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Groundwater Quality and Contaminant Pathways in the Raisin River Agricultural Watershed; Susceptibility to Groundwater Contamination, Cornwall, Ontario

By

Greg Cane

Thesis submitted to the School of Graduated Studies and Research
for the Degree of Master in Earth Sciences (M.Sc.)

OTTAWA-CARLETON GEOSCIENCE CENTRE

AND

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Groundwater Quality and Contaminant Pathways in the Raisin River Agricultural Watershed; Susceptibility to Groundwater Contamination, Cornwall, Ontario

Abstract

The Raisin River watershed, located approximately 130 kilometres east of Ottawa, is the site of an environmental project examining the groundwater quality and contamination potential of a fractured bedrock aquifer in an agricultural basin discharging to the St. Lawrence River.

Groundwater quality was monitored in five tile drains, four piezometers, and thirteen domestic wells over a period of 14 months (May-94 to June-95). Temporal variations in total dissolved solids (TDS), water level, and major element concentrations, as well as fluctuations in dissolved organic carbon (DOC), δ^2H and $\delta^{13}C$ were used to distinguish between regionally recharged groundwaters and recharge occurring by local infiltration through agricultural fields. Nitrate, agricultural pesticides, and heavy metals were analyzed as the principal components of groundwater quality.

Water level, dissolved solids, δ^2H, and $\delta^{13}C_{DIC}$ fluctuated according to seasonal change. Springtime showed high water levels coupled with depleted δ^2H values. In addition, nitrate and DOC values were elevated due to local infiltration through the soil zone into the bedrock aquifer. The $\delta^{13}C$ values show that recharge contributions from (i) bedrock recharge areas, and (ii) infiltration through cultivated fields, vary on a seasonal basis. Spring and summer periods are dominated by recharge through cultivated fields where $\delta^{13}C$ values are governed by infiltration of C_4 plant (corn) carbon. Contributions of local recharge during the fall and winter months are reduced.

The watershed's susceptibility to groundwater contamination is considered high since the aquifer responds to seasonal climatic variations. The mean residence time of these groundwaters is in the range of several months, based on cross-correlations between air temperature and δ^2H values of Raisin River waters. The most potentially harmful times of year occur during rapid groundwater infiltration during the spring and periods of high precipitation. The effect of tile drains in diverting agro-contaminants to the Raisin River contributes to overall good bedrock groundwater quality as tile drainage effluent shows elevated concentrations of pesticides, nitrate, and trace metals.

Qualité de l'eau et réseau routier des contaminants dans le bassin agricole de la rivière Raisin: potentiel de contamination de l'eau souterraine à Cornwall en Ontario

Résumé

Le bassin de la rivière Raisin, situé à environ 130 kilomètres à l'Est d'Ottawa, est le site d'une étude environnmentale examinant la qualité d'eau et le potentiel de contamination d'un aquifère carbonaté fracturé dans un bassin agricole se déversant vers la rivière Saint-Laurent.

La qualité de l'eau souterraine était analysée en échantillonnant l'eau dans cinq égouts agricoles, quatre piézomètres, et treize puits domestiques pendant quatorze mois entre mai 1994 et juin 1995. La variation temporelle en matières solides dissoutes, les niveaux d'eau, et les éléments majeurs, ainsi que la fluctuation en carbone organique dissout (COD), le δ^2H, et le $\delta^{13}C$ ont été utilisés pour distinguer la recharge des eaux souterraines sous un contexte régional et la recharge se produisant par infiltration locale à travers les sols agricoles.

Le niveau d'eau, les matières solides dissoutes, le δ^2H, et le $\delta^{13}C_{DIC}$ ont démontré une variation saisonnière d'où les printemps ont vu des niveaux d'eau très élevés ainsi que des valeurs de δ^2H appauvries. De plus, les valeurs de nitrate et COD étaient en surplus suite à l'infiltration de matières organiques à travers le profil terrestre. Les valeurs de $\delta^{13}C$ ont démontré que les contributions de recharge provenant de (i) zone de recharge de la roche mère, et (ii) l'infiltration à travers des champs cultivés, varient selon un cycle saisonnier. Les périodes de printemps et d'été démontrent une recharge dominée à travers les sols agricoles où les valeurs de $\delta^{13}C$ sont influencées par l'infiltration de carbone provenant de plantes (maïs) C_4. Durant les périodes hivernales, les contributions de recharge locale sont réduites.

Le potentiel de contamination du bassin est considéré élevé étant donné la variation saisonnière des paramètres chimiques analysés. La résidence moyenne des eaux souterraines est une question de plusieurs mois selon l'analyse de corrélations croisées entre la température atmosphérique et des valeurs de δ^2H de la rivière Raisin. Les

périodes annuelles de potentiel élevé demeurrent durant les moments d'infiltration d'eau souterraine rapide durant le printemps et durant des tempêtes de pluviométrie persistente. Cependant, les égouts agricoles ont pour but de dévier les contaminants agricoles dans la rivière Raisin, produisant ainsi une qualité d'eau excellente. Les effluents provenant de ces égouts démontrent des concentrations de nitrate, de pesticides, et de métaux lourds très élevées par rapport aux normes recommendées pour les milieux aquatiques.

Acknowledgments

I would like to extend my thanks to the Institute for Research on the Environment and Economy (IREE) for providing funding for this project. It was only in late March of 1994 that IREE decided to grant funding for an additional study on the Raisin River Watershed, a moment at which time I was hopelessly searching for a Master's thesis.

Thanks also go to the Ottawa-Carleton Geoscience Centre's Stable Isotope Laboratory, including Gilles St. Jean, Nathalie Morisset, and Wendy Abdi, for the use of isotope extraction lines and mass spectrometers. In addition, geochemistry results were obtained with the invaluable help of John Loop and his HPLC and ICP instruments at the Geochemistry Laboratory, University of Ottawa.

There are certain graduate students who deserve recognition for contributing analytical instruments and providing information leading to the completion of this project. In particular, Sandra Porter for field assistance and drill log data, Anne Watelet for agricultural land-use maps, and a special thank you to Johannes Barth who graciously lent his pH and conductivity meters month after month with which tons of useful data was obtained.

A heartfelt appreciation goes out to the residents involved in the domestic well sampling program, including Winifred Coleman, Allan Valade, Susan Poitras, Tim McDougall, René Lozon, Dave & Christie Tate, Pete & Kathleen Koepers, Donna Dunbar, Barry Grant, and Frank & Beverly Hincks. I would also like to send my deepest sympathies to Mrs. Ernie Seale, whose husband passed away in March 1995. The news came as a shock because he never passed up the chance to shoot the breeze with me when I did my sampling. Here's to you Ernie.

Thanks also go to Michel Robin and George Dix for spending their time reviewing "The Brick".

I bestow my deepest gratitude to my supervisor, Dr. Ian Clark, whose important guidance has helped me learn a great deal about hydrogeology and the way projects are managed. One quote I'll always remember is; "You do what you can with what you have". Thanks again Ian.

Last but not least, I would like to thank those people who are closest to me. To my folks, Dad, thanks for the use of your colour printer. Aussi, à ma future épouse, Ma Belle, merci pour ton encouragement, ton aide avec les photos et le travail de labo, et ton appui au niveau moral. Je t'aime à tout jamais.

Table of Contents

List of Figures

List of Tables

List of Plates

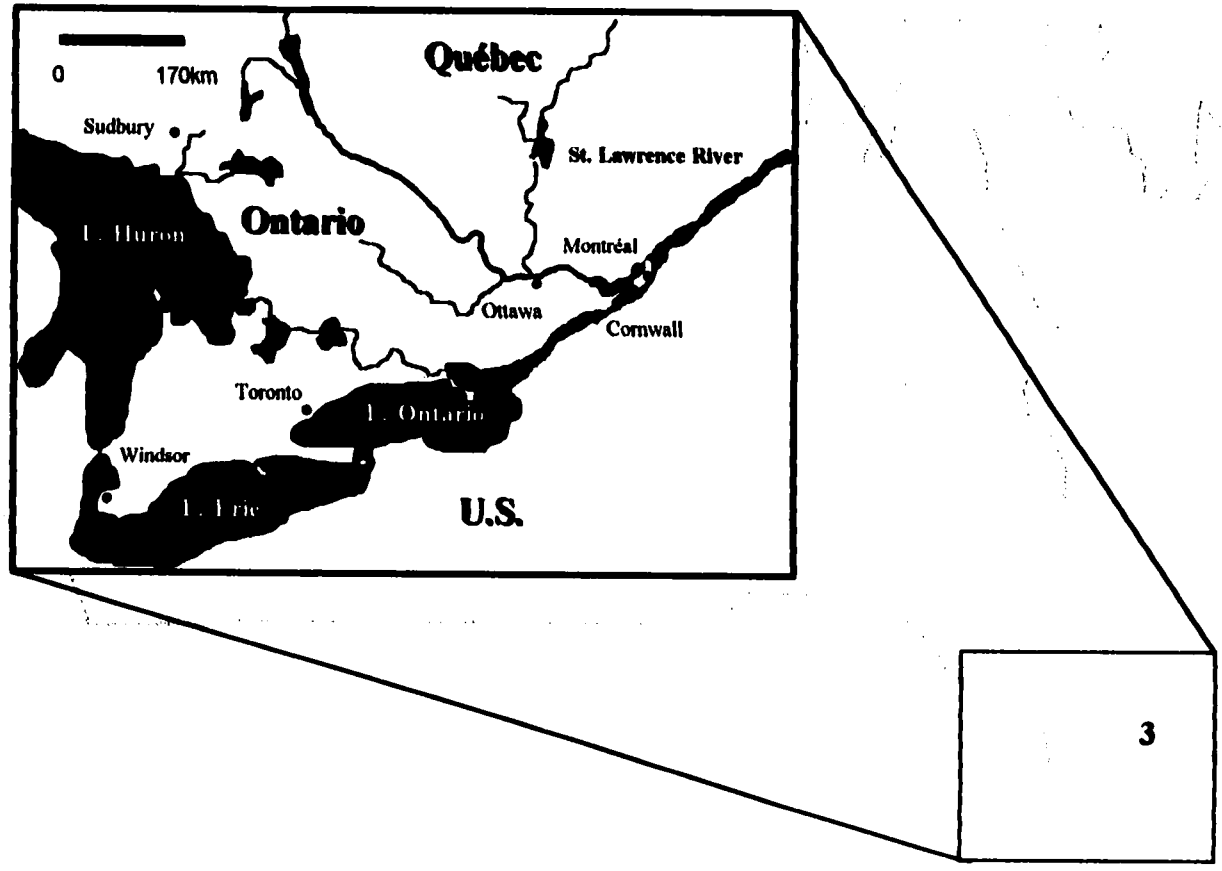
Chapter 1: Introduction

1.1 Prologue

The St. Lawrence River has been an important seaway passage for the past several centuries linking the Atlantic Ocean with the Great Lakes and the North American interior (Fig. 1.1). Throughout its history, this easy access route for maritime traffic has lead to the development of industry on both sides of the St. Lawrence in Canadian and American territory. As a result of the increased economic and industrial activity, pollution of this waterway has increased over the years (Plate 1-1 and 1-2).

The University of Ottawa's Institute for Research on the Environment and Economy (IREE) has begun to address this problem by examining the impact of industry on pollution in what is known as the "St. Lawrence River Ecosystem Recovery Project". Several studies are dealing with ecosystem degradation along the St. Lawrence itself. However, the detection of contaminants in the St. Lawrence River may not rest entirely with sources originating from industry directly on the river's shorelines. The characteristics of onshore watersheds and groundwater flow to and from local rivers draining into the St. Lawrence may be essential components of contaminant contribution to this seaway. It is for this reason that the Raisin River watershed has been selected for an intense hydrological and hydrogeological study examining the impacts this river and its watershed have on the St. Lawrence Seaway in terms of contaminant contribution (Fig. 1.2).

Figure 1.1 Map of Canada showing St. Lawrence Seaway with respect to Atlantic Ocean, Cornwall, and Great Lakes.



1. St. Lawrence River
2. Atlantic Ocean
3. Cornwall

Plate 1-1. View of the St. Lawrence River with eastern part of Cornwall Island in background (October 1994; distance to island is approximately 500 meters).

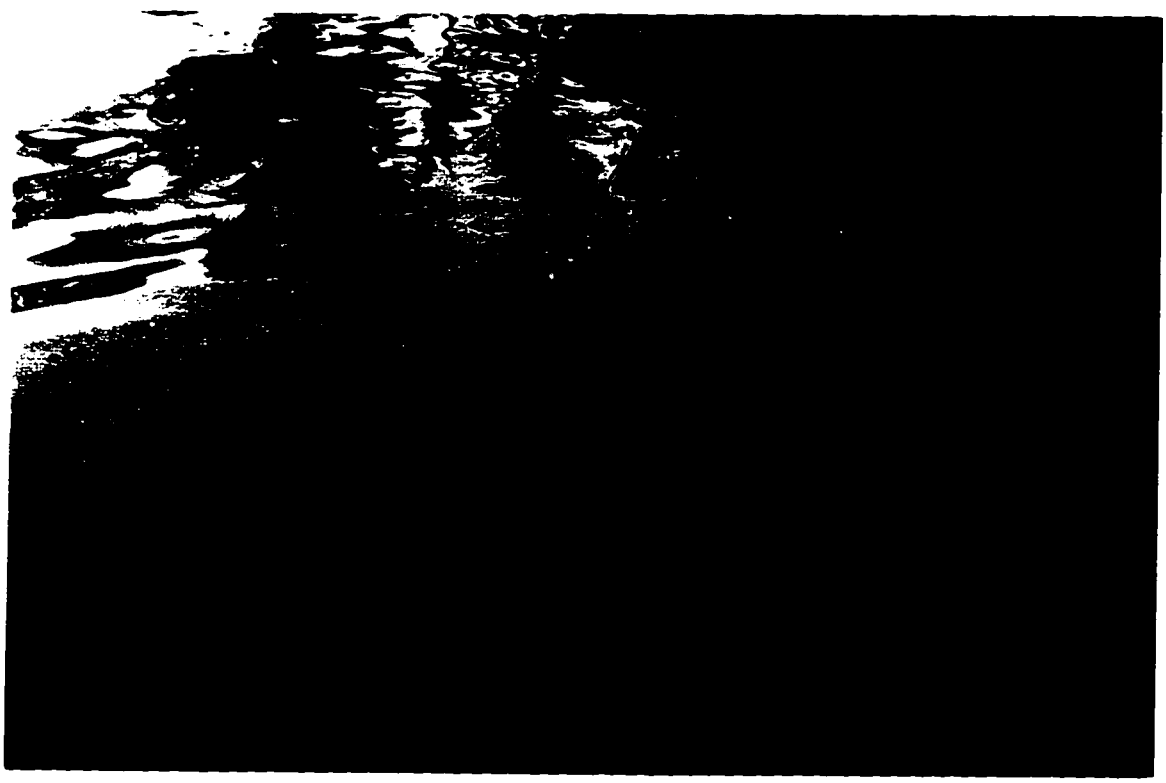


Plate 1-2. Pollution in the St. Lawrence is of major concern. Here, as sediment is displaced, contaminant patches rise to the surface and float around in the form of miny oil slicks (submerged rock in upper right-hand corner is 1 meter long; October 1994).

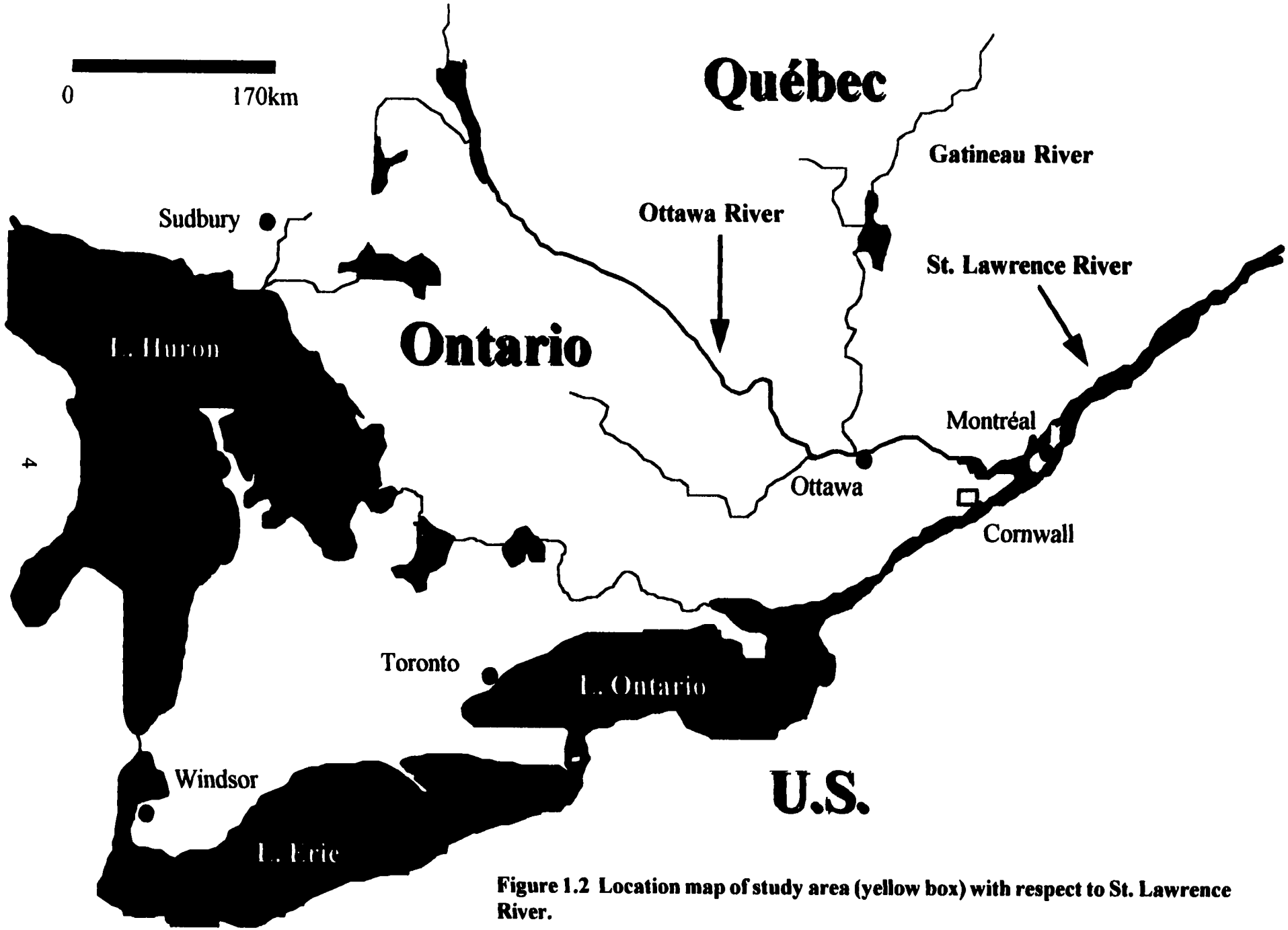


Figure 1.2 Location map of study area (yellow box) with respect to St. Lawrence River.

1.2 Introduction

Since the Raisin River watershed has been farmed for the past several decades, the possibility that fertilizers, heavy metals, or pesticides are reaching the seaway valley via the Raisin River itself cannot be ignored. In dealing with this potential problem, the Raisin River has been the focus of an agricultural and environmental management study conducted by Anne Watelet of the Department of Geography, University of Ottawa, where the relationship between land use and surface water quality have been examined. Watelet's (1996) study focuses on correlating hydrological events and land use practices adjacent to the Raisin River while monitoring surface water quality for parameters such as nitrate, cations, anions, heavy metals, and pesticides over time.

Surface water systems, however, are directly related to the hydrogeological sub-system and vice versa. Thus, the study of groundwater flow is important in order to assess the potential for contaminant contributions from groundwater discharging into the Raisin River and from the Raisin River recharging the groundwater system. Sandra Porter from the Department of Geology, University of Ottawa, has worked on the physical interaction between groundwater and surface water of the Raisin River watershed by delineating areas of groundwater discharge into the river and groundwater recharge from the river. Other important hydrogeological characteristics include the hydraulic conductivity of the watershed's sediment and the rate of groundwater discharge into the river.

For the third portion of the watershed study, this thesis addresses groundwater quality and potential contaminant pathways from surface applied chemicals.

Assessing groundwater quality and a watershed's susceptibility to groundwater contamination can be accomplished by monitoring a series of wells through time. Temporal variation in environmental isotopes, water level, total dissolved solids, and a

water's chemistry are parameters which can be used to assess whether or not groundwater is influenced by meteoric events or seasonal change. In addition, the monitoring of domestic well waters, tile drainage effluent, and river sediment for agro-contaminants can illustrate the state of groundwater quality and impacts of several years of contaminant use on the watershed.

1.3 Objectives of this Study

The Raisin River watershed was selected as part of the St. Lawrence River Ecosystem Recovery Project because it is the largest watershed in the Cornwall area draining to the St. Lawrence River (Fig. 1.3) and for its long agricultural history. This coupled with past detections of agro-contaminants in the St. Lawrence (St. Lawrence RAP Team, 1994) warrants research into possible contaminant contributions from agricultural industry in the area.

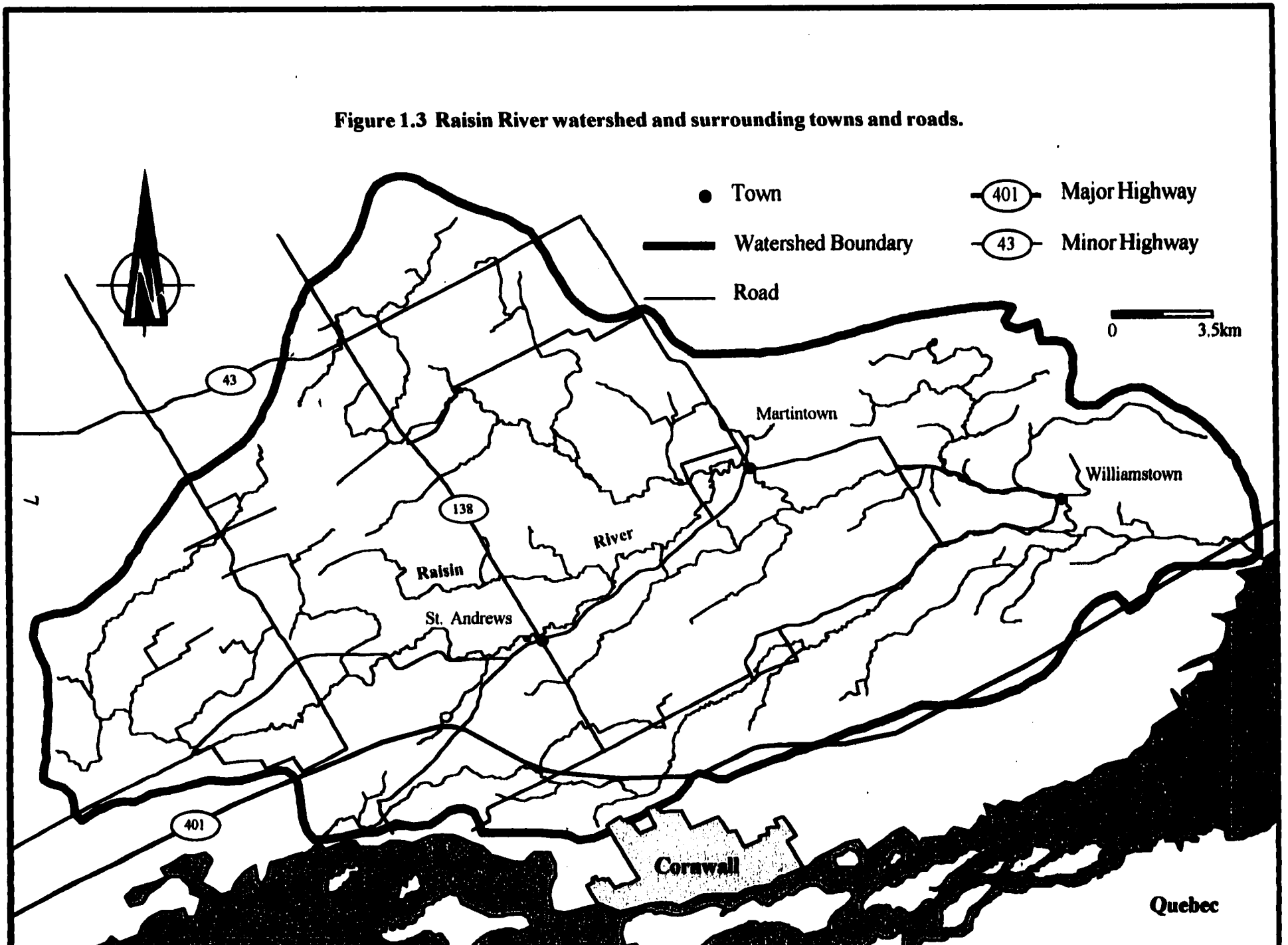
The major objectives of this study are to determine groundwater quality and the potential for groundwater contamination of the Raisin River watershed. Specific objectives are:

1) The identification of seasonal or storm-related water level fluctuations within the watershed and rates of groundwater circulation.

2) The identification of potential groundwater contamination zones.

3) Evaluation of the quality of tile drainage effluent, domestic well water in the limestone bedrock, and the level of agro-contaminants in surficial sediments along the Raisin River

Figure 1.3 Raisin River watershed and surrounding towns and roads.



1.4 Location and Physiography of Study Area

The study area is situated north of Cornwall, 130 km east of Ottawa (Fig.1.2) and measures approximately 800 km^2 (Fig. 1.3). The northwestern part is typically at an elevation of 100 to 120 meters above sea level (m.a.s.l) set within till plains and peat bogs.

South and east, elevations gradually fall to 50 m.a.s.l.. To the east, till plains are mostly overlain by alluvial sands. Relief is described as undulating to rolling hills with till ridges forming the majority of the topography with only a gradual decline in elevation on a southeasterly heading (Terasmae, 1965).

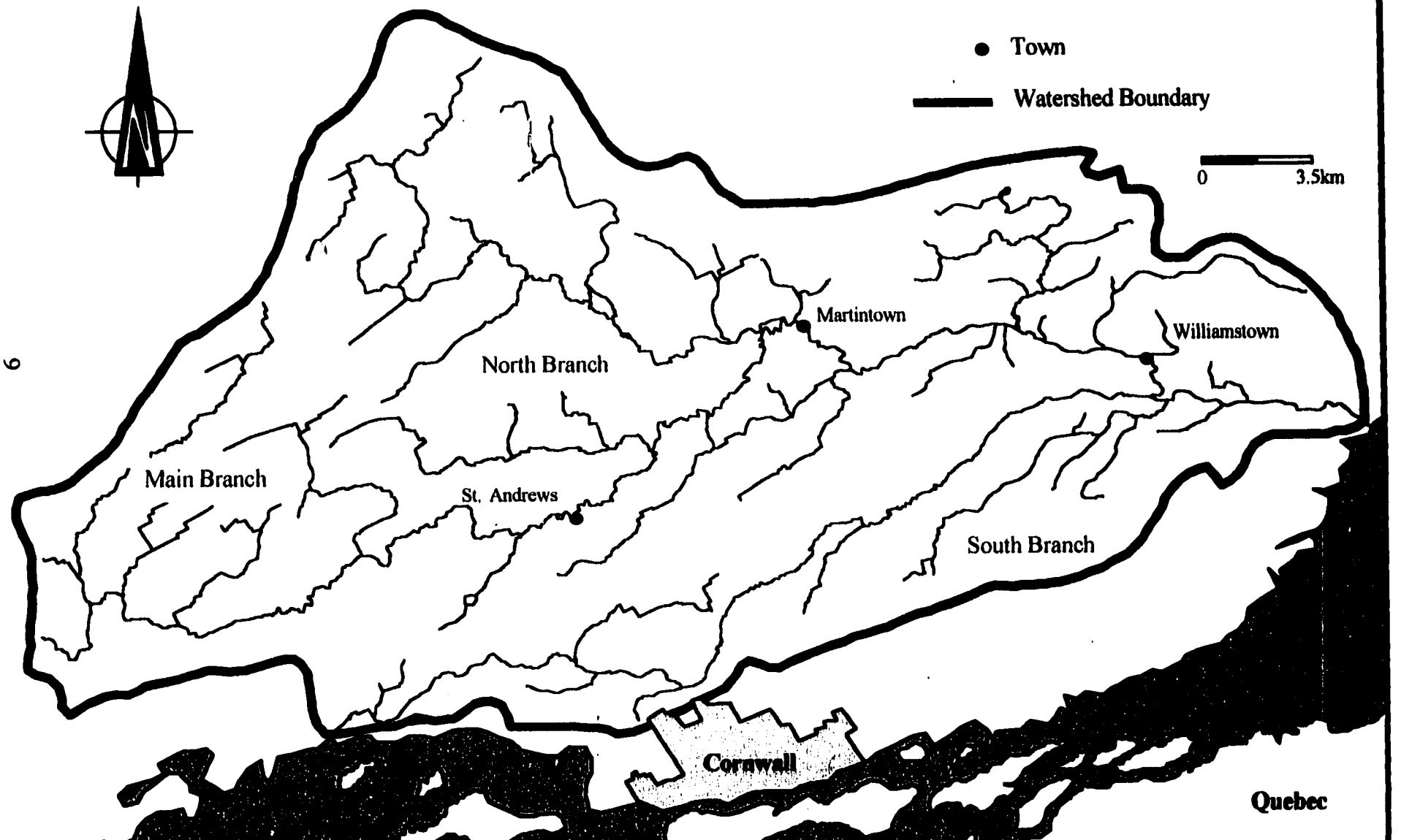
The area is characterized by a temperate climate. Total annual precipitation is approximately 100 cm with 43 cm falling during the months of June, July, and August. Air temperatures peak between 30 and 35^{0}C in July and are lowest in February dipping to -30^{0}C. First signs of frost begin near the end of November and spring thaw commences in mid-March.

