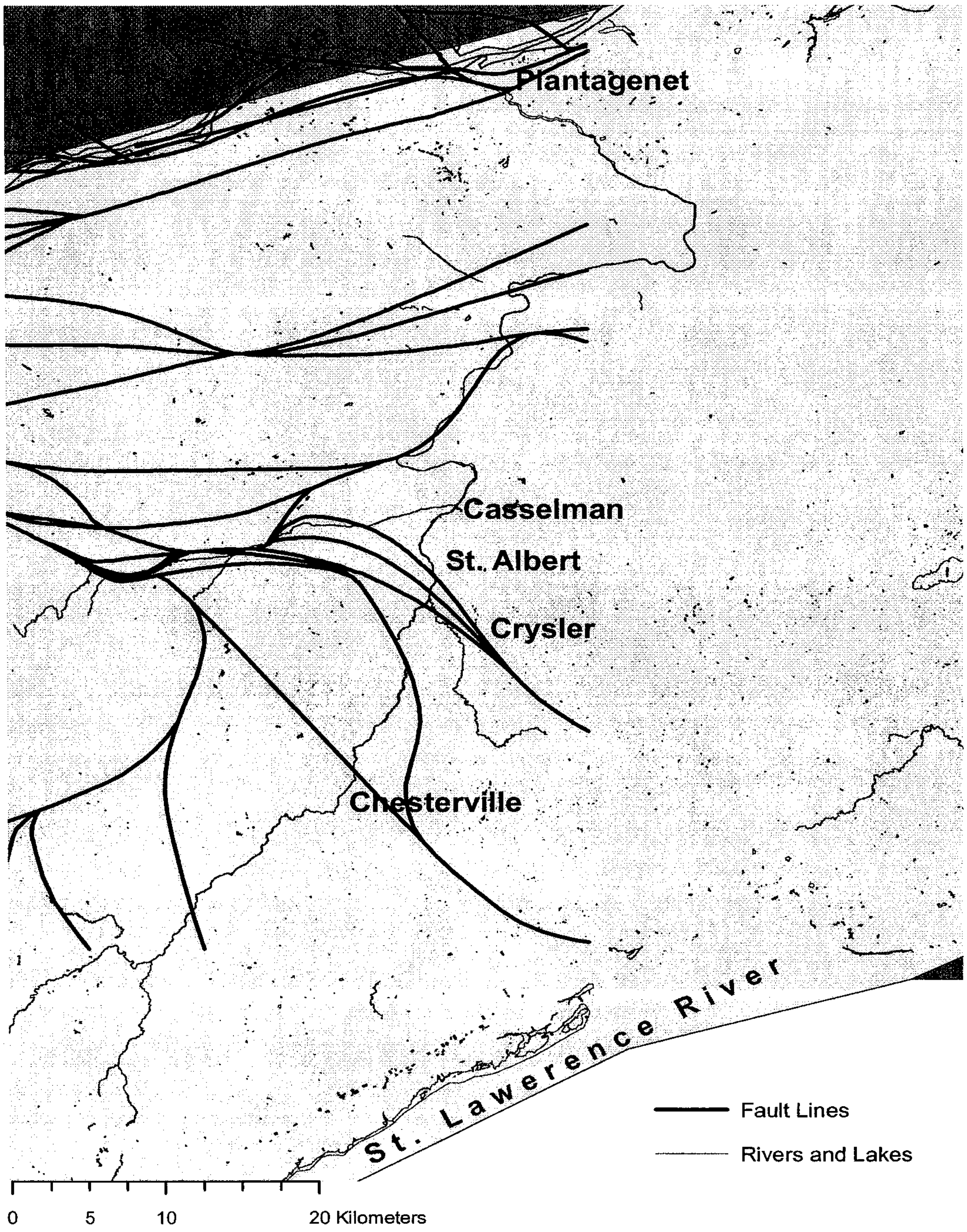


Figure 3: Several major fault zones are found along the South Nation River. Major geological faults can sometimes act as conduits for deep groundwater circulation systems, and act as recharge or discharge features where they strike. (EOWRMS, 2001).

Figure 4: Map depicting the use of land in the study area (EOWRMS, 2001)~~.~~

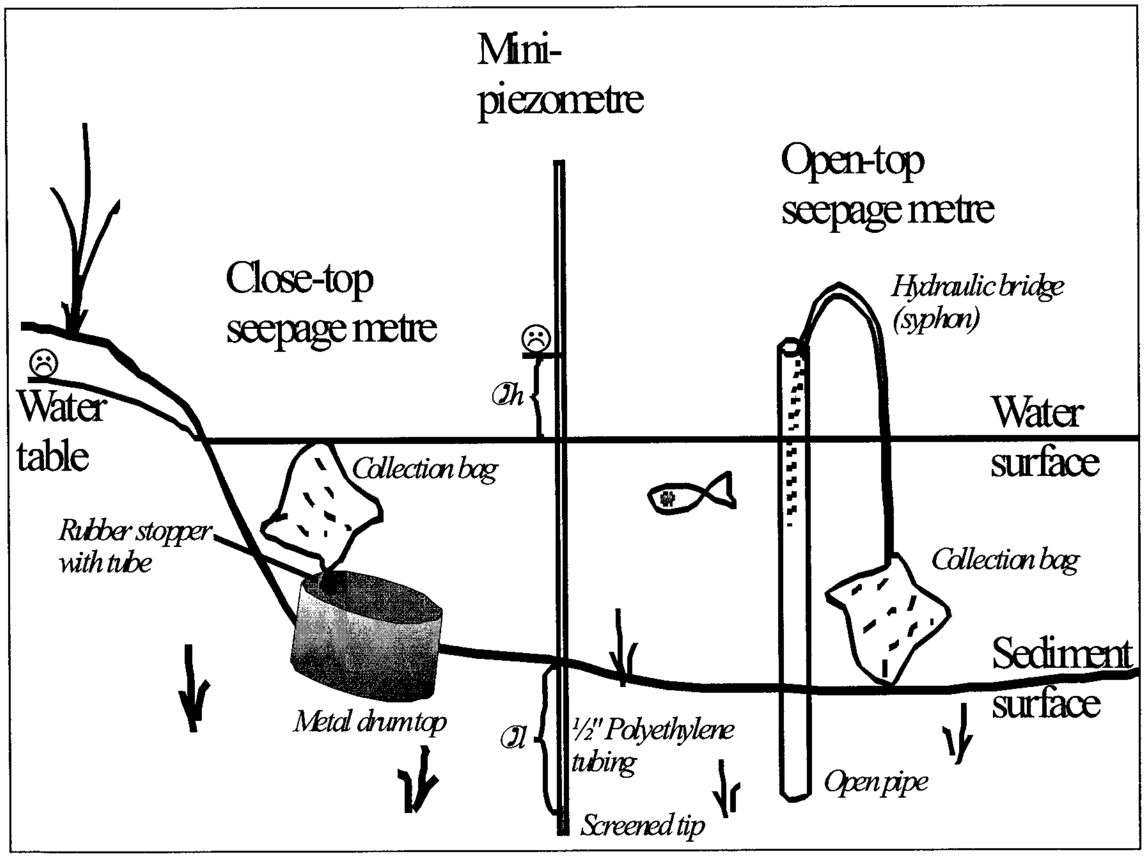


Figure 5: Diagram depicting a mini-piezometer (center) a closed-top seepage meter (left) and an open-top seepage meter (right). The mini-piezometer is used to measure hydraulic head but when used in an open body of water (as shown in the diagram), it can be used to measure the vertical component of the 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 (Robin, 2003).

Figure 6: Photo of open-top seepage meter installation using a "monkey" hammer.

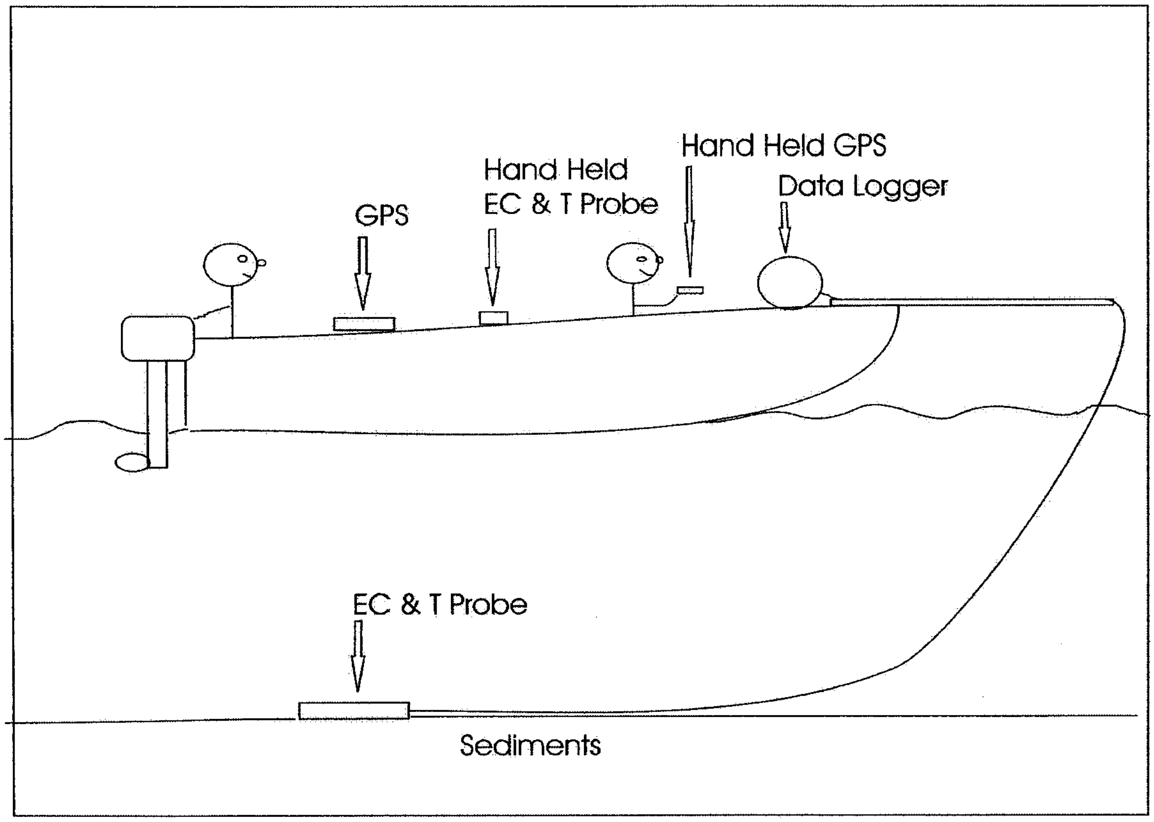


Figure 7: Field set-up during summer 2002 field season. The ECT was dragged along the bottom sediment and measured electrical conductivity and temperature while the GPS was kept in a motorboat and measured position. The boat traveled at approximately 4 -7 km/hr while the ECT and GPS took measurements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

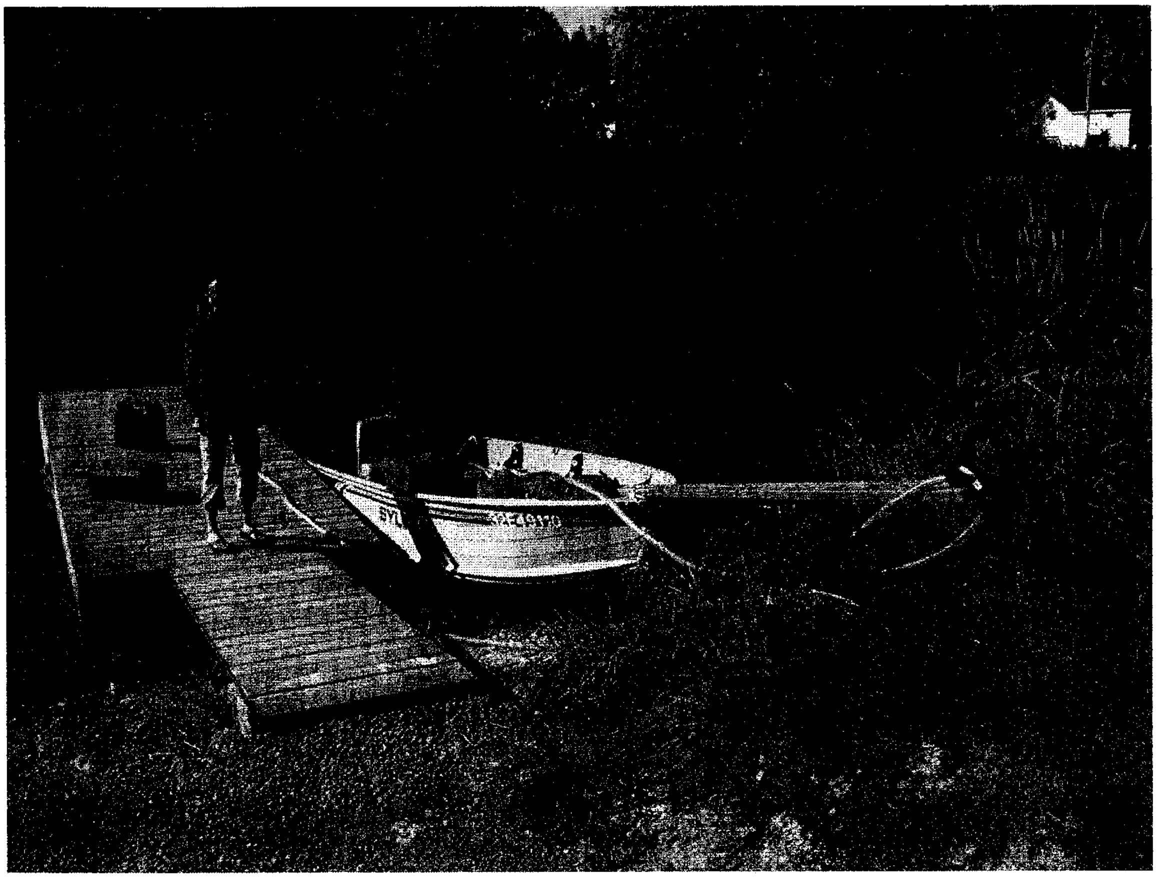


Figure 8: Photo of field set-up at Cass Bridge launching site.

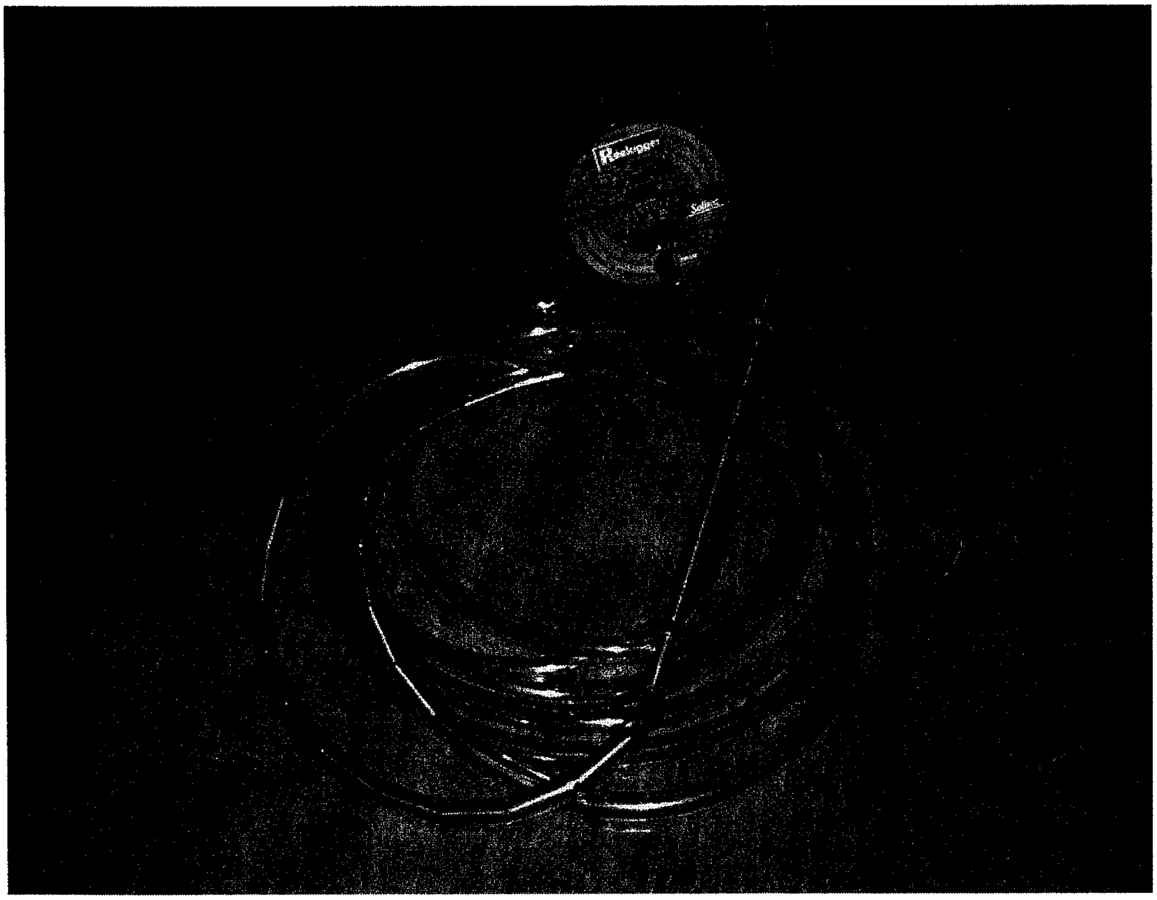


Figure 9: ECT Probe, tygon casing and data acquisition system that is manufactured by Solinst Canada. The photo actually shows a pressure probe in tandem with the ECT probe. The pressure probe was not used for this study. The ECT probe is a 25-cm-long, 8-cm-diameter, stainless steel cylinder that weighs 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.

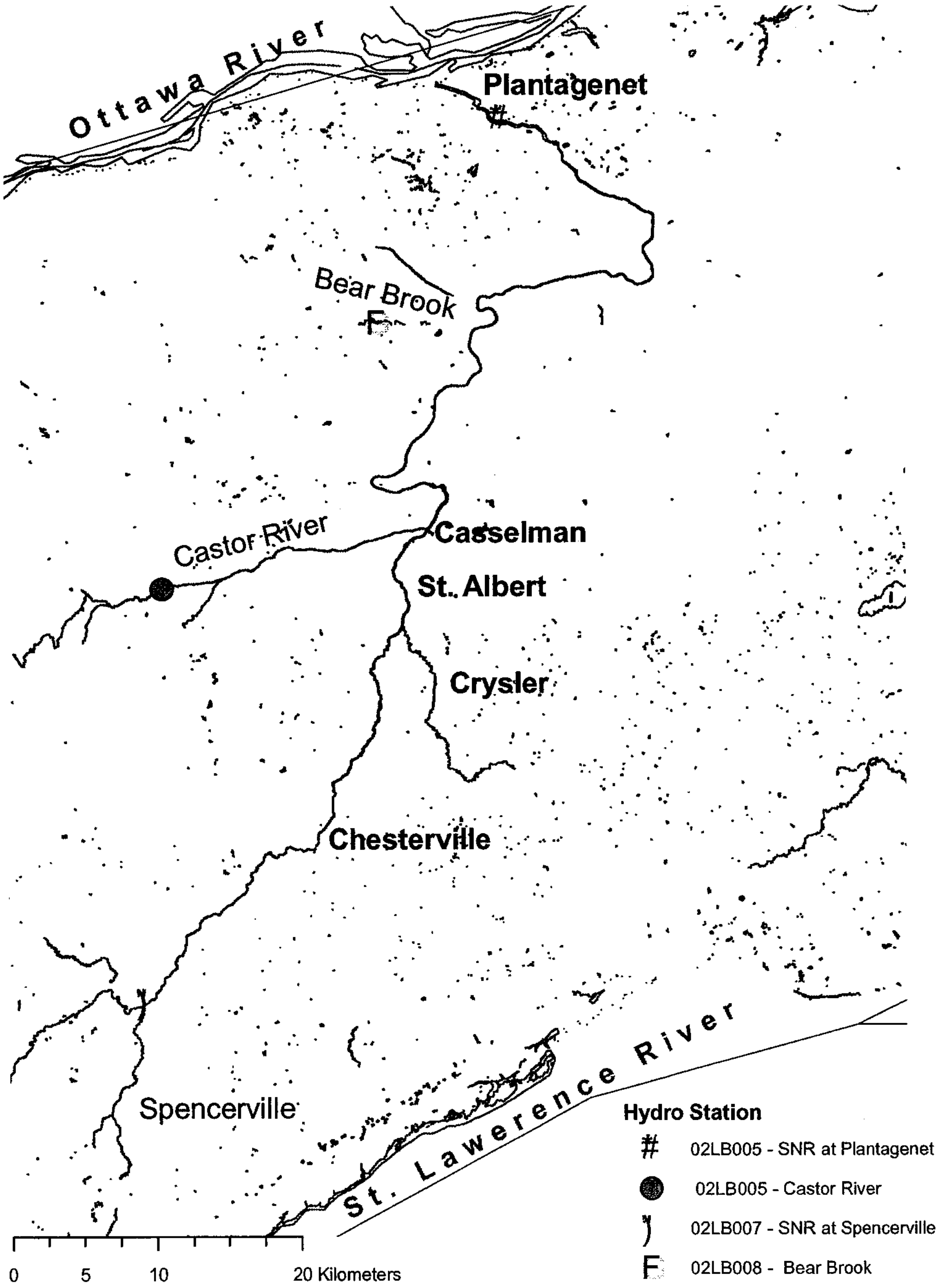


Figure 10: Locations of the 4 hydrometric stations that were used in this study

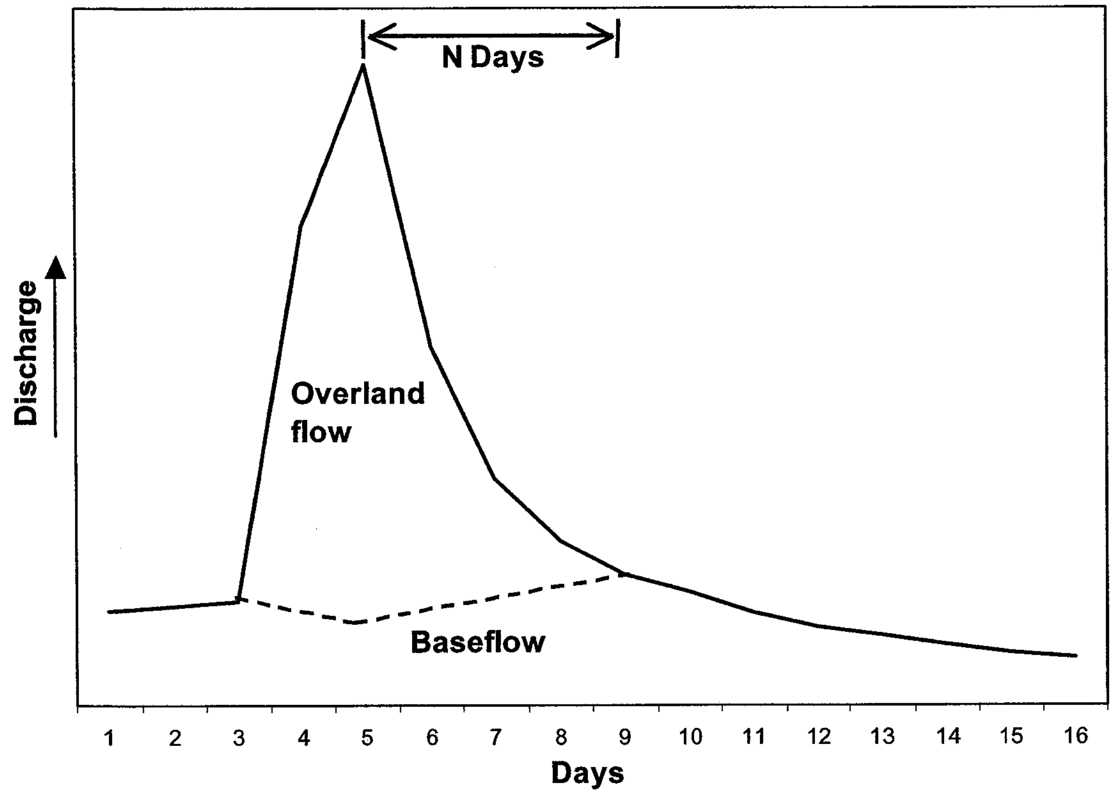


Figure 11: Hydrograph separation into overland flow component and baseflow component for a stream using the Fixed Base Method. Modified from Fetter, 1997.