1.5 General Hydrology

The Raisin River is comprised of three principal sections including the north branch, the south branch, and the main branch (Fig. 1.4). All three branches are oriented west to east parallel to the flow of the St. Lawrence River.

The south branch joins the main branch 1.5 km south of Williamstown and the north branch joins the main branch at Martintown. The whole of the Raisin River flows into the St. Lawrence Seaway via South Lancaster situated approximately 7 km south-east of Williamstown.

Figure 1.4. Raisin River watershed displaying the North, South, and Main branches.



The Water Survey of Canada (1994) measures discharge from the Raisin River at a location near Williamstown using a stream vax. This device places the discharge between 0.041 m^3/s for August 1994 and 84.6 m^3/s for April 1994.

1.6 Agricultural History & Practices

The study area has seen a change in land practices over the past 200 years. Before farming was industrialized, the Cornwall area had a much more abundant and diversified forest composition, with hardwood maples, beech, basswood, birch, elm, ash, and white pine comprising most of the vegetation and covering a large portion of the land (Terasmae, 1965). Early settlers cleared away most of the forested areas giving way to small-scale agricultural practices providing the needs for individual households. In the past century, development of farmland has increased and small-scale farming practices were abandoned in order to meet the needs of increases in demand and population. Dairy farming thus became an industry and has been thriving over the past 50 years (Plate 1-3 and 1-4).

With advances in technology, farms have been able to start their growing season earlier in the spring thanks to better drainage with the insertion of tile drains within large portions of the study area (Plate 1-5 and 1-6). Today, a typical farmer on the Raisin River watershed can begin planting his/her crops as early as the end of April-beginning of May (Plate 1-7). The growing season lasts approximately 190 days.

Most of the area surrounding Cornwall, St. Andrews, Williamstown, and Martintown is used for the production of corn, hay, and alfalfa (Fig. 1.5; Land use areas were mapped by Watelet, 1996). These crops are subjected to continuous pesticide and fertilizer applications each spring before and during crop growth (Plate 1-8 and 1-9).

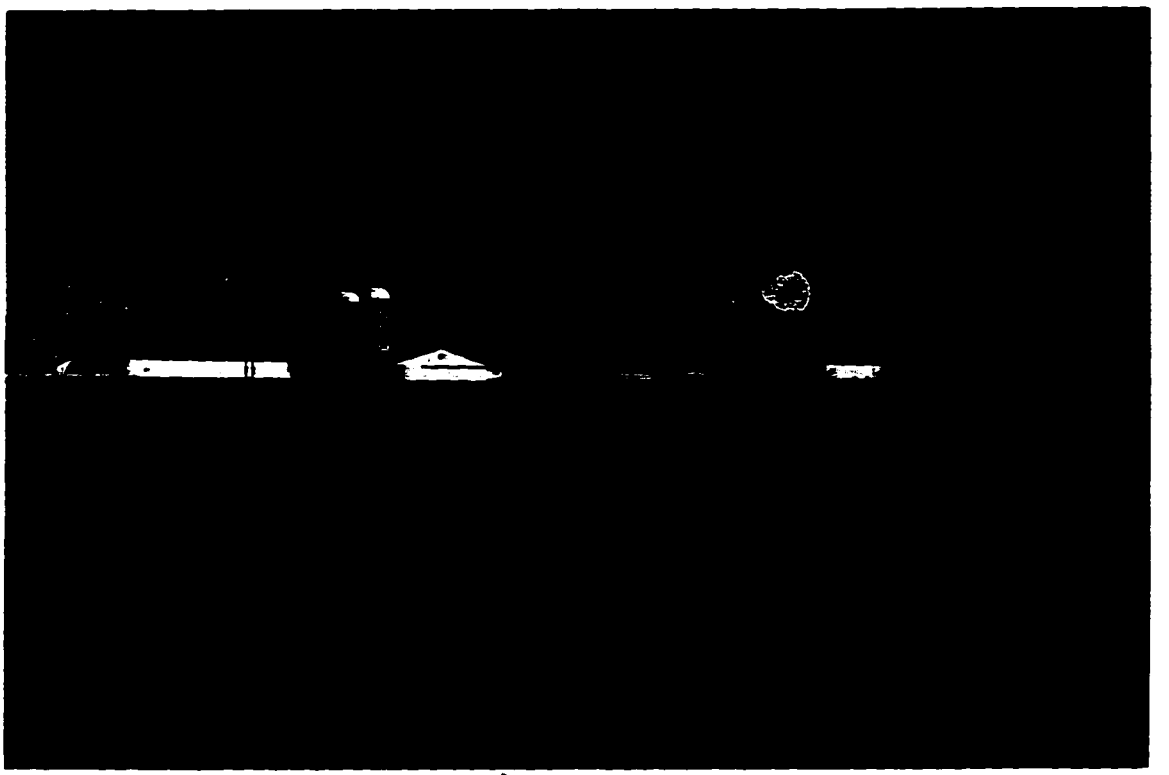


Plate 1-3. Typical farm on the Raisin River watershed. Note harvested corn stocks in field (Grants Corners; site G10, October, 1994).

Plate 1-4. Increases in population and worldwide demand for agricultural produce make farming today an important industry. Here, several acres of oats are ready for harvest (October, 1994).

Plate 1-5. Tile drains ready to be inserted in a field 800 meters northwest of Martintown (Fall 1994). Mounds of black earth are where 1.5 meter deep trenches have been dug.

Plate 1-6. Two tile drainage spouts gushing effluent into a Raisin River tributary (MacGillivrays Bridge; site G7F, May 1995).

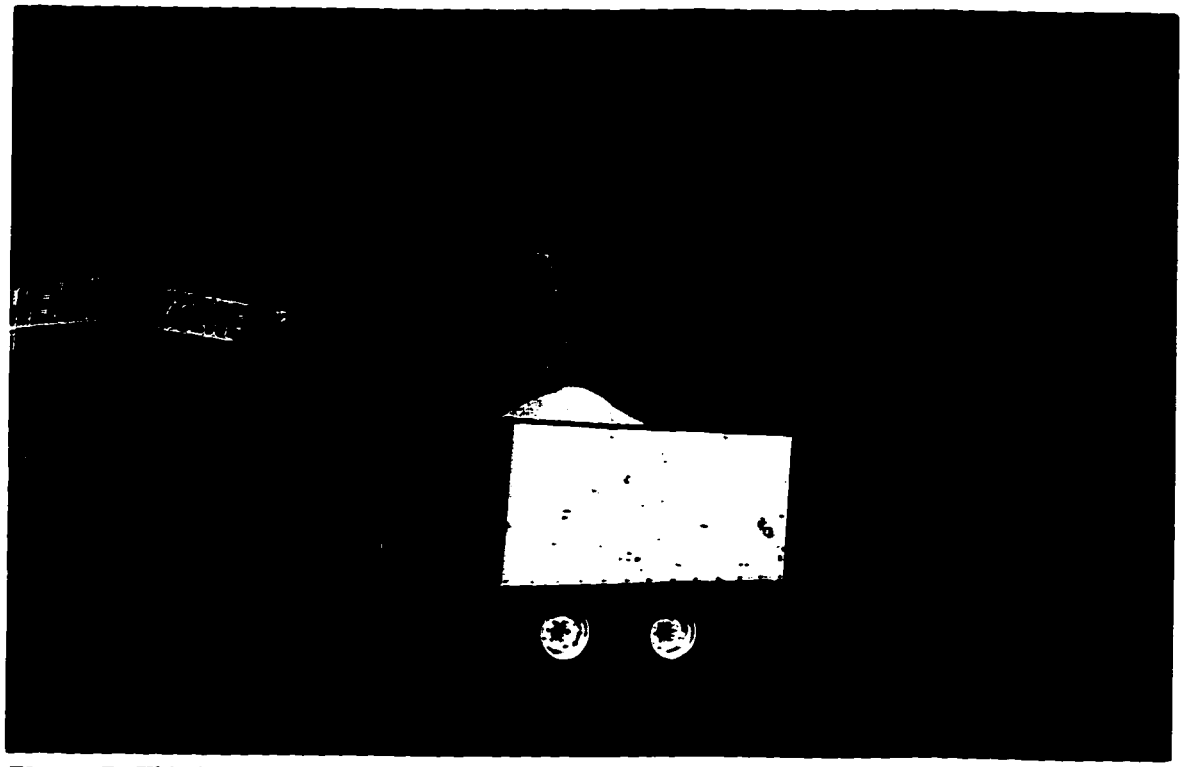
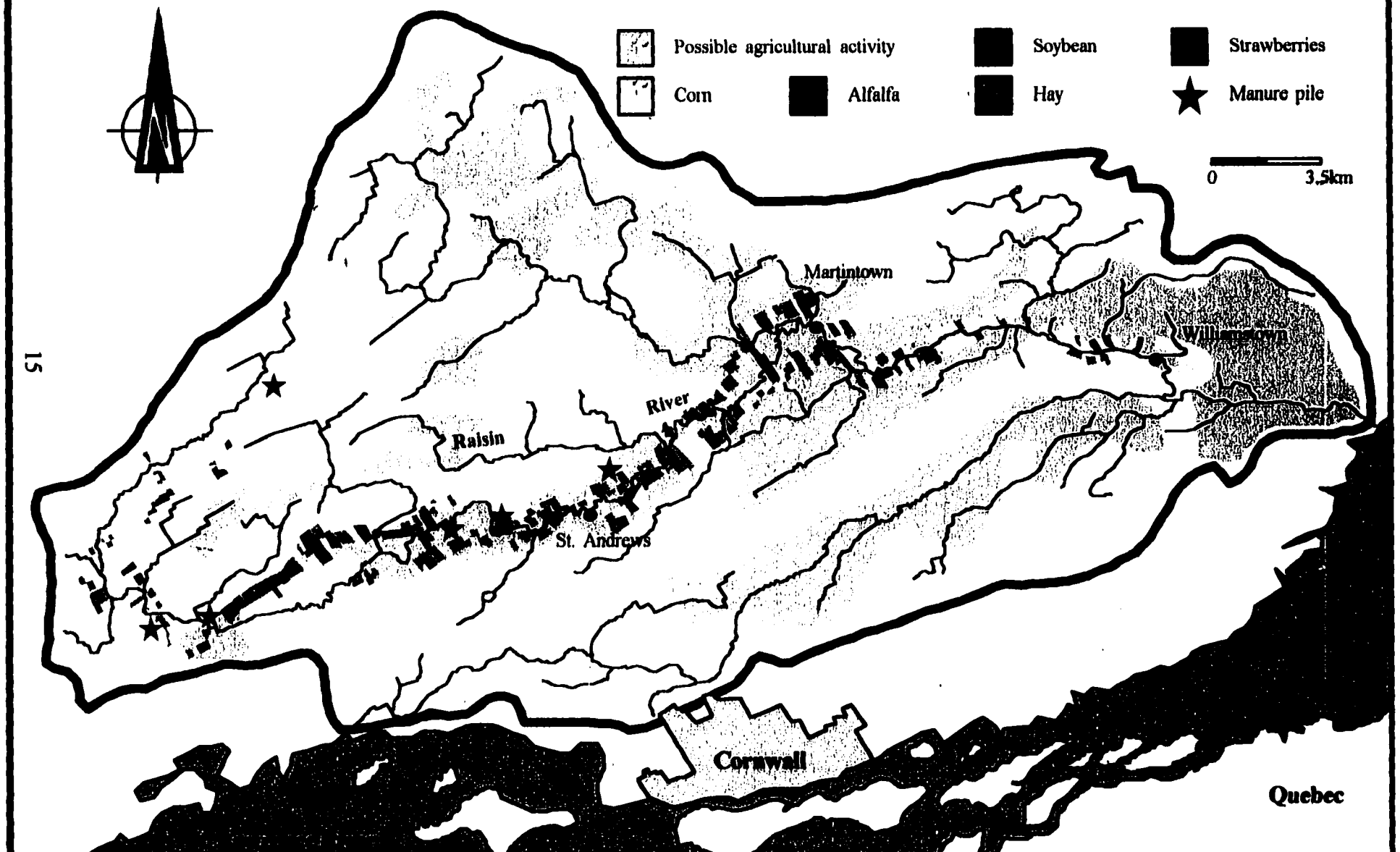


Plate 1-7. This field, which has been tile drained (Plate 1-6), allows farmers to apply nitrogen fertilizers and plant crops earlier in the spring (MacGillivrays Bridge; site G7F; April 26, 1994).

Plate 1-8. The spreading of manure is one way to increase soil fertility at the possible expense of groundwater quality (1 km north of Apple Hill, highway 20; April 26, 1994).

Plate 1-9. Farmer getting ready to apply herbicide Primextra Light on field T3F (Beaver Creek; May 30, 1995).

Figure 1.5. Extent of agricultural land use.



Nitrogen fertilizers such as manure and powdered forms are applied in late April to stimulate microorganic growth (Plate 1-7). Pesticides are occasionally applied during this period as well, but are usually sprayed when corn is at the three leaf stage (10-15 cm high) during the end of May or beginning of June.

Crop rotation is a common practice where every other year, a different crop is planted and harvested on a given field. However, this is not always the case since most farmers in the area rely on corn as the principal livestock feed. Given the restriction on the amount of farmland a farmer owns, it may be 2 or 3 years before a certain field is switched to another crop type. Thus, the potential for contaminant loading is high. Since rural communities within this agricultural watershed rely on a groundwater supply, pesticide and nitrate migration into the principal aquifers pose a potential water quality problem.

Chapter 2: General Geology

2.1 Introduction: The St. Lawrence Lowlands

The St. Lawrence Lowlands, extending from Ottawa to Quebec city, are part of the Laurentian plateau situated to the northwest of the Appalachian Mountains (Turcotte *et al.*, 1992). This plateau forms a roughly rectangular basin within the southeastern Canadian Shield and the Adirondack Mountains in northern New York State (Fig. 2.1). The basin is bordered to the northeast by the Beauharnois anticline forming an elevation of approximately 182 m above sea level, then dips to the minimum elevation of 21 m above sea level towards the center of the axis at the mouth of the Ottawa River. Continuing on a southerly trend along the Beauharnois anticline, the basin rises progressively to 76 m, then abruptly to 182 m cresting on the other side of the St. Lawrence River into the Adirondack Mountains. The basin rises constantly from its 21 m minimum at the middle of the Beauharnois anticline to a maximum elevation of 152 m above sea level in the west (Wilson, 1946).

The basin can be divided geologically into two well defined zones: i) A Paleozoic bedrock sequence composed mainly of Ordovician (440-505 Ma) limestone overlying the Precambrian basement; and ii) Overlying Quaternary deposits composed mainly of glacial tills, peat, clay, silt, and sand.

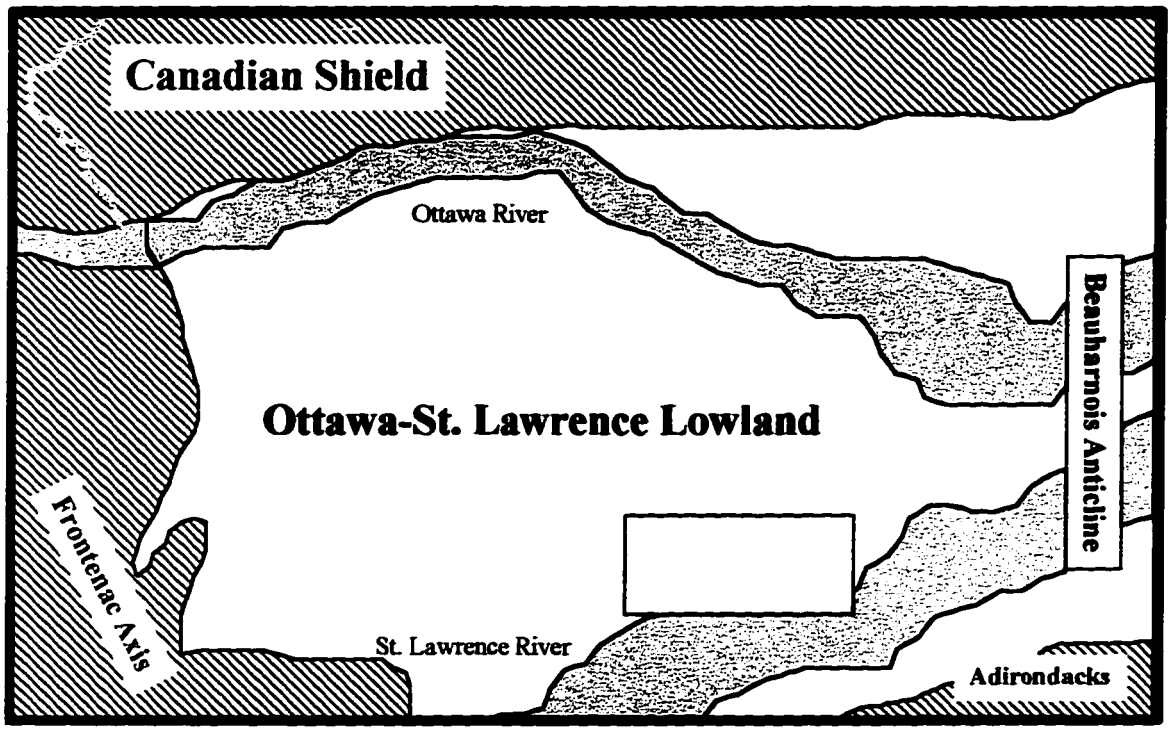


Figure 2.1. The Ottawa-St. Lawrence Lowland depicting the rectangular shape of the basin (modified from Wilson, 1946). Yellow box represents mapped surficial geology (see Figure 2.4).

2.2 Bedrock Geology

Figure 2.2 depicts the bedrock geology of the Raisin River watershed. Figure 2.3 displays a stratigraphic section of the bedrock units encountered at depth. The reader is referred to these figures when describing the various bedrock units of the study area.

2.2.1 Beekmantown Group

The Beekmantown Group is a medium to thick bedded rusty weathered limestone and blue-gray dolomite sequence. Near the top of the formation, it is commonly found to contain thin, dark shale beds, where several cavities filled with pink calcite are found throughout its entirety (Bernstein, 1992). Its thickness is variable across the St. Lawrence Lowland, however, it reaches a total thickness of 198 m to the northeast of the study area in Alexandria (Williams *et al.*, 1985).

2.2.2 Rockcliffe Formation

The Rockcliffe formation lies on top of the Oxford formation. Between these two formations lies a sharp disconformity. The Rockcliffe formation is composed of brittle light green shale and contains large sandstone pods up to 6m thick and several kilometers in length (Wilson, 1946). Its thickness is variable as with the Oxford formation, however, well borings in Alexandria display a thickness of 113 m.

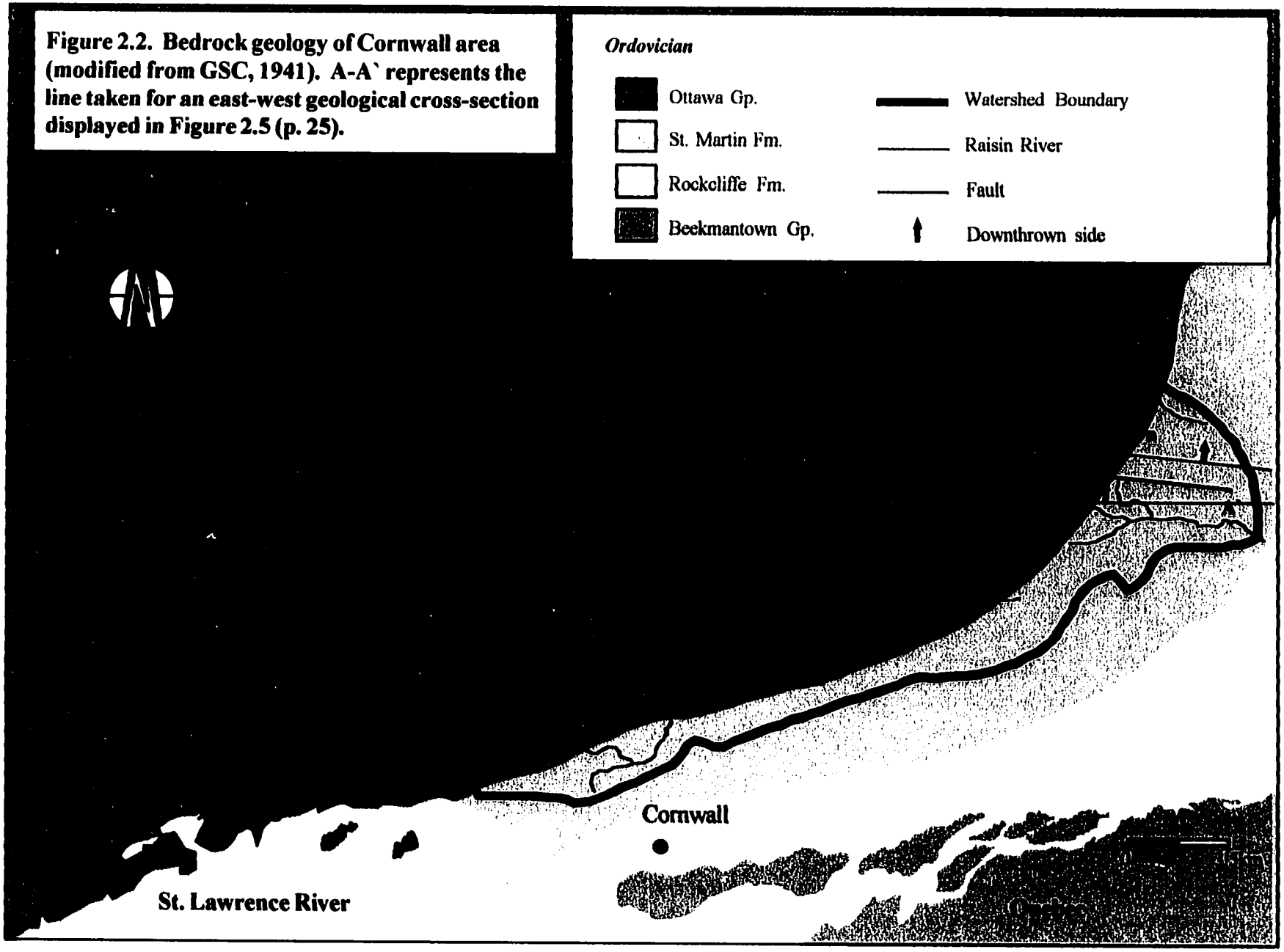


Figure 2.2. Bedrock geology of Cornwall area (modified from GSC, 1941). A-A` represents the line taken for an east-west geological cross-section displayed in Figure 2.5 (p. 25).

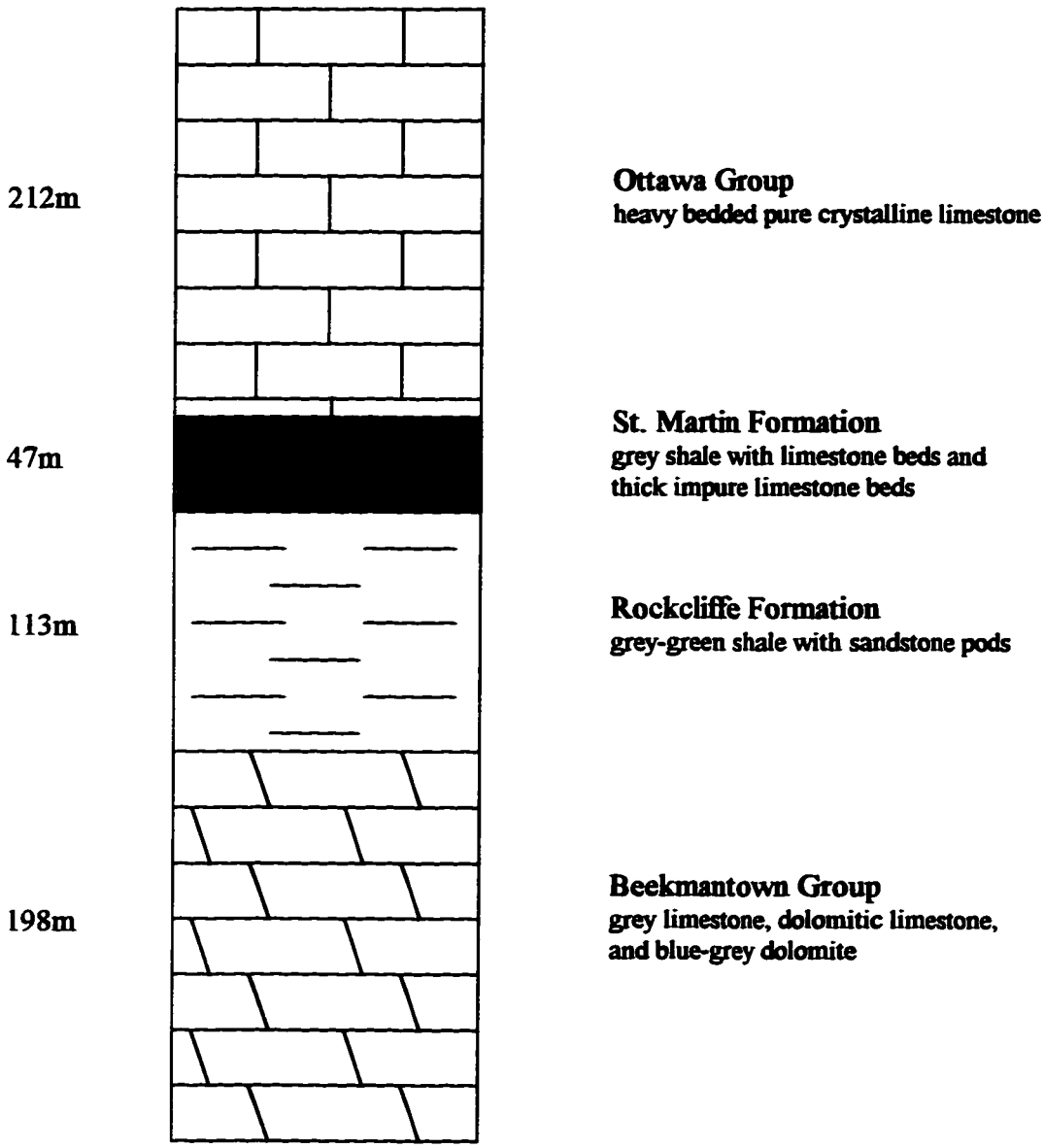


Figure 2.3 Stratigraphic column of the different bedrock units found at depth within the study area.

2.2.3 St. Martin Formation

The St. Martin formation conformably overlies the Rockcliffe formation and is unconformably overlain by the Ottawa formation. It is a thick bedded impure gray limestone sequence interspersed with gray shale beds (Wilson, 1946). The thickness of the St. Martin formation is variable but well borings in Alexandria display a thickness of 47 m (Hewitt, 1972).

2.2.4 Ottawa Group

The Ottawa Group lies unconformably over the St. Martin formation. It displays a sequence of 3 units: a basal unit consisting of sandstone, shale, dolomite, and impure limestone, a thick middle unit consisting of pure crystalline limestone, and an upper bed containing shale and impure limestone (Wilson, 1946). The thickness of the different beds of the Ottawa Group is variable across the basin however, the entire formation remains uniform displaying a thickness of 212 m (Hewitt, 1972).

2.3 Surficial Geology

Two episodes characterize the late Quaternary geological history. The first began some 80 thousand years B.P. during the Wisconsin glaciation. Here, glacial till was deposited during two separate sequences of glaciation.

The second is the deglaciation of the region with sub-aqueous sediment and marine clay, silt, and beach sands of the Champlain Sea. After complete regression of the Champlain Sea, alluvial deposits composed of sand and clay were laid down in the eastern

portion of the study area (Fig. 2.4). Capping the deposition sequence are occasional peat and marsh deposits occurring mostly in the north and north-western parts of the study area. The total thickness of surficial deposits as stated by Williams *et al.* (1985) is up to about 50 meters, however well logs and Figure 2.5 show surficial units are no more than 20 meters thick.

2.3.1 Glacial Deposits

As previously mentioned, two separate glaciations account for the till deposits observed within the St. Lawrence Lowland. Both tills account for a total thickness of 3.3 to 24 meters. The lowermost till sequence, approximately 3-15 m in thickness (Terasmae, 1965), is described as dark blue-gray clay till containing Paleozoic sedimentary pebbles oriented parallel to the north-northwest flow direction of the main ice sheet (MacCLintock & Dreimanis, 1964; Terasmae, 1965).

The uppermost till sequence, approximately 0.3-9 m in thickness (Terasmae, 1965), is described as a sandy till containing several crystalline pebbles. This till sequence covers much of the study area with the exception of the eastern portion (Fig. 2.4 & 2.5).

2.3.2 Champlain Sea Deposits

Three deposits can be associated to the Champlain Sea episode: i) the invasion phase bringing fossiliferous (*Yoldia arctica*) marine clay overlying the uppermost till sequence with silt and sand beds (Gadd, 1960); and ii) deep-sea clay described as massive to stratified clay overlying the *Yoldia* clay, commonly 15 meters in thickness (Terasmae, 1965; Gadd, 1960).

Figure 2.4. Surficial Geology of Cornwall and Surrounding Area (modified from GSC, 1965). A-A` represents the line taken for an east-west geological cross-section shown in Figure 2.5 (p. 25).

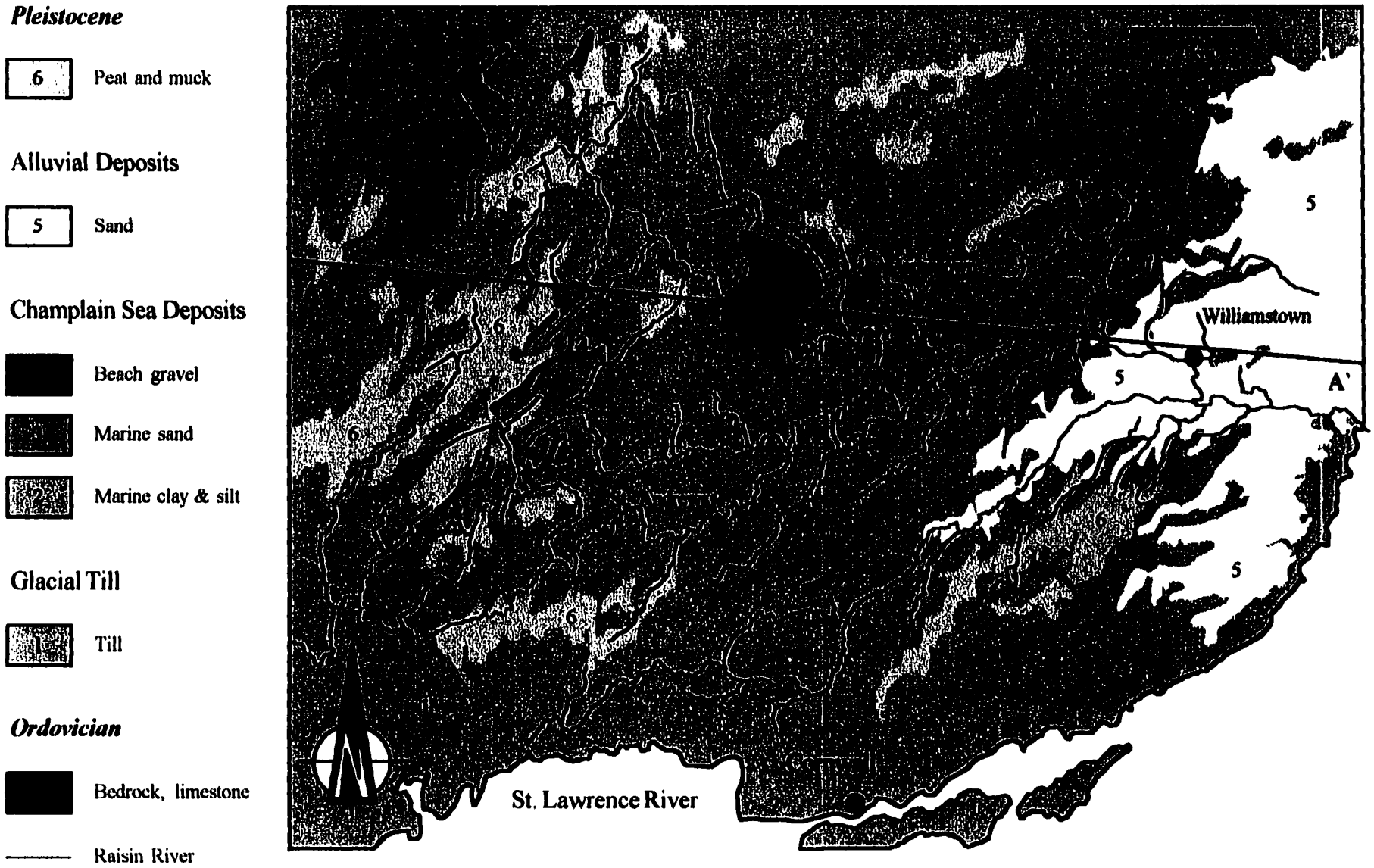
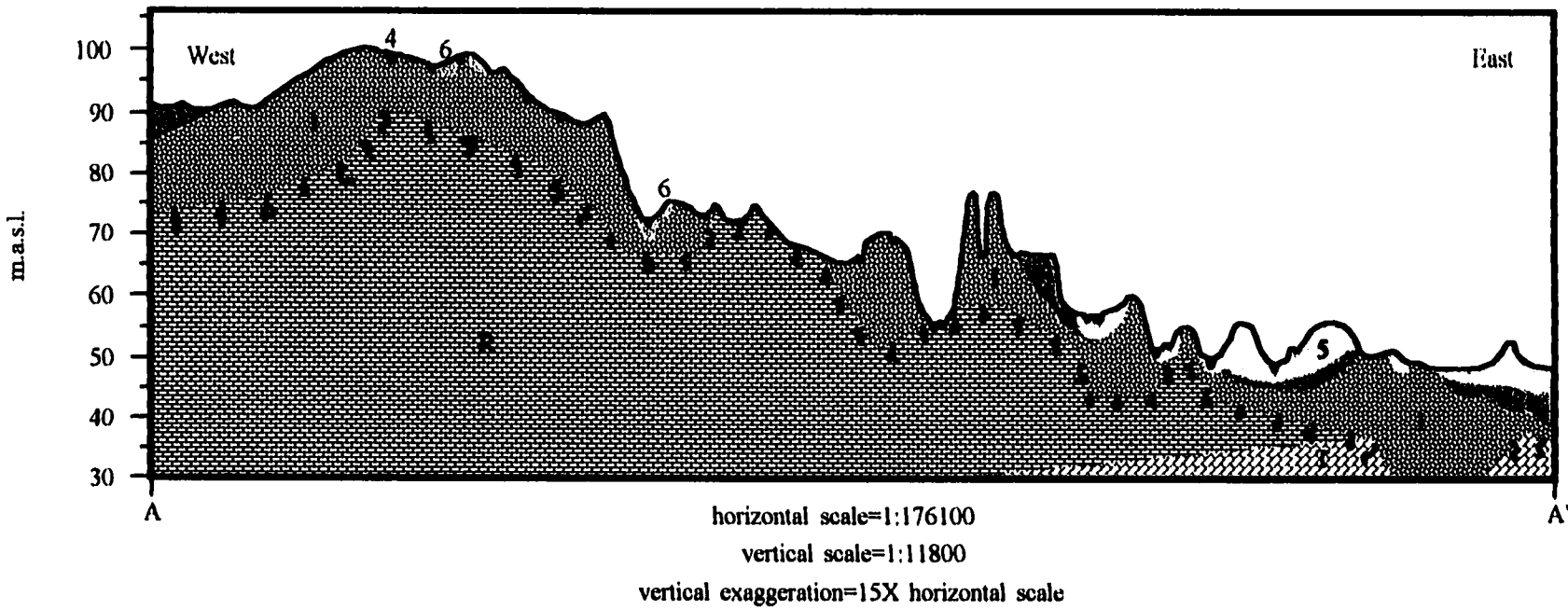


Figure 2.5. Cross-section A-A` of Raisin River Watershed.



iii) The regression phase leaving behind a mixture of beach sand and gravel with clay pockets commonly no thicker than 3 meters (Gadd, 1960).

2.3.3 Alluvial Deposits

The eastern portion of the Cornwall area has stratified sand and silty sand deposited in alluvial and estuarine settings. Total thickness ranges between 1 and 3 meters which rest upon the marine beds of the Champlain Sea phase. Plate 2-1 displays the vertical grading into this sand unit, which is found at approximately 30 cm from the surface.

2.3.4 Peat

The northwestern portion of the field area (Fig. 2.4) is highlighted by the presence of the Newington Bog, which consists of several dark peat formations. Plate 2-2 displays the occurrence of peat at Dixon Creek (site P1). The extent of these deposits ranges from a few hundred meters to several kilometers (Gadd, 1960).

Plate 2-1. Alluvial sand (brownish yellow) deposited following the regression of the Champlain Sea. This fine sand unit is commonly found at approximately 30 cm from the surface in the eastern portion of the study area (Kinloch Road; site T4F; June 1995).

Plate 2-2. Peat commonly found in the northwestern portion of the study area (Dixon Creek; site P1; November 1994).

2.4 Structural Geology

The study area is transected by two major fault lines striking sub-parallel to the Raisin and St. Lawrence Rivers (Fig. 2.2). Both these faults are steeply dipping normal faults with a total vertical displacement of 400 m (north side down) and 100 m (south side down) (Williams *et al.*, 1985). The lack of any topographic effects by these faults is attributed to the thick surficial deposit sequence.

The presence of faults is important to groundwater movement due to the higher hydraulic conductivities within these zones. Contaminant transport, an important aspect of groundwater quality, can be aided by faulting in bedrock.

Chapter 3: Aquifers

Two principal aquifers are identified in the study area. The first is the upper fractured limestone bedrock, and the second is set within the uppermost till sequence.

3.1 Bedrock Aquifer

Of the 4000 wells dug and/or drilled over the past 70 years, more than 80% tap the underlying fractured limestone. It is not specified from which limestone unit these wells tap their groundwater, however based on well records provided by well owners (Table 3.1), the Ontario Ministry of the Environment, and Figure 2.5, it is the upper part of the Ottawa Group that provides potable water.

3.1.1 Bedrock Topography

Regional groundwater flow paths within the bedrock aquifer are controlled by areas of high bedrock topography where groundwater recharge occurs. Local flow paths are controlled by small areas where topographic bedrock highs are surrounded by topographic lows. These areas would act as local groundwater recharge sites.

The bedrock topography follows much the same variation in altitude as surficial topography. As displayed in Figure 3.1, bedrock highs occur in the north-west of the study area, varying from 90 to over 100 m.a.s.l.. Bedrock elevation declines to less than 45 m.a.s.l. in the south-east.

For the most part, surficial deposits display constant thickness however, bedrock occasionally breaks the surface where little or no surficial deposits exist. Figure 2.4 shows that bedrock outcrops occasionally in the north-western section of the study area where topography is high (Fig. 3.1). At no point is bedrock exposed in the southeast. Cross-sectional observations and well logs show that occasional clay pockets act as a confining medium on a local scale. However, a large scale interpretation of the study area indicates the bedrock aquifer is unconfined.

Table 3.1 Well log information for the domestic wells studied. Information on each well was acquired by the Ontario Ministry of the Environment Water Well Data System. Data in meters.

Well	County	Township	Conc.	Lot	Type	Depth	Geology (formation depth)	Water Found	Altitude (masl)
G1	Stormont	Cornwall	9	28-29	drilled	19	loam: 0-0.3 clay: 0.3-8.5 clay-sand: 8.5-14.5 limst.-sandst: 14.5-25	23	98
G2	Stormont	Cornwall	4	3-4	dug/ drilled	26	dug: 0-6.4 gravel: 6.4-20 limst.: 20-29.4	26	83
G3	Stormont	Cornwall	6	20	dug/ drilled	17	hardpan: 0-21 limst: 21-37	35	79
G4	Stormont	Cornwall	6	9-10	drilled	21	hardpan: 0-6 sand: 6-10.9 limst:10.9-22	22	70
G5	Stormont	Cornwall	1	7	drilled	21	till/boulders: 0-9.1 gravel: 9.1-10.6 limst:10.6-21.2	18	91
G6	Stormont	Cornwall	6	33	dug/ drilled	15	till: 0-1.5 hardpan: 1.5-7.6 gravel:7.6-9.1 hardpan: 9.1-16 limst: 16-18.2	15	91
G7	Glengarry	Charlottenburgh	RRN-1	41	dug/ drilled	14.5	till: 0-1.5 clay:1.5-7.6 till: 7.6-10.3 limst: 10.3-15.2	14.5	61
G8	Glengarry	Charlottenburgh	RRN-1	45	drilled	14.5	red clay:0-5.5 hardpan: 5.5-12.1 limst: 12.1-15.2	14.5	53
G9	Glengarry	Charlottenburgh	RRS-1	18	drilled	20	clay: 0-7.3 till/boulders: 7.3-13 gravel/sand: 13-14.2 limst: 14.2-20	18	62
G10	Stormont	Cornwall City	-	-	drilled	24	-	-	51
G11	Glengarry	Kenyon	2	11	dug	8.5	-	-	91
G11 A	Glengarry	Kenyon	2	11	dug	8.5			91
G12	Stormont	Cornwall City	-	-	-	-	-	-	51

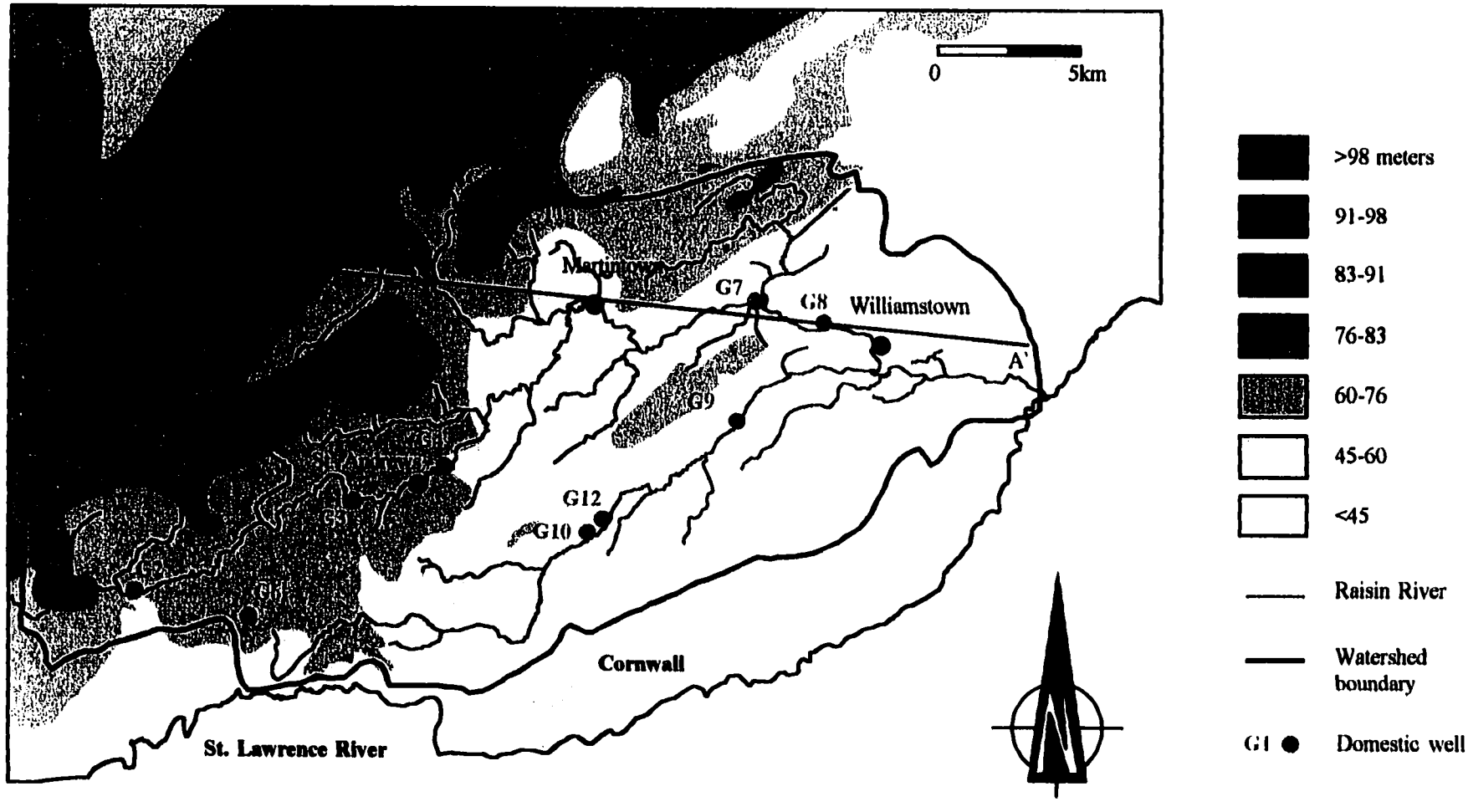


Figure 3.1. Bedrock topography of Raisin River Watershed (adapted from Gwyn *et al.*, 1974). A-A` represents the line taken for an east-west geological cross-section displayed in Fig. 2.5 (p. 25).

3.1.2 Groundwater Recharge & Flow Paths

Figure 3.2 displays the potentiometric surface (Porter, 1996) of the Raisin River watershed. Water levels are highest in the northwest sector along the watershed boundary. Levels decline southeastwardly along the Raisin River drainage basin. Regional groundwater flow is shown in Figure 3.2.

The areas of high bedrock topography and exposure are identified on Figure 3.2 as zones of recharge. Groundwater discharge would be in areas of topographic lows such as the Raisin River and in the southeast. In some areas within the Raisin River, Ottawa limestone is exposed as a result of erosion of surficial deposits (Plates 3-1 and 3-2). Thus, the Raisin River at these sites is being fed directly from groundwater discharging from the limestone. Groundwater flow and Raisin River basin hydraulics are described more fully by Porter (1996).

3.2 Surficial Aquifer

In addition to the bedrock aquifer, water can also be developed in the surficial sediments. Only 20% of the rural population derives potable water from this source. The surficial aquifer does not extend throughout the entire region because of the fine textured-low permeability nature of tills, clays, and silts. However, local aquifers found within shallow sand and gravel tills are often used for domestic supplies (Ontario Ministry of the Environment, 1991). Local contamination sources such as septic tanks, fertilizers and pesticides can thus pose a serious hazard to surficial aquifers.

Figure 3.2. Potentiometric surface of bedrock wells for Raisin River watershed (modified from Porter, 1996).

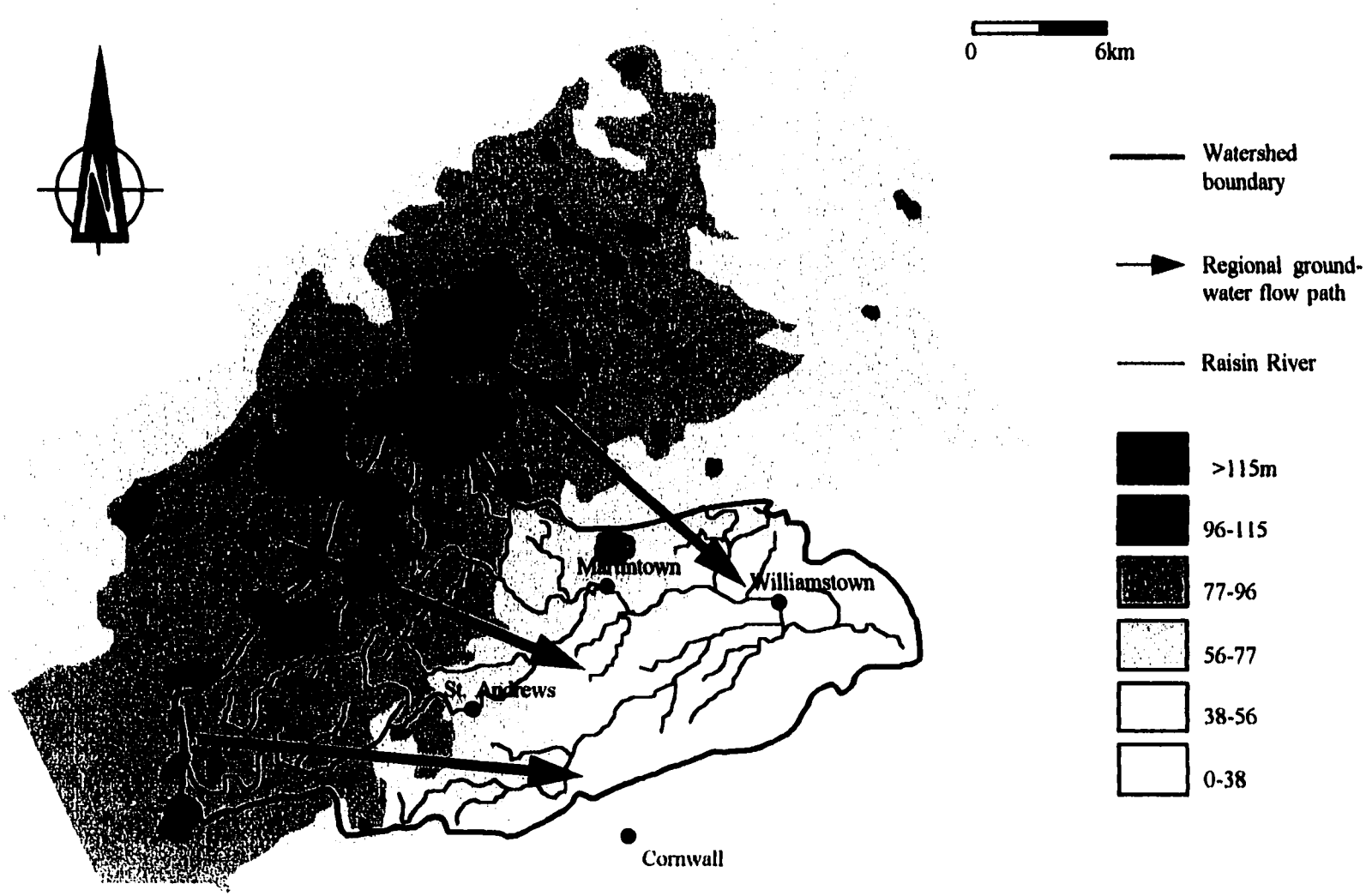


Plate 3-1. Ottawa Limestone outcropping within the Main branch of the Raisin River approximately 4 km northwest of Williamstown (October 1994).

Plate 3-2. Ottawa Limestone outcropping within the Main branch of the Raisin River (Black River Road ; site P3; October 1994).

Chapter 4: Contaminant sources and Transport to Groundwater

Within the study area, there are three possible sources of groundwater contamination. The major source comes from agricultural practices, namely pesticide spraying on crops. A second source of groundwater contamination is from domestic septic systems, from liquid manure sumps or the spraying of liquid manure on fields, or from the contribution of nitrogen and phosphate fertilizers. The third source under consideration are organics and metals coming from local landfill sites. The ability for these contaminants to reach an aquifer depends on several factors which rely on the contaminants themselves and the materials through which they pass.

4.1 Pesticides

Pesticides, including herbicides, insecticides, and fungicides, represent a potential source of groundwater contamination in the Raisin River watershed mainly because they are so widely used. Prolonged exposure to pesticides, whether it be from direct contact or ingestion from domestic groundwater, can cause an oxygen deficiency within the body, or a restraining of cholinesterase, an enzyme regulating nerve impulses, in which case continuous signals flow within the nervous system (McNeely et al., 1979; Encyclopédie de la Langue Française, 1990, p.246) . In both cases, death is the unfortunate outcome.

Several factors inhibit the movement of pesticides downwards towards an aquifer. When they are sprayed, pesticides can be lost to the atmosphere through volatilization. Surface runoff can carry a significant portion of pesticides towards surface water reservoirs. They can also be lost by plant uptake (Cheng and Koskinen, 1986), sorption onto soil particles, or degradation in the soil zone by microorganic activity (Boyce Thompson Institute, 1971). The type of soil itself plays an important role in allowing or

preventing pesticides from entering watersheds (Rudolph and Goss, 1993). Soil temperature can as well play a pivotal role in the degradation or persistence of a herbicide within a soil profile (Webster & Reimer, 1976; Korpraditskul, Korpraditskul, & Kuwatsuka, 1992). All these transport factors are controlled by the pesticide's chemico-physico parameters such as solubility (Spalding *et al.*, 1989; Smith, 1982), octanol-water partition coefficient (K_{OW}), volatility (Hartley *et al.*, 1980), and the organic carbon partition coefficient (K_{OC}). In other words, a pesticide's ionic bonding capabilities to soil particles or organic matter regulate its movement within a soil column (Johnson & Sims, 1993).

Cheng and Koskinen (1986) state that adsorption and degradation are the major processes that prevent pesticides from reaching an aquifer. Adsorption affects the total amount of pesticide available for transport by groundwater in the soil , however, it does not affect the total amount of pesticide in the soil. Degradation processes attenuate pesticide concentrations within the soil by chemical, photochemical and biochemical degradation. However, the predominant transformation process is by biochemical (microbial) degradation.

Table 4.1 lists physical properties of major pesticides used in order of decreased popularity within the study area.

The most popular pesticides applied are metolachlor, atrazine, and dicamba, all of which pose little ecological risk. Atrazine and dicamba are the least likely to pose an ecological hazard due to their high leachability. Although atrazine has a high affinity for sorbing onto soil particles containing high organic carbon, it is easily washed away when in contact with water and so has a difficult time remaining attached to soil particles. Although dicamba is similar to atrazine in terms of leachability, it is because of its high solubility in water and low sorption coefficient that restrict its ability to remain in the soil system. Metolachlor has a lower leaching potential because its fate is directly related to the amount of clay particles and organic matter present within the soil. The higher the

clay and organic matter fraction, the more impervious it becomes to leaching. Under these circumstances, metolachlor can become a problem for contaminant loading, especially if crop rotation is not enforced.

Table 4.1 Commonly used pesticides on the Raisin River watershed (from most widely used to least used) (references for pesticide properties include; Canadian Water Quality Guidelines, 1987; Spalding *et al.*, 1989; Becker *et al.*, 1991; McNeely *et al.*, 1979).