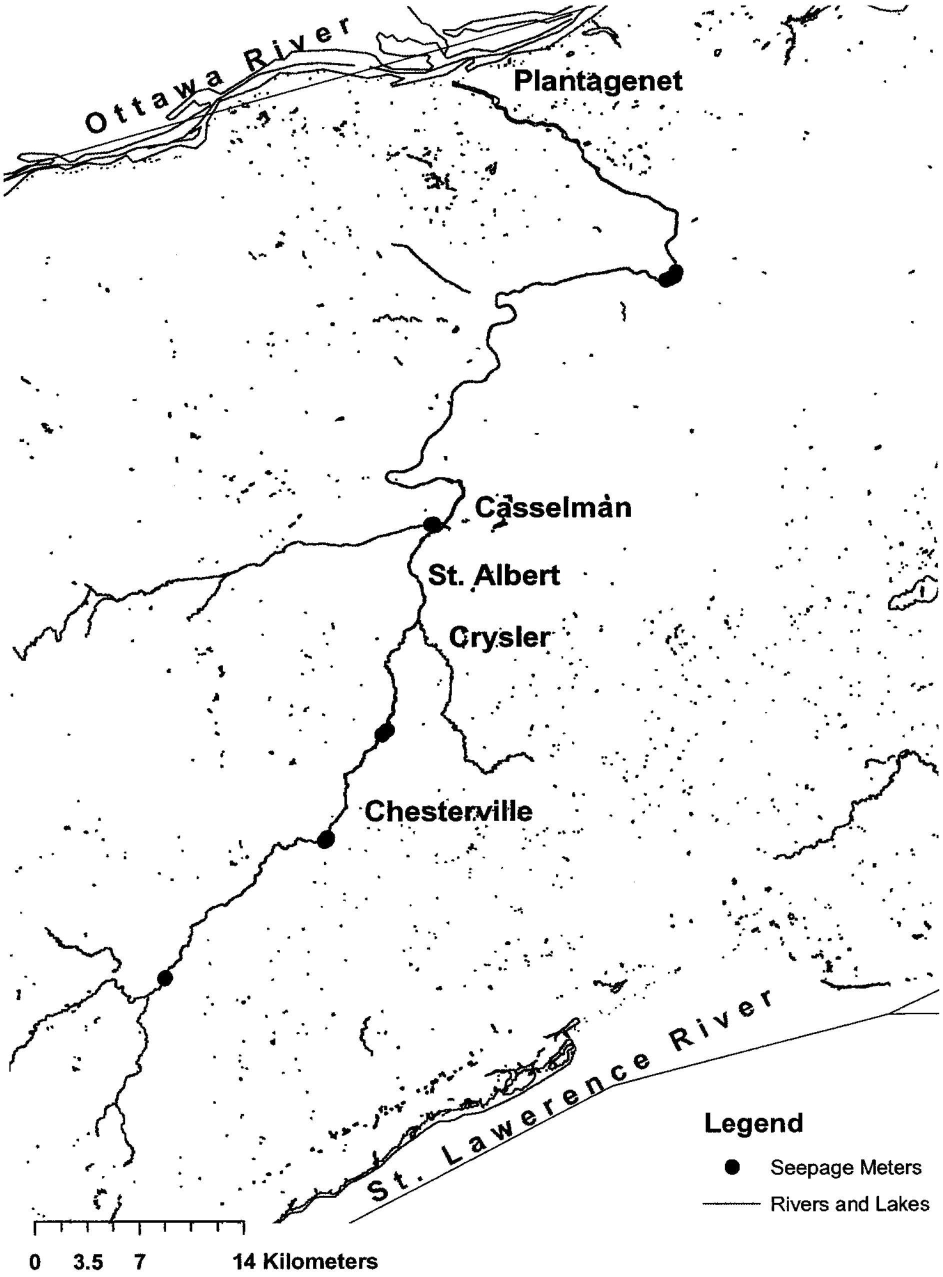


Figure 12: The locations of 17 piezometers/seepage meters along the South Nation River.

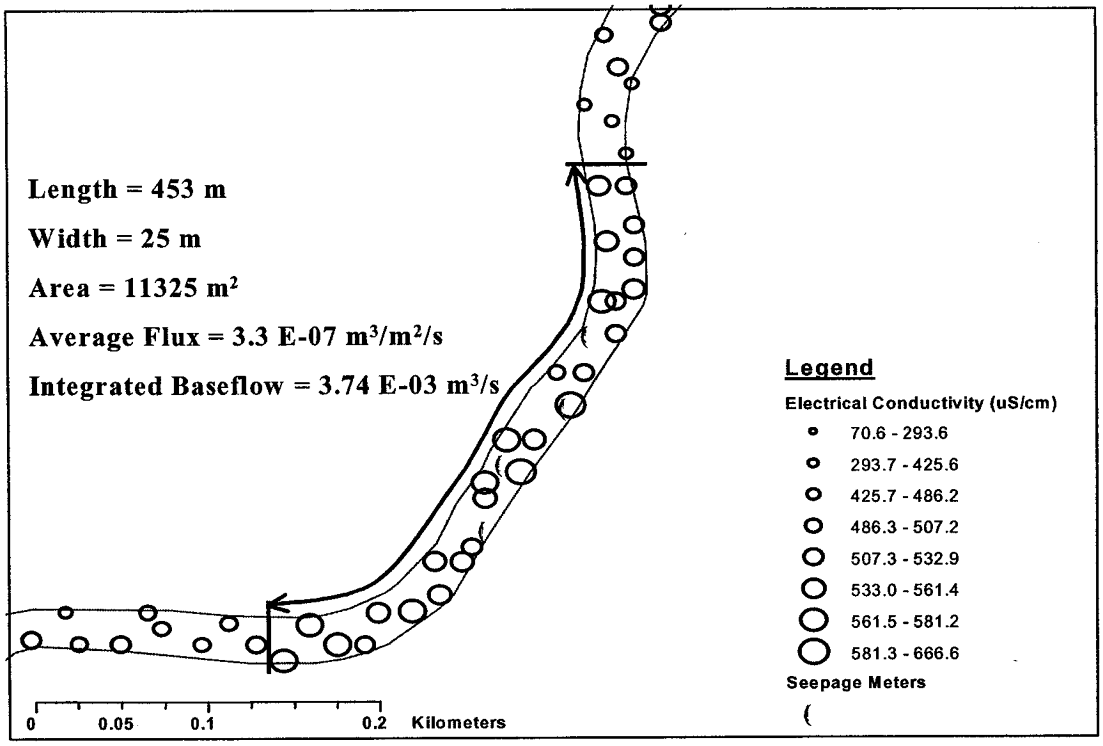


Figure 13: An example of baseflow integration from direct seepage measurements.

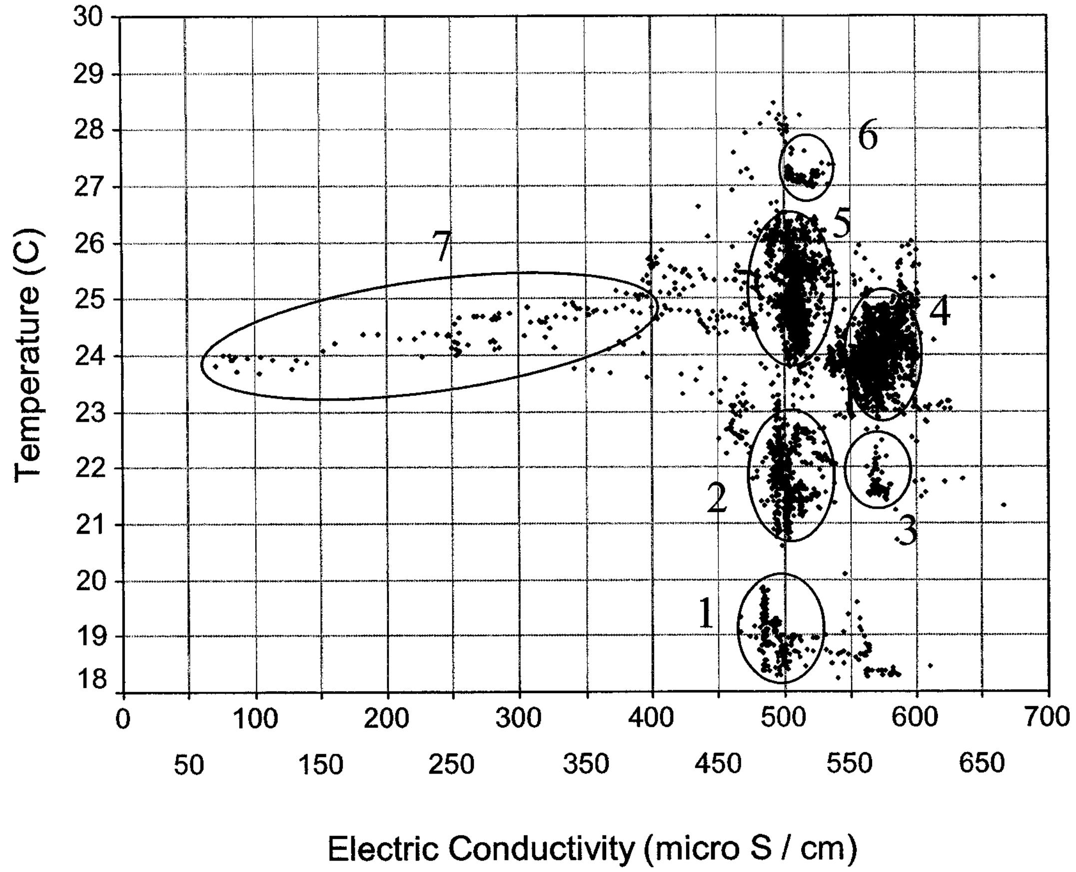


Figure 14: Graph of Temperature versus Electrical Conductivity. Values are grouped into 7 classes, shown below.

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

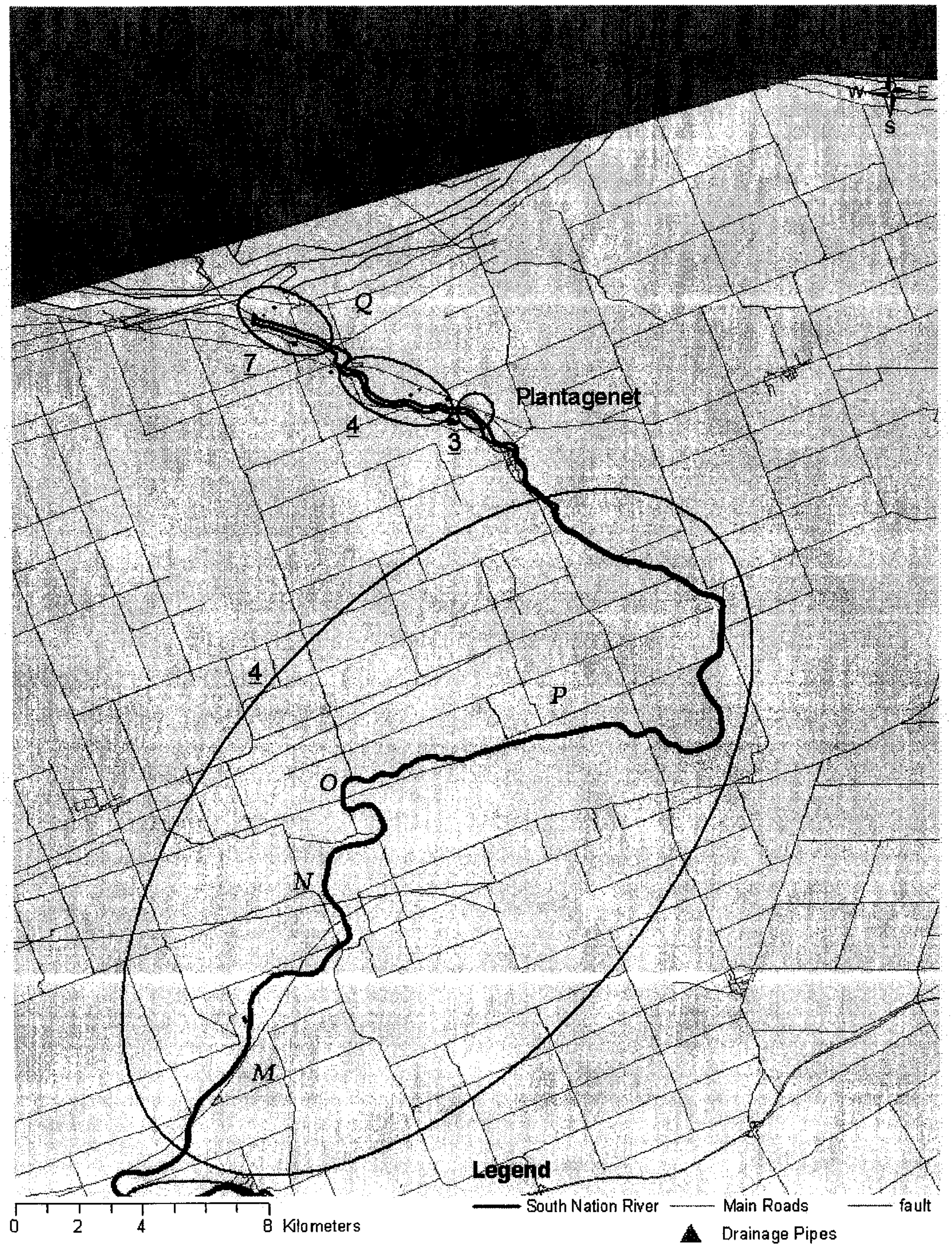


Figure 15(a): EC & T are grouped into 7 classes (Fig. 8). The locations of these values are shown here and in Figure 15(b). (EOWRMS, 2001).

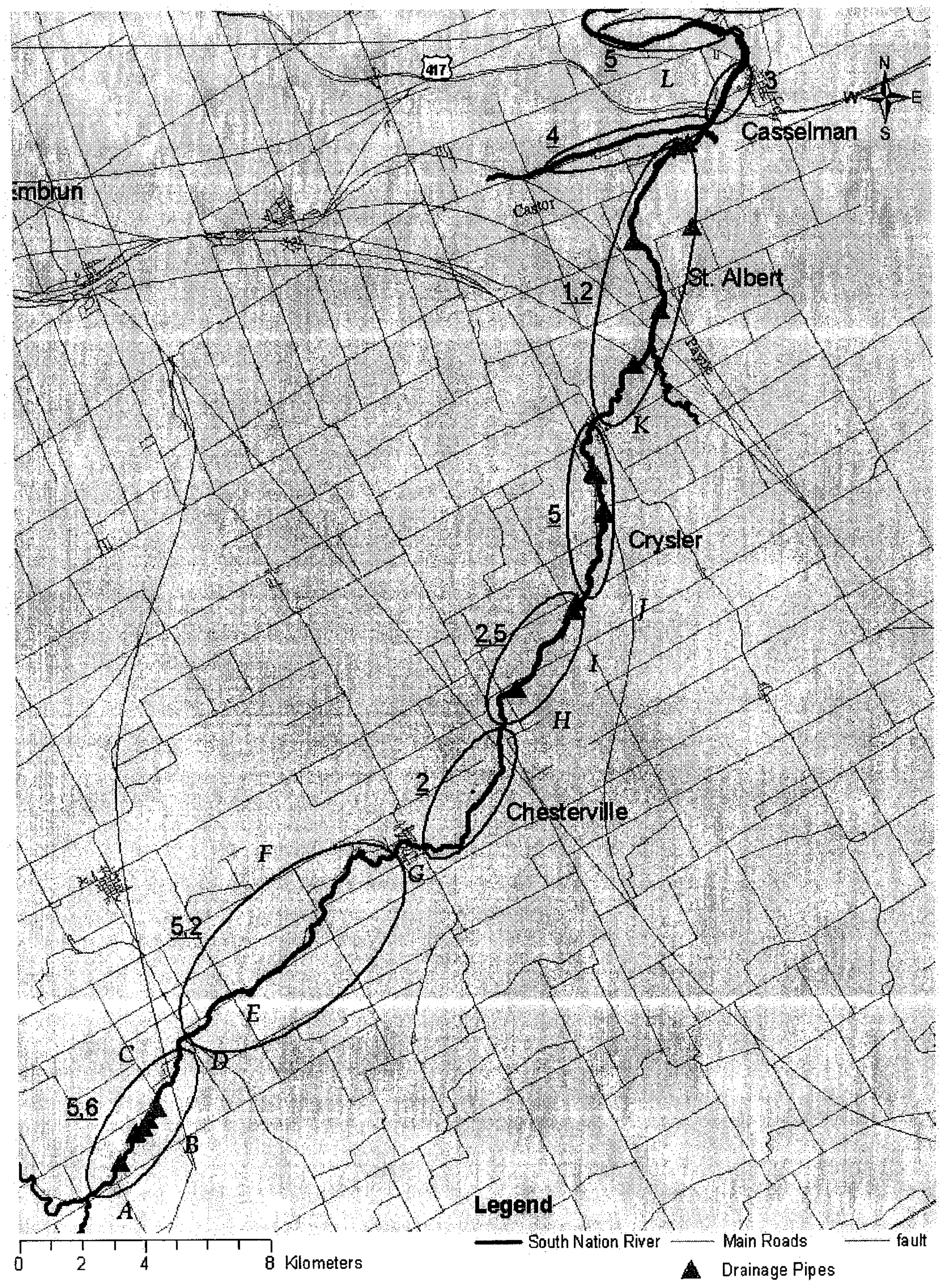


Figure 15(b) : EC & T are grouped into 7 classes (Fig. 8.). The locations of these values are shown here and in Figure 15(a). (EOWRMS, 2001).

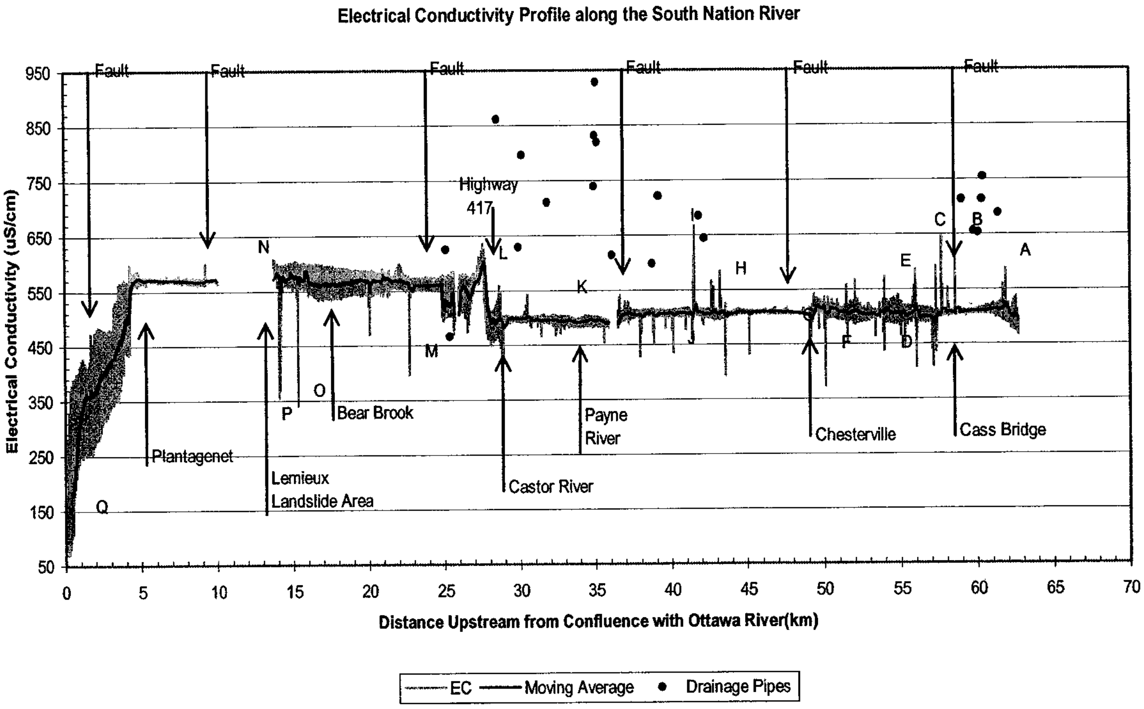


Figure 16: EC profile along the South Nation River. Distance is measured as a straight line from the "headwaters" (most upstream measurement location), rather than along the river. Blank spaces are where the river is non-navigable. The figure shows the locations of landmarks along the river (for reference), 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.

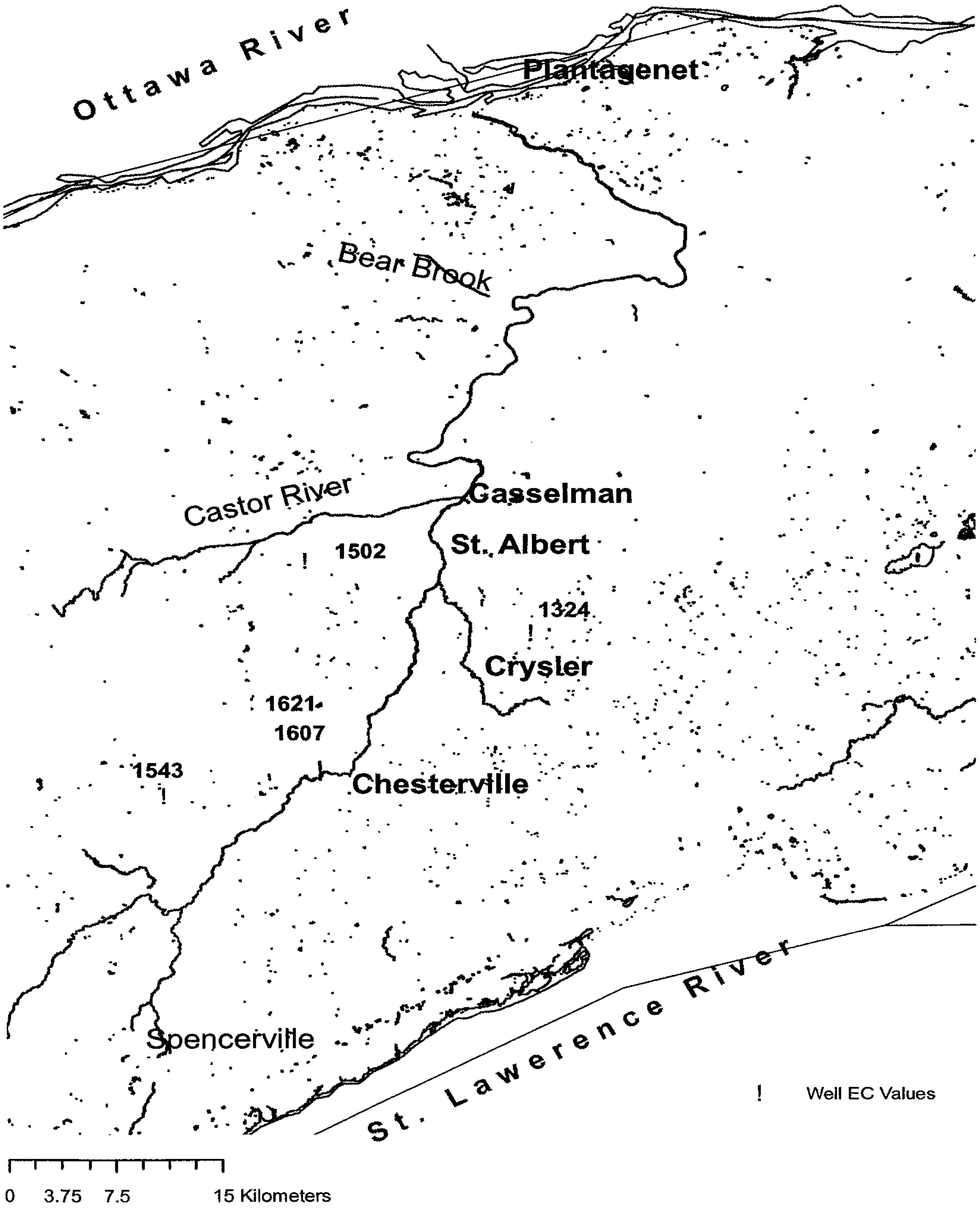


Figure 17: The locations and values of EC of wells measured in the area.