Pesticide	Use	Solubility (*mg/L*)	K_{OC}	Soil Adsorption Index (K)	Soil $T_{1/2}$ (days)	Leaching Rating	Ecological Hazard
Metolachlor	Herb.	530	200	medium	30-50	med	moderate
Atrazine	Herb	33	160	21	variable	large	slight
Dicamba	Herb	6500	2	2	14	large	moderate
Butylate	Herb	45	540	-	12	small	-
Ultim	Herb	A brand new herbicide (no research available)					
Glyphosate	Herb	12000	-	24000	47	small	slight
Bromoxynil	Herb	0.08	-	190	5	small	-
Metribuzin	Herb	1200	-	-	-	small	-
Carbaryl	Insec	40	-	200	10	small	moderate
MCPA	Herb	Insol.	-	pH dependent	14	-	high
2-4 D	Herb	540	1000	20	10	med	moderate
2-4 DB	Herb	Insol.	-	-	-	-	slight
Bentazon	Herb	2300000	35	35	20	large	-

4.1.1 Pesticide Degradation; Where do They Go?

In summary, the loss of pesticides from soil can be described as a series of contributing processes. The first process involves pesticide losses initially from application, either from volatilization, photochemical degradation, or spray drift. Volatilization can occur initially during application or once on or in the soil. Since pesticides require that they be dissolved in water for conventional spraying techniques, initial loss due to volatilization can occur as daytime temperatures reach their maximum. Pesticide spraying requires it be done during good weather conditions and not during precipitation events. After spraying, pesticides can ultimately reach their vapour point, where evaporation of the contaminant takes place and it is lost to the atmosphere (Smith,

1982; Hartley & Graham-Bryce, 1980; Wienhold *et al.*, 1993). However, volatilization can also occur within the soil subsequent to application. As soil temperatures fluctuate with the advent of daytime and nighttime, soil moistures increase during the night and decrease during the day, allowing volatilization to occur during mid-day, as water is retained on soil particles.

Photodecomposition can also take place after spraying. A pesticide's molecular structure is attacked by the ultraviolet spectrum in sunlight, chemically breaking down the pesticide molecule into different chemical agents (Matsumura, 1982; Crosby, 1978; Dodge, 1983).

A second process of pesticide loss occurs when it is in contact with soil particles. Different types of soils will either leach or adsorb pesticides. Finer soils such as clays act as adsorption sites for pesticide molecules moving downward through the soil column (Helling & Gish, 1986; Barnes *et al.*, 1992). Coarser grained soils such as sands act as a leaching medium, where they can be flushed through the soil horizon following a precipitation event (Bowman, 1988; Di Muccio *et al.*, 1990). Also, as soil moisture increases overnight, pesticides are able to slowly migrate further into the soil column, eventually reaching the groundwater table or being discharged into a fluviatile environment (Walker & Zimdahl, 1981). Any residue remaining at or a few centimeters below the surface is either attacked photochemically or volatilized.

The final process of pesticide loss also occurs in the soil medium. This involves two methods of removal. The first includes diffusion of the pesticide molecule within soil aggregates and soil grains (Gamble, 1994; Gamble & Ismaily, 1991). The longer the agent is in contact with the soil, the more it diffuses to the interior pores of individual soil aggregates and soil grains. Although this is not a method of degradation, the pesticide molecule will be released from the interior walls of a soil grain more slowly than from the surrounding walls when leaching occurs.

The second method of residue loss within the soil system is through biodegradation. Soil microorganisms act in two ways, the first being a retardation factor of the advancing pesticide-solute front (Knaber *et al.*, 1991; Johnson & Sims, 1993; Payà-Pérez *et al.*, 1992; Harrod *et al.*, 1991; Weber & Swain, 1993). Microorganisms retard pesticides from advancing deeper within the soil column by either binding themselves to the pesticide molecule or by destroying the molecule indirectly with regards to the enzymes present as a result of microbial activity. The second manner by which pesticides are obstructred is through the direct destruction of the molecule as microorganisms free enzymes to break down the residue, either totally or partially, and use it as a source of nutrients (Alexander, 1980; Matsumura, 1982). This fuels the microbial population and enhances the destruction of the residue. The degradation occurs within the first few centimeters of the soil horizon, since the microorganisms that destroy the molecule need oxygen to survive. So long as residues exist in the aerobic zone, degradation is the likely outcome. However, if an agent is able to reach deeper anoxic levels within the soil horizon, its chances of survival are greatly enhanced. The outcome is a possible contamination of the groundwater table, eventually reaching wells, and possibly reaching fluviatile systems. In the case where fields are lined with a tile drainage system, the chances of pesticides reaching an aquifer are limited. However, there is a direct contribution of tile drainage water into streams which lead into rivers, subsequently contaminating the ecosystem.

4.2 Heavy Metals

In an agricultural setting, metals such as copper, molybdenum, zinc, chromium, and magnesium are present within pesticides, fertilizers, and animal manures applied to crops (Gamble *et al.*, 1994; McNeely *et al.*, 1979; Domenico & Schwartz, 1990). Landfill sites are also contributors of heavy metals, leaching cadmium, lead, zinc, and aluminum from domestic waste in the form of leachate. The mobility of heavy metals is greatly

affected by i) complexation with other ions, ii) sorption onto the soil medium, iii) redox conditions (Freeze & Cherry, 1979), and iv) intraparticle diffusion within soil grains (Lam *et al.*, 1995).

Complexation involves metals (cations) that combine with anion ligands such as CO_3^{2-}, NO_3^-, SO_4^{2-}, and HCO_3^-, and organic ligands in solution to form ionic compounds. Under this scenario, the mobility of complexes increases and this facilitates the transport of metals within the aqueous phase (Domenico & Schwartz, 1990).

The oxidation-reduction potential of the aqueous phase also influences whether metals will complex with anions as the metal's oxidation state is changed. For example, in a sulfur system, sulfur can exist as SO_4^{2-}, H_2S, HS^-, S^{2-}, and other intermediary species. Under reducing conditions H_2S, HS^-, and S^{2-} dominate, whereas under oxidizing conditions the sulphate ion (SO_4^{2-}) is the predominant species. When oxidizing conditions prevail, there are no solubility constraints present which can account for the removal of metals from solution. Thus, sulphur concentrations in solution can be quite high. However, in anoxic conditions the sulphate ion loses its oxygen and tends to bind and precipitate with other metals in solution thus reducing the metal concentration in solution (Domenico & Schwartz, 1990).

Sorption of metal ions onto soil particles occurs in two fashions: i) electrostatic interaction between clay minerals and heavy metals in the soil, and ii) chemical complexation involving the sorption of metals to hydrous manganese and iron oxides.

Electrostatic interactions are present in soil particles between charged cations and the charge existing in clay minerals. Most clay minerals have a fixed negative charge and therefore are exchanging positive charges for the charge with the lowest "magnetization" potential. When heavy metals are introduced into the system, exchange can take place where metals are incorporated into the lattice of clay minerals because they have a higher electrostatic charge than the cations they are replacing.

In soils with high hydrated manganese and iron oxide concentrations, sorption of metals by these compounds is extremely elevated. However, the pH and redox potential of the system invariably regulates the sorption of metals when in the presence of these compounds. Moderate to high pH values enhances the sorption of metals to hydrous manganese and iron oxides, and the process of desorption is highly irreversible. If the system is subjected to reduction processes, desorption of these metals occurs and their mobility is greatly increased (Clark, 1993).

In retrospect, groundwaters containing large amounts HCO_3^- and CO_3^{2-} at pHs of between 6 and 8 would tend to drive metal concentrations towards low levels simply because metals tend to chelate with dissolved inorganic carbon in neutral-oxidizing conditions. The metal species are preferentially removed from solution, often to form insoluble complexes. Freeze & Cherry (1979) state that this is the case especially if there is an absence of inorganic and organic complexing substances. In addition, at low pH and high Eh conditions, carbonate systems favour the presence of metals in solution, thereby increasing their mobility in the aqueous phase.

The adsorption of heavy metals is not only governed by the redox potential and pH of the solution, but also with respect to the clay content of a soil. Since clay minerals are involved, cation exchange can occur as the metals are transported within an aqueous phase towards the clay constituents. Clay minerals, exhibiting a negatively charged surface, attract metals such as Fe^{3+} and replace the least charged cations within the lattice with the higher charged metals. Thus, the clay content acts as a retardant for heavy metals trying to reach a watershed.

4.3 Nitrate

Nitrate contamination in groundwaters is a problem in several regions of the world. Even industrialized nations such as Canada and the United States report findings of elevated levels of nitrate in wells drilled in shallow aquifers (Kolpin *et al.*, 1994). Excessive ingestion of nitrate contaminated water can lead to the production of cancer compounds (Domenico & Schwartz, 1990) or methaemoglobinaemia in young children, a condition where iron in the blood is in the ferric state reducing the oxygen carrying capacity of blood (McNeely *et al.*, 1979; Encyclopédie de la langue française, 1990).

4.3.1 Sources of Nitrate

There are several sources of nitrate in nature, resulting from man's activities and also occurring naturally (Goss *et al.*, 1991). Most nitrate found in contamination situations occurs as a result of agricultural activities (Goodrich *et al.*, 1991), or from landfills where organic nitrogen is oxidized when mixed with other groundwater. Nitrate and ammonium based fertilizers are used to boost crop yields and are deposited directly onto soil surfaces where they are dissolved and allowed to enter the sub-surface. In the case of ammonium based fertilizers, oxidation of ammonium results in nitrification, leading to the production of NO_3^- (Freeze & Cherry, 1979). Another agricultural practice includes the spraying of liquid manure on fields, resulting in the mineralization of organic nitrogen to NO_3^- on the soil surface (Plate 1-8 and 4-1).

Liquid manure is used to enrich the soil in nutrients allowing organic material to fertilize the soil. Farmers tend to use this approach during the springtime before seeding their crops, although fall applications are not uncommon.

Plate 4-1. Liquid manure being spread in the fall of 1994 (Grants Corners, 7 km southeast of St. Andrews; Note: Raisin River is beyond treeline).

Nitrate is also present as a result of discharge of ammonium from septic systems which is oxidized during infiltration from the tile field. Wells in proximity to septic systems are potentially at great risk for groundwater contamination since the human waste contained within the system is leached directly into the saturated zone.

4.3.2 Pathways for Entering a Watershed

Nitrate is contributed to groundwater contamination either from the soil surface, within the soil zone, or from wastes that are buried within the soil serving as direct contributors (Freeze & Cherry, 1979). The main method by which nitrate is carried deeper into the soil zone is with infiltrating groundwaters during precipitation and spring melt. Soils that have been treated with fertilizers or liquid manure and exposed to precipitation allow nitrate to leach further into the subsystem. The main difference between nitrate and metals/pesticides is the mobility in the aqueous system. Nitrate is a highly soluble species and does not readily bind with other ions. Therefore, solubility constraints imposed by the geochemistry of the water does not affect the mobility of nitrate. However, the major hurdle it must circumvent is denitrification. Denitrifying bacteria present within the soil zone uses organic matter and nitrogen as nutrients to sustain its biomass. Denitrification is a process whereby nitrate is reduced according to the following equation;

$$CH_2O + NO_3^- \Rightarrow N_2(g) + HCO_3^- + H^+ + H_2O$$

In the above equation, organic matter (CH_2O) fuels itself by reducing the nitrate (NO_3^-) present in manures, sewage waste, and fertilizers, producing byproducts including nitrogen, bicarbonate, hydrogen, and water. Thus, the presence of organic matter in the soil horizon combined with large amounts of nitrate sustains the denitrification process. However, denitrification is inhibited when the system contains some component of

oxygen. This factor greatly enhances the ability for nitrate to reach the groundwater table. Once in groundwater, denitrification is still possible given the right conditions. Groundwater containing limited amounts of dissolved oxygen, hence low Eh, subject nitrate ions to reduction, forming either N_2O or N_2 (Freeze & Cherry, 1979).

4.3.3 Synthesis of Nitrate Contamination

Nitrate originates from agricultural fertilizers, liquid manure spreading, leaky septic systems, and landfill leachates. In groundwater, nitrate levels can be attenuated by possible denitrification which requires an organic carbon source and anoxic conditions. Fertilizers and liquid manure are deposited directly onto the oxygenated soil surface where they experience nitrification as they enter the first few centimeters of the subsurface. Nitrate is a highly soluble and mobile anion. It is easily carried to depth by infiltrating surface waters and follows the same pathway as pesticides, although pesticides are more easily constrained by factors such as adsorption and decay by microbial activity.

The ability for nitrate to reach deep wells is substantially reduced due to denitrification. Thus, shallow dug wells are more susceptible to nitrate contamination than deep drilled wells (Rudolph & Goss, 1993; Sievers & Fulhage, 1992; Kolpin *et al.*, 1991).

Sands and gravels would tend to be highly susceptible to groundwater contamination from nitrate since these soils tend to have higher permeabilities, higher hydraulic conductivities, and reduced bulk densities (Spalding *et al.*, 1989; Rudolph & Goss, 1993). Soils that are fine grained such as silts and clays incorporate higher bulk densities, higher compaction, and lower hydraulic conductivities which reduces the rate of groundwater flow and aids denitrification.

Chapter 5: Methodology, Sample Analysis, & Presentation of Results

5.1 Site Selection & Sampling Protocol

Figure 5.1 displays the thesis area with selected domestic well, tile drain, and piezometric sampling sites. Domestic wells were selected according to local topography, spatial distribution, and proximity to cultivated fields. Thus, thirteen wells were selected for this study, all more or less evenly distributed throughout the watershed. Five tile drainage sites and four mini-piezometer sites were selected within the Raisin River (Plate 5-1). Four of the five tile drainage sites were selected for fields with crops requiring pesticide applications (Plate 5-2, 5-3, 5-4).

The field period for this project started on May 7th, 1994 and ended on June 13th, 1995, lasting a little over one year. During this time, groundwater was collected at two week intervals from May 7th, 1994 until September 23rd, 1994. From October 14th, 1994 until June 13th, 1995, groundwater was collected at one month intervals on the 15th ($\pm$ 3 days) of each month. Domestic well waters were collected from the homeowners tap after letting the water run for at least 5 minutes. Sites G6 and G9 had water softeners connected to the tap in the basement.

Tile drainage effluent was not always flowing, and so was sampled less frequently.

Figure 5.1. Domestic well, piezometre, and tile drainage sampling locations.

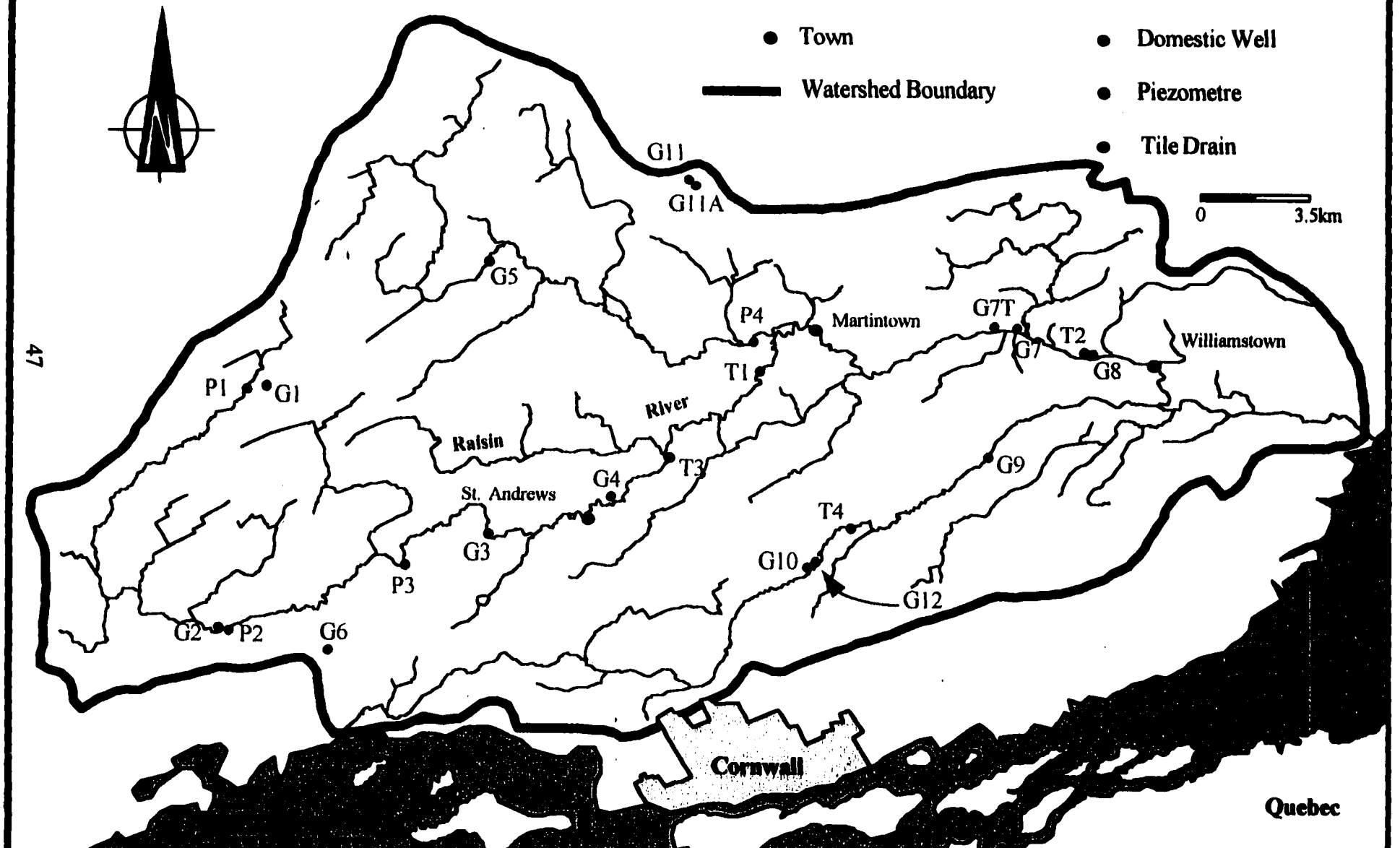


Plate 5-1. Piezometers set within the Raisin River at site P4 (November 1994).

Plate 5-2. Tile drainage effluent flowing into a creek. Raisin River is approximately 100 meters behind photo (site T2; May 7, 1994).

Plate 5-3. Groundwater sampling of tile drain T4 in November 1994. Note cornfield above.

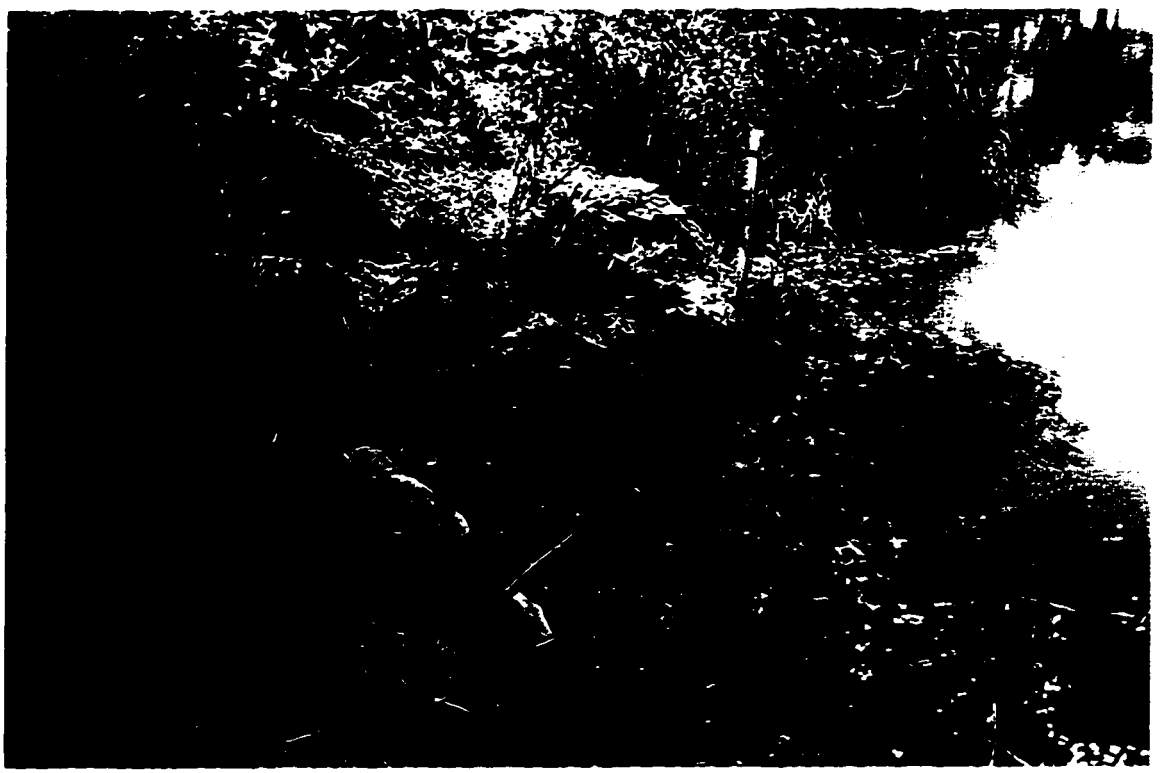


Plate 5-4. Tile drainage effluent flowing from site T4 on June 13, 1995. Note Raisin River at right-hand edge of photo.

5.2 Field Measurements

Certain physical parameters were measured in the field during sample collection. These included pH, temperature, conductivity, alkalinity, and the domestic well's water level.

5.2.1 pH & Temperature

Groundwater pH and temperature were measured in the field for the first 4 months, whereas during the following 8 months, they were measured within 24 hours. Differences in field and laboratory pH were negligible, while water temperature showed marked variation. Groundwater pH and temperature were measured using a Hach pH meter with potassium chloride (KCl) electrolyte cartridges calibrated with Hach pH 4, 7 and 10 buffer solutions. For samples measured in the field, the pH meter was calibrated with pH buffer solutions at 4^0C, representing approximate groundwater temperature. Samples brought back to the laboratory were refrigerated along with the buffer solutions. Weekly and monthly results for groundwater temperature and pH are displayed in *Appendix A1.1* and *A1.2*, respectively.

5.2.2 Alkalinity

Alkalinity was measured in the field during the first four months of field work, but was then measured in the laboratory during the remaining 8 months following collection. Alkalinity was measured using a Hach alkalinity kit with 1.6N H_2SO_4 cartridges provided with the kit. When these cartridges were empty, a 1.925N titrating sulphuric acid solution

was prepared. *Appendix A2.1* summarizes the steps taken in preparing the titrating sulphuric acid, as well as the results of the acid titration. *Appendix A2.2* gives the results of the bicarbonate standard check. Alkalinity values are given in *Appendix A2.3.*

5.2.3 Conductivity

Conductivity measurements were performed using a Hach model 44600 conductivity meter. Calibration was performed using a 1000 *mg/L* sodium chloride solution with 1.990 *ms/cm.* The probe was then rinsed thoroughly with distilled and sample water, immersed in a beaker containing sample water, and a measurement was noted. The probe was thoroughly rinsed with deionized water between sample measurements to prevent cross-contamination. Results are given in *Appendix A3.*

5.2.4 Water Level

At domestic well sites, providing the owner had an accessible well, the water level was measured before turning on the tap for sample collection. This ensured that the water level was the static level, since turning on the owner's tap would start the pump and lower the water level in the well. A Solinst model 101 water level tape and P4 probe were used for water level measurements. *Appendix A4* displays results obtained for 7 of the 13 wells.

5.3 Geochemical Analysis of Water

Groundwater samples were analyzed for standard chemistry parameters including major cations, anions, and heavy metals. Analyses were performed at the University of Ottawa's geochemistry laboratory, room 211, Marion building, under the supervision of John Loop.

The sampling of groundwaters prior to analysis included filtering before sealing the waters in 30 ml high density polyethylene bottles. The filtration mechanism consisted of a Sartorius SM16517E filter cap attached to a 60 cc syringe. A Sartorius cellulose acetate membrane filter with a 0.45 μm pore opening was inserted into the filter cap and the sample water was filtered accordingly. Between filtered samples, the filter paper was discarded, the filter cap and syringe were rinsed three times with deionized water, and then purged with sample water to prevent cross-contamination. Latex rubber gloves were worn to prevent further cross-contamination. The sample bottle was rinsed with sample water before being filled.

5.3.1 Anions

Groundwaters were collected for the analysis of major anions, including fluoride (F^-), bromide (Br^-), chloride (Cl^-), nitrate (NO_3^-), sulphate (SO_4^{2-}), nitrite (NO_2^-), and hypophosphate (HPO_4^{2-}).

The analysis for major anions was performed by high pressure liquid chromatography (HPLC) using a Dionex DX-100 ion chromatography system accompanied by a Dionex AS40 automated sampler, and a 2.7 mM $NaCO_3$/0.3 mM

$NaHCO_3$ eluent solution (Dionex, 1992). Sample analysis results are given in *Appendix B1*.

5.3.2 Cations/Heavy Metals

Groundwaters were collected for the analysis of major cations including, Ca^{2+}, Mg^{2+}, K^{+}, and Na^{+}, minor elements including Al^{3+}, Fe^{2+}, and Ba^{2+}, and trace metals including Be, Cd, Cr, Cu, Co, Mo, Ni, Pb, and Zn. Sample bottles were rinsed with filtered sample water and filled below the brim. Three drops of 50/50 nitric acid were then added to prevent chelation and precipitation of metals.

The analysis of cations and metals was performed using a sequentially scanning Thermo Jarrell Ash Atom Scan 25 inductively coupled plasma atomic emission spectrometer (ICP-AES). Results are given in *Appendix B2* and *B3*, respectively.

5.4 Stable Isotope Analysis

Groundwater samples were analyzed by gas-source mass spectrometry for ^{2}H, ^{18}O, and ^{13}C contents at the Stable Isotope Laboratory in the Department of Geology, University of Ottawa.

5.4.1 ^{2}H and ^{18}O

Deuterium (^{2}H) and ^{18}O in groundwater were used in this study as tracers of groundwater provenance, seasonality of recharge, and recharge processes. Analysis of ^{18}O has only been performed on piezometric waters collected by Porter (1996). Sample bottles were rinsed and filled with filtered sample water, and tightly sealed to prevent evaporation and fractionation. One bottle was used for both ^{2}H and ^{18}O. The samples were refrigerated upon arrival at the lab.

The preparation involved for analysis is different for both isotopes considered here. For deuterium, 3µl of water is injected in a breakseal containing zinc (Plate 5-5) and heated to 500°C for 30 minutes. The zinc is oxidized by the oxygen in the water and hydrogen is reduced to elemental H_2 gas. *Appendix C1* summarizes the deuterium extraction method. Within two days, the hydrogen in the breakseal is analyzed using an automated gas source double collector VG 602D mass spectrometer. Results for deuterium analyses are tabulated in *Appendix C2.*

For the analysis of ^{18}O in water, groundwaters are equilibrated with CO_2 at 25°C for 6 hours. Fractionation occurs between the CO_2 and the water with an equilibrium fractionation factor of 1.0412 at 25°C (Friedman & O'Neal, 1977). Results for ^{18}O are given in *Appendix C2.*

5.4.2 Dissolved Inorganic Carbon (^{13}C)

Groundwater samples were collected for dissolved inorganic carbon to be used as a groundwater tracer as well. The sampling technique involved filtering 30 ml of sample water and killing bacterial activity with mercuric chloride ($HgCl_2$).

Plate 5-5. Deuterium extraction line with breakseals containing zinc immersed in liquid nitrogen (styrofoam cups).

Plate 5-6. Sampling of deep sediment using a 1.5 meter long hollow pole pushed into the riverbed (site G9S; November 30, 1994).

The extraction procedure for ^{13}C involves reacting 85% phosphoric acid with sample water to generate CO_2. The carbon dioxide is then cryogenically purified, frozen in a breakseal, then analyzed on a triple collector VG SIRA 12 gas source mass spectrometer. The extraction procedure is presented in greater detail in *Appendix C3*. DIC results are given in *Appendix C4*.

5.5 Dissolved Organic Carbon

Groundwater samples were collected for the analysis of dissolved organic carbon. Approximately 20 ml of sample water was filtered into a 25 ml clear glass bottle. The sample was then acidified with 2 drops of 50% hydrochloric acid to prevent loss of DOC. Tin foil was placed under the cap. The bottle was then sealed, labeled, and sent to Accutest Laboratories in Ottawa for analysis. The analysis of DOC was performed on a Astro 2001 total organic carbon autoanalyzer. Results are displayed in *Appendix D*.

5.6 Pesticides

Since the study area is situated within an intensely agriculturally cultivated area, the presence or absence of pesticides has been included within groundwater quality parameters. However, an additional factor related to this work is the fate of pesticides once they are sprayed on crops. Therefore, four kinds of samples have been collected to determine levels in groundwater, and to determine the fate of pesticides applied to fields. These include;

i) Soils taken from fields sprayed with pesticides in close proximity to the Raisin River
ii) Sediment samples taken from the riverbed adjacent to sampled fields

iii) Domestic well samples in proximity to pesticide applied fields
iv) Tile drainage effluent collected for soil sampled fields

5.6.1 Soil Sampling

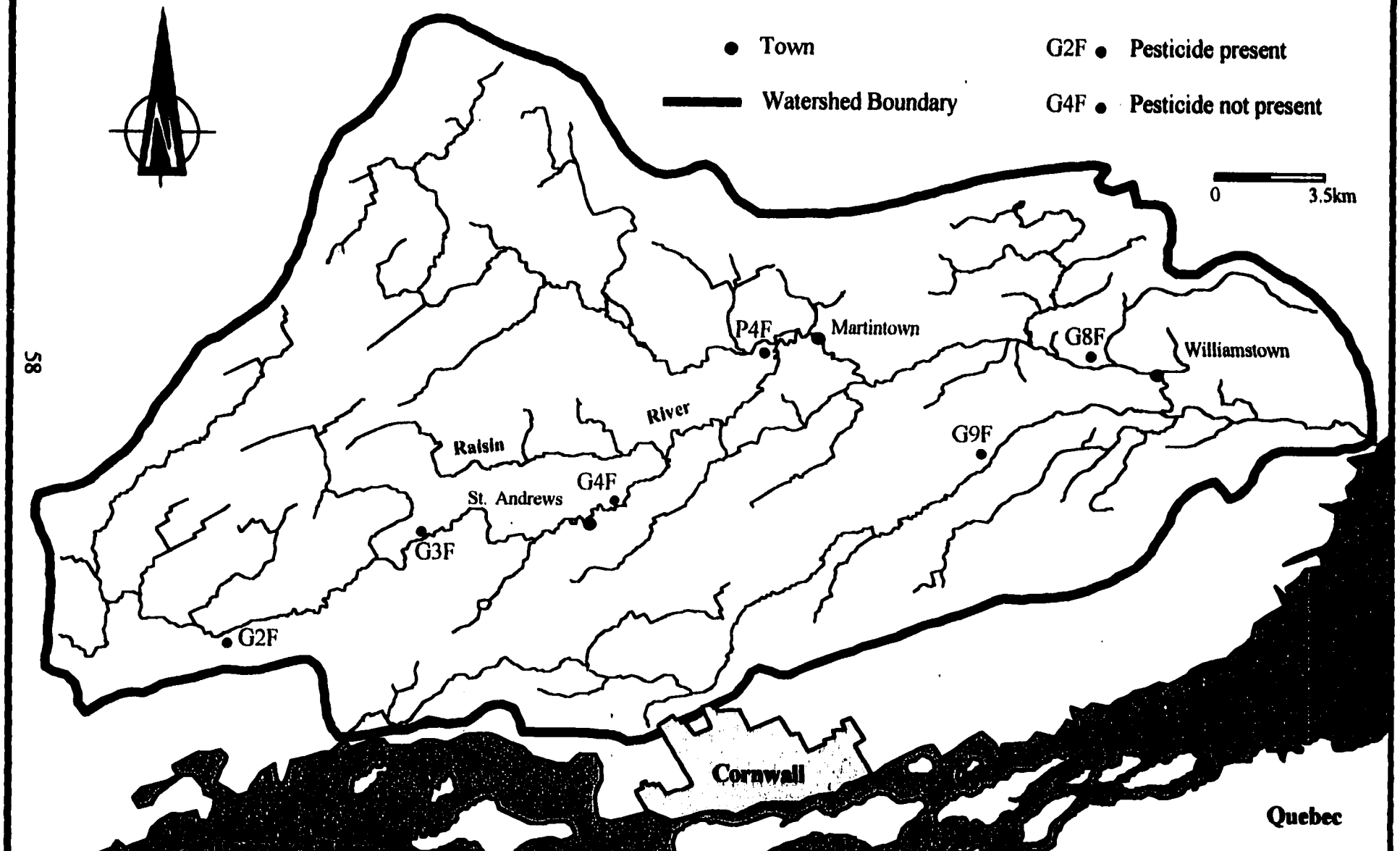
Three soil sampling trips were performed for fields in and around the Raisin River. The procedure involved getting permission from the local farmer, sampling the field at four different localities (three corners and once in the middle) at a depth of 30 cm using a shovel and plastic sacs (Plate 2-3). All four samples from the same field were brought back to the lab, dumped in a box and thoroughly mixed using a shovel (which was thoroughly cleaned before mixing the next sample). A sub-sample was then bottled in a 250 g mason jar, covered with tin foil, labeled, and sent to Accutest Laboratories for analysis.

The first sampling period was a preliminary round performed on November 30th, 1994 for 6 fields, P4F, G2F, G3F, G4F, G8F, and G9F (Fig. 5.2). Table 5.1 lists the pesticides applied during the spring of 1994 for each field and the time at which they were applied according to the local farmer.

Table 5.1 Pesticide application periods for the spring of 1994.

Site	Brand Name	Chemical Name	Crop	Date of Application
G2F	-	Atrazine	Corn	-
G3F	Primextra Light	Atrazine, Metolachlor	Corn	May 27
	Laddoc	Atrazine, Bentazon		June 17
G4F	Embutox	2,4-DB	Oats	July 11
G8F	-	Atrazine	Corn	June 11
G9F	Primextra Light	Atrazine, Metolachlor	Corn	May 11, June 2
	Sevin	Carbaryl		July 11
	Ambush	Permethrin		July 11
P4F	Dual	Metolachlor	Corn	June 1
	Banvel	Dicamba		June 1

Figure 5.2. Soil sampling sites for pesticides (November 30, 1994).



The second and third sampling periods were performed during the spring and summer of 1995 after herbicide application. Fields T3F, G7F, G8F, G9F1, G9F2, T4F, P4F, and G13F were sampled a few days after herbicide application (Fig. 5.3) and 1 month after application (Fig. 5.4). Field G2F was sampled before herbicide application and field P4F1 was sampled 1 month after application only. Table 5.2 summarizes the pesticides applied and the time at which they were applied for each field according to the local farmer.

Two extraction methods were used depending on the herbicide being extracted. These methods are summarized in *Appendix E1*. Once extracted, the analyte was analyzed using an Ion Varian Saturn 3 Gas Chromatograph Mass Spectrometer. Results are displayed in *Appendix E2*.

Table 5.2 Pesticide application periods for the spring of 1995.

Site	Brand Name	Chemical Name	Crop	Date of Application	Concentration
G2F	-	-	Corn	-	-
G7F	-	Atrazine	Corn	April 27	0.5kg/acre
	Dual	Metolachlor		April 27	2L/acre
G8F	Dual	Metolachlor		May 22	1L/acre
	Sencor	Metribuzin		May 22	0.2L/acre
	Lorox	Linuron		May 22	0.5L/acre
G9F1	Dual	Metolachlor	Corn	May 30	17.1L/acre
	Buctrilm	Bromoxynil		May 30	0.5L/acre
G9F2	Dual	Metolachlor	Corn	May 30	17.1L/acre
	Buctrilm	Bromoxynil		May 30	0.5L/acre
G13F	Banvel	Dicamba	Corn	June 13	1125L/acre
	Ultim	-		June 14	-
T3F	Primextra -	Atrazine, Metolachlor	Corn	April 24	3L/acre
	Light	Glyphosate_			
	Roundup	Dicamba		April 24	1L/acre
	Banvel			June 5	0.5L/acre
T4F	Primextra -	Atrazine, Metolachlor	Corn	May 23	3L/acre
	Light	Dicamba			
	Banvel			May 23	0.5L/acre
P4F	Dual	Metolachlor	Corn	June 5	1L/acre
	Banvel	Dicamba		June 5	0.5L/acre
P4F1	Banvel	Dicamba	Corn	-	-

Figure 5.3. Soil sampling sites for pesticides (June 15, 1995).

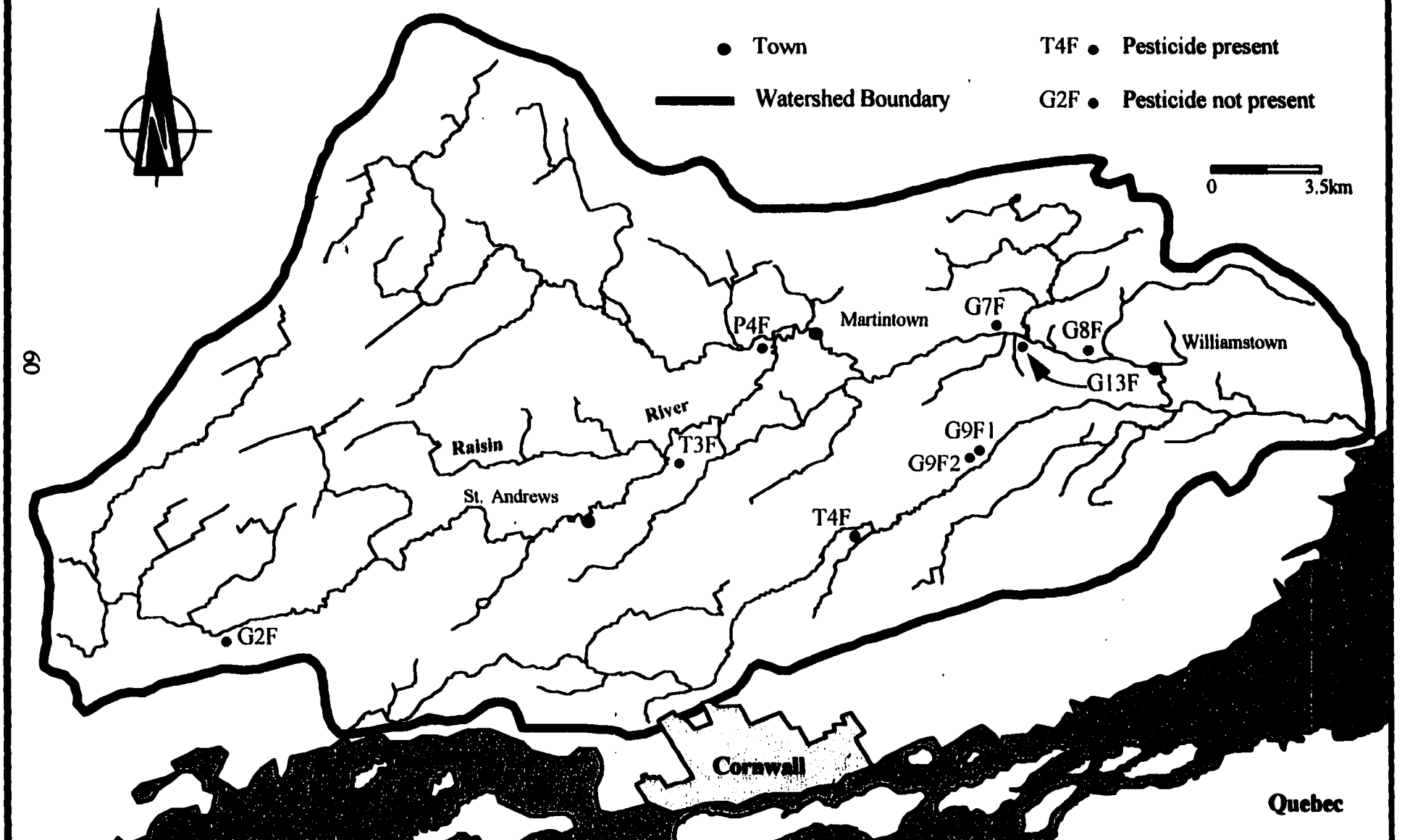
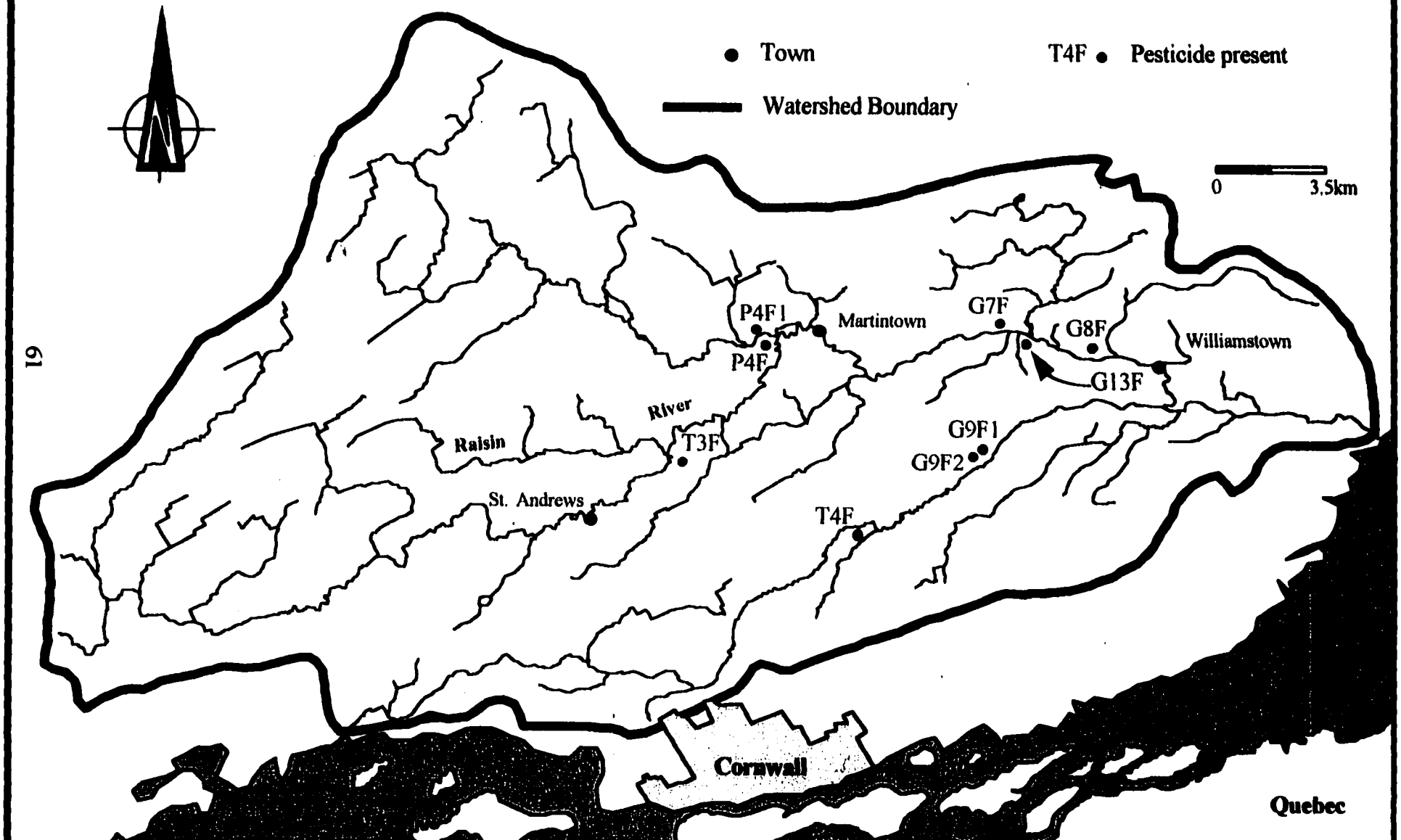


Figure 5.4. Soil sampling sites for pesticides (July 15, 1995).



5.6.2 Sediment Sampling

Sediment from the Raisin Riverbed was also collected to determine the migration of pesticides with runoff. One sampling round was performed during July 1995 for 6 sites plus 3 more for sediment just below the tile drain outlet (Fig. 5.5). Another sampling round was performed in October of 1995 for 9 sites (Fig. 5.6).

Most sites correspond with soil sample sites in fields adjacent to the Raisin River, and involved taking 4 specimens at 30 foot intervals along a section of the river for a given site. The four individual samples for one site were then mixed together, bottled in a 250ml mason jar, lined with tin foil in the cap, sealed, and sent to Accutest Laboratories for pesticide analysis. *Appendix E1* summarizes the methods used for pesticide extraction. *Appendix E3* represents analysis results for the different sites.

The July 1995 sampling session involved taking sediment cores to approximately 1 meter in depth within the riverbed (Plate 5-6, p. 55). Sites P4S and T3S represent sediment samples that were taken at a depth of 1 foot using a shovel. Deeper samples for these two sites could not be obtained due to the coarse nature of the sediment and presence of many pebbles and cobbles. Sites G13S, T4S, G2S, and G9S were sampled at a depth of approximately 1 meter using a hollow pole pushed into the sediment.

The October 1995 sampling session involved taking sediment samples from the upper 5 cm of the riverbed using a spring activated sediment sampler lowered from a bridge into the river (Plate 5-7, 5-8).

Sediment retrieved from the riverbed ranges from a silty clay (G9S, G13S, T4S), sandy silt (G2S, G15S), glacial till (T3S, P4S, G14S), to mud (G16S, G17S).

Figure 5.5. Sediment sampling sites for pesticides (July 1995).

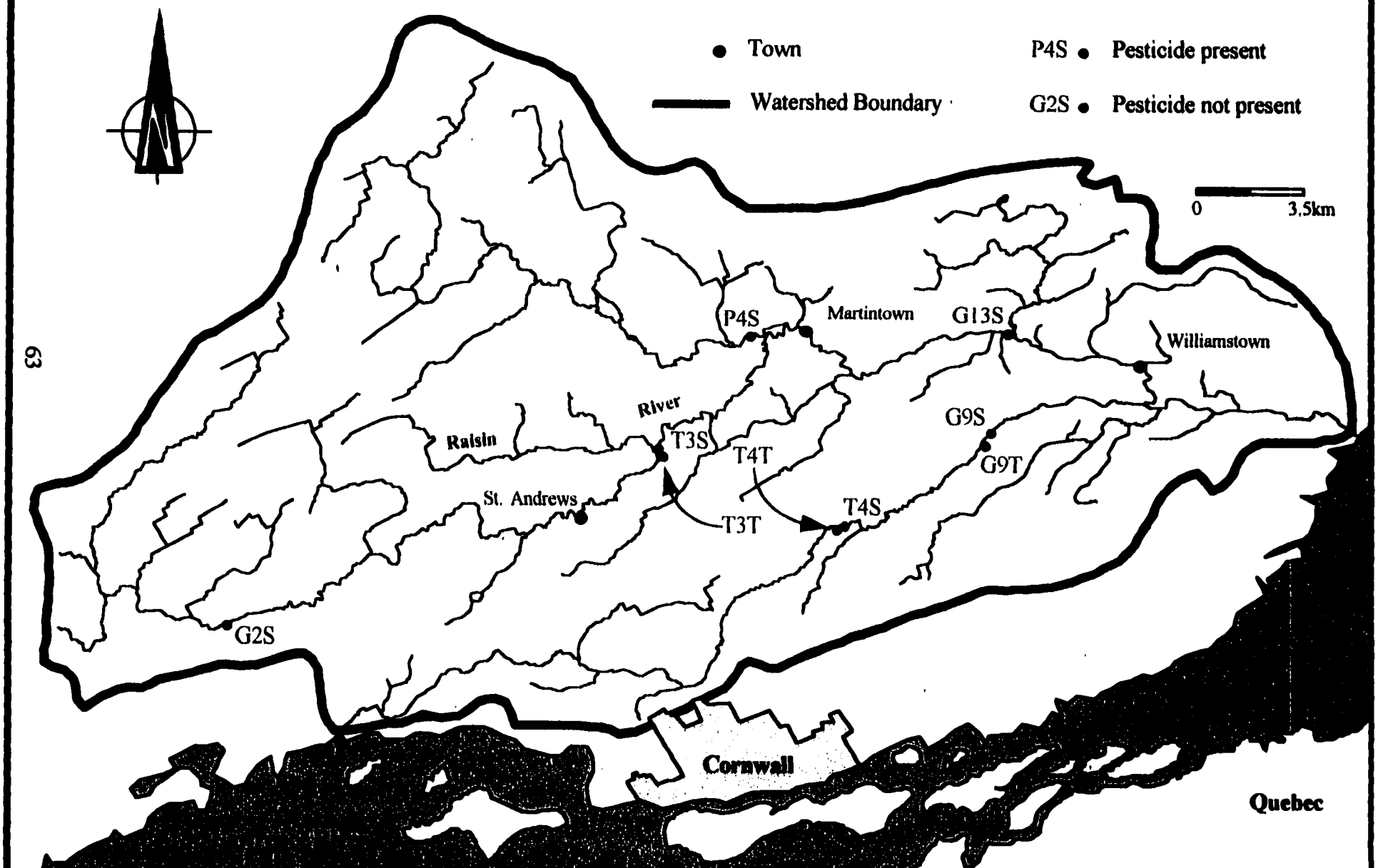


Figure 5.6. Sediment sampling sites for pesticides (October 19, 1995; surficial sediment layer)

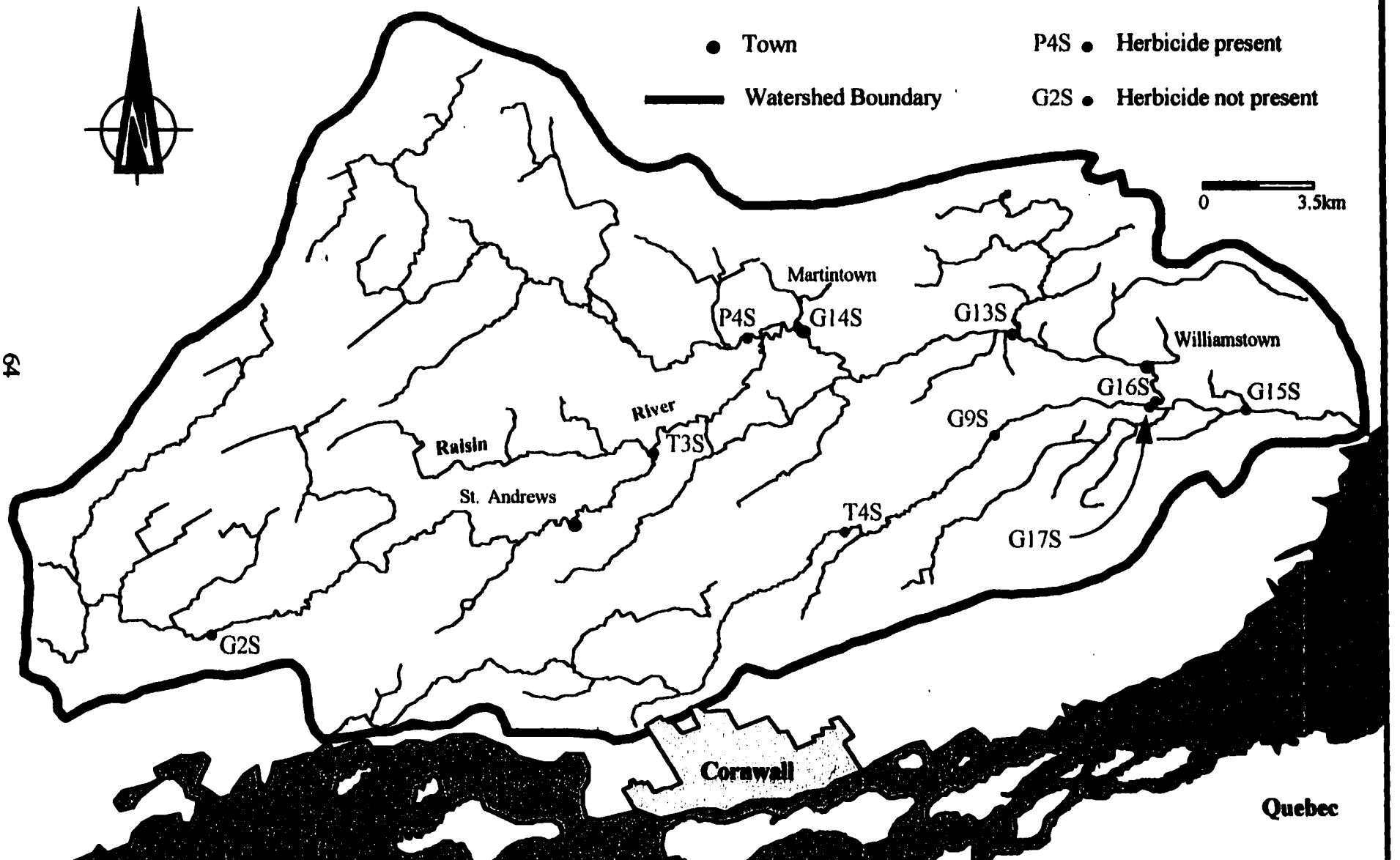


Plate 5-7. Sediment sampler with spring activated jaws.