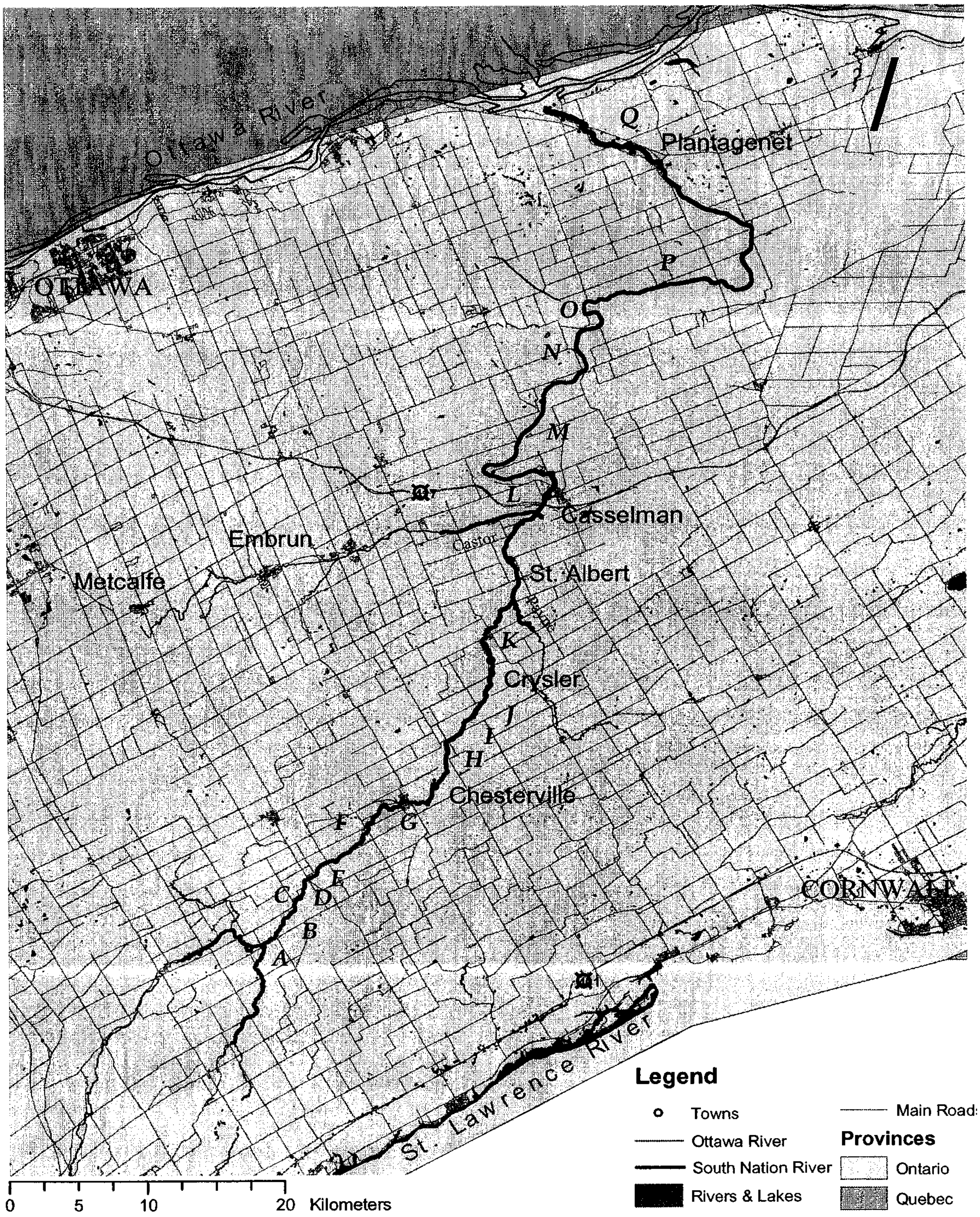


Figure 18: Locations of EC anomalies found in the study area.

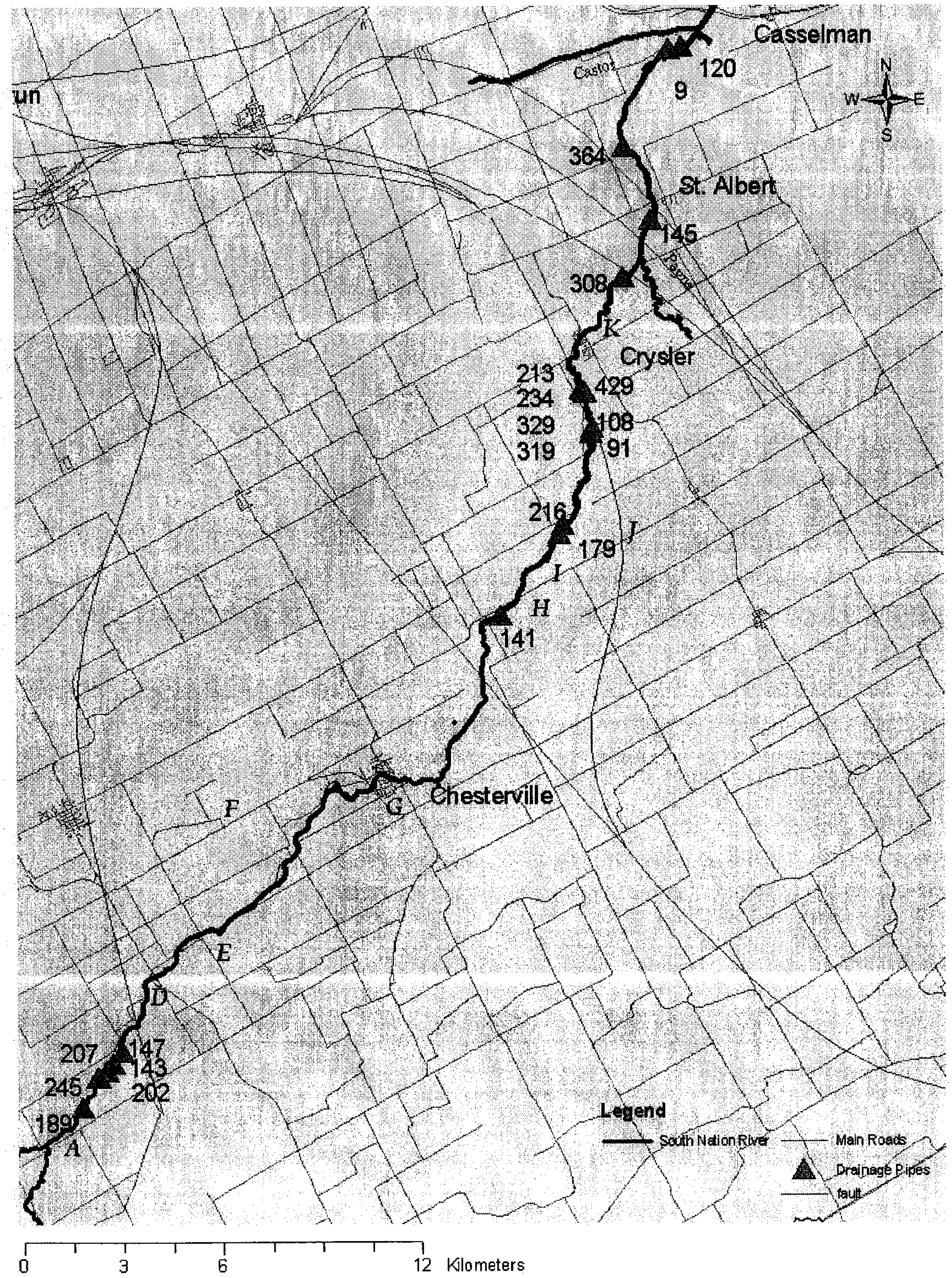


Figure 19: Drainage pipe ec discrepancies

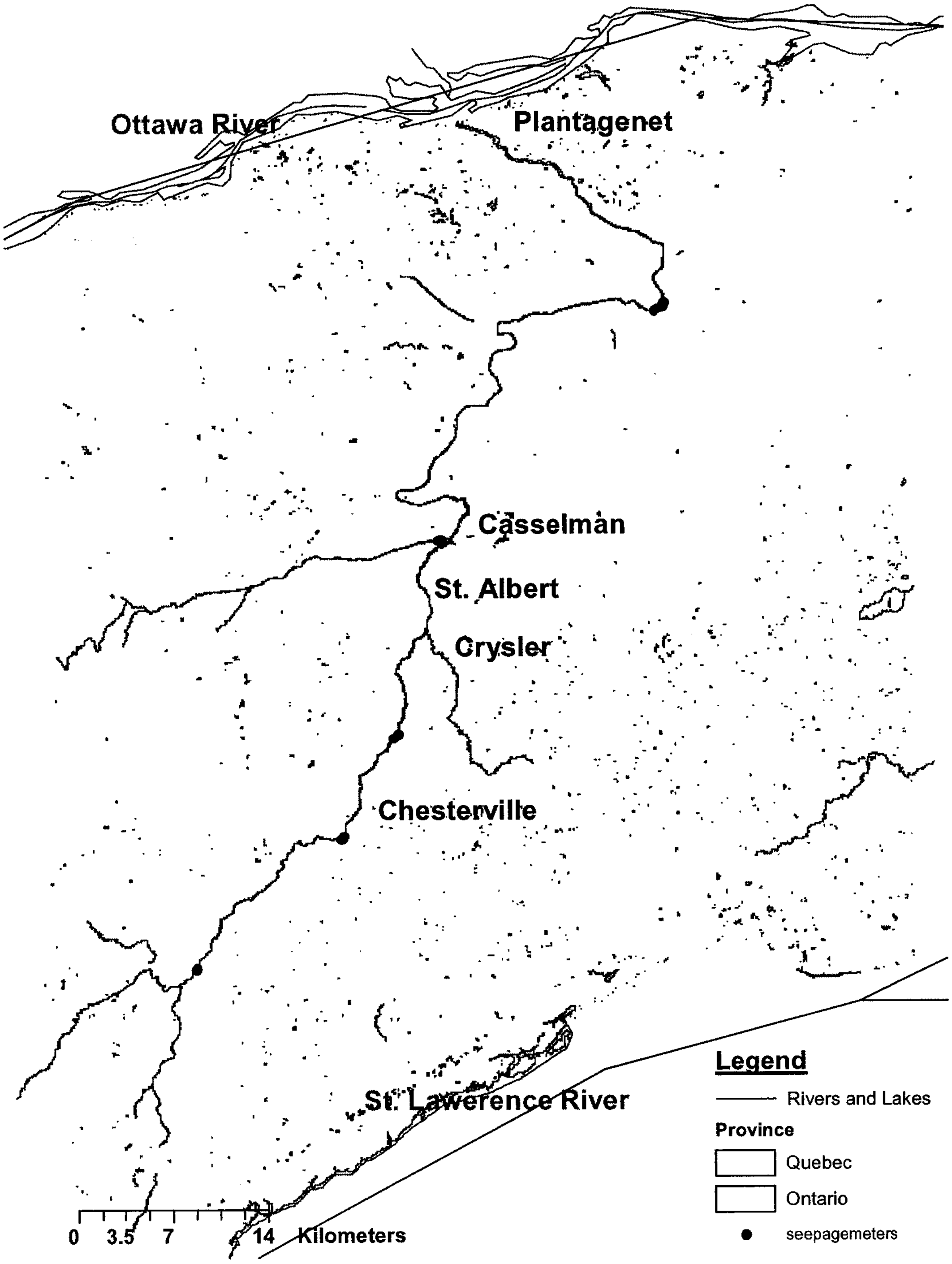


Figure 20: Location of direct seepage measurements

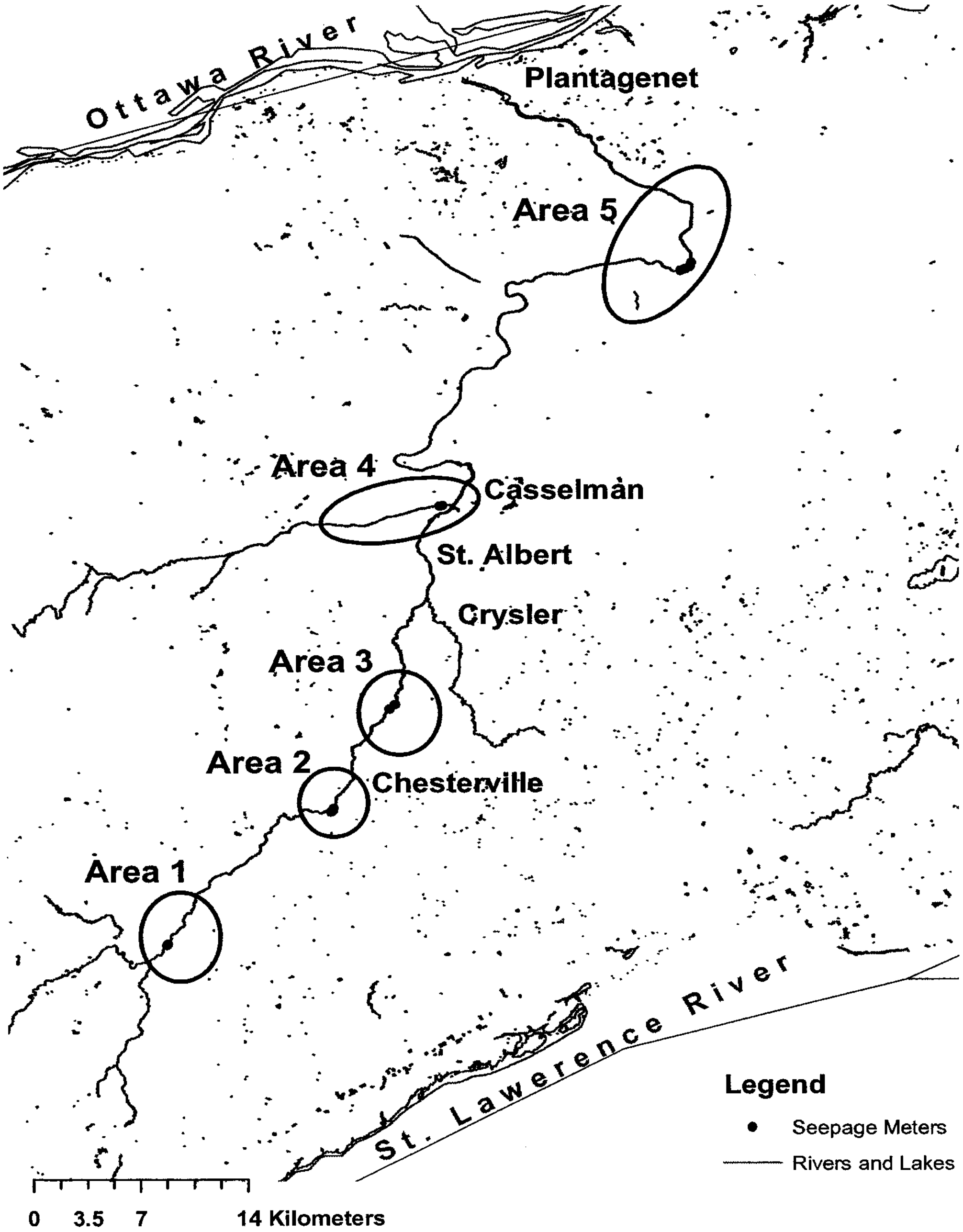


Figure 21: Confirmed zones of groundwater seepage that should be permanently instrumented with piezometers.

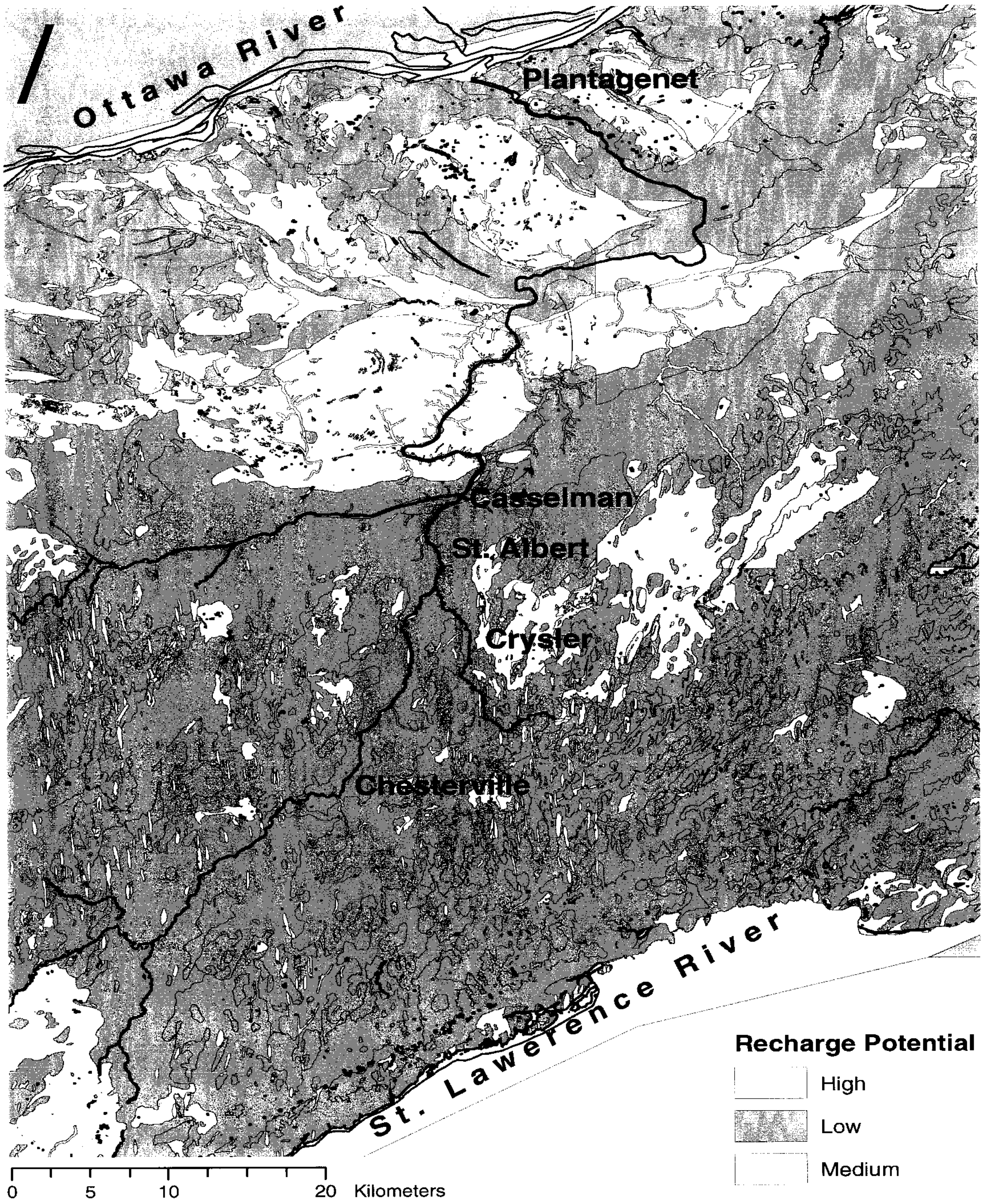


Figure 22: Potential recharge in the study area. Areas of high potential recharge should be verified with seepage meters and piezometers (EOWRMS, 2001).

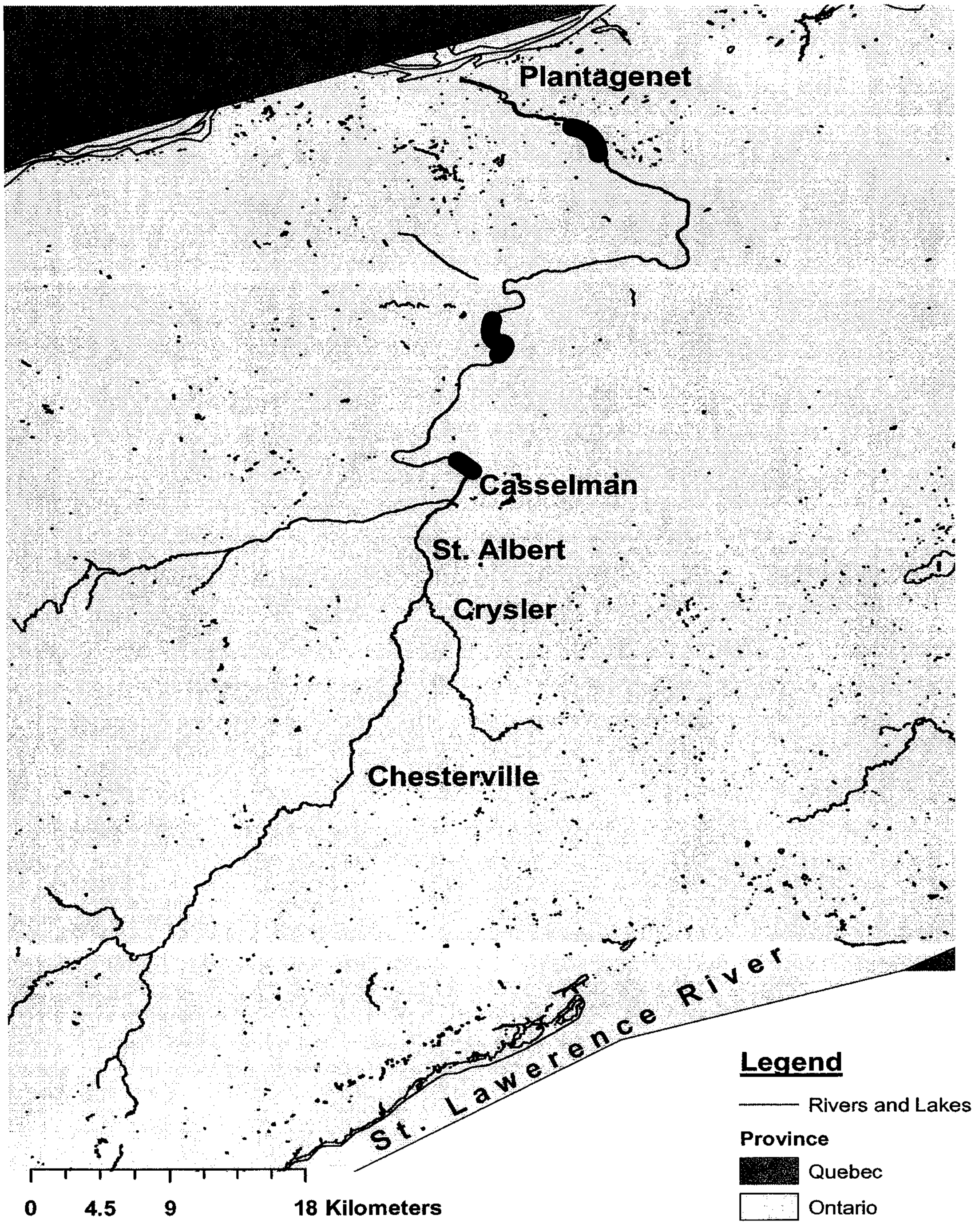
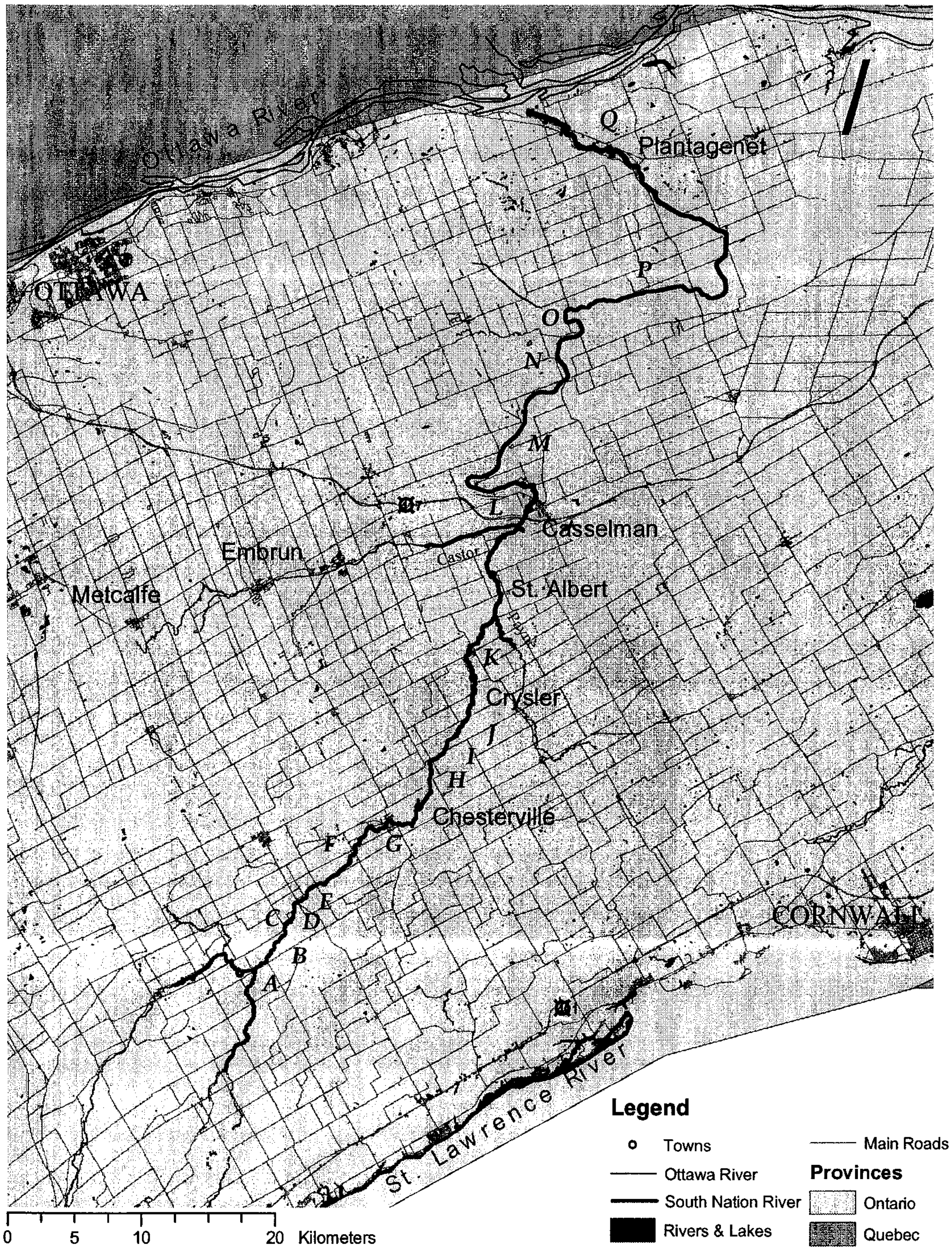