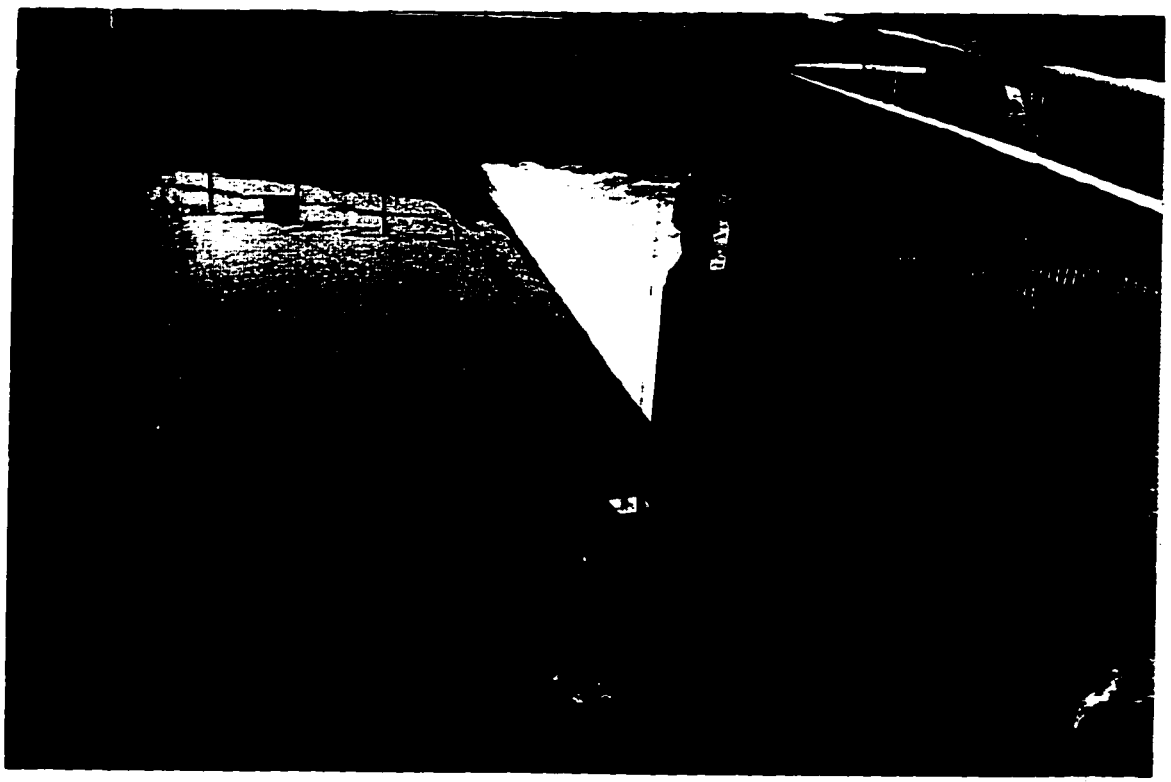


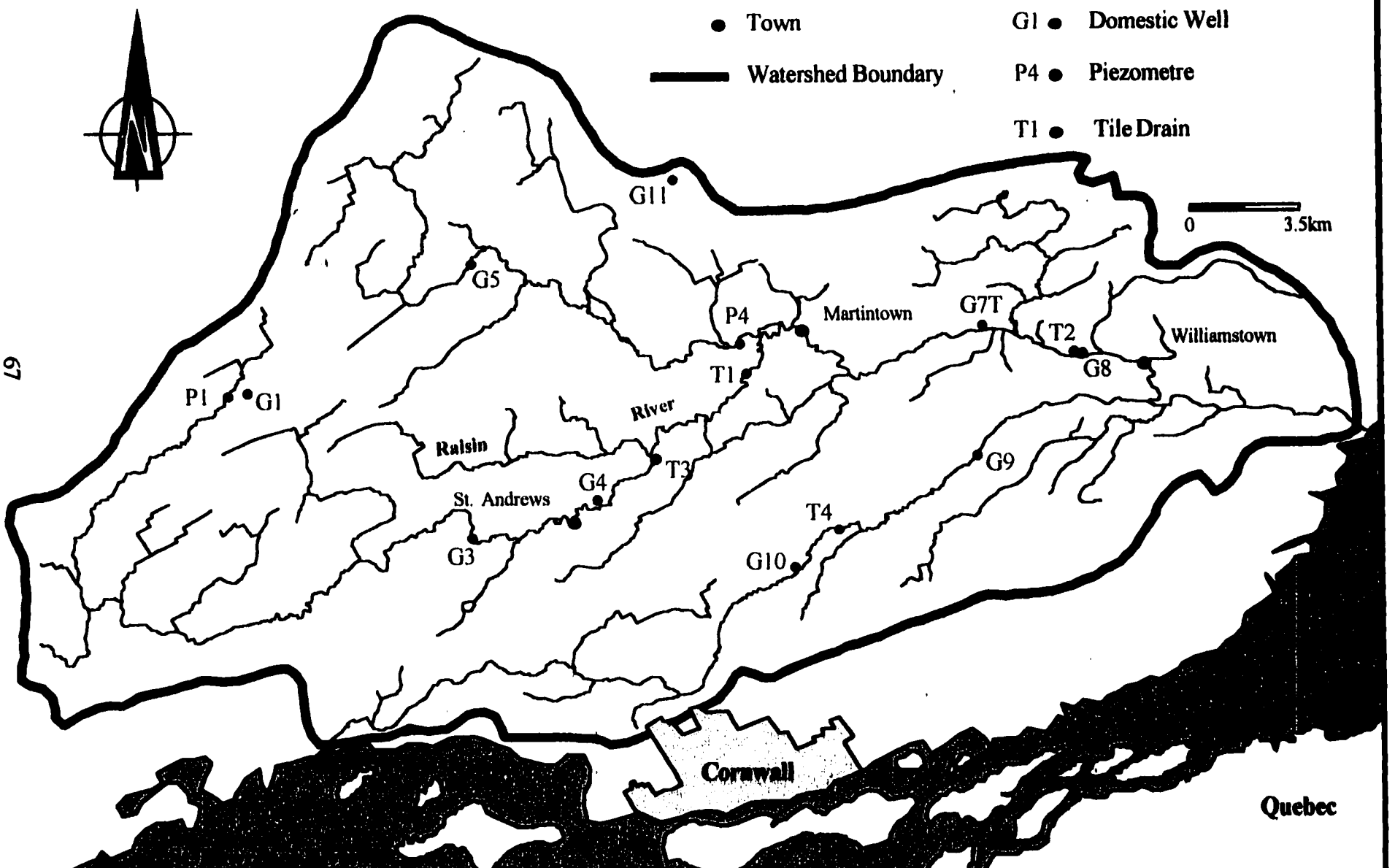
Plate 5-8. Sediment sampler being pulled from Raisin River (site G14S; October 18, 1995). Note weight at end of string. This weight is dropped down the rope triggering the release mechanism which spring the jaws closed.

5.6.3 Pesticides in Water

Groundwater quality samples within the study area were collected from domestic well waters for analysis of pesticides. In addition, the presence of tile drainage in several fields is addressed in the context of preventing pesticide migration to depth. Therefore, tile drainage effluent has also been collected.

A total of 8 domestic wells (G1, G3, G4, G5, G8, G9, G10, G11), 5 tile drains (T1, T2, T3, T4, G7T), and 2 piezometers (P1, P4) were sampled for pesticides during the spring and summer of 1994 and 1995 (Fig. 5.7). Sampling was performed using 1L amber glass bottles capped with teflon tops. The samples were preserved with mercuric chloride and stored in a large ice packed cooler to prevent herbicide degradation. Upon return to the laboratory, the samples were refrigerated until analysis. Well waters were sampled from the residents indoor tap 5 minutes after the water had been continuously run. Water samples were then extracted according to standard EPA methods 507, 525, and 625, using C_{18} teflon extraction disks prepared with methanol and analyzed on an Ion Varian Saturn 3 gas chromatograph mass spectrometer. Extraction and analysis were performed at Carleton University's Environmental Chemistry Laboratory and at Accutest Laboratories in Ottawa. Results for tile drain water and domestic well waters are tabulated in *Appendix E4* and *Appendix E5*, respectively.

Figure 5.7. Groundwater sampling locations for pesticides.



Chapter 6: Susceptibility to Groundwater Contamination

Successful rehabilitation of the St. Lawrence ecosystem involves establishing contamination sources to the seaway and performing the necessary remedial treatment. However, the substantiation of the Raisin River basin's contamination potential is necessary to any future understanding of pollution risks to the St. Lawrence River. Thus, the temporal monitoring of this watershed for water level, chemistry, and isotopic variations plays an important role in determining the pollution potential of this basin.

6.1 Water Level

Water levels in domestic wells show a seasonal response, rising during the snowmelt in April and declining over the summer of 1994 monitoring period after spring recharge (Fig. 6.1). As air temperatures decrease during the onset of fall, the result is an increase in the water table due to a decrease in evapotranspiration from the landscape.

The highest water table conditions occurred in January when a mid-winter thaw and associated rain melted most of the snow (Environmental Services, 1995). However, winter conditions returned in February 1995, resulting in a lowering of the water table. Water levels rose again in mid-March due to the spring thaw, and then declined again with the onset of summer (June-July).

A large rainfall event in late August 1994 did not generate a water level response in most bedrock wells. Average air temperature during June, July, and August is approximately 26^{0}C and cumulative rainfall up until that precipitation event indicates 200 mm of rain fell on the region. This is well below the normal 430 mm usually received during this time of year. The absence of a peak in late August could thus be a reflection of

very dry conditions where any rain is absorbed by the soil profile and evapotranspirated. However, the surficial well (site G11) shows measurable response to rainfall events in August 1994, January and the spring of 1995 (Note: surficial well values are 20 m below real values in order to fit the graph).

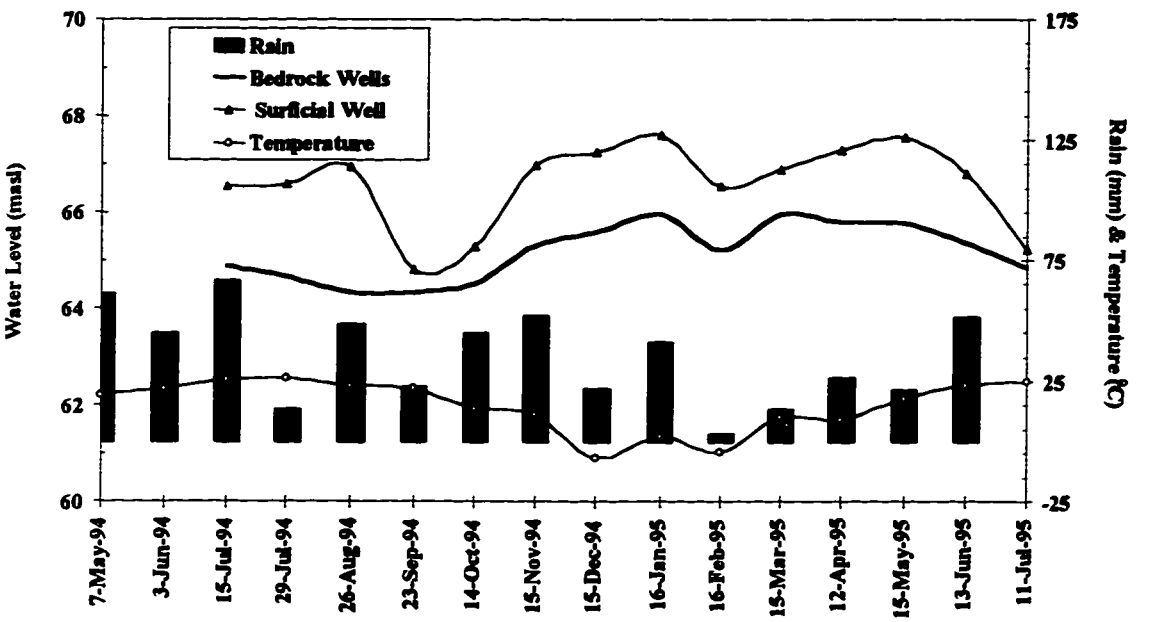


Figure 6.1. Average water level in 6 domestic wells and one surficial well with time.

Autocorrelation statistics of water level data for bedrock wells suggests a possible periodicity of six months indicating that the water table follows a seasonal function throughout the watershed (Fig. 6.2). A crosscorrelation between air temperature and water levels (Fig. 6.3) shows that water levels are positively correlated with temperature at lag -3 months indicating that a rise (or drop) in water level follows a rise (or drop) in temperature. Furthermore, water levels are negatively correlated with temperature at lag +2, which indicates that a rise (or drop) in water level follows a drop (or rise) in temperature after two months.

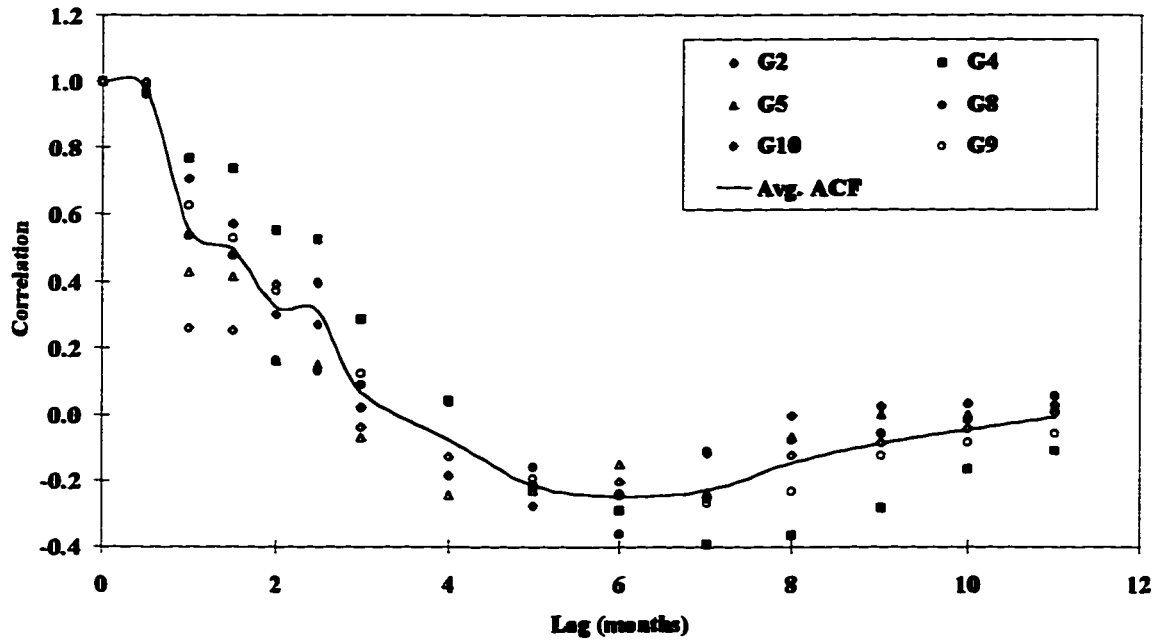


Figure 6.2. Autocorrelation function of water level for bedrock wells (*statistics in Appendix F1*).

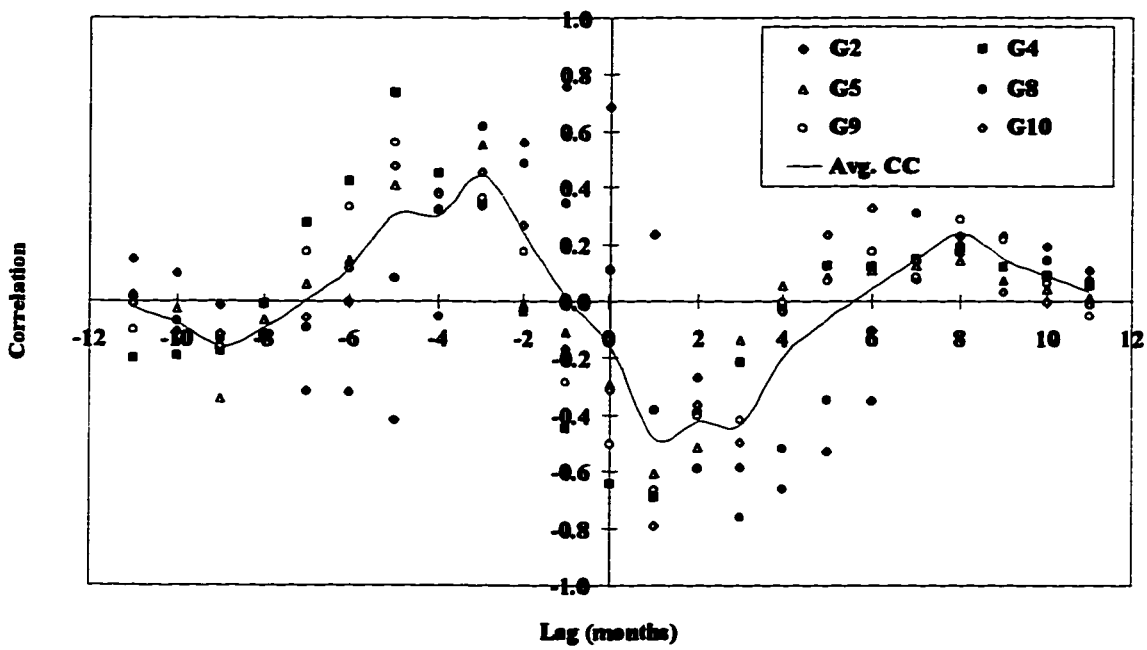


Figure 6.3. Crosscorrelation of water level (domestic wells) and air temperature (*statistics in Appendix F2*).

6.2 Groundwater Geochemistry

6.2.1 Background

The presence of shallow groundwater in most basins is attributed to the infiltration of snowmelt and rain. Rain waters from the site are diluted in most major ions, have a slightly acidic to moderate pH, and are low in total dissolved solids (TDS) compared to groundwater (Table 6.1).

Table 6.1 Geochemistry of rainwater (Watelet, 1996) for site G3 compared to groundwater for the same site (concentrations in *mg/L*).

	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^{-}	SO_4^{2-}	Cl^{-}	TDS	pH
Rain	2.85	0.71	0.18	14.9	36.6	0	7.1	28.5	6.28
Rain	3.95	0.85	0.13	3.3	12.2	6.9	3.3	-	6.56
Rain	5.90	1.16	0.63	16.5	47.4	4.0	3.6	-	6.88
Rain	6.13	1.54	0.26	14.3	41.4	6.0	8.3	-	6.89
Rain	5.02	0.86	0.18	8.5	26.1	7.8	6.1	-	5.70
Grnd.	92.33	24.88	8.33	2.5	355.2	60.4	9.1	330	7.33

Upon infiltration, rain and meltwaters are supercharged in dissolved oxygen of atmospheric origin. However, the upper layers of the soil horizon contain abundant organic matter which decays to carbon dioxide, consuming oxygen (eq. 6.1). Hydration of CO_2 produces carbonic acid (H_2CO_3) (eq. 6.2), which dissociates to form HCO_3^- and CO_3^{2-} anions (eq. 6.3 & 6.4).

(6.1) $$CH_2O + O_{2(g)} \Rightarrow CO_{2(g)} + H_2O$$

(6.2) $$CO_{2(g)} + H_2O \Leftrightarrow H_2CO_3$$

(6.3) $$H_2CO_3 \Leftrightarrow H^+ + HCO_3^-$$

(6.4) $$HCO_3^- \Leftrightarrow H^+ + CO_3^{2-}$$

Thus, the dissociation of carbonic acid contributes hydrogen ions in solution and affects the solution's pH (Fig. 6.4). As the solution's pH increases, it passes from a carbonic acid composition to a more bicarbonate-rich end-member. Carbonic acidity, in limestone terrain, is attenuated by calcite dissolution, which contributes Ca^{2+} to solution, increases pH, and accounts for the Ca-HCO_3 geochemical facies found in such groundwaters.

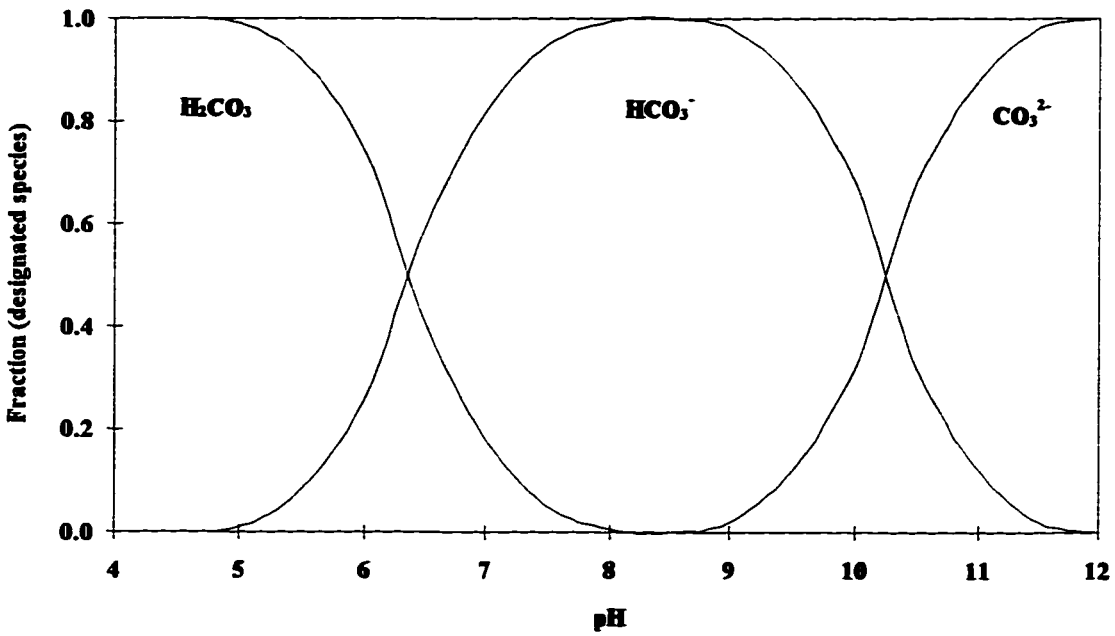


Figure 6.4. Dissociation of carbonic acid as a function of pH (adapted from Freeze & Cherry, 1979).

6.2.2 Geochemistry of Groundwaters

Surficial aquifer groundwaters collected from tile drains (T1 to T4) in April 1995 and wells G11 and G11A in October 1994 plot in the high Ca,Mg-HCO_3 area (>60% Ca^{2+} and >65% HCO_3^-) (Fig. 6.5). All sites contain mostly Ca^{2+} and HCO_3^- while Mg^{2+} has an average concentration of 22.2 *mg/L* (Fig. 6.6 & 6.7).

Figure 6.5. Piper diagram showing the geochemistry of groundwaters from tile drains (April 12, 1995), domestic wells (October 14, 1994), and piezometers (October 14, 1995).

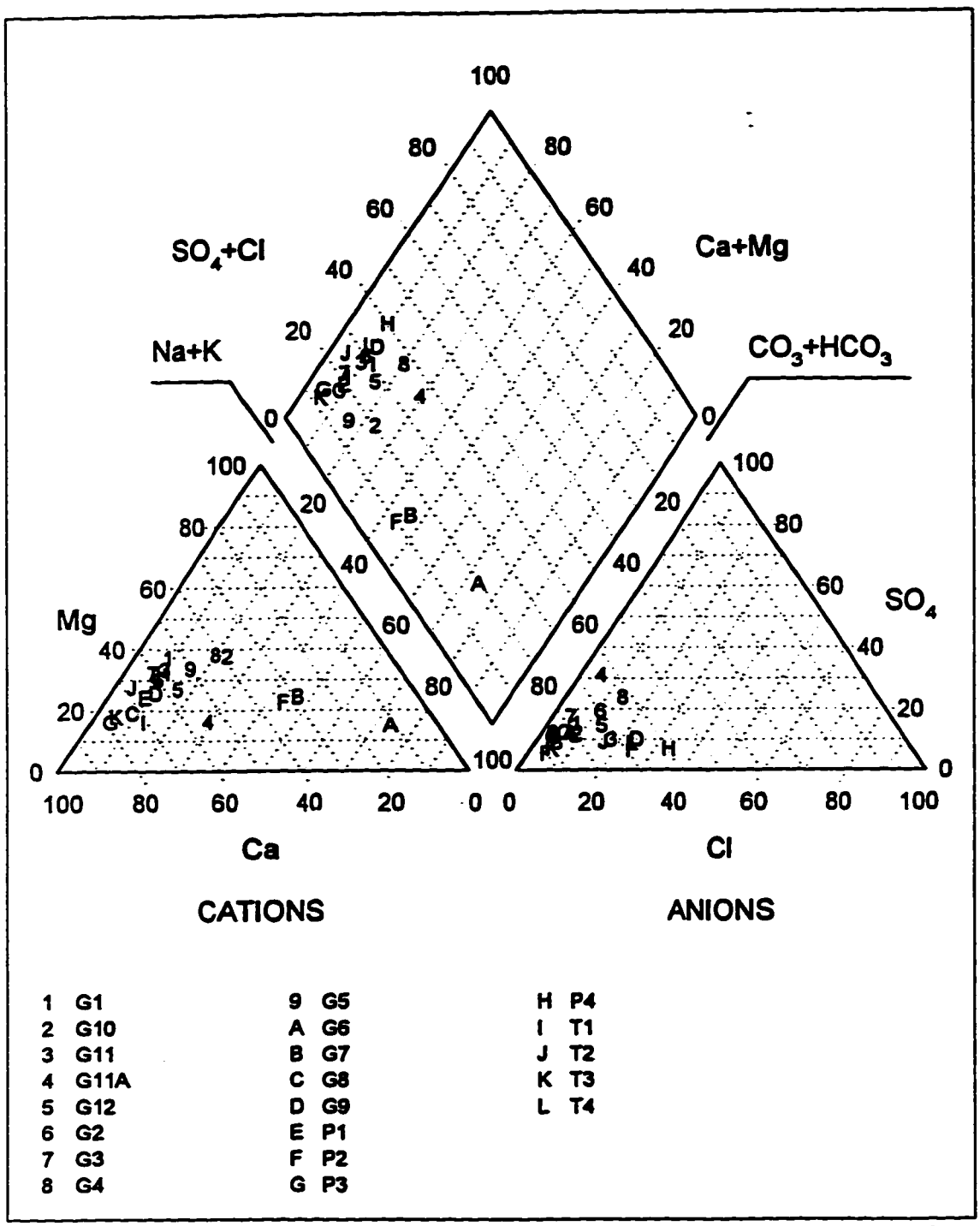


Figure 6.6. Schoeller diagram showing the predominant ionic composition of tile drainage effluent (April 12, 1995).

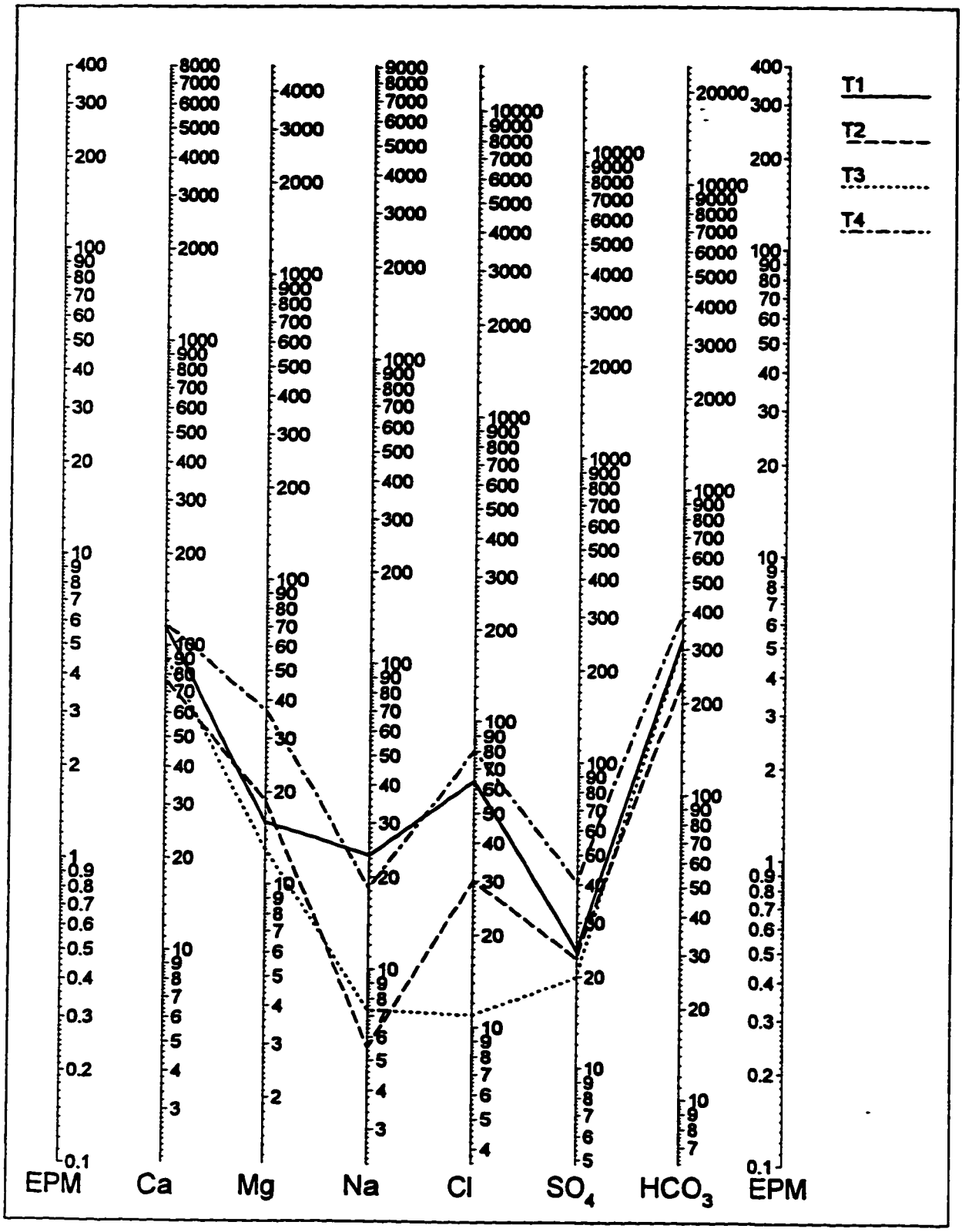


Figure 6.7. Schoeller diagram showing the predominant ionic composition of domestic wells (October 14, 1995).