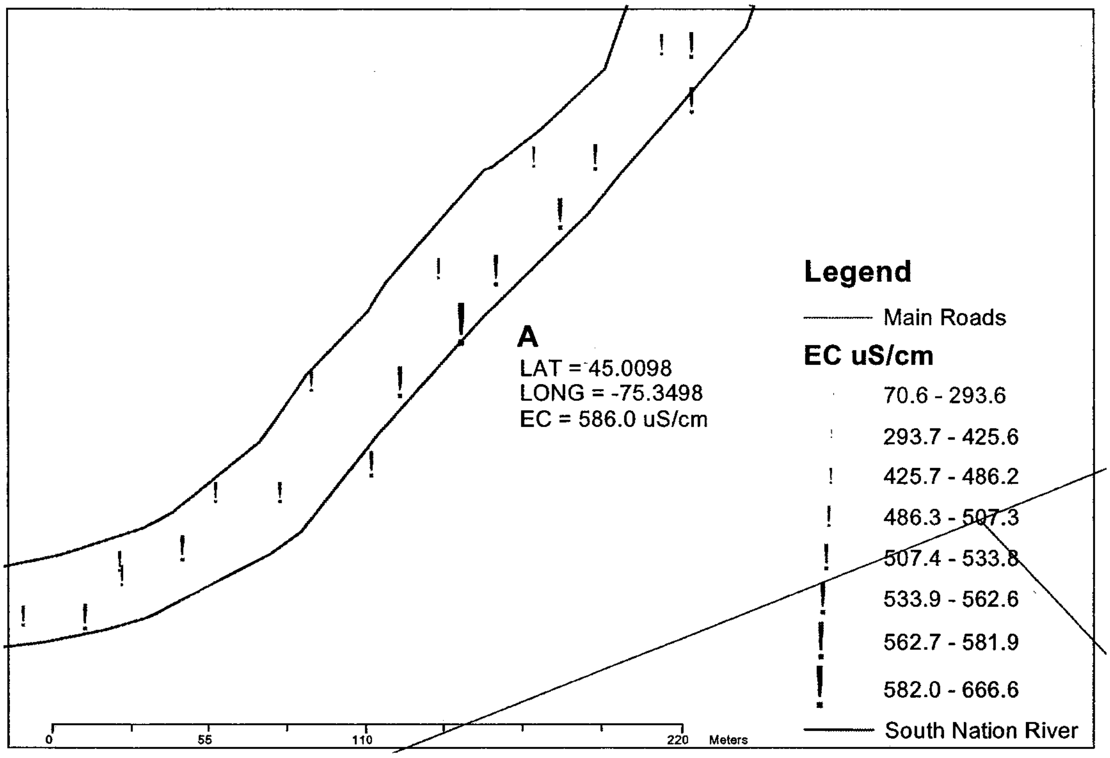
Figure 23: Areas that were non-navigable during the survey. These areas should be navigated during times when water level is higher or other means of navigation.

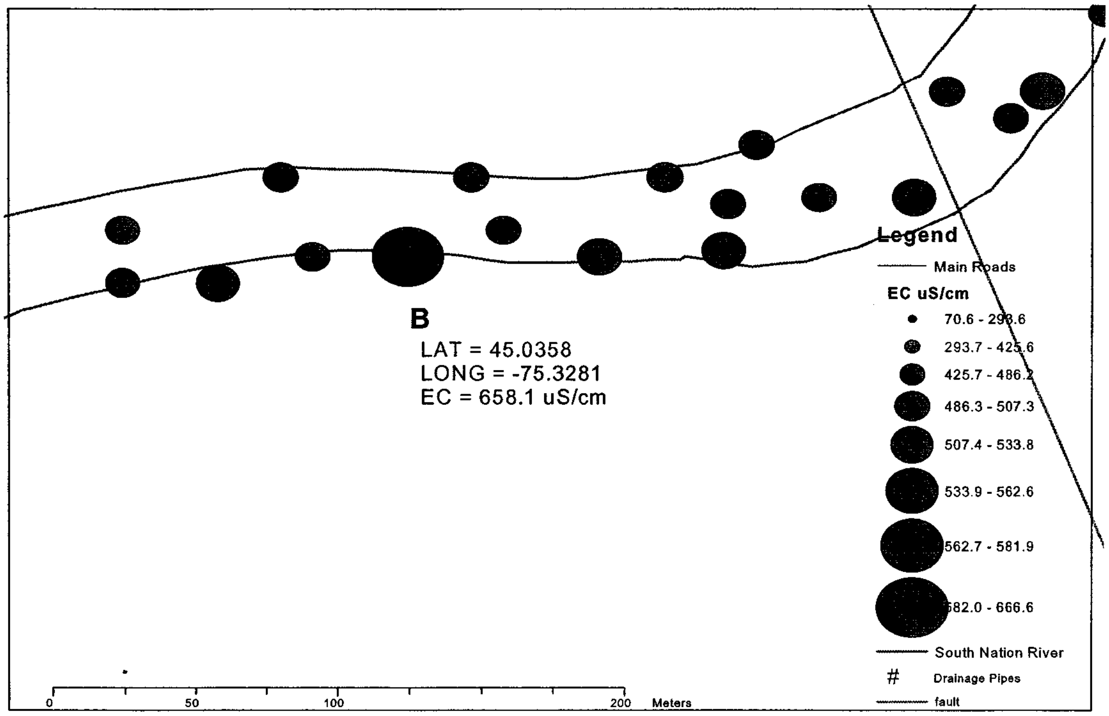
APPENDIX I

CLOSE-UP VIEWS OF ESTIMATED DISCHARGE AREAS

This Appendix shows close-up views of estimated discharge areas. The first map contains labels (letters), which show where all the subsequent follow-up maps are located.




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
55
110
220
Meters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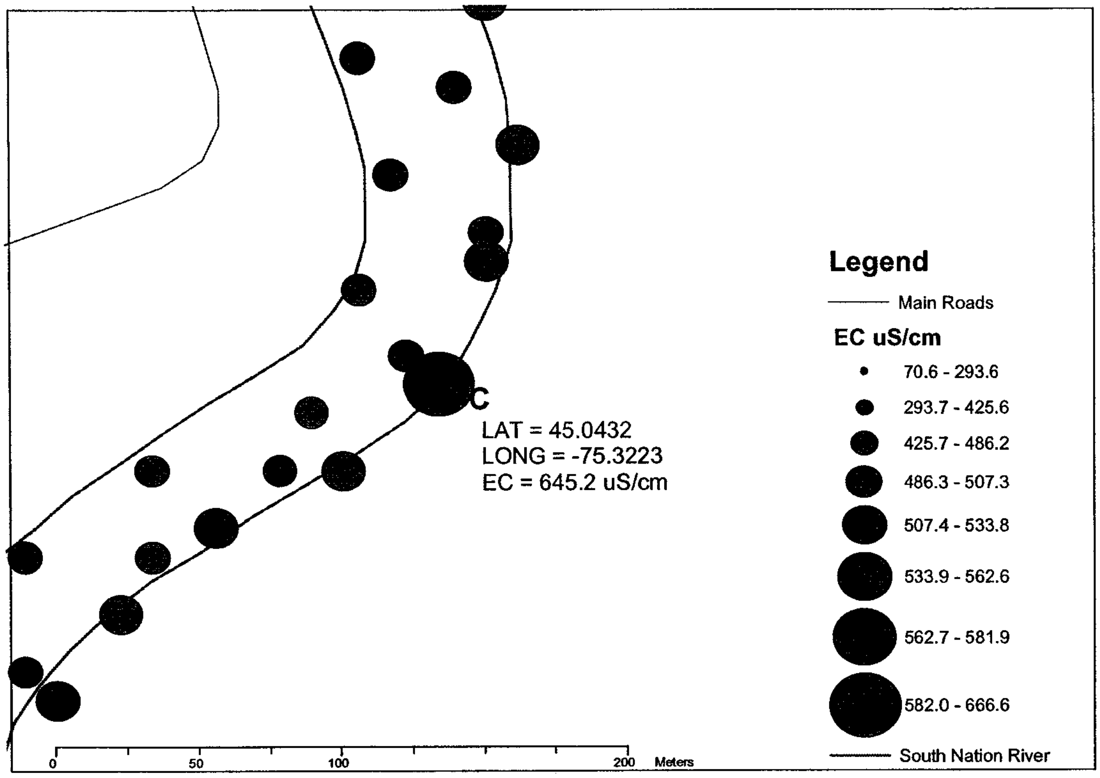
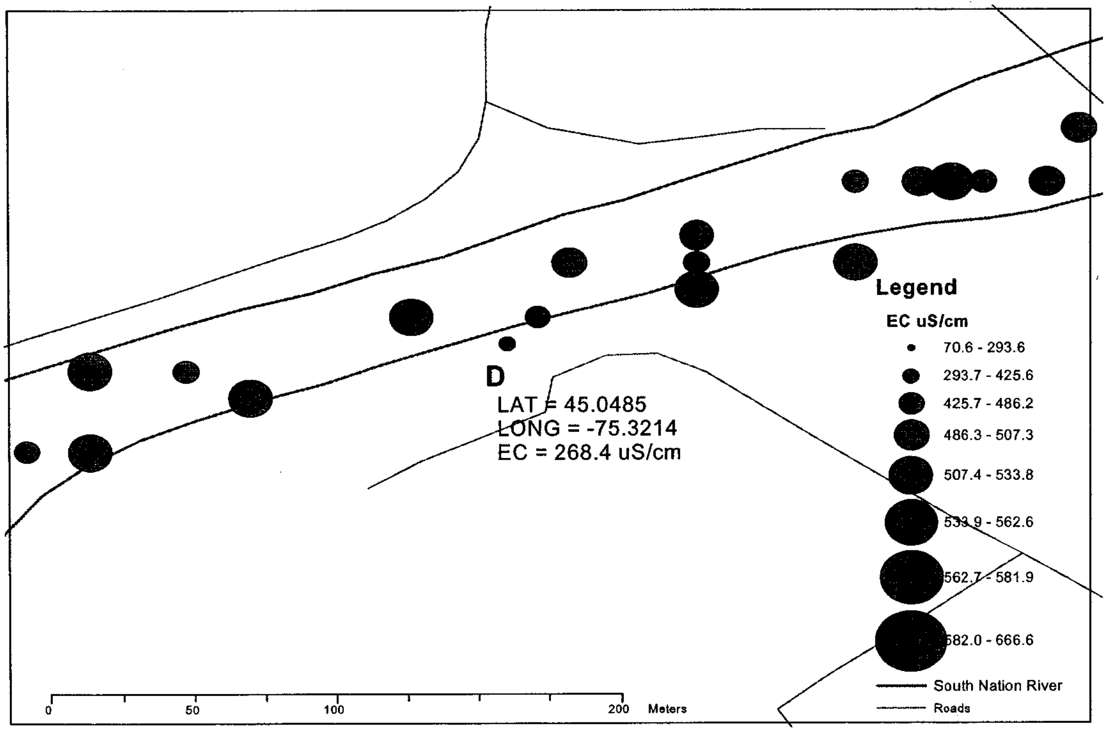
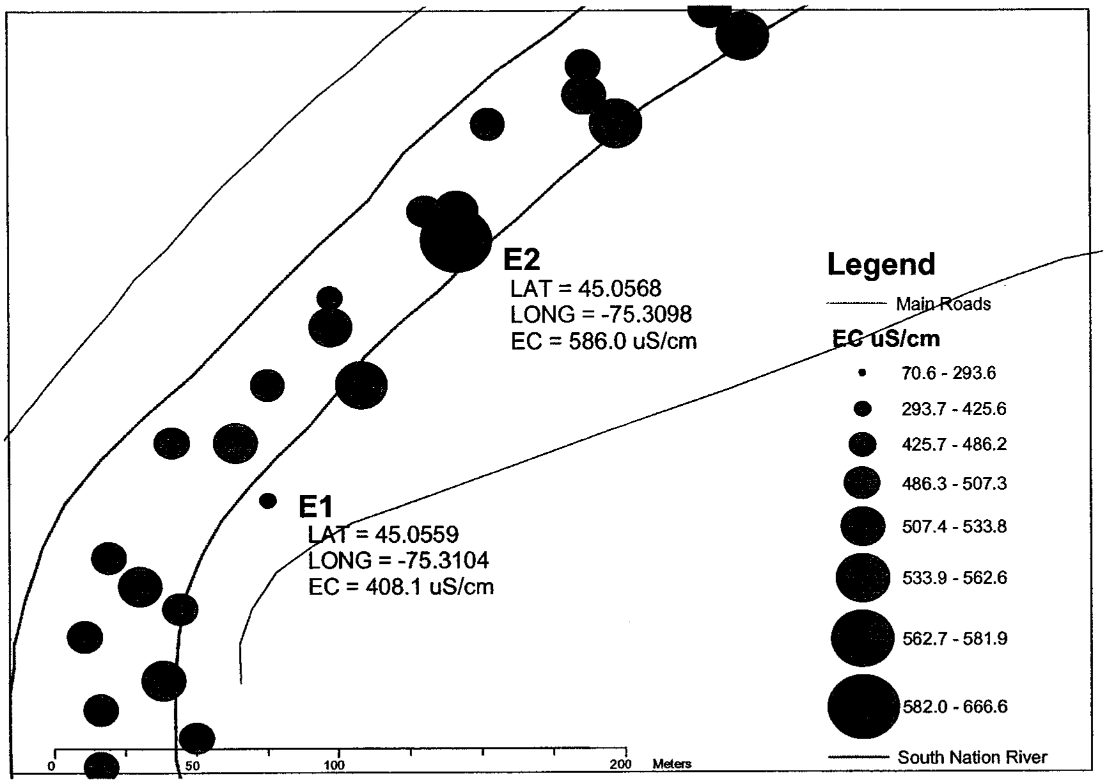
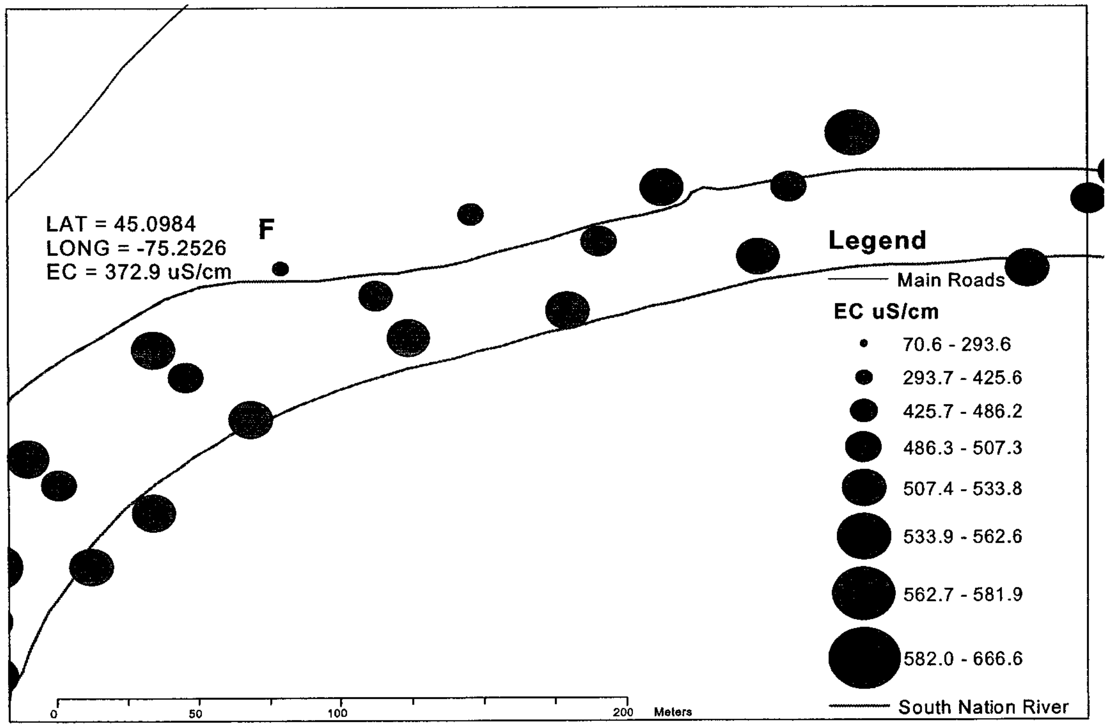
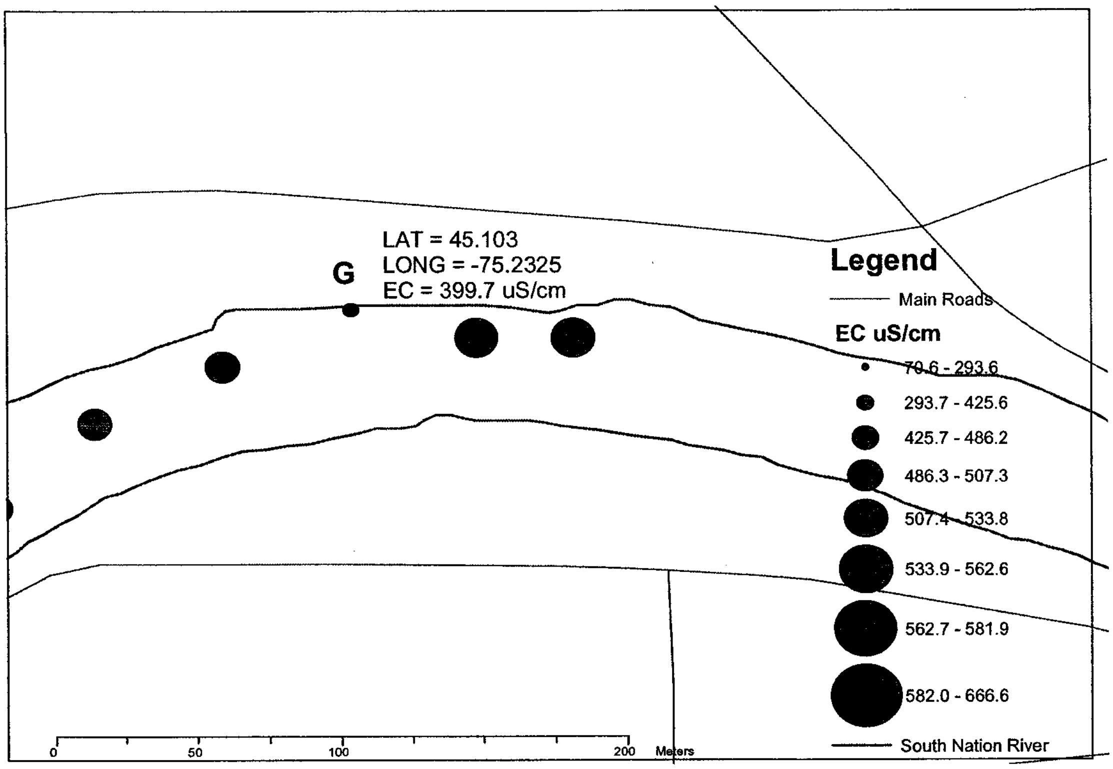
LAT = 45.0358
LONG = -75.3281
EC = 658.1 uS/cm
Legend
Main Roads
EC uS/cm
70.6 - 293.6
293.7 - 425.6
425.7 - 486.2
486.3 - 507.3
507.4 - 533.8
533.9 - 562.6
562.7 - 581.9
582.0 - 666.6
South Nation River
Drainage Pipes
fault
0
50
100
200
Meters

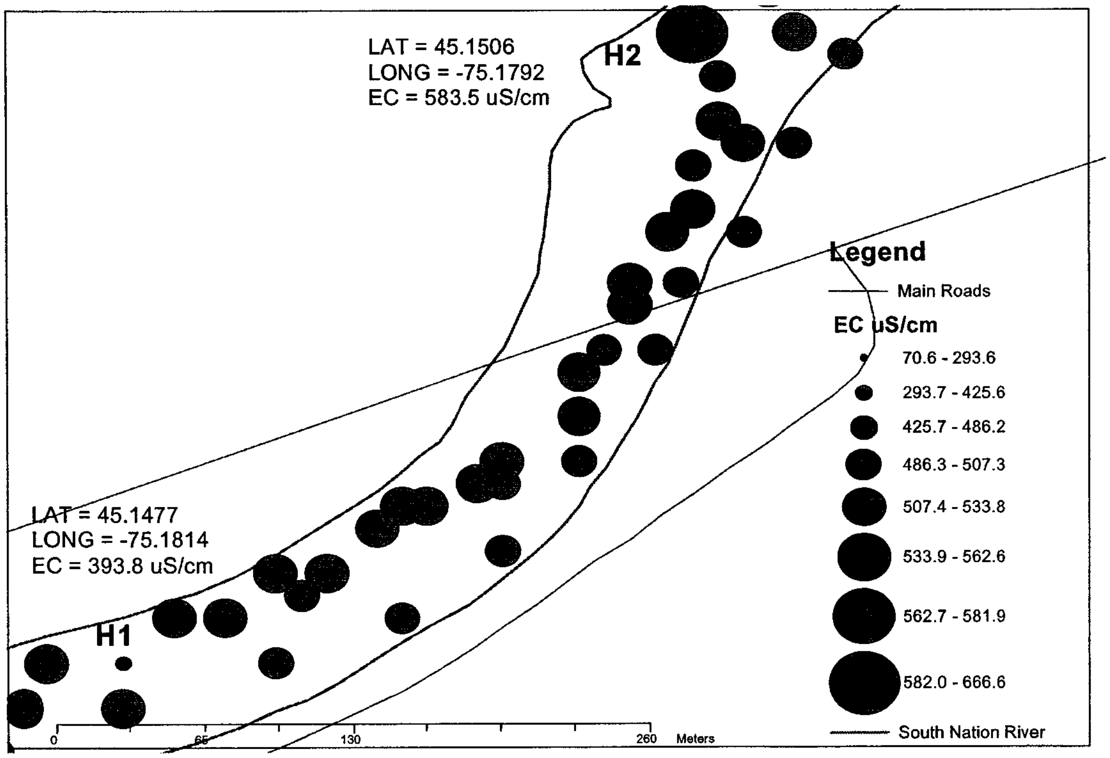

C
LAT = 45.0432
LONG = -75.3223
EC = 645.2 uS/cm
Legend
Main Roads
EC uS/cm
70.6 - 293.6
293.7 - 425.6
425.7 - 486.2
486.3 - 507.3
507.4 - 533.8
533.9 - 562.6
562.7 - 581.9
582.0 - 666.6
South Nation River
0
50
100
200
Meters

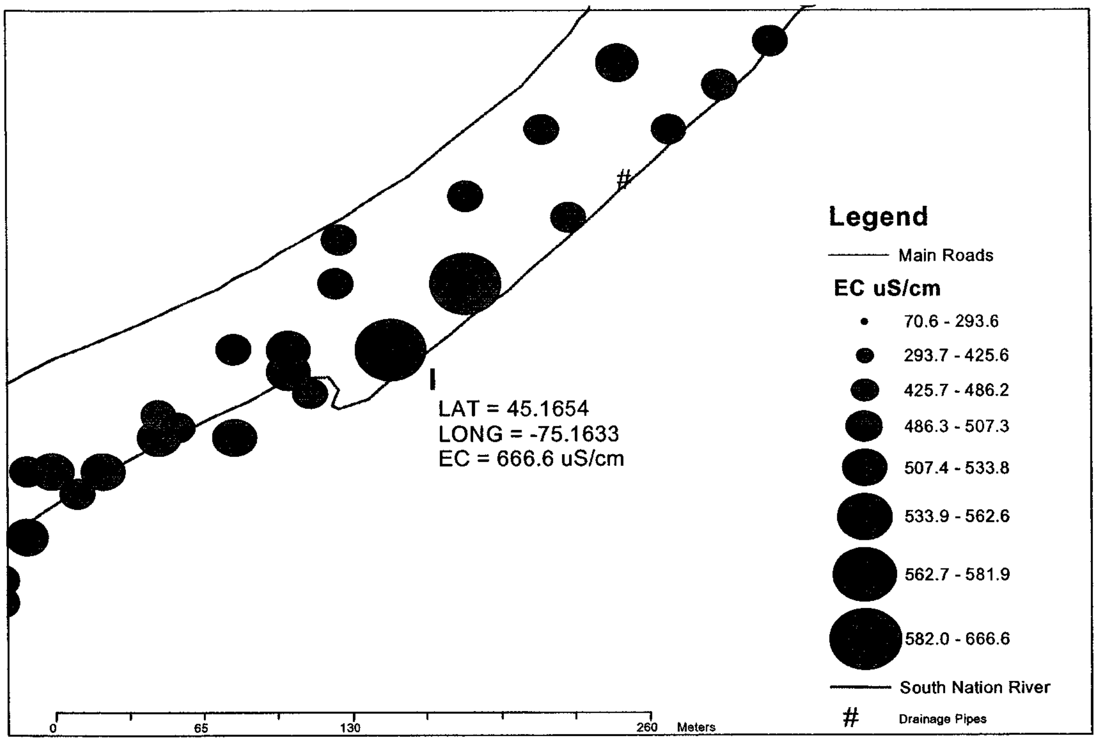

D
LAT = 45.0485
LONG = -75.3214
EC = 268.4 uS/cm
Legend
EC uS/cm
70.6 - 293.6
293.7 - 425.6
425.7 - 486.2
486.3 - 507.3
507.4 - 533.8
533.9 - 562.6
562.7 - 581.9
582.0 - 666.6
South Nation River
Roads
0
50
100
200
Meters

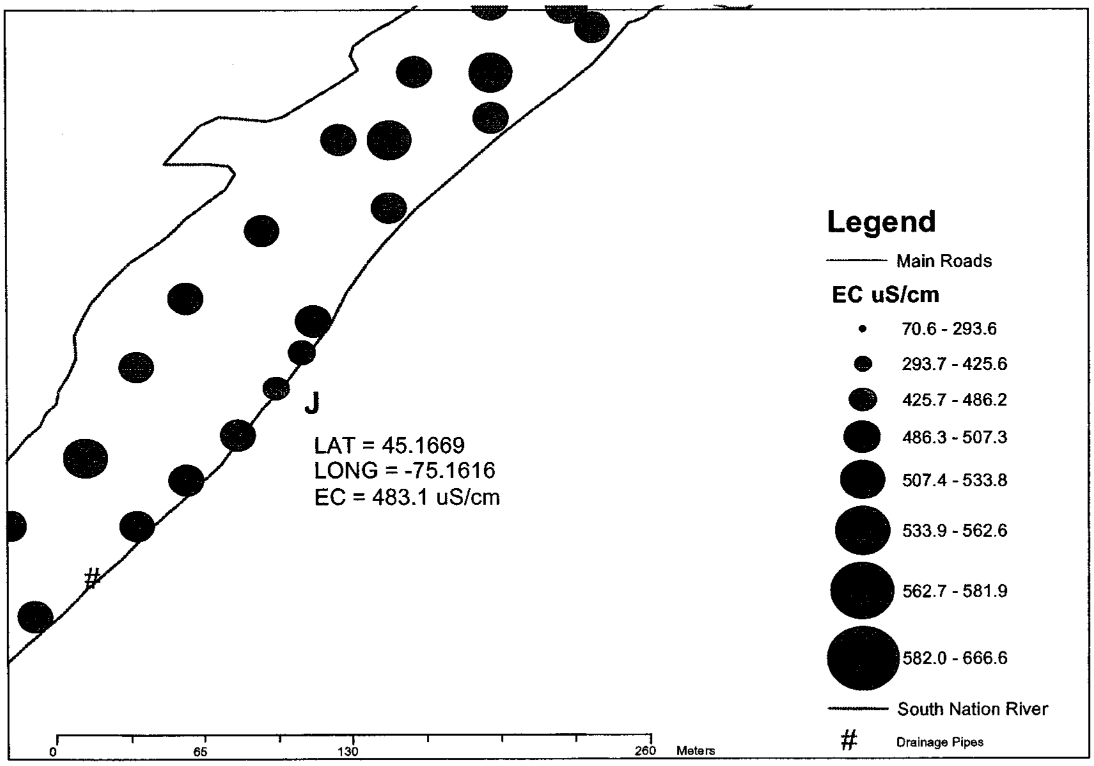

E2
LAT = 45.0568
LONG = -75.3098
EC = 586.0 uS/cm
E1
LAT = 45.0559
LONG = -75.3104
EC = 408.1 uS/cm
Legend
Main Roads
EC uS/cm
70.6 - 293.6
293.7 - 425.6
425.7 - 486.2
486.3 - 507.3
507.4 - 533.8
533.9 - 562.6
562.7 - 581.9
582.0 - 666.6
South Nation River
0
50
100
200
Meters

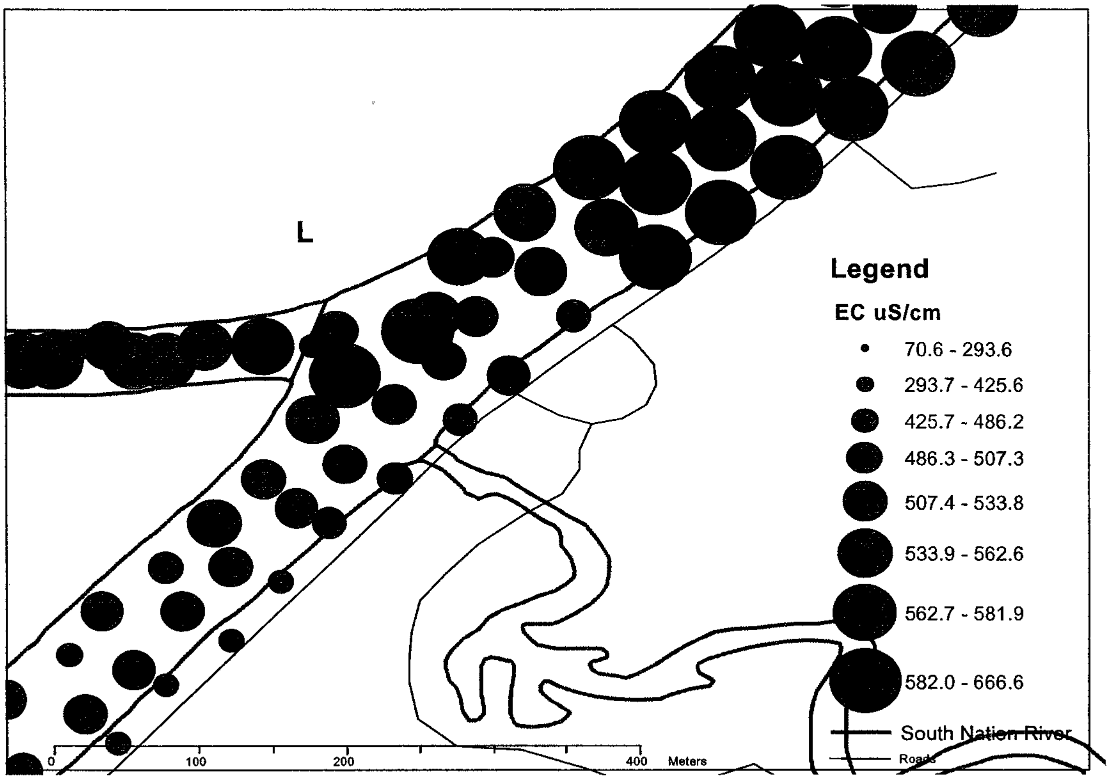

LAT = 45.0984
LONG = -75.2526
EC = 372.9 uS/cm
F
Legend
Main Roads
EC uS/cm
70.6 - 293.6
293.7 - 425.6
425.7 - 486.2
486.3 - 507.3
507.4 - 533.8
533.9 - 562.6
562.7 - 581.9
582.0 - 666.6
South Nation River
0
50
100
200
Meters

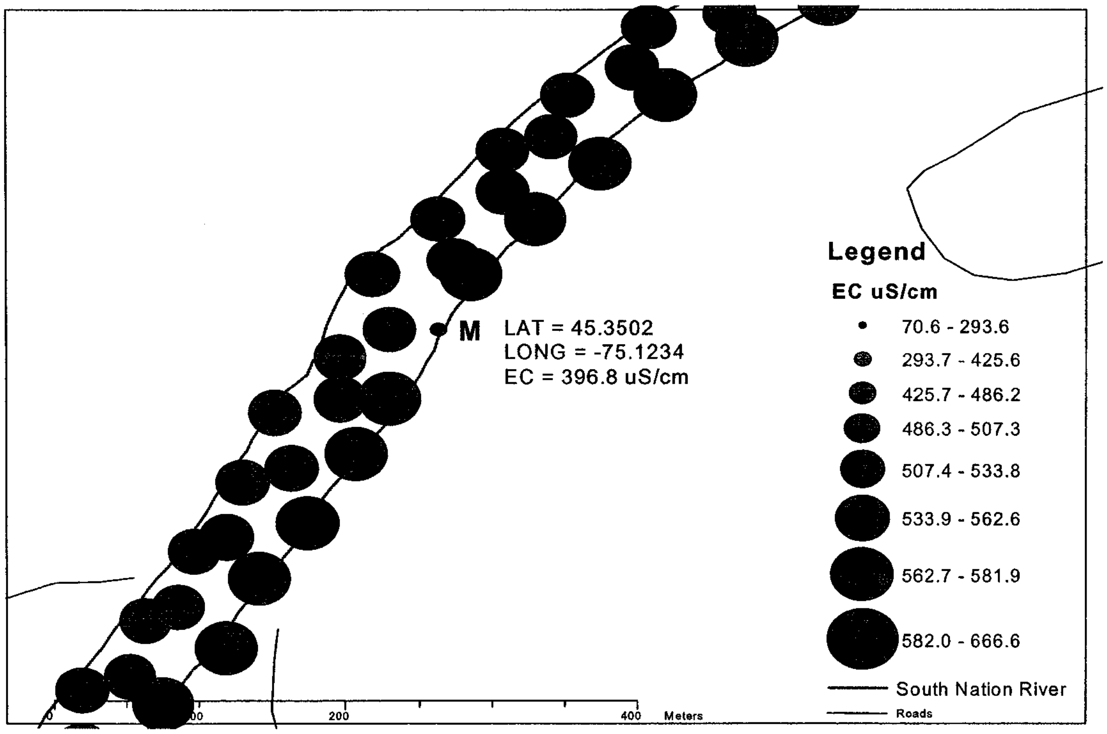

LAT = 45.103
LONG = -75.2325
EC = 399.7 uS/cm
G
Legend
Main Roads
EC uS/cm
70.6 - 293.6
293.7 - 425.6
425.7 - 486.2
486.3 - 507.3
507.4 - 533.8
533.9 - 562.6
562.7 - 581.9
582.0 - 666.6
South Nation River
0
50
100
200
Meters


LAT = 45.1506
LONG = -75.1792
EC = 583.5 uS/cm
H2
LAT = 45.1477
LONG = -75.1814
EC = 393.8 uS/cm
H1
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
130
260
Meters

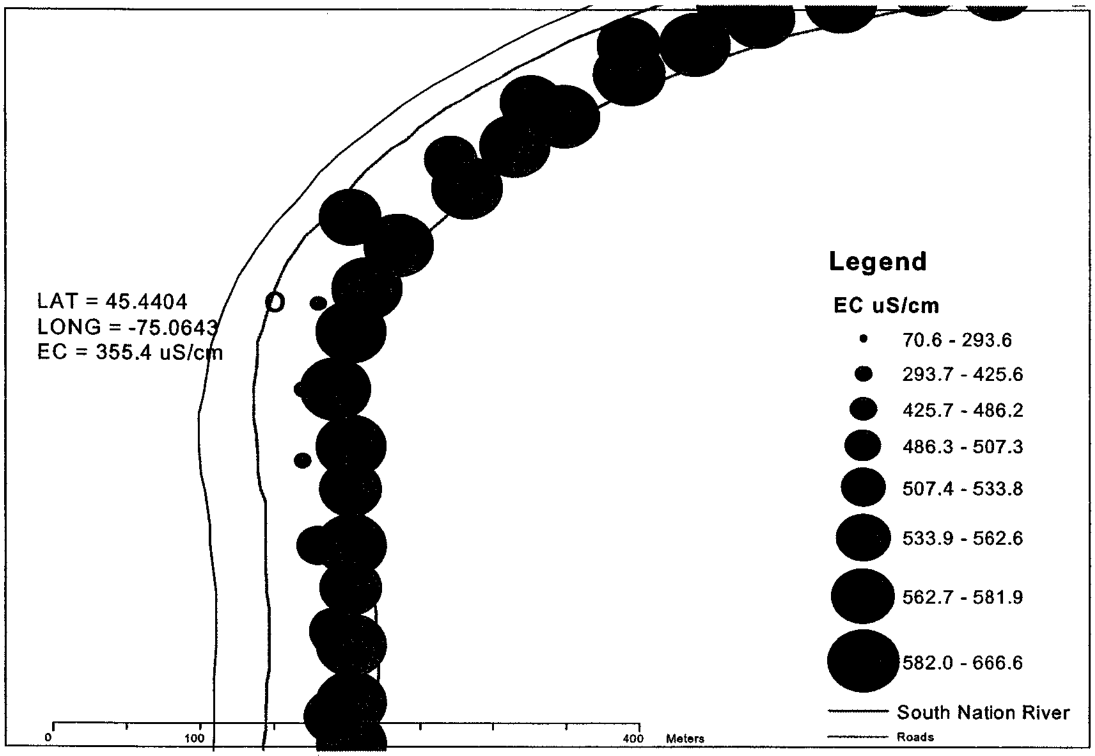

I
LAT = 45.1654
LONG = -75.1633
EC = 666.6 uS/cm
Legend
Main Roads
EC uS/cm
70.6 - 293.6
293.7 - 425.6
425.7 - 486.2
486.3 - 507.3
507.4 - 533.8
533.9 - 562.6
562.7 - 581.9
582.0 - 666.6
South Nation River
#
Drainage Pipes
0
65
130
260
Meters

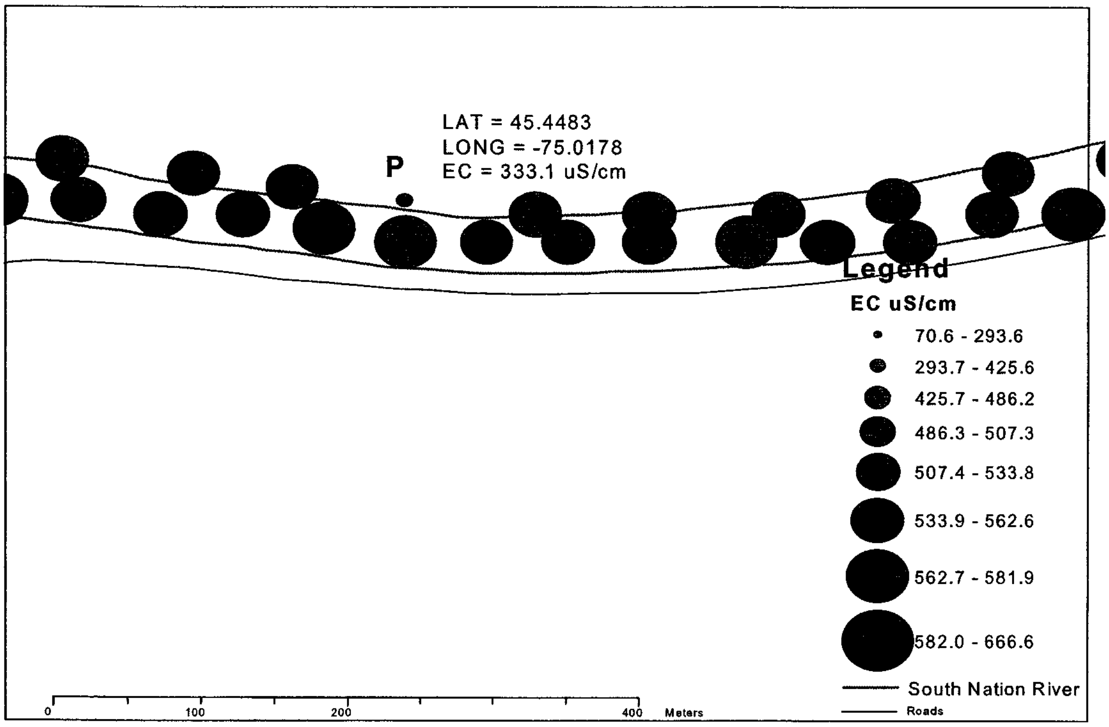

J
LAT = 45.1669
LONG = -75.1616
EC = 483.1 uS/cm
Legend
Main Roads
EC uS/cm
70.6 - 293.6
293.7 - 425.6
425.7 - 486.2
486.3 - 507.3
507.4 - 533.8
533.9 - 562.6
562.7 - 581.9
582.0 - 666.6
South Nation River
#
Drainage Pipes
0
65
130
260
Meters

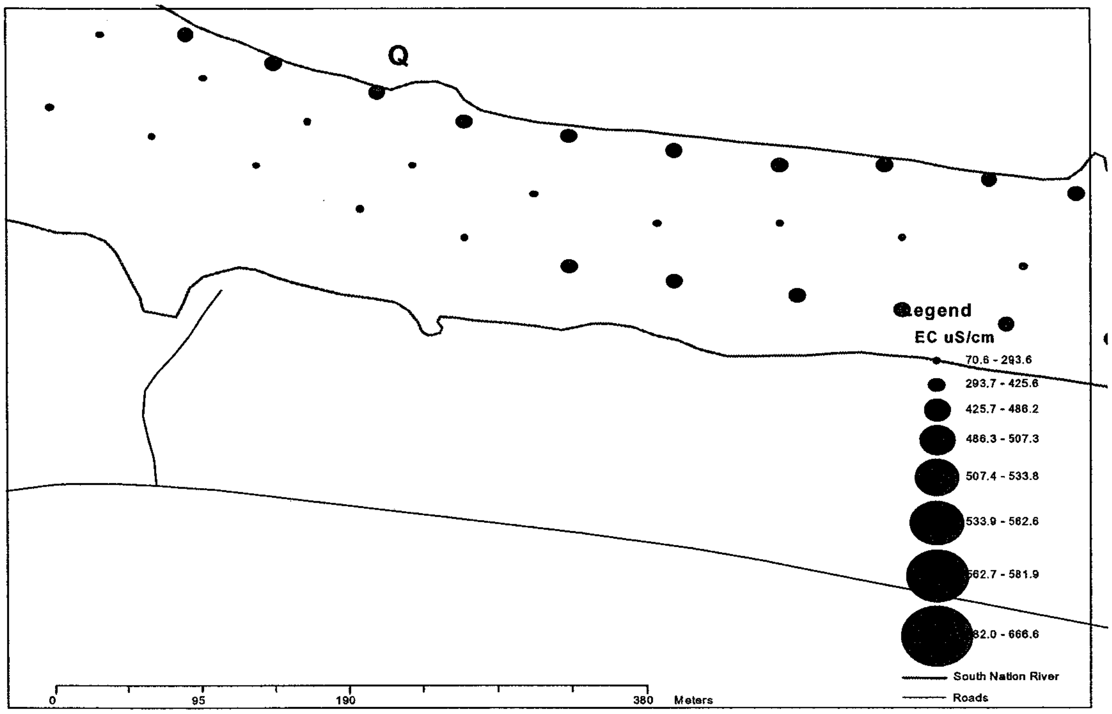




LAT = 45.3502
LONG = -75.1234
EC = 396.8 uS/cm


LAT = 45.4404
LONG = -75.0643
EC = 355.4 uS/cm
O
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


LAT = 45.4483
LONG = -75.0178
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


Q
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
82.0 - 666.6
South Nation River
Roads
0
95
190
380
Meters

APPENDIX II

DIRECT SEEPAGE MEASUREMENTS

This Appendix contains values obtained when installing and checking the open-top seepage meters. The first table is from the piezometer installation. The second table is measurements taken to find hydraulic head. After hydraulic head measurements were made, siphons and bags were installed. The next three tables are checks to find out how much water had been collected in the bag and the change in water level.

Explanation of Values

1. Corrected area of pipe: area of pipe after it was taken out of the ground
2. Seepage correction: change in SN water level/area of pipe
3. Corrected seepage: seepage correction/seepage
4. Flux: corrected seepage/corrected area of pipe/change in time
5. Hydraulic conductivity (K): flux/dh/dz
6. Seepage: what was added to the original 1000mL
7. Uncorrected seepage: change in SN * area of pipe

Piezometer Installation

Location #	Piezo	Date	Time	Latitude	Longitude	Length of Pipe (cm)	dz (cm)	Diameter (cm)	Area (cm^2)
1	A	9/5/03	11:15	45.00630	-75.35780	306.7	98.7	4.85	18.47
	B	9/5/03	12:10	45.00620	-75.35810	287.0	68.0	4.90	18.86
	C	9/5/03	12:30	45.00658	-75.35757	305.0	99.4	4.90	18.86
	D	9/5/03	1:00	45.00634	-75.35820	294.0	40.0	4.80	18.10
2	E	9/12/03	8:35	45.00873	-75.35155	289.0	44.5	4.90	18.86
	F	9/12/03	9:03	45.00883	-75.35115	306.0	96.5	4.80	18.10
	G	9/12/03	9:45	45.00903	-75.35135	307.0	110.0	4.85	18.47
	H	9/12/03	10:00	45.00895	-75.35156	301.5	91.5	4.90	18.86
3	I	9/12/03	10:47	45.02313	-75.33853	288.0	78.0	4.85	18.47
	J	9/12/03	12:17	45.02301	-75.33886	305.0	92.5	4.80	18.10
4	K	9/12/03	12:40	45.29859	-75.11907	290.5	54.0	4.85	18.47
	L	9/12/03	1:10	45.29877	-75.11977	298.0	88.0	4.90	18.86
	M	9/12/03	1:25	45.29896	-75.11892	306.0	43.0	4.95	19.24
5	N	9/19/03	12:17	45.45100	-75.00405	305.5	75.5	4.90	18.86
	O	9/19/03	12:52	45.45083	-75.00466	155.0	53.0	4.85	18.47
	P	9/19/03	1:35	45.45067	-75.00383	307.0	106.0	4.90	18.86
	Q	9/19/03	1:50	45.45046	-75.00495	299.0	90.0	4.95	19.24

Bag Installation

Location #	Piezo	Date	Time	Water in bag (L)	dh (cm)	dz (cm)	dh/dz (cm/cm)	Δt* (s)	Piezo Stick-up (cm)	Change in SN** (cm)
1	A	9/12/03	2:35	1	11.0	98.7	0.11	616800	105.00	1.5
	B	9/12/03	2:55	1	23.0	68.0	0.34	618000	92.50	1.5
	C	9/12/03	3:15	1	46.0	99.0	0.46	619200	98.00	0.0
	D	9/12/03	3:32	1	8.0	40.0	0.20	620220	69.50	1.5
2	E	9/19/03	8:52	1	33.0	45.0	0.73	620700	84.00	-1.0
	F	9/19/03	9:10	1	16.0	97.0	0.16	621780	97.00	0.5
	G	9/19/03	9:27	1	10.0	110.0	0.09	622800	99.00	-0.5
	H	9/19/03	9:40	1	16.0	92.0	0.17	623580	98.50	0.5
3	I	9/19/03	9:56	1	25.0	78.0	0.32	624540	94.00	-0.5
	J	9/19/03	10:05	1	13.0	85.0	0.15	625080	96.50	-0.5
4	K	9/19/03	10:20	1	18.0	54.0	0.33	625980	107.00	1.8
	L	9/19/03	10:32	1	9.0	88.0	0.10	626700	98.00	0.5
	M	9/19/03	10:55	1	7.0	43.0	0.16	627480	112.00	1.5
5	N	9/26/03	8:54	1	15.0	76.0	0.20	595380	105.00	-0.5
	O	9/26/03	9:15	1	26.0	53.0	0.49	596520	43.00	-0.5
	P	9/26/03	9:20	1	37.0	106.0	0.35	597780	100.00	1.0
	Q	9/26/03	9:56	1	9.0	90.0	0.10	599940	84.50	1.5