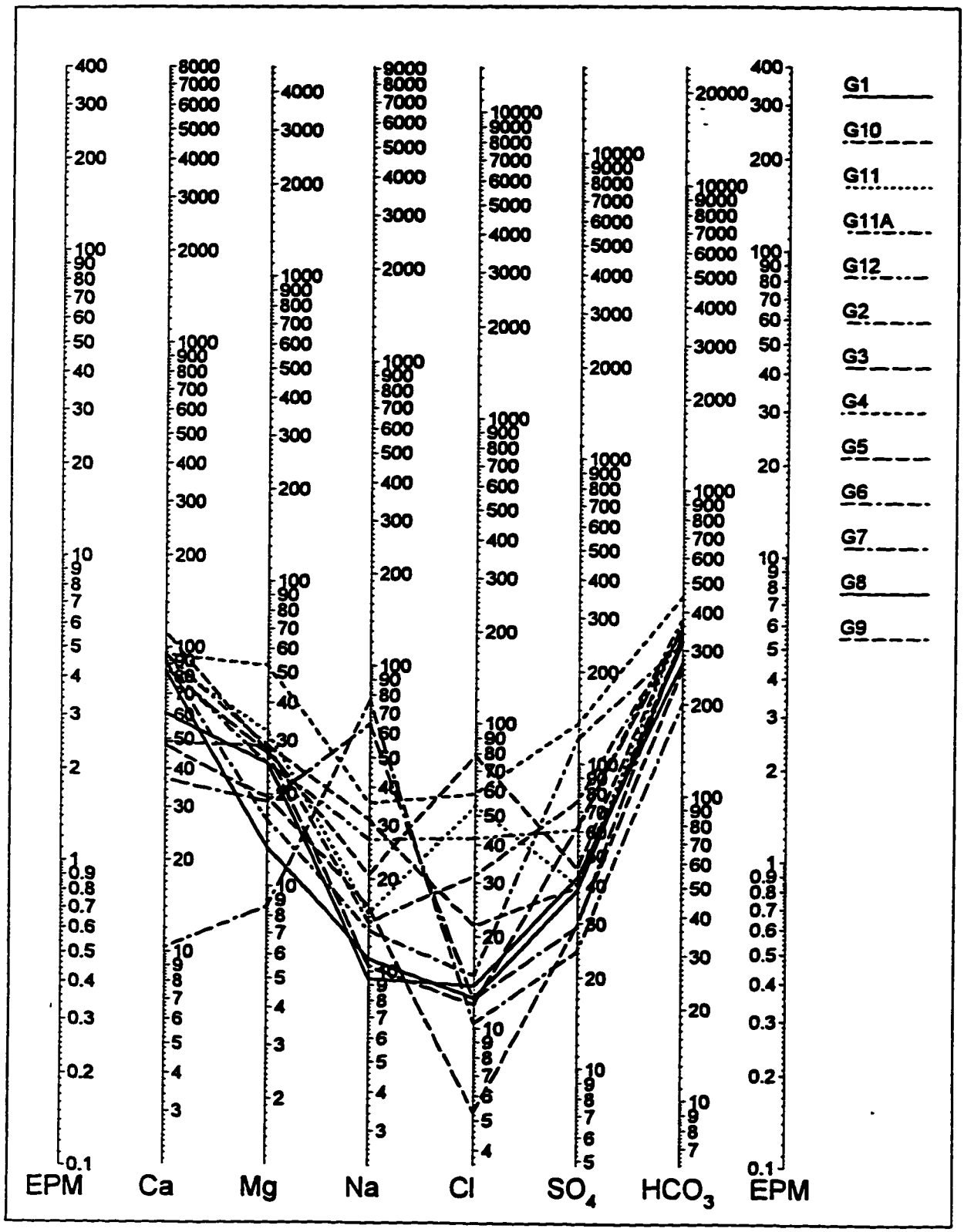
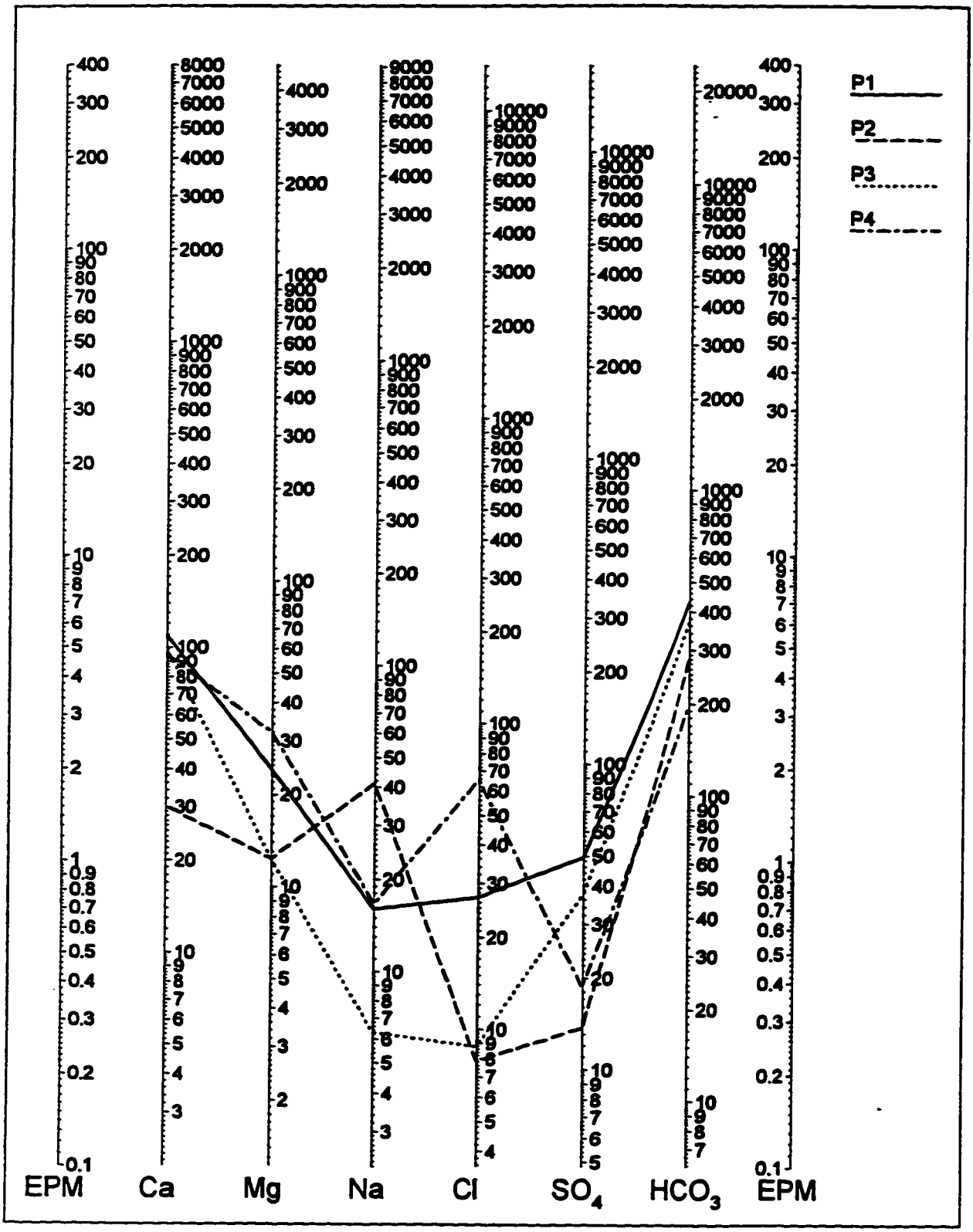


Figure 6.8. Schoeller diagram showing the predominant ionic composition of piezometric groundwaters (October 14, 1995).



Average field pH values (tile drains only) for the summer of 1994 is 6.86, and average total dissolved solids is 365 *mg/L*. Tile drains in the study area are approximately 1 metre below surface. Thus, rainwater (Table 6.1) passing through this 1 metre soil column acquires a significant amount of dissolved solids.

Bedrock groundwaters (G1 to G12) collected from domestic wells show ten of eleven sites have a high Ca,Mg-HCO_3 facies with G7 lying just outside the main grouping (Fig. 6.5). G6 has a geochemical signature (Na-HCO_3) showing use of a water softener. Like the tile drain effluent, Ca^{2+} and HCO_3^- are the dominant species found in these waters (Fig. 6.7). However, Mg^{2+} has a higher average concentration of 30 ppm, compared to 21.3 ppm for tile drainage waters. Average pH values for these well waters is 7.54, compared to 6.86 for tile drainage effluent. Average total dissolved solids is 337 *mg/L*, which is slightly less than tile drainage waters (365 *mg/L*). The increase in pH and Mg^{2+} concentrations is due to the dissolution of limestone from which these wells provide water. However, magnesium may be incorporated into the geochemistry from dissolution of clay minerals as groundwaters infiltrate the soil profile.

A mixture of bedrock and surficial groundwaters were collected from four piezometers installed in the Raisin Riverbed. Groundwater geochemistry indicates highest concentrations in Ca^{2+} and HCO_3^- compared to all other geochemical species (Fig. 6.5 and 6.8). Mg^{2+} is variable compared to domestic well waters with an average concentration of 20.2 ppm. The average of pH readings is 7.72, compared to 7.56 for well waters. Average total dissolved solids is 336 *mg/L*, which is comparable to bedrock groundwater. Higher pH values compared to domestic wells indicate an increased buffering capacity.

The water quality program WAT4 (Rollins, 1988) and database Datagen 4 (Rollins, 1990) was used with field pH, temperature, and major cation and anion values to compute saturation indices for certain minerals. All results are tabulated in *Appendix G* with selected mineral saturation indices given in Table 6.2.

Table 6.2 Saturation indices of different groundwaters within the study area according to WAT4: SI<-0.1= undersaturated (U), SI>+0.1 = supersaturated (SP), -0.1<SI<0.1 = saturated (S).

Site/date collected	Aragonite ($CaCO_3$)	Calcite ($CaCO_3$)	Dolomite ($CaMg(CO_3)_2$)	Quartz (SiO_2)
		Domestic Wells		
G1/1-Jul.-94	-0.11 S	0.05 S	-0.34 U	0.58 SP
G2/15-Jul.-94	-0.34 U	-0.19 U	-0.96 U	0.28 SP
G3/1-Jul.-94	-0.09 S	0.07 S	-0.32 U	0.47 SP
G4/15-Jul.-94	-0.75 U	-0.59 U	-1.32 U	0.47 SP
G5/1-Jul.-94	-0.48 U	-0.32 U	-1.16 U	0.48 SP
G6/1-Jul.-94	-0.07 S	0.09 S	0.00 S	0.24 SP
G7/15-Jul.-94	-0.46 U	-0.30 U	-0.93 U	0.40 SP
G8/1-Jul.-94	-0.26 U	-0.10 S	-1.05 U	0.34 SP
G915-Jan-95	0.25 SP	0.40 SP	0.59 SP	0.03 S
G10/15-Jul.-94	-0.03 S	0.13 SP	-0.06 S	0.50 SP
G11/1-Jul.-94	0.08 S	0.24 SP	-0.44 U	0.42 SP
G12/26-Aug.-94	0.05 S	0.21 SP	0.07 S	0.16 SP
		Piezometers		
P1/1-Jul.-94	-0.18 U	0.02 S	-0.67 U	0.58 SP
P2/15-Nov.-94	0.16 SP	0.32 SP	0.24 SP	0.29 SP
P3/15-Nov.-94	-0.01 S	0.15 SP	-0.59 U	-0.13 U
P4/15-Nov.-94	0.29 SP	0.45 SP	0.43 SP	0.29 SP
		Tile Drains		
T1/1-Jul.-94	-0.74 U	-0.58 U	-2.09 U	0.39 SP
T2/1-Jul.-94	-0.94 U	-0.78 U	-2.21 U	0.44 SP
T3/15-may-95 (T^0C=6, pH=6.5)	-0.96 U	-0.80 U	-2.48 U	0.21 SP
T4/15-may-95 (T^0C=6, pH=6.5)	-0.81 U	-0.65 U	-1.80 U	0.30 SP

There are two major groupings between the three categories of groundwater present. The first group shows that, for the most part, domestic wells and piezometric waters are supersaturated in quartz with variable saturations for calcite, aragonite, and dolomite. The second group sees tile drainage waters undersaturated in aragonite, calcite, and dolomite and supersaturated in quartz. A common distribution for all three waters is that, for those that are undersaturated in aragonite and calcite, the saturation index displayed in Table 6.2 is quite close to the point of saturation.

However, an interesting fact is the undersaturation of dolomite in 7 of the 11 bedrock wells (G11 being from the surficial aquifer). The four remaining sites (G6, G9, G10, and G12) show conditions of dolomite saturation or supersaturation and lie along the

South Branch of the Raisin River in contact with the St. Martin formation, a source of magnesium from chlorite and smectite found within the shale. The undersaturation of dolomite in the remaining bedrock wells suggests a different groundwater pathway, generating the observed geochemical facies. Groundwater infiltrating the soil zone has shown that dolomite is well below the point of saturation ranging from -1.80 to -2.48 for tile drainage effluent. As groundwater continues to infiltrate the subsurface, magnesium may have been incorporated in the geochemistry through the dissolution of magnesium-bearing clay minerals, as surficial wells G11 and G11A show increased Mg^{2+} concentrations (Fig. 6.7). Lam *et al.* (1995) report that for field soils in the study area, mineralogy consists primarily of quartz followed by microcline, plagioclase, amphiboles, micas, vermiculite, and chlorite. Vermiculite and chlorite both contain magnesium which could provide Mg^{2+}. Calcite saturation may also have been achieved through the dissolution of carbonate nodules in the soil zone. Continued groundwater infiltration may have allowed for calcite saturation and increased Mg^{2+} levels to occur in most wells prior to incorporation in the bedrock source. Migration toward discharge zones would allow sufficient time for groundwaters to become saturated in calcite as demonstrated by the supersaturated nature of groundwaters from piezometres. In addition, groundwaters in the southern sector of the watershed are saturated to supersaturated with respect to dolomite and calcite, respectively. This may reflect increased residence time compared to groundwaters in the north and central portions of the study area.

In retrospect, the Raisin River watershed is possibly being sustained by meteoric water infiltrating the surficial sediment layer with continued migration into the bedrock aquifer. These groundwaters would have acquired the necessary chemistry to become saturated in calcite, however would not have been able to achieve dolomite saturation given their possibly short residence time in the bedrock. Groundwater flow through the bedrock would have to have been short enough so that discharge from limestone directly in the Raisin River would have occurred with groundwaters saturated in calcite, but not dolomite. Wells in the south would have felt the effects of an increase in residence time

prior to discharge either in the Raisin River or the St. Lawrence, as these have shown saturated conditions with respect to dolomite.

6.2.3 Total Dissolved Solids (Electrical Conductivity)

The average of total dissolved solids (TDS) in bedrock wells was low during the summer of 1994 but gradually rose in the fall (Table 6.3; Fig. 6.9). The mid-winter thaw in January 1995 corresponded to a sharp decline in TDS as meltwater and rain recharged the aquifer and diluted groundwaters. The surficial aquifer also showed dilution in January corresponding to the mid-winter thaw.

Table 6.3 Average TDS values (*mg/L*) of bedrock wells computed from individual TDS levels measured in each well. Surficial well is G11.

Date	G2	G3	G4	G5	G8	G10	Avg. TDS	G11
7-May-94	342.5	276.5	575.0	206.0	234.5	317.5	325.3	-
3-Jun.-94	251.5	261.5	493.5	214.0	240.5	257.0	286.3	261
1-Jul.-94	466.0	267.0	526.5	231.5	235.5	316.5	340.5	348
29-Jul.-94	370.5	286.5	498.0	218.5	229.5	298.5	316.9	354
26-Aug.-94	326.0	282.0	417.0	211.0	241.5	297.5	312.5	353
23-Sept.-94	380.0	320.0	530.0	235.0	275.0	295.0	339.2	430
14-Oct.-94	375.0	330.0	555.0	230.0	275.0	295.0	343.3	375
14-Nov.-94	400.0	325.0	660.0	270.0	285.0	310.0	375.0	455
15-Dec.-94	385.0	320.0	650.0	250.0	290.0	315.0	368.3	530
16-Jan.-95	345.0	300.0	490.0	245.0	285.0	240.0	317.5	70
16-Feb.-95	400.0	335.0	620.0	255.0	300.0	320.0	371.7	520
15-Mar.-95	400.0	380.0	600.0	255.0	310.0	340.0	380.8	520
12-Apr.-95	405.0	335.0	610.0	235.0	295.0	375.0	375.8	510
15-May-95	414.5	340.5	606.5	233.0	280.0	345.0	369.9	510
13-Jun.-95	408.5	332.0	631.0	247.0	278.0	315.5	368.7	515

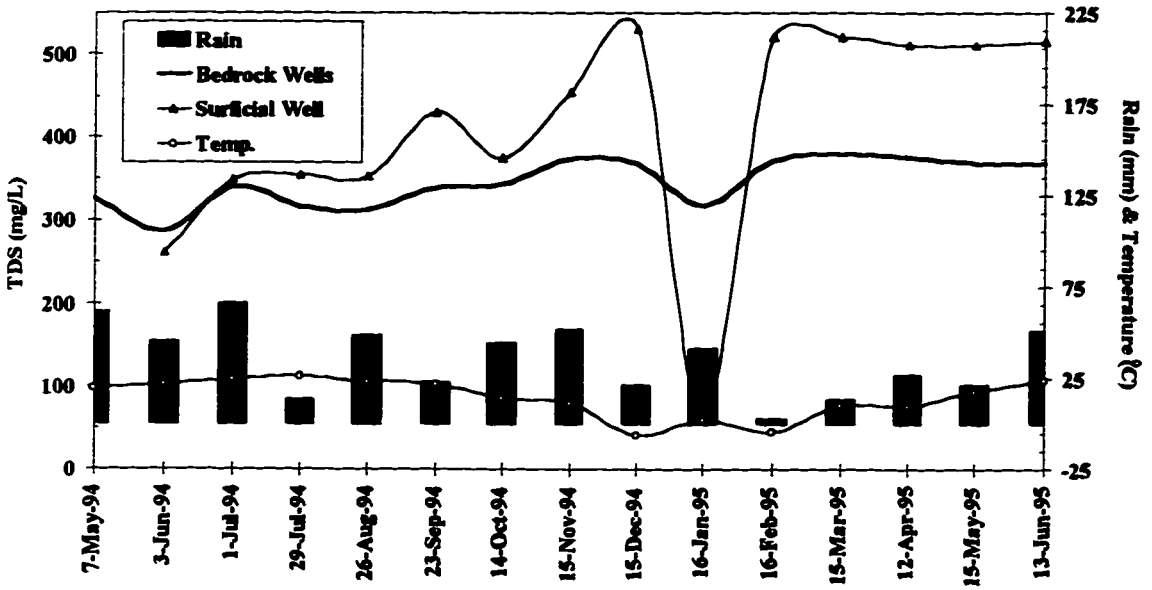


Figure 6.9. Average total dissolved solids of bedrock wells and surficial well with time.

The autocorrelation function of total dissolved solids for bedrock wells shows a slight seasonal variation throughout the watershed (Fig. 6.10). However, considering the scatter in the ACF, the seasonality is probably not significant. The crosscorrelation function of water level and total dissolved solids for wells G2, G4, and G5 reveals a positive correlation with no lag effect (Fig. 6.11) indicating that increases in water level are associated with a simultaneous increase in TDS. The positive correlation may be the result of groundwater contribution from the surficial aquifer to the bedrock aquifer where infiltration during higher flow periods carries a greater abundance of dissolved solids. Conversely, higher water levels are attributed to increased groundwater flow, which usually involves increased dissolution of limestone accounting for the elevation in TDS. Well G10 shows a positive correlation offset by a two-three month lag time. Groundwaters represented by high bedrock topography (G2 and G5), and recharging the northern section of the study area could take three months to reach the southeastern sector (G10) which is topographically low. This could represent the time it takes for total dissolved solids to increase in wells in this vicinity following an increase in water level.

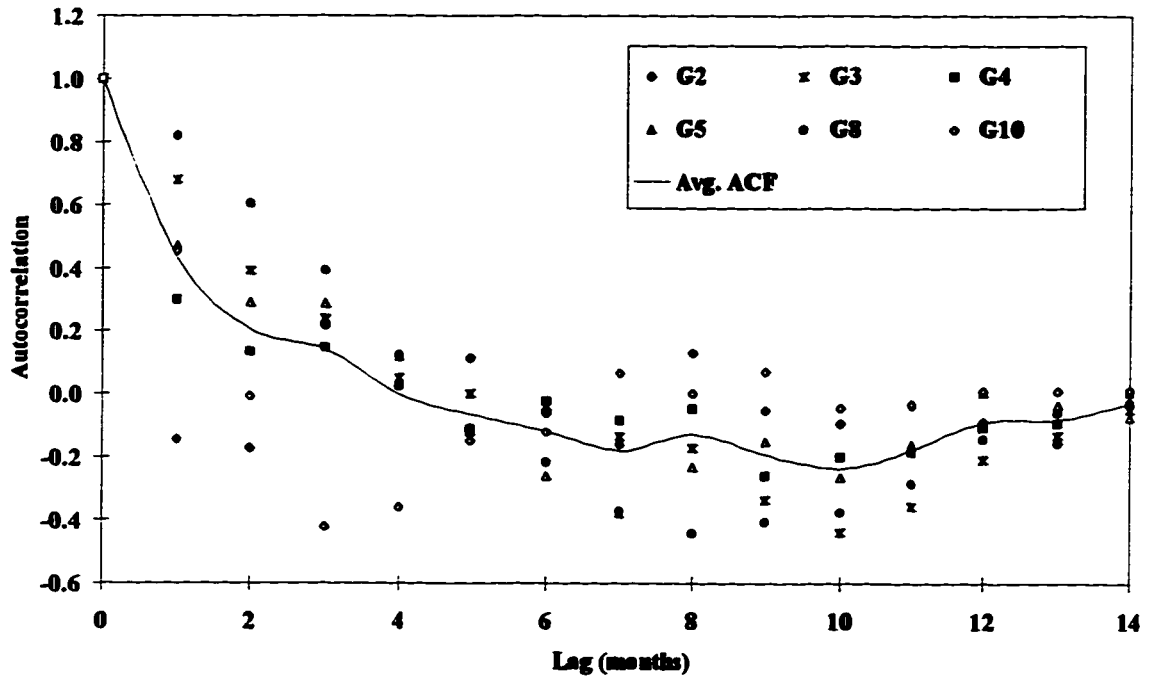


Figure 6.10. Autocorrelation Function of Total Dissolved Solids for bedrock wells (*statistics in Appendix F3*).

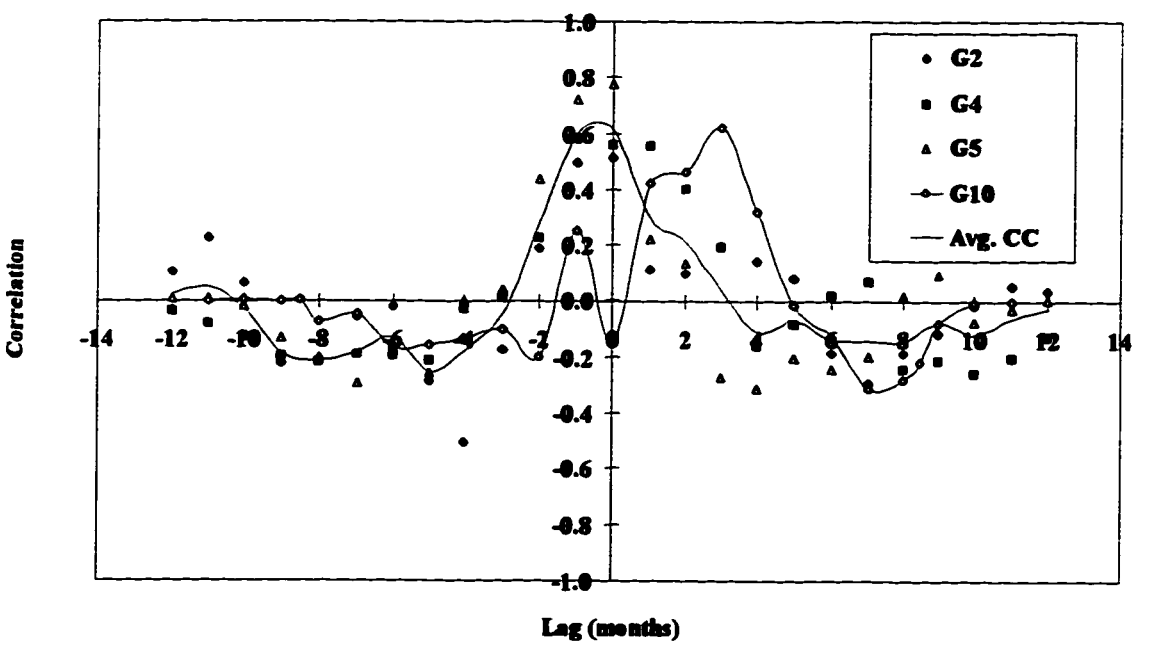


Figure 6.11. Crosscorrelation of water level and total dissolved solids for bedrock wells (*statistics in Appendix F4*).

6.2.4 Calcium

Calcium is used as a temporal monitoring parameter because it is a geogenic solute representing contributions from the limestone aquifer. The average calcium concentration in bedrock groundwaters correlates well with the TDS signature throughout the 1994-95 field season, decreasing over the summer of 1994 and rising in the fall with a sharp decline in January of 1995 (Table 6.4; Fig. 6.12). Calcium levels rose gradually following spring melt in 1995. Summer values for 1994 show declining concentrations which is contrary to expected resonse. Under warm and dry conditions, water levels declined throughout this period, demonstrating the increase in demand but also the lack of any meteoric infiltration (Fig. 6.1). Reduced groundwater flow in the summer should have increased calcium concentrations as groundwater would have dissolved the carbonate bedrock, thereby inducing saturation. Nevertheless, Figure 6.12 does show that the basin responds to a dilution of the bedrock aquifer in January 1995, as the mid-winter thaw affected the entire watershed and calcium levels dropped.

Table 6.4 Average calcium concentration (*mg/L*) calculated from levels in 7 bedrock wells.

Date	G2	G3	G4	G5	G7	G8	G10	Avg. Ca
7-May-94	78.15	71.33	80.80	57.11	39.28	94.54	82.20	71.91
3-Jun.-94	84.68	72.41	80.22	58.76	42.51	94.00	73.72	72.33
1-Jul.-94	82.55	74.43	83.93	66.19	41.15	92.23	72.91	73.34
29-Jul.-94	78.92	73.50	75.65	57.70	39.82	89.54	57.43	67.51
26-Aug.-94	75.81	69.61	77.26	55.15	37.31	91.29	52.15	65.51
23-Sept.-94	105.52	89.59	100.29	52.88	41.75	90.51	52.24	76.11
14-Oct.-94	95.42	85.90	94.83	47.85	37.01	83.63	49.06	70.53
15-Nov.-94	102.00	92.33	129.52	59.34	39.44	92.15	54.23	81.29
15-Dec.-94	104.10	90.44	129.71	59.69	41.75	94.97	55.00	82.24
16-Jan.-95	87.33	78.54	79.78	51.10	36.03	81.86	53.00	66.81
16-Feb.-95	101.52	90.10	110.38	54.11	46.19	91.01	54.00	78.19
15-Mar.-95	102.31	100.00	109.04	53.00	44.78	93.37	58.30	80.11
12-Apr.-95	107.88	88.69	111.06	56.15	47.23	88.27	66.40	80.81
15-May-95	107.50	96.35	120.00	56.86	45.82	92.54	64.45	83.36
13-Jun.-95	110.38	97.12	129.13	64.29	46.38	91.02	62.89	85.89

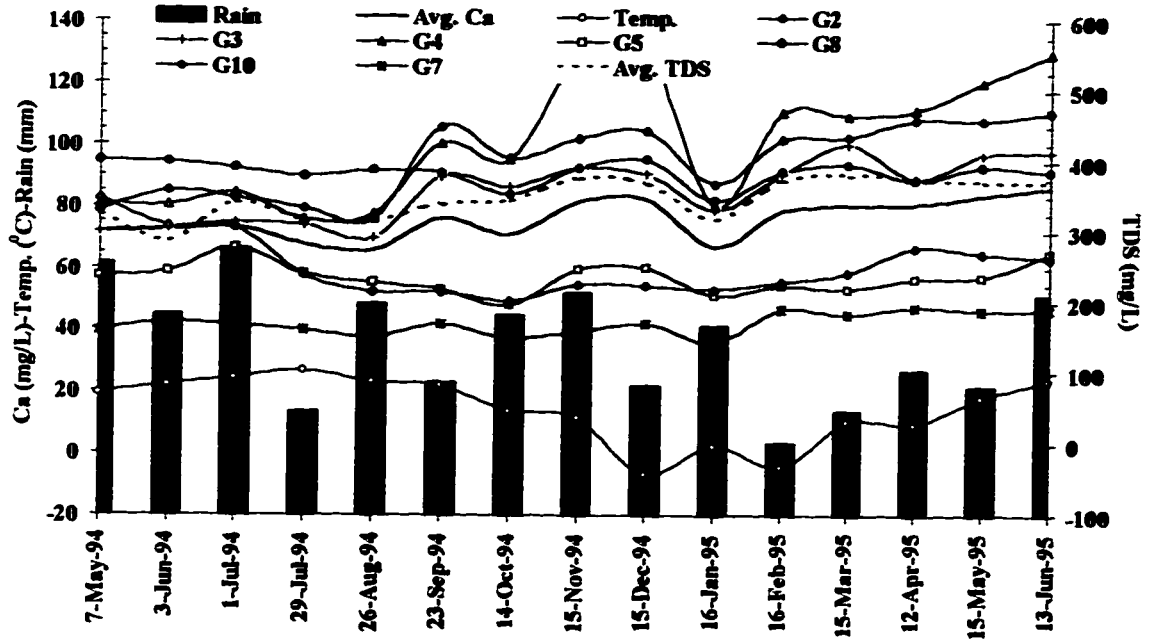


Figure 6.12 Average calcium concentration in domestic wells compared to rainfall, temperature, and average TDS.

6.3 Environmental Isotopes

Variable masses exist for most elements of the periodic table, hence the term isotope. An isotope is an element that differs in the number of neutrons it holds within its nucleus, which gives it a range of masses. For example, hydrogen has three different isotopes; hydrogen, deuterium, and tritium. Each contain one proton, but hydrogen contains 0, deuterium contains 1, and tritium contains 2 neutrons, respectively.

Isotopic abundance in a material is expressed as the relative ratios between the two most abundant isotopes of a given element. Thus, for oxygen, the ratio of ^{18}O to ^{16}O is used. Isotope ratios are measured with a mass spectrometer, which analyzes the $^{18}O/^{16}O$ ratio and compares it to that of a known standard using the following equation:

$$\delta_x = \left(\left(\frac{R_x}{R_{ref}}\right) - 1\right) * 1000 \text{ SMOW}$$

where δ_x is the expression of the isotope contents in sample "x" compared to an internationally recognized reference material, R_x is the isotope ratio of the sample (e.g. $^{18}O/^{16}O$), and R_{ref} is the isotope ratio ($^{18}O/^{16}O$) of the reference material. For water, the reference is usually Standard Mean Ocean Water (SMOW) (Friedman et al., 1977).

^{18}O and ^{2}H are useful isotopes in determining groundwater source as they act as natural tracers in the hydrological cycle. Their tracer quality stems from their ability to fractionate between vapour and liquid phases according to changes in temperature. In a vapour mass (clouds), temperature must decline in order for precipitation to occur. Upon condensation, the heavier isotope is fractionated into the liquid phase (rain) while the lighter isotope remains in the cooling vapour. The initial rain will thus be isotopically enriched in the heavier isotope compared to any successive precipitation events. As precipitation in the study area occurs on a seasonal basis, the difference in temperature will affect the fractionation effect between the vapour and liquid phases. The fractionation factor has been shown to increase with decreasing temperature. Warmer temperatures during the summer allow for a decreased fractionation factor between the liquid and vapour phases, whereas cooler temperatures in the fall and winter increase the fractionation factor. Consequently, summer rains will be isotopically enriched both in ^{18}O and ^{2}H relative to winter precipitation.

6.3.1 Deuterium

Raisin River deuterium values show a strong seasonal trend that can be positively correlated with temperature (Table 6.5; Fig. 6.13). The sharp decline in March 1995 represents the sudden addition of spring melt to the runoff, with isotopically light values

from winter snow. Seasonal variations in the isotopic composition of precipitation are attenuated during infiltration and runoff. Furthermore, the seasonal variation in runoff can lag the cycle of seasonal temperatures. This lag in temperature correlation can reflect the rate of movement of meteoric water through the watershed.

Table 6.5 Deuterium values of Raisin River (all values in ‰).

	Altitude (masl)=	97	74	60	80	90	60	
Date	T (^{0}C)	P1	P3	P4	G2	G5	G9	Avg. δ^2H
3-Jun.-94	22.5	-82.2	-	-72.9	-81.5	-78.1	-73.4	-78.8
1-Jul.-94	25.0	-72.9	-68.6	-71.8	-68.2	-64.5	-66.0	-68.5
29-Jul-94	-	-	-	-	-	-	-	-
26-Aug.-94	26.0	-	-61.3	-	-	-	-	-61.3
10-Sept.-94	17.5	-69.2	-65.9	-59.3	-64.1	-	-	-66.7
23-Sept.-94	16.5	-	-	-	-	-	-53.6	-53.6
14-Oct.-94	12.5	-70.8	-63.8	-61.6	-64.0	-61.0	-54.9	-62.7
15-Nov.-94	13.0	-70.4	-67.3	-68.6	-69.1	-67.4	-70.9	-69.5
14-Dec.-94	-4.0	-74.7	-	-	-74.1	-70.4	-78.9	-74.5
16-Jan.-95	5.5	-73.1	-	-	-75.5	-75.6	-68.6	-73.2
16-Feb.-95	2.0	-73.9	-	-	-76.3	-77.6	-77.8	-76.4
15-mar-95	12.0	-88.0	-	-	-101.7	-102.5	-103.7	-99.0
12-Apr.-95	13.0	-78.1	-	-81.1	-79.4	-80.5	-77.4	-78.9
15-may-95	15.5	-72.8	-	-67.5	-72.5	-73.0	-68.9	-71.8
13-Jun.-95	25.5	-	-	-	-66.8	-64.2	-64.9	-65.3

The crosscorrelation of δ^2H (river water) and air temperature shows negative correlation existing at lag -3, and a positive correlation at +3 (Fig. 6.14). The positive peak at lag +3 and the negative peak at -3 indicates that the two variables are cyclical (with a 4X3=12 month cycle) and offset by approximately three months. So an increase in temperature is followed by a ^{2}H enrichment three months later in the river. If the process is cyclical, then the residence time could be ¼ of a year, 1¼ years, 2¼ years, and so forth. Thus, the crosscorrelation could be disappearing since the time series was severed at one year. So three months is the shortest possible groundwater residence time, but the actual residence time could be much longer. This suggests an approximately three month average residence time for precipitation in the watershed contributing the most to runoff.

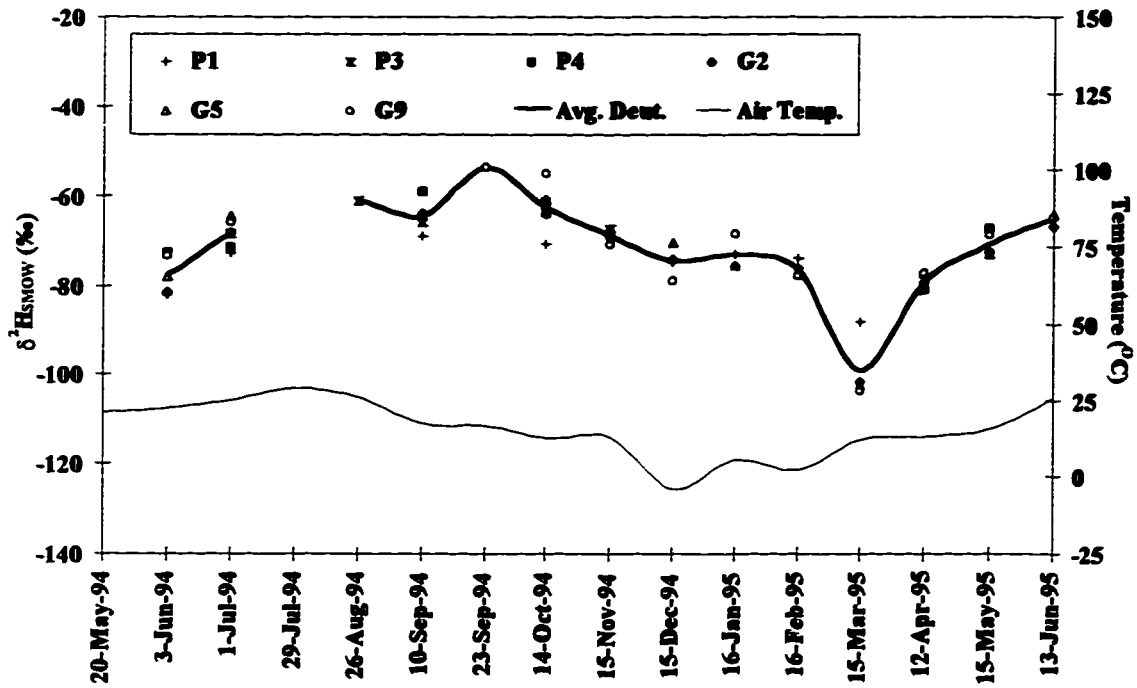


Figure 6.13. Temporal variation of deuterium in Raisin River.

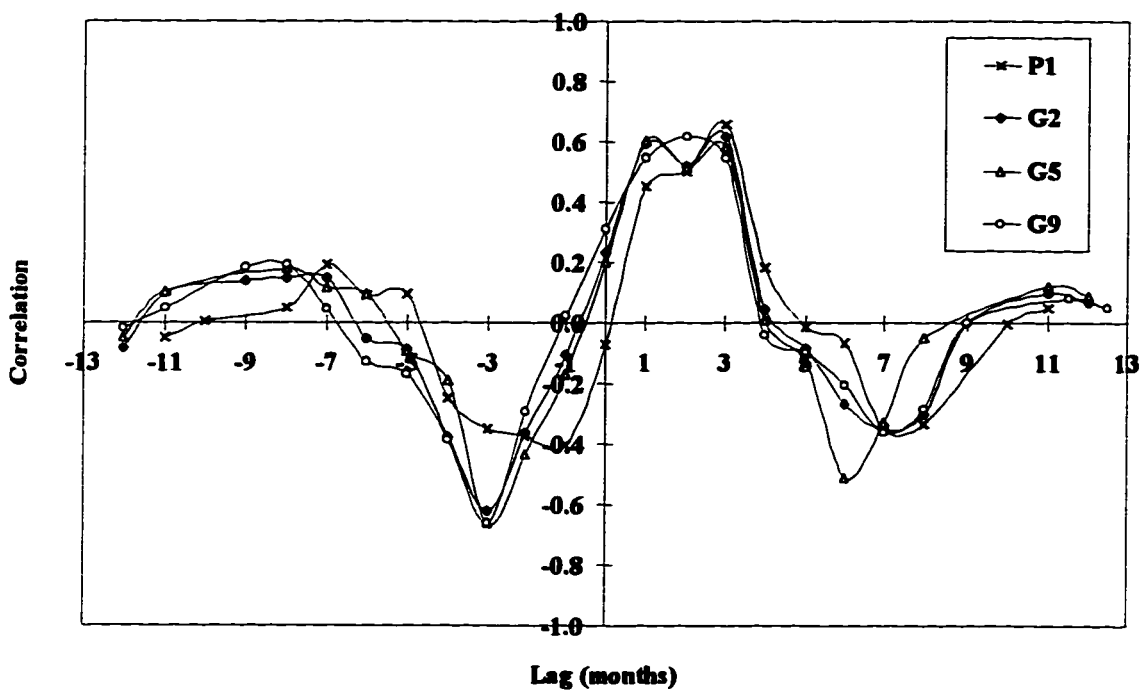


Figure 6.14. Crosscorrelation of ^{2}H (Raisin River) and air temperature (*statistics in Appendix F5*).

The deuterium signature for domestic well waters also follows a seasonal cyclicity (Table 6.6; Fig. 6.15).

Table 6.6 Deuterium values of bedrock groundwaters (domestic wells). All values in ‰.

	Altitude	83 masl	91 masl	62 masl	51 masl	51 masl	
Date	T (°C)	G2	G5	G9	G10	G12	Avg. δ^2H
20-may-94	21.0	-67.9	-73.5	-71.1	-76.5	-	-72.25
17-Jun.-94	34.5	-67.4	-75.4	-73.8	-75.2	-	-72.95
15-Jul.-94	26.5	-64.1	-73.8	-71.6	-70.7	-	-70.05
12-Aug.-94	26.0	-71.3	-74.3	-73.0	-75.0	-72.9	-73.30
10-Sept.-94	17.5	-72.6	-76.3	-72.8	-75.9	-74.3	-74.38
23-Sept.-94	16.5	-71.6	-76.4	-73.0	-74.3	-75.9	-74.24
14-Oct.-94	12.5	-71.9	-75.0	-72.3	-73.8	-76.3	-73.86
15-Nov.-94	13.0	-70.0	-74.0	-73.3	-74.8	-73.4	-73.10
15-Dec.-94	-4.0	-70.3	-73.9	-72.1	-75.7	-75.6	-73.52
16-Jan.-95	5.5	-71.3	-73.2	-72.3	-73.7	-76.0	-73.30
16-Feb.-95	2.0	-71.5	-74.2	-69.3	-73.8	-75.4	-72.84
15-mar-95	12.0	-73.3	-76.6	-74.0	-71.5	-73.9	-73.86
12-Apr.-95	13.0	-69.0	-76.6	-72.4	-73.9	-75.2	-73.42
15-May-95	15.5	-66.5	-77.1	-71.2	-71.2	-	-71.50
13-Jun.-95	25.5	-67.1	-73.5	-73.3	-71.6	-	-71.38

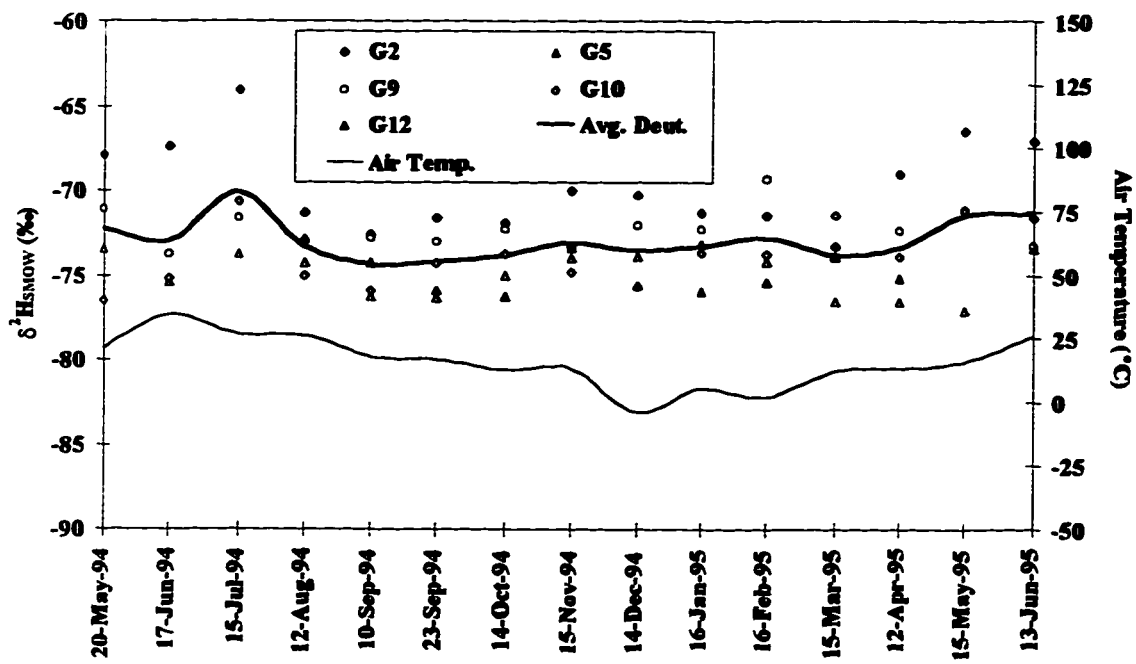


Figure 6.15. Temporal variation of δ^2H in bedrock wells.

Enriched values are found mostly during the summer when temperatures are high, with depleted values in the fall and winter months as atmospheric temperatures decline. As with Raisin River waters (Fig. 6.13), the deuterium signature for groundwater dips in the month of March 1995. This is a result of spring melt passing through the watershed where the highly depleted signature from snow and ice shows up. Enrichment subsequently occurs beginning in April into June. Unlike Raisin River waters (-60‰ to -100‰), the deuterium signature in domestic wells shows much less variation in average values, ranging between -70‰ and -75‰. This is a consequence of a dampening effect in bedrock wells as groundwaters undergo much longer residence times.

The effect of groundwater recharge on a local scale is shown by high altitude areas receiving more depleted ^{2}H values compared to low altitude zones, with the exception of site G2 (Table 6.6).

6.3.2 Carbon-13

Dissolved inorganic carbon (DIC) in bedrock groundwaters was monitored as another tool to determine rates of groundwater movement through the watershed. The DIC in groundwater is controlled by several factors including root respiration and bacterial decay in the soil, and mineral dissolution/precipitation. Unlike $\delta^{18}O$ and $\delta^{2}H$, DIC as a tool traces solutes in groundwater rather than the water molecule itself.

Soil carbon dioxide plays an integral role in the DIC signature imparted by groundwaters since it provides acid necessary to dissolve carbonate materials. Rain entering the subsurface may contain CO_2, however, the carbon dioxide present within the atmosphere is so minimal ($pCO_2=10^{-3.5}$) that it is overwhelmed by the CO_2 derived from the soil horizon through the decay of plant material by microorganisms (Salomons *et al.*, 1980). The partial pressure of CO_2 in the soil atmosphere ranges from $10^{-2.5}$ to $10^{-1.5}$.

Following the incorporation of soil CO_2 from oxidized organic material, DIC in groundwater can increase through;

- dissolution of $CaCO_3$ by the action of CO_2 in groundwater
- weathering of silicate minerals
- dissolution of $CaCO_3$ by humic acids

These processes can be represented according to the following reactions:

(6.5) $$CH_2O + O_2 \Rightarrow CO_2 + H_2O \Rightarrow H_2CO_3 \Rightarrow H^+ + HCO_3^-$$

(6.6) $$CaCO_3 + H^+ + HCO_3^- \Rightarrow Ca(HCO_3)_2 \Rightarrow Ca^{2+} + 2HCO_3^-$$

where CH_2O denotes organic material. The $\delta^{13}C$ signature of CO_2 produced in the soil is approximately -25‰ for C_3 type plants, including most natural vegetation in temperate climates. Grasses and certain crops such as corn fix their carbon according to a more efficient photosynthetic pathway resulting in a $\delta^{13}C$ for soil CO_2 close to -12‰. Carbon fractionation occurs during transformation of the CO_2 to HCO_3^-, giving a $\delta^{13}C_{HCO3}$ of approximately -17‰ to -21‰. Prior to carbonate dissolution (eq. 6.6), bedrock carbonate generally has a $\delta^{13}C$ value of approximately 0‰ (Pawellek & Veizer, 1994). Thus, the final $\delta^{13}C$ of the bicarbonate ranges from -10 to -14‰.

These carbonate dissolution reactions can be presented on a bicarbonate-pH diagram (Fig. 6.16), which shows the evolution of pH, HCO_3^-, and $\delta^{13}C$ as the groundwater dissolves carbonate to the point of calcite saturation. The diagram assumes an initial soil CO_2 $\delta^{13}C$ of -26‰ for groundwaters at 5°C with a variable initial pCO_2, and for open and closed system conditions.

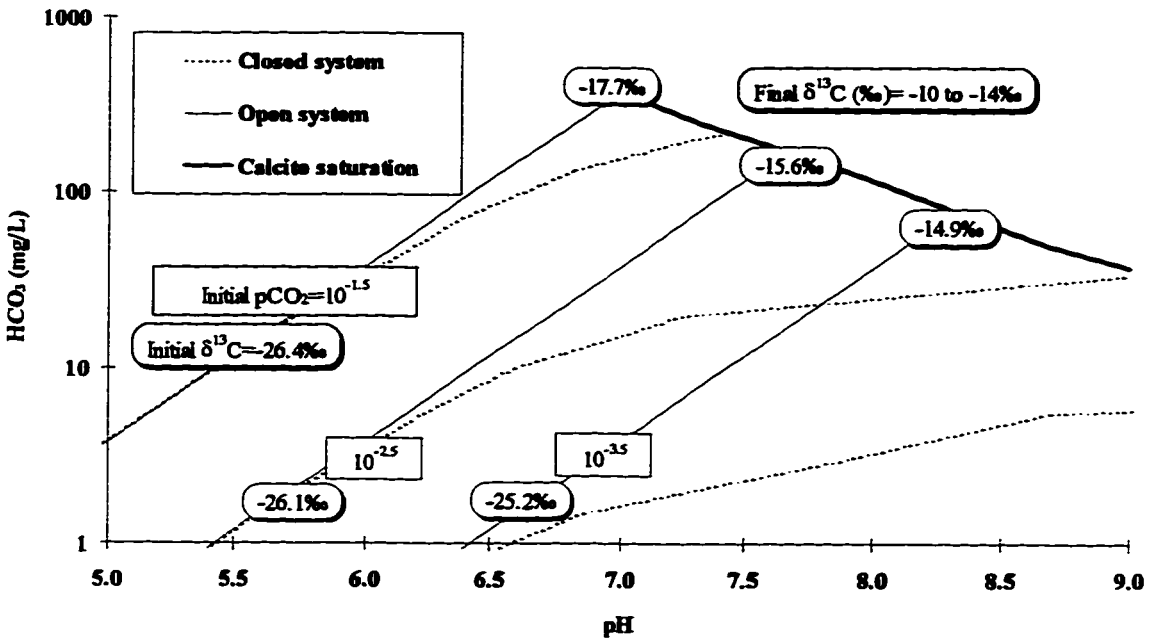


Figure 6.16. Geochemical evolution path of groundwater under open and closed system dissolution of calcite.

If the dissolution of carbonate material takes place in the non-saturated soil zone in constant contact with soil CO_2, the dissolution is said to be under open system conditions. Under these conditions, the $\delta^{13}C$ imparted by the final groundwater will not have been influenced by the $\delta^{13}C$ of the dissolving calcium carbonate because a continuous supply of CO_2 generated by the soil is available. Thus, the $\delta^{13}C$ signature of the groundwater is only influenced by the $\delta^{13}C$ of soil CO_2 and the pH, which controls ^{13}C fractionation between CO_2 and DIC.

If groundwater equilibrates with a CO_2 source, then moves below the water table beyond access to soil CO_2, then dissolution of carbonate material is under closed system conditions. The dissolved CO_2 hydrates to form carbonic acid, and is consumed through the dissolution of calcium carbonate. The final $\delta^{13}C$ signature of the groundwater will thus be influenced by the $\delta^{13}C$ imparted by the dissolving calcium carbonate.

For the Raisin River basin, domestic well waters fall on or above the calcite saturation line with most $\delta^{13}C$ values ranging between -10‰ and -14‰ PDB (Table 6.7; Fig. 6.17). Tile drain waters fall beneath the calcite saturation line with $\delta^{13}C$ values ranging between -11‰ and -14‰ for T1, and -4‰ and -8‰ for T2. Piezometric waters are saturated with respect to calcite with $\delta^{13}C$ values between -9 and -13‰.

Table 6.7 pH, alkalinity, and $\delta^{13}C$ values of summer groundwaters (*see* Figure 6.17).

Site	Date	T (^{0}C)	pH	Alkalinity (*mg/L*)	$\delta^{13}C_{DIC}$ (‰)
		Domestic Wells			
G1	1-Jul.-94	4.0	7.54	294.0	-9.45
G2	17-Jun.-94	3.7	7.30	386.7	-12.44
G3	17-Jun.-94	3.7	7.20	386.7	-14.44
G4	17-Jun.-94	4.8	7.01	459.9	-10.90
G5	17-Jun.-94	4.3	7.45	262.3	-9.19
G6	17-Jun.-94	6.6	8.62	211.1	-8.08
G7	17-Jun.-94	4.7	7.62	340.4	-11.57
G8	17-Jun.-94	4.6	7.37	295.2	-9.51
G9	17-Jun.-94	5.1	7.41	356.2	-11.67
G10	17-Jun.-94	4.3	7.60	324.5	-10.10
G11	17-Jun.-94	4.8	6.95	623.0	-11.45
G11A	17-Jun.-94	11.2	7.41	324.5	-12.35
		Tile Drains			
T1	3-Jun.-94	2.8	7.04	307.4	-12.76
	17-Jun.-94	4.9	6.95	359.9	-11.17
	1-Jul.-94	6.8	6.53	363.6	-14.25
T2	3-Jun.-94	3.2	7.12	239.1	-8.20
	17-Jun.-94	5.6	6.70	228.1	-4.39
	1-Jul.-94	3.7	6.82	244.0	-7.40
		Piezometers			
P1	29-Jul.-94	7.2	7.72	394.1	-13.13
P2	29-Jul.-94	14.8	8.14	392.8	-12.70
P3	29-Jul.-94	-	7.10	316.0	-11.00
P4	29-Jul.-94	14.0	7.82	200.0	-9.38

Domestic well and piezometric groundwaters show $\delta^{13}C$ values that are representative of meteoric waters having dissolved soil CO_2 and calcium carbonate largely under open system conditions. Tile drainage effluent displays $\delta^{13}C$ values that are above the normal signature obtained before calcite saturation. Site T2 was used for growing corn (Plate 5-2, p. 48), which is a C_4 plant type with an enriched $\delta^{13}C$ signature.

Groundwater acquiring CO_2 from this field would thus be isotopically enriched. Site T1 shows $\delta^{13}C$ values that are representative of natural vegetation as this field is in fallow.

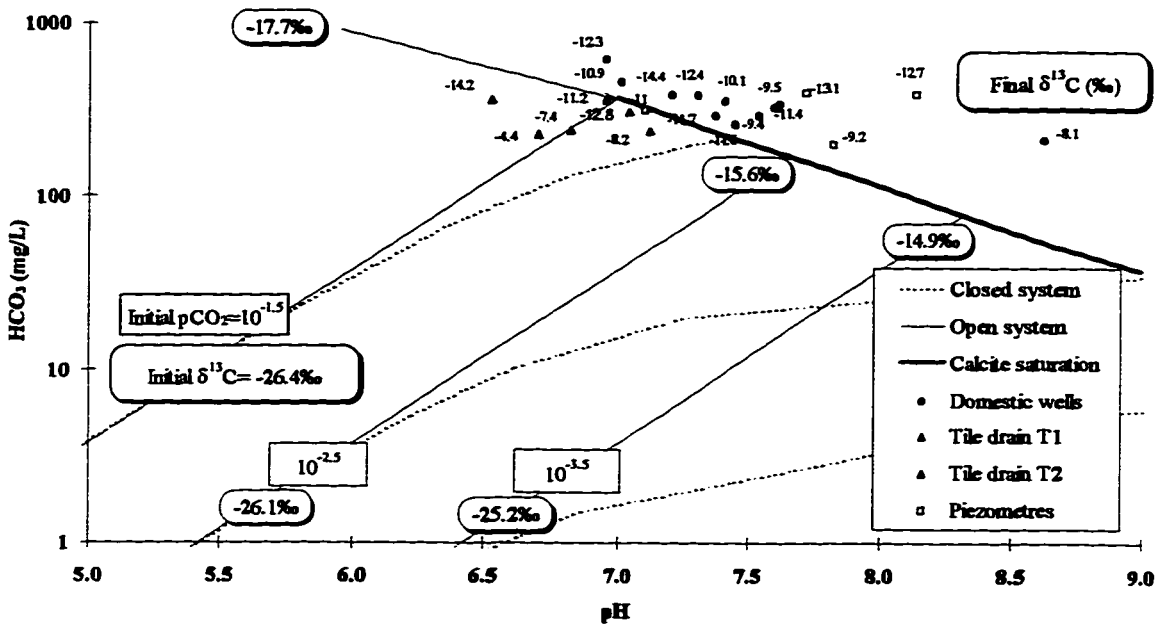


Figure 6.17. Geochemical evolution path for groundwater collected in the summer of 1994 under open and closed system dissolution of calcite.

Figure 6.18 shows the variable nature of ^{13}C in bedrock wells over time. This marked divergence can be attributed to three processes; i) the decay of C_4 plant types which incorporate a depleted ^{13}C signature (-12‰ to -14‰) relative to limestone (0‰), ii) limestone