*change in time between piezometer installation and bag installation (s)

**change in South Nation water level between piezometer installation and bag installation (cm)

Check 1

Location#	Piezo	Date	Time	seepage (cm^3)	change in t (s)*	change in SN(cm)**	area of pipe (cm^2)
1	A	9/26/03	11:45	345	1199400	1.00	18.47
	B	9/26/03	12:00	240	1200300	1.50	18.86
	C	9/26/03	12:10	569	1200900	1.50	18.86
	D	9/26/03	12:22	434	1201620	-0.50	18.10
2	E	9/26/03	1:00	210	599100	2.00	18.86
	F	9/26/03	1:10		599700		18.10
	G	9/26/03	1:17	207	600120	0.00	18.47
	H	9/26/03	1:20	309	600300	1.50	18.86
3	I	9/26/03	1:32	60	601020	0.20	18.47
	J	9/26/03	1:40	105	601500	0.50	18.10
4	K	9/26/03	2:15	107	603600	1.75	18.47
	L	9/26/03	2:27	80	604320	1.50	18.86
	M	9/26/03	2:35	95	604800	1.00	19.24
5	N	10/3/03	9:10	125	605640	2.50	18.86
	O	10/3/03	9:21	106	606300	2.00	18.47
	P	10/3/03	9:35	155	607140	-0.50	18.86
	Q	10/3/03	9:40	121	607440	1.00	19.24

*change in time between bag installation and check 1(s)

**change in South Nation water level between bag installation and check 1 (cm)

Location#	Piezo	corrected Area of pipe (cm^2)	seepage correction (cm^3)	corrected seepage (cm^3)	flux (cm/s)	flux (m/s)	K (cm/s)
1	A	18.47	18.47	363.47	1.6E-05	1.6E-07	1.47E-05
	B	18.86	28.29	268.29	1.2E-05	1.2E-07	3.50E-05
	C	12.57	28.29	597.29	4.0E-05	4.0E-07	8.51E-05
	D	10.34	-9.05	424.95	3.4E-05	3.4E-07	1.71E-04
2	E	9.50	37.72	247.72	4.4E-05	4.4E-07	5.93E-05
	F	15.25	0.00		0	0	0
	G	15.50	0.00	207.00	2.2E-05	2.2E-07	2.45E-05
	H	18.75	28.29	337.29	3.0E-05	3.0E-07	1.72E-04
3	I	12.50	3.69	63.69	8.5E-06	8.5 E-08	2.65E-05
	J	18.25	9.05	114.05	1.0 E-05	1.0E-07	6.79E-05
4	K	17.25	32.32	139.32	1.3E-05	1.3E-07	4.01E-05
	L	18.47	28.29	108.29	9.7E-06	9.7E-08	9.49E-05
	M	16.75	19.24	114.24	1.1E-05	1.1E-07	6.98E-05

Location#	Piezo	corrected Area of pipe (cm^2)	seepage correction (cm^3)	corrected seepage (cm^3)	flux (cm/s)	flux (m/s)	K (cm/s)
5	N	18.86	47.15	172.15	1.5E-05	1.5E-07	7.64E-05
	O	10.50	36.94	142.94	2.2E-05	2.2E-07	4.58E-05
	P	14.00	-9.43	145.57	1.7E-05	1.7E-07	4.91E-05
	Q	17.50	19.24	140.24	1.3E-05	1.3E-07	1.32E-04

Check 2

Location#	Piezo	Date	Time	seepage (cm^3)	change in t (s)*	change in SN (cm)**	area of pipe (cm^2)	corrected area of pipe (cm^2)
1	A	10/3/03	11:05	102	602400	1.0	18.47	18.47
	B	10/3/03	11:12	360	602820	-0.5	18.86	18.86
	C	10/3/03	11:18	90	603180	2.0	18.86	12.57
	D	10/3/03	11:25	335	603600	0.0	18.10	10.34
2	E	10/3/03	11:45	309	604800	-1.0	18.86	9.50
	F	10/3/03	11:52	209	605220	0.0	18.10	15.25
	G	10/3/03	12:00	295	605700	-0.5	18.47	15.50
	H	10/3/03	12:05	456	606000	-1.5	18.86	18.75
3	I	10/3/03	1:05	67	606600	1.0	18.47	12.50
	J	10/3/03	1:12	45	607020	1.0	18.10	18.25
4	K	10/3/03	1:14	892	607140	-0.5	18.47	17.25
	L	10/3/03	1:22	190	607620	-0.5	18.86	18.47
	M	10/3/03	1:30	640.5	608100	0.0	19.24	16.75
5	N	10/12/03	10:40	455	772800	-2.5	18.86	18.86
	O	10/12/03	10:52	607	773280	-1.0	18.47	10.50
	P	10/12/03	10:58	489	773640	0.0	18.86	14.00
	Q	10/12/03	11:05	306	774060	-0.5	19.24	17.50

*change in time between check 1 and check 2 (s)

**change in South Nation water level between check 1 and check 2 (cm)

Location#	Piezo	uncorrected seepage (cm^3)	corrected seepage (cm^3)	flux (cm/s)	flux (m/s)	hydraulic conductivity (cm/s)
1	A	18.47	120.47	1.083E-05	1.0827E-07	9.72E-05
	B	-9.43	350.57	3.084E-05	3.0835E-07	4.12E-05
	C	37.72	127.72	1.684E-05	1.6841E-07	3.62E-05
	D	0	335	5.366E-05	5.3661E-07	2.68E-04
2	E	-18.86	290.14	5.05E-05	5.0498E-07	6.89E-05
	F	0	209	2.264E-05	2.2645E-07	4.38E-05
	G	-9.235	285.765	3.044E-05	3.0438E-07	3.35E-04
	H	-28.29	427.71	3.764E-05	3.7642E-07	2.16E-04
3	I	18.47	85.47	1.127E-05	1.1272E-07	3.52E-05
	J	18.1	63.1	5.696E-06	5.6959E-08	3.72E-05
4	K	-9.235	882.765	8.429E-05	8.4288E-07	2.53E-04
	L	-9.43	180.57	1.609E-05	1.609E-07	1.57E-04
	M	0	640.5	6.288E-05	6.2882E-07	3.86E-04

Location#	Piezo	uncorrected seepage (cm^3)	corrected seepage (cm^3)	flux (cm/s)	flux (m/s)	hydraulic conductivity (cm/s)
5	N	-47.15	407.85	2.798E-05	2.7983E-07	1.42E-04
	O	-18.47	588.53	7.248E-05	7.2484E-07	1.48E-04
	P	0	489	4.515E-05	4.5148E-07	1.29E-04
	Q	-9.62	296.38	2.188E-05	2.1879E-07	2.19E-04

Check 3

Location#	Piezo	Date	Time	seepage (cm^3)	change in t (s)*	change in SN (cm)**	area of pipe (cm^2)
1	A	10/12/03	12:15	504	778260	-1.3	18.47
	B	10/12/03	12:22	602	778680	-0.6	18.86
	C	10/12/03	12:32	647	779280	-0.7	18.86
	D	10/12/23	12:45	355	780060	-1	18.10
2	E	10/12/03	1:10	289	781560	-0.6	18.86
	F	10/12/03	1:17	278	781980	-0.5	18.10
	G	10/12/03	1:30	195	782760	-0.4	18.47
	H	10/12/03	1:42	232	783240	-0.4	18.86
3	I	10/12/03	2:15	130	785220	0.5	18.47
	J	10/12/03	2:32	13	786240	0.2	18.10
4	K	10/12/03	2:45	147	787020	-0.3	18.47
	L	10/12/03	2:56	155	787680	0.7	18.86
	M	10/12/03	3:05	560	788220	-1	19.24
5	N	10/14/03	2:47	145	187620	-0.5	78.5
	O	10/14/03	2:25	209	185580	0.2	70.9
	P	10/14/03	3:05	156	187620	-0.5	198.6
	Q	10/14/03	3:45	95	189600	0	201.1

*change in time between check 2 and check 3 (s)
**change in South Nation water level between check 2 and check 3 (cm)

Location#	Piezo	corrected area of pipe (cm^2)	seepage correction (cm^3)	corrected seepage (cm^3)	flux (cm/s)	flux (m/s)	hydraulic conductivity (cm/s)
1	A	18.47	-24.01	479.99	3.34E-05	3.34E-07	3.00E-04
	B	18.86	-11.32	590.68	4.02E-05	4.02E-07	1.19E-04
	C	12.57	-8.80	638.20	6.51E-05	6.51E-07	1.40E-04
	D	10.34	-10.34	344.66	4.27E-05	4.27E-07	2.14E-04
2	E	9.50	-5.70	283.30	3.82E-05	3.82E-07	5.20E-04
	F	15.25	-7.63	270.38	2.27E-05	2.27E-07	1.71E-04
	G	15.50	-6.20	188.80	1.56E-05	1.56E-07	4.35E-05
	H	18.75	-7.50	224.50	1.53E-05	1.53E-07	8.79E-05
3	I	12.50	6.25	136.25	1.39E-05	1.39E-07	4.33E-05
	J	18.25	3.65	16.65	1.16E-06	1.16E-08	7.59E-06
4	K	17.25	-5.18	141.83	1.04E-05	1.04E-07	3.13E-05
	L	18.47	12.93	167.93	1.15E-05	1.15E-07	1.13E-04
	M	16.75	-16.75	543.25	4.11E-05	4.11E-07	2.53E-04

Location#	Piezo	corrected area of pipe (cm^2)	seepage correction (cm^3)	corrected seepage (cm^3)	flux (cm/s)	flux (m/s)	hydraulic conductivity (cm/s)
5	N	18.86	-9.43	135.57	3.83E-05	3.83E-07	1.94E-04
	O	10.50	2.10	211.10	0.000108	1.08E-06	2.21E-04
	P	14.00	-7.00	149.00	5.67E-05	5.67E-07	1.63E-04
	Q	17.50	0.00	95.00	2.86E-05	2.86E-07	2.86E-04

APPENDIX III

HYDROGRAPHIC SEPARATION

This Appendix is in 3 sections. The first section is a table that contains the actual values of mean daily discharge (m^3/s), baseflow estimates from the fixed base method (m^3/s), and the baseflow estimates from baseflow recession method (m^3/s) from each hydrograph.

The second section provides hydrographs from the 4 hydrometric stations. There are 2 hydrographs for each station. The first hydrograph is from the whole year 2003, while the subsequent hydrograph is a close up view of the time frame when direct seepage measurements were taken (September 5 to October 14, 2003).

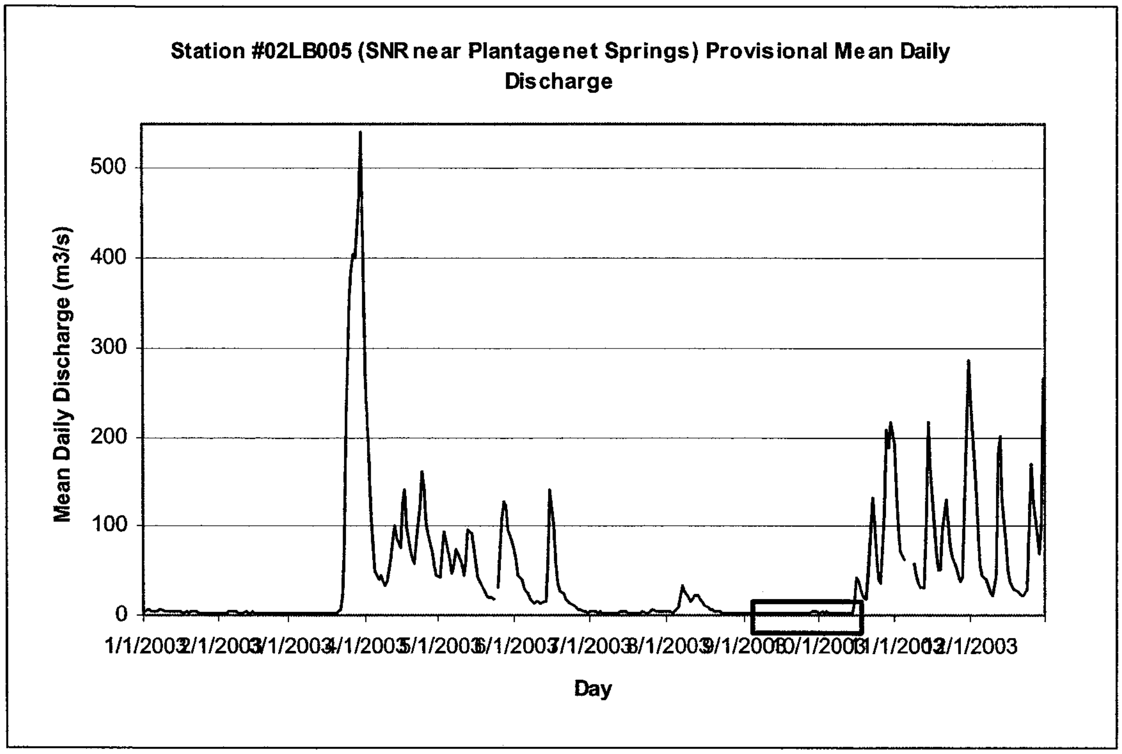
The third section of the appendix is hydrograph separation techniques. Baseflow estimates using the Fixed Base Method and the Baseflow Recession Method were found for each station. "Main Trunk" baseflow values (i.e. Plantagenet values – (Spencerville values + Castor values + Bear Brook values)) were obtained for both techniques and are also contained in this section.

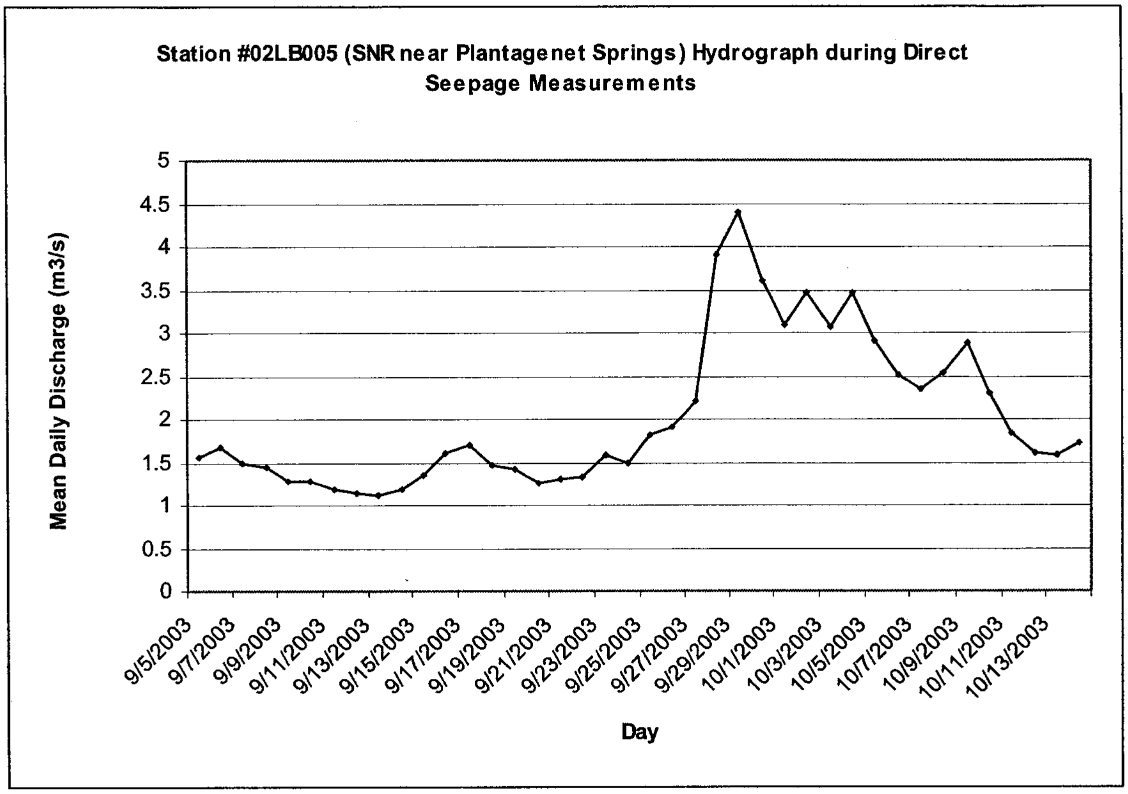
10/13/03	1.57	1.57	1.4	0.41	0.48	0.41	0.12	0.12	0.12	0.38	0.32	0.34	0.54	0.64	0.53
10/14/03	1.71	1.71	1.38	0.43	0.47	0.4	0.13	0.13	0.12	0.49	0.33	0.35	0.64	0.77	0.51
Total	**81.02**	**55.1**	**65.31**	**20.15**	**15**	**16.51**	**4.13**	**1.93**	**3.36**	**14.21**	**9.45**	**11.58**	**41.95**	**28.65**	**33.85**
Average	**2.02**	**1.38**	**1.63**	**0.51**	**0.38**	**0.41**	**0.10**	**0.04**	**0.08**	**0.35**	**0.23**	**0.28**	**1.04**	**0.71**	**0.84**

*MDD = Mean Daily Discharge (m^3/s)
*BRB = Baseflow Recession Baseflow (m^3/s)
*FBB = Fixed Base Baseflow (m^3/s)

Part 2: Hydrographs

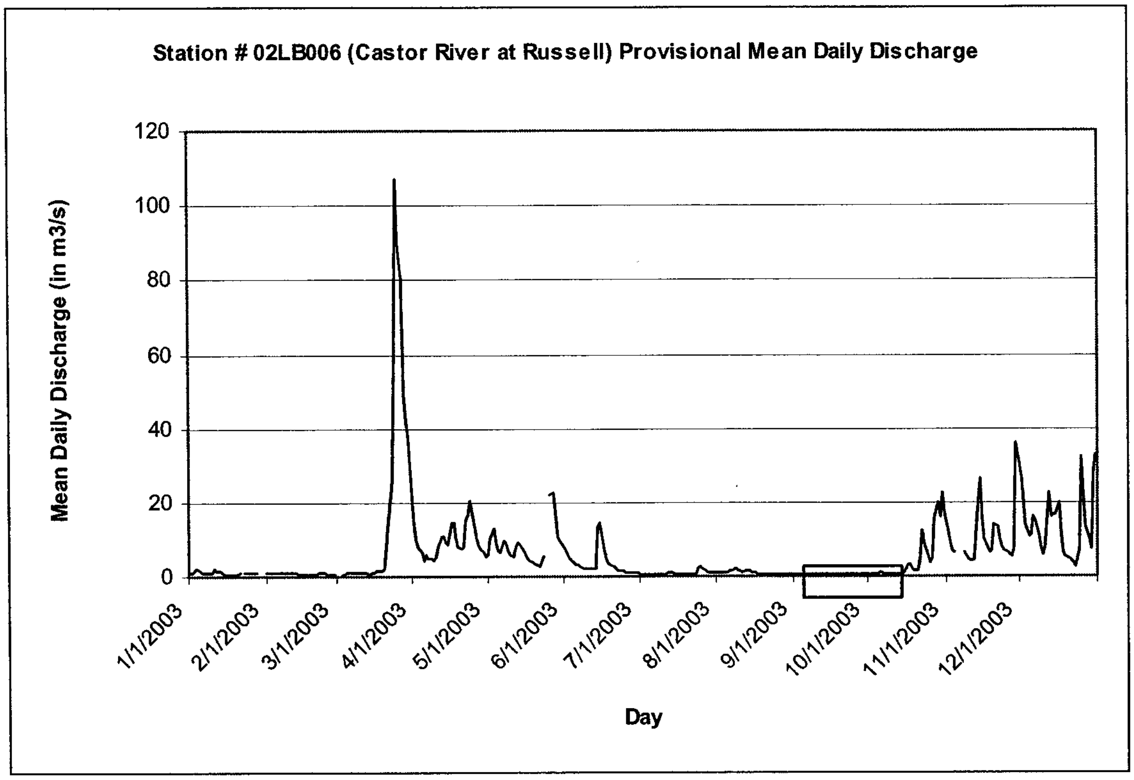
Hydrographs for Station #02LB005 (SNR near Plantagenet Springs)

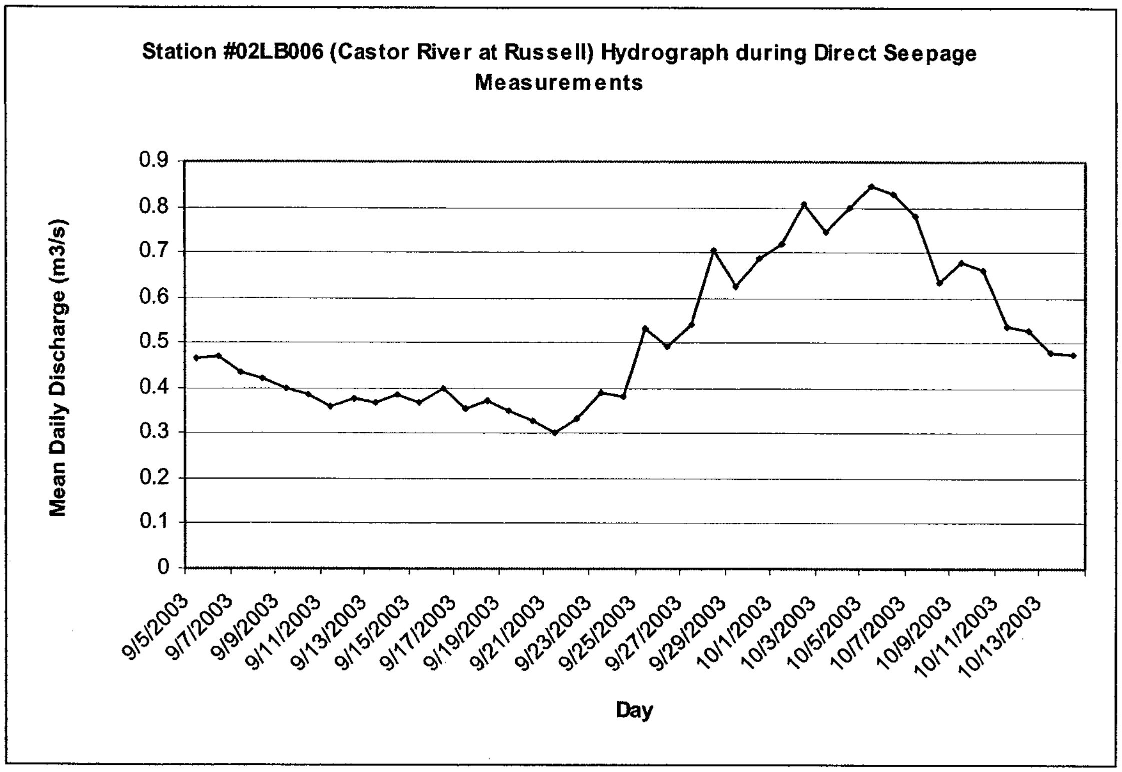




Station #02LB005 (SNR near Plantagenet Springs) Hydrograph during Direct Seepage Measurements

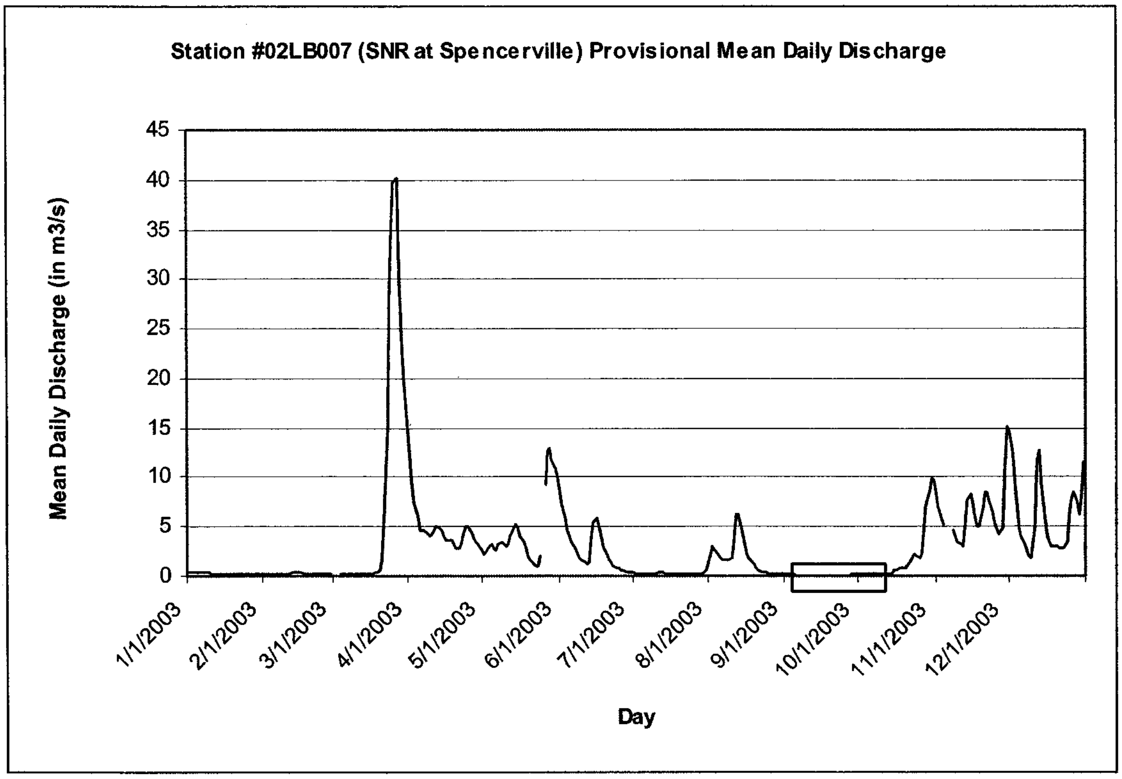
Hydrographs for Station #02LB006 (Castor River at Russell)

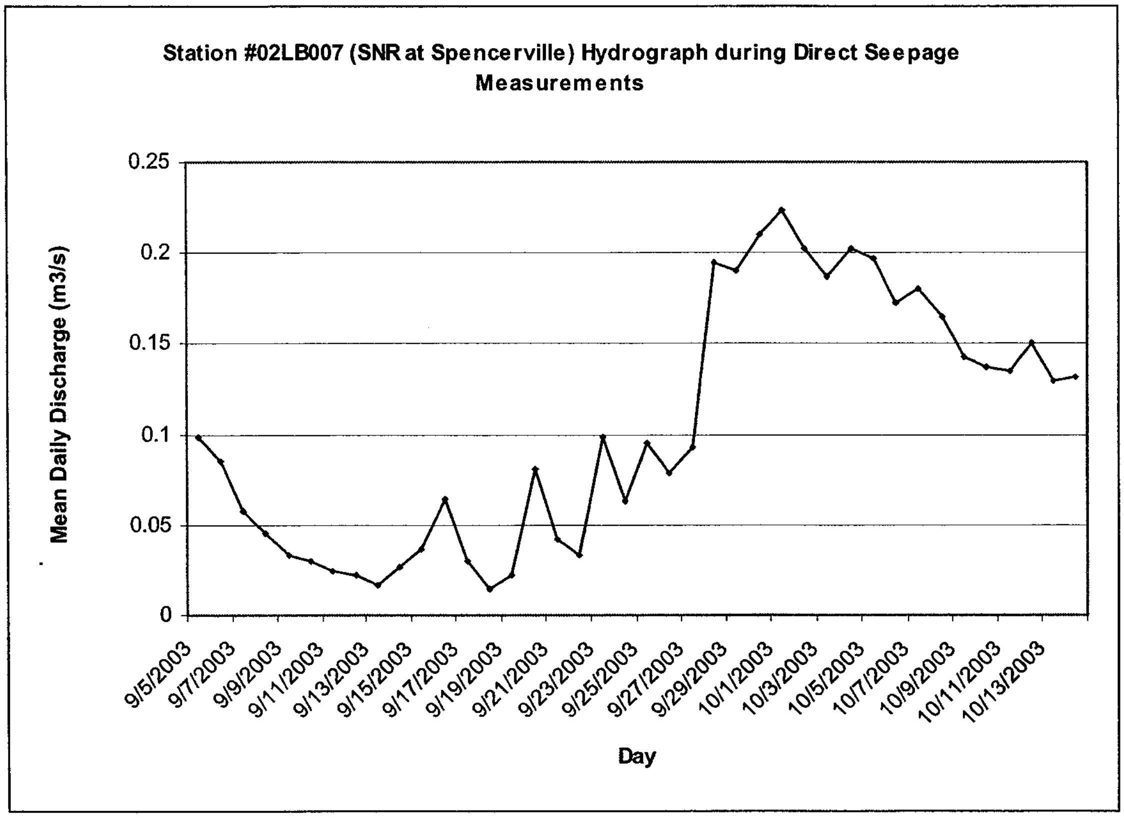




Station #02LB006 (Castor River at Russell) Hydrograph during Direct Seepage Measurements

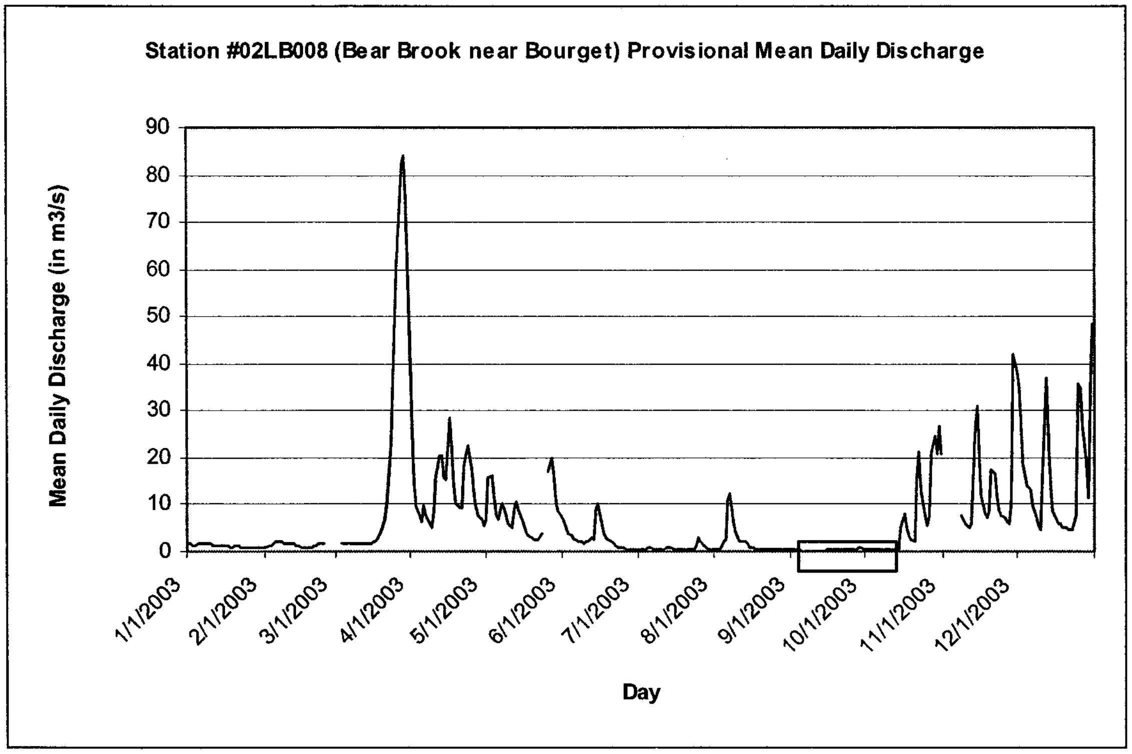
Hydrographs for Station #02LB007 (SNR at Spencerville)

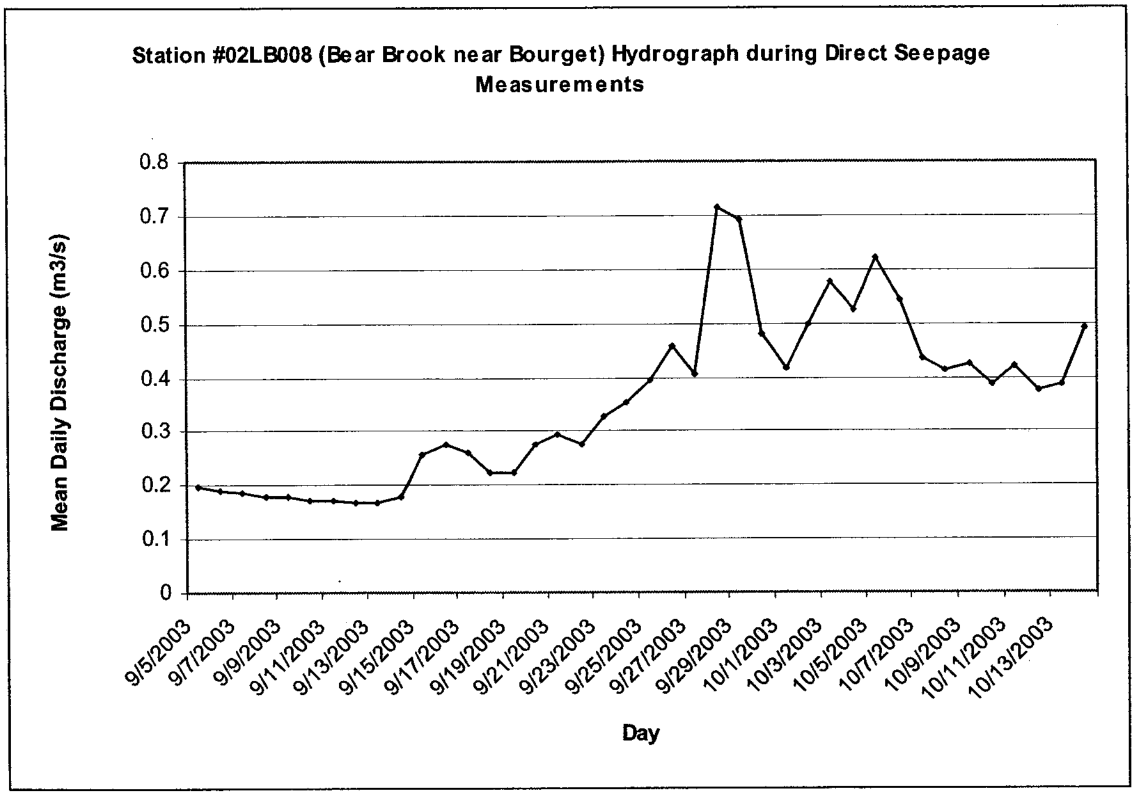




Station #02LB007 (SNR at Spencerville) Hydrograph during Direct Seepage Measurements

Hydrographs for Station #02LB008 (Bear Brook near Bourget)





Station #02LB008 (Bear Brook near Bourget) Hydrograph during Direct Seepage Measurements

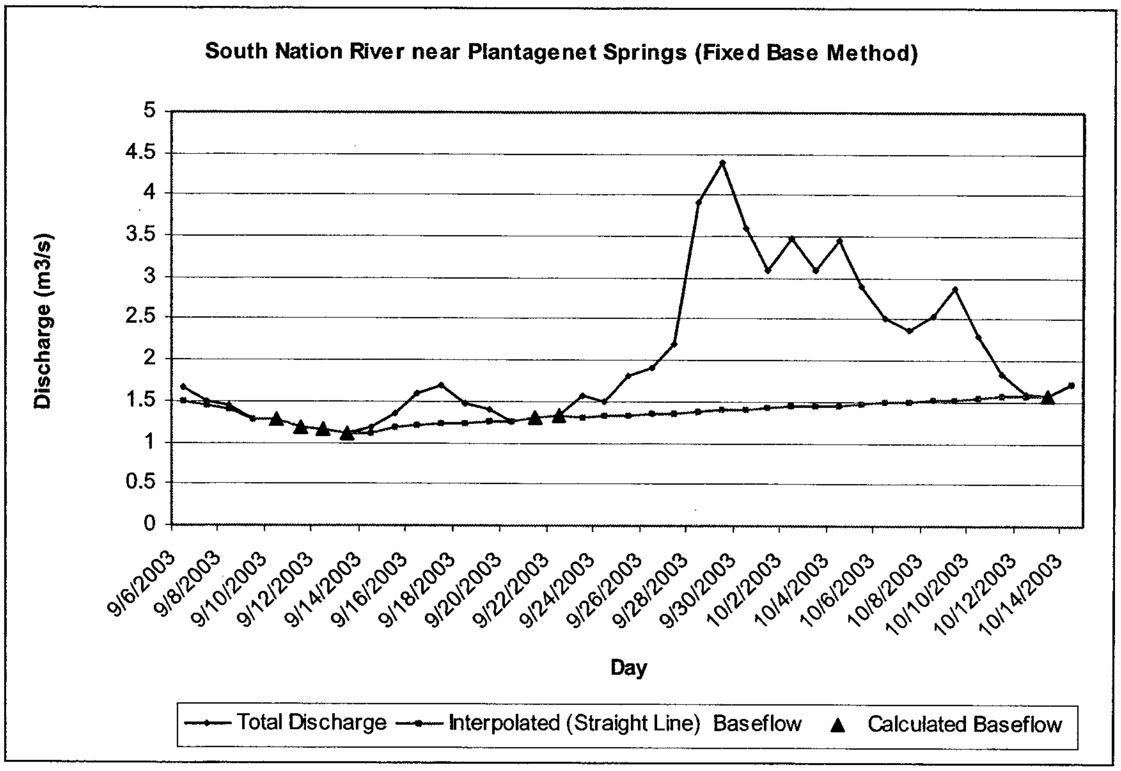
Part 3: Hydrograph Separation Techniques

Station # 02LB005 (South Nation River near Plantagenet Springs)

Fixed Base Method:

The Gross Drainage Area for this station is 3810 km^2. Therefore, discharge should be entirely baseflow 4.2 days after peaks in mean daily discharge.

$N=0.827A^{0.2}$
$N=0.827(3810)^{0.2}$
N=4.2 days



During periods of increased discharge and for the following N days of the recession baseflow values were obtained by linear interpolation. These values are indicated as squares on the graphs. Once baseflow is reached (4.2 days after the peak in this case) the values from the hydrograph are used directly. These values are indicated as triangles in the figures. The interpolated values at the extreme left of the hydrograph were obtained from interpolation with values not shown on the graph.

Base flow Recession

In order to find the recession constant, values from the hydrograph must be plugged into the equation. In this case, Q_o will be the largest peak on the graph for the period. Therefore;

$Q_o = 4.39$
$Q = 3.1$
$t = 2$ days

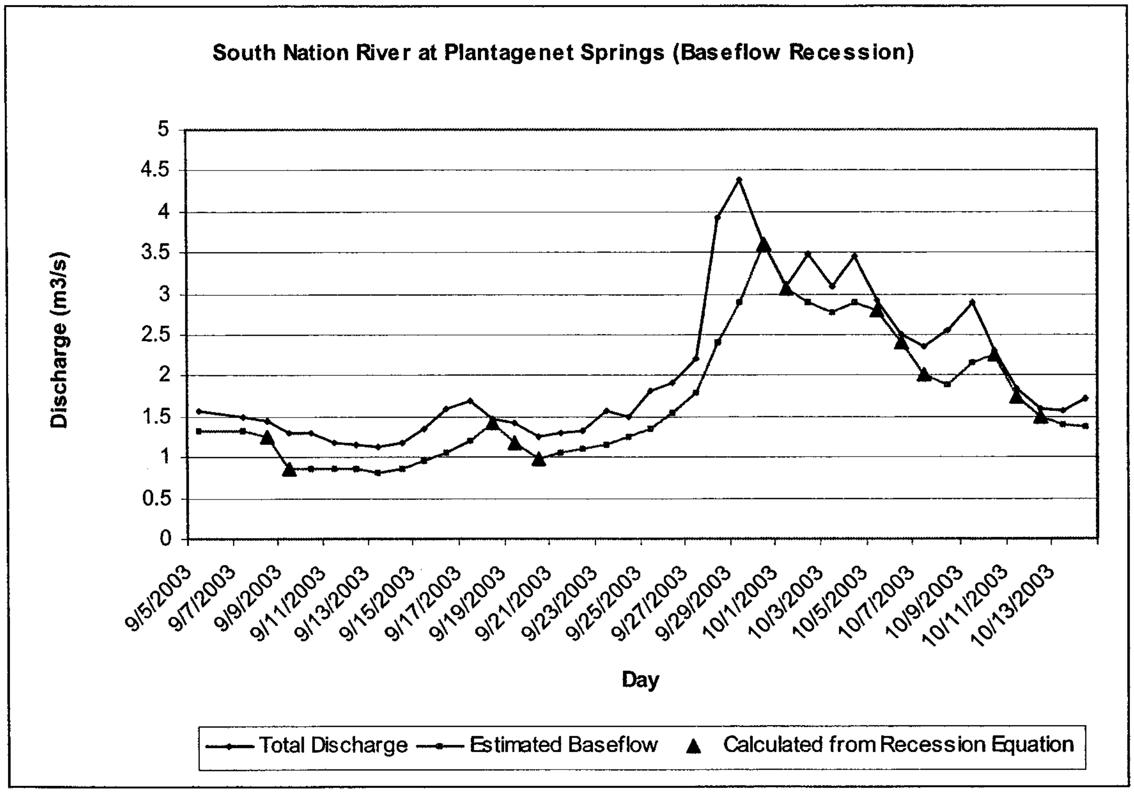
So;

$a = -(1/t)\ln(Q/Q_o)$
$= -(1/2)\ln(3.1/4.39)$
$= 0.18$

Since we now know the recession constant for the basin, we can find the baseflow (Q) at any time in the hydrograph during a recession period by using the equation:

$$Q = Q_o e^{-at}$$

Periods with increased discharge are estimated by creating a smooth line between recession periods.



During each recession the values of baseflow were obtained from the above equation based on the Q_0 of the peak immediately preceding the recession. These points are indicated as triangles. For periods of increased discharge the baseflow values were interpolated using a line that approximately followed the actual hydrograph – these values are given as squares. The values at the extreme left of the graph were obtained by interpolation from a period preceding those shown on the graph.

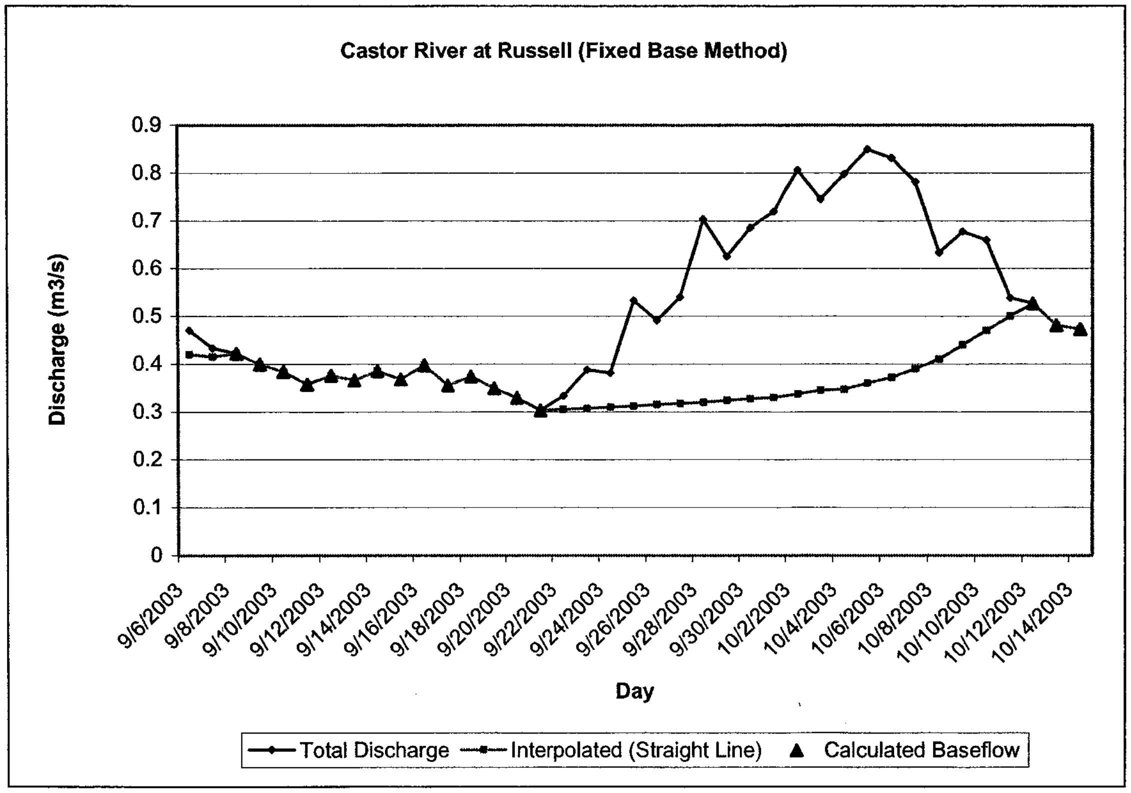
The calculated and interpolated baseflows were then averaged for the period and used to calculate the baseflow contribution to the main trunk of the SNR (See Section 1).

Station # 02LB006 (Castor River at Russell)

Fixed Base Method:

The Gross Drainage Area for this station is 433 km^2. Therefore, discharge should be entirely baseflow 2.7 days after peaks in mean daily discharge.

$N=0.827A^{0.2}$
$N=0.827(433)^{0.2}$
$N=2.7$ days

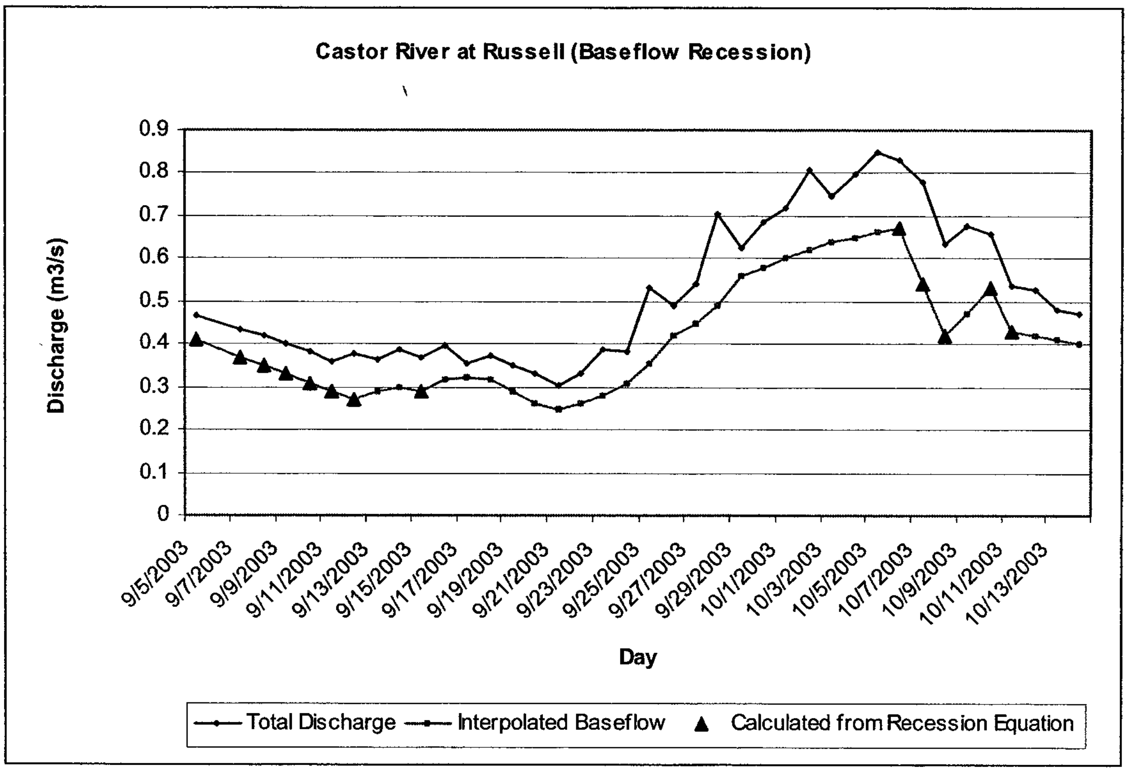


Base flow Recession

$Q_o = 0.89$
$Q = 0.71$
$t = 2$ days

So;

$$a = -(1/t)\ln(Q/Q_o)$$
$$= -(1/2)\ln(0.71/0.89)$$
$$= 0.11$$

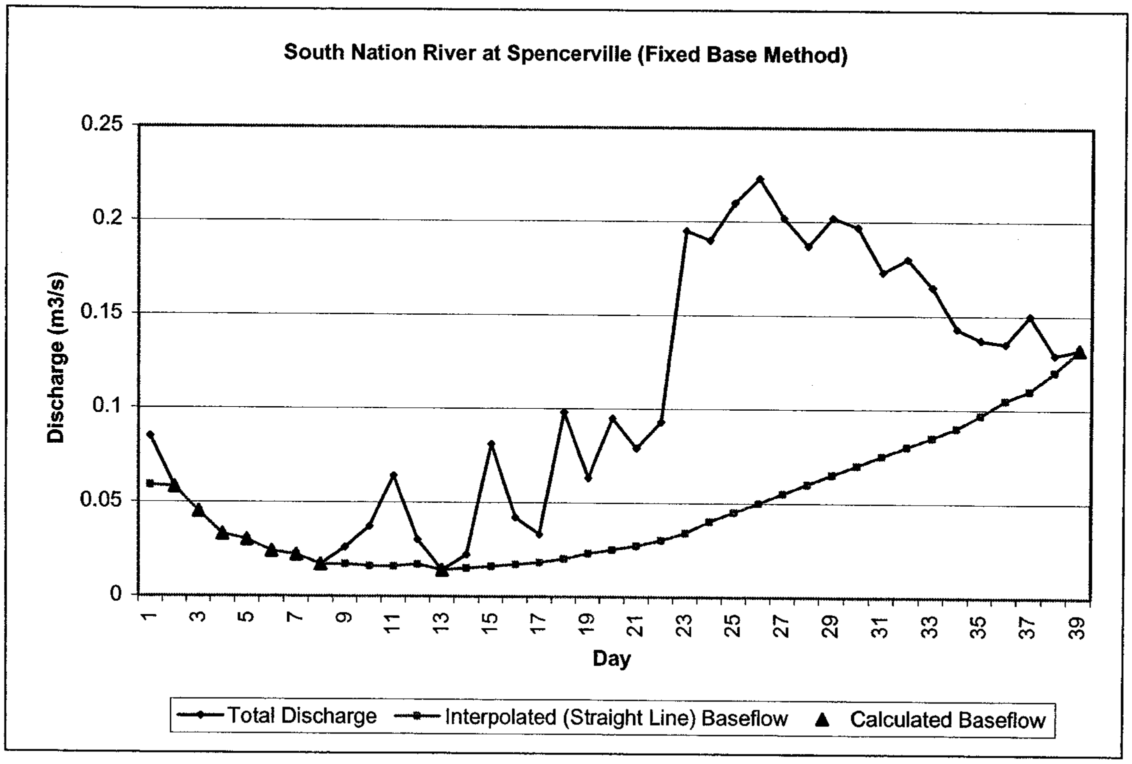


Station #02LB007 (South Nation River at Spencerville)

Fixed Base Method:

The Gross Drainage Area for this station is 246 km^2. Therefore, discharge should be entirely baseflow 2.4 days after peaks in mean daily discharge.

$N=0.827A^{0.2}$
$N=0.827(246)^{0.2}$
$N=2.4$ days

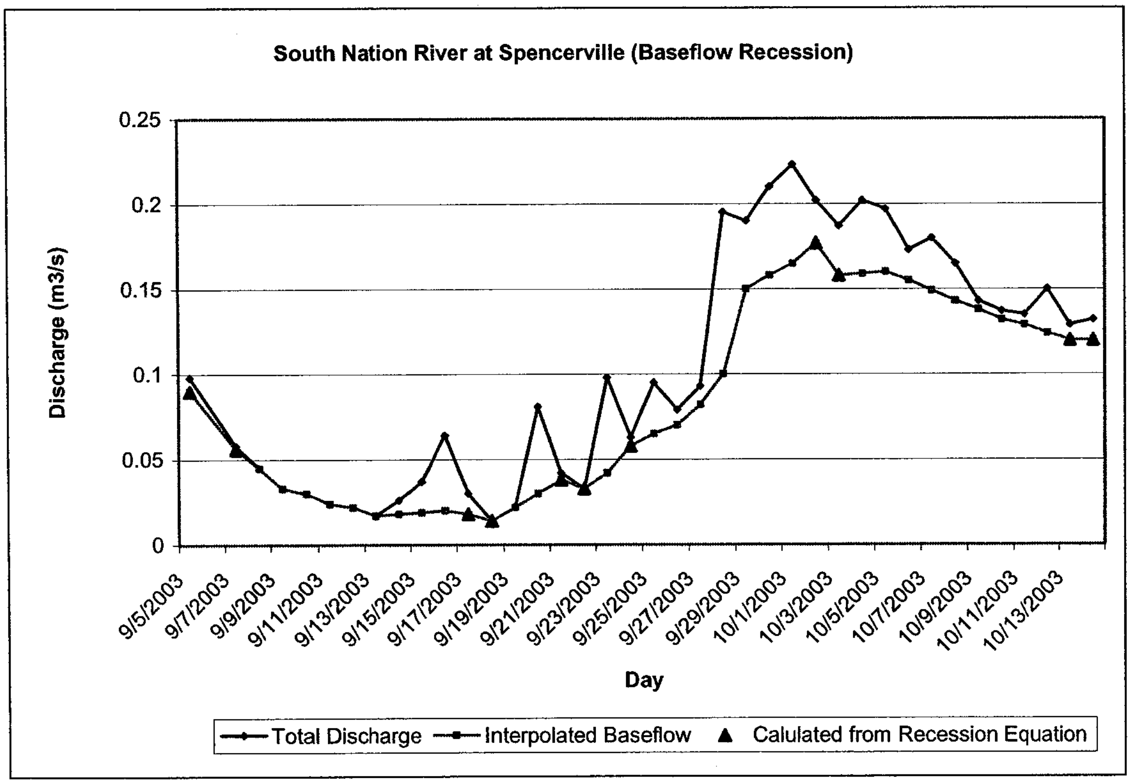


Base flow Recession:

$Q_o = 0.22$
$Q = 0.18$
$t = 2$ days

So;

$$a = -(1/t)\ln(Q/Q_o)$$
$$= -(1/2)\ln(0.71/0.89)$$
$$= 0.11$$

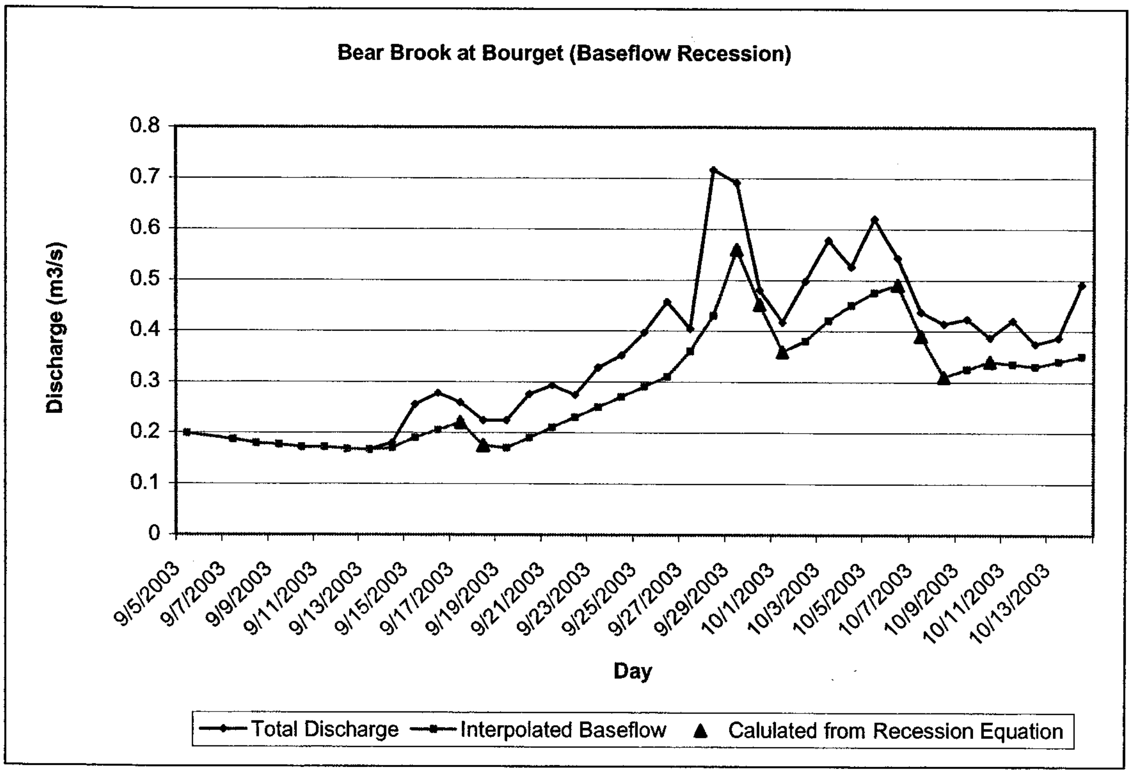


Station # 02LB008 (Bear Brook near Bourget)

Fixed Base Method:

The Gross Drainage Area for this station is 440 km^2. Therefore, discharge should be entirely baseflow 2.7 days after peaks in mean daily discharge.

$N=0.827A^{0.2}$
$N=0.827(440)^{0.2}$
$N=2.7$ days

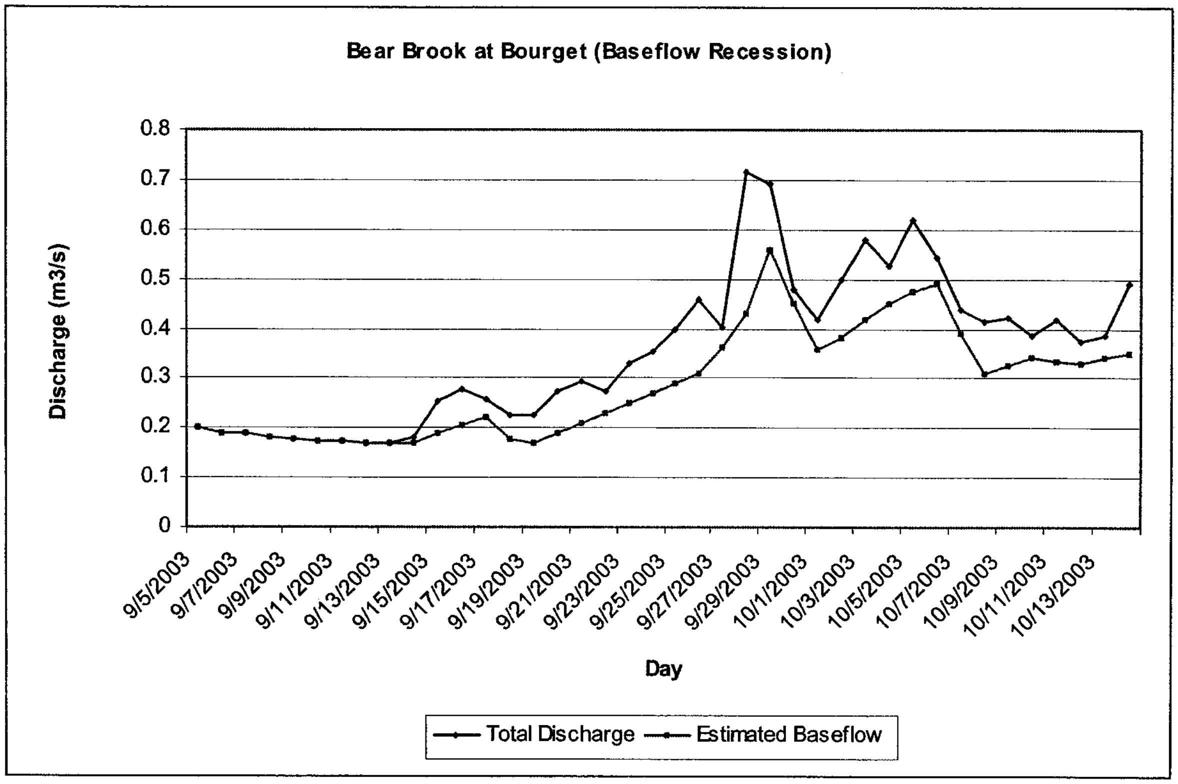


Base flow Recession

$Q_o = 0.76$
$Q = 0.48$
$t = 2$ days

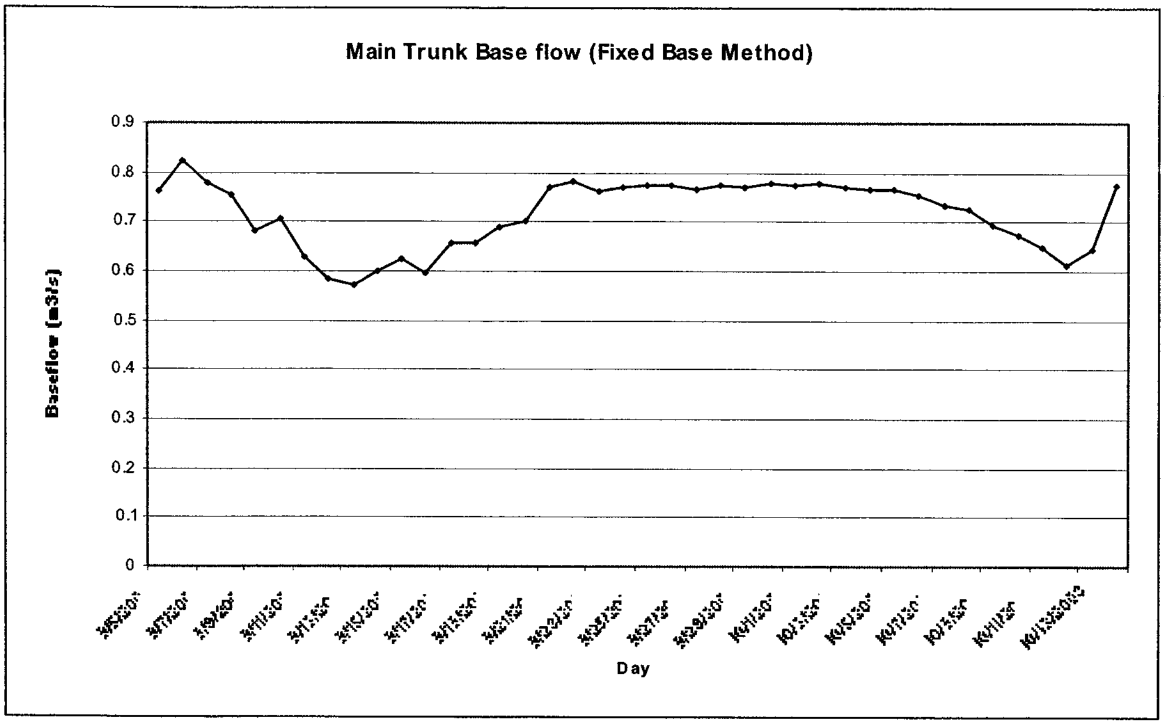
So;

$$a = -(1/t)\ln(Q/Q_o) = -(1/2)\ln(0.48/0.76) = 0.23$$



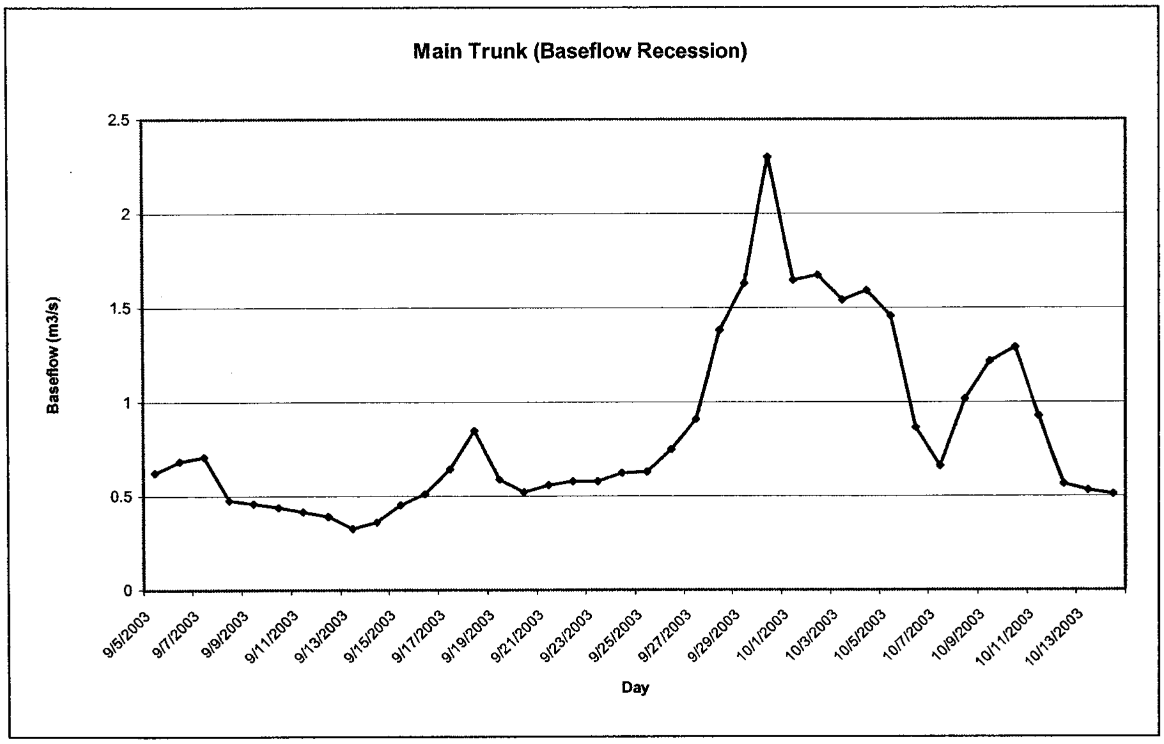
“Main Trunk”

Fixed Base Method



Average base flow from 9/5/2003 to 10/14/2003 = 0.716 m^3/s

Baseflow Recession Method

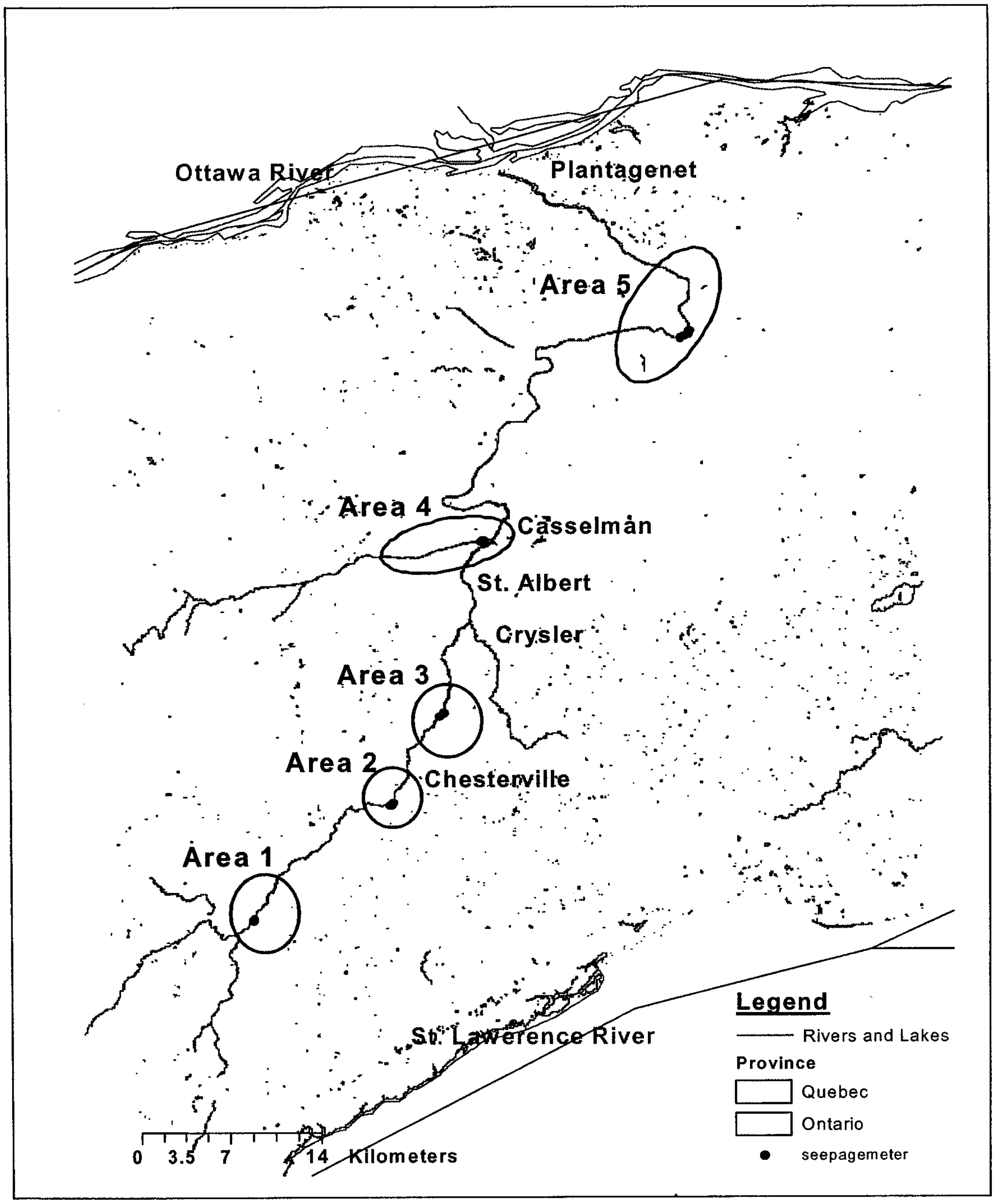


Average Base flow from 9/5/2003 to 10/14/2003 = 0.846 m^3/s

APPENDIX IV

BASEFLOW INTEGRATION VALUES AND THE AREAS WHERE THEY WERE MEASURED

Seepage Areas



Baseflow Integration

Area	Piezo	Width (m)	Length (m)	Area (m^2)	Check 1 Flux(m/s)	Check 2 Flux(m/s)	Check 3 Flux(m/s)	Average Flux(m/s)	Baseflow (m^3/s)	Avg. BF (m^3/s)
1	A	25	453	11551	1.64E-07	1.08E-07	3.34E-07	2.02E-07	2.33E-03	3.74E-03
	B	24	453	11080	1.19E-07	3.08E-07	4.02E-07	2.76E-07	3.06E-03	
	C	28	453	12693	3.93E-07	1.68E-07	6.51E-07	4.04E-07	5.13E-03	
	D	25	453	11551	3.42E-07	5.37E-07	4.27E-07	4.35E-07	5.03E-03	
2	E	31	345	10729	4.35E-07	5.41E-07	3.82E-07	4.53E-07	4.86E-03	3.58E-03
	F	32	345	11129	5.40E-07	2.98E-07	2.17E-07	3.52E-07	3.91E-03	
	G	32	345	11371	2.23E-07	3.04E-07	1.56E-07	2.27E-07	2.59E-03	
	H	31	345	10729	3.00E-07	3.76E-07	1.53E-07	2.76E-07	2.96E-03	
3	I	30	563	17042	8.48E-07	1.13E-07	1.39E-07	3.66E-07	6.24E-03	5.57E-03
	J	33	563	18601	1.04E-07	5.70E-07	1.16E-07	2.63E-07	4.90E-03	
4	K	51	1134	58162	1.34E-07	8.43E-07	1.04E-07	3.60E-07	2.10E-02	2.04E-02
	L	44	1134	50497	9.70E-07	1.61E-07	1.15E-07	4.15E-07	2.10E-02	
	M	44	1134	50032	1.13E-07	6.29E-07	4.11E-07	3.84E-07	1.92E-02	
5	N	50	1562	79052	1.51E-07	2.80E-07	2.68E-07	2.33E-07	1.84E-02	2.59E-02
	O	48	1562	76459	2.25E-07	7.25E-07	7.50E-07	5.67E-07	4.33E-02	
	P	53	1562	83254	1.71E-07	4.51E-07	3.69E-07	3.31E-07	2.75E-02	
	Q	49	1562	78068	1.32E-07	2.19E-07	2.02E-07	1.84E-07	1.44E-02	
									SUM* =	**5.93E-02**

*Sum of the average baseflows from the 5 locations

The width of the river was measured in GIS, which causes error in the calculation. GIS does not measure the width of the river by its waterline but by its banks. Therefore, there is an estimated width error of 5 meters, or 10-20%, depending on the location of the measurement. There is also error in the length calculation due to the fact that it is found by a visual estimation. An estimated length error is 10 meters, or 1-3%, again depending on the location. Therefore, the worst scenario would be 25% error. This would reduce the volumetric flow rate by 0.25, or 4 factors. For example;

Width at piezometer A = 25m +/- 5m (20%)

Length at piezometer A = 453m +/- 10m (5%)

Total Error = 25%

Estimated Baseflow = 3.74E-03 +/- 25%

APPENDIX V

ELECTRICAL CONDUCTIVITY AND TEMPERATURE VALUES (ON CD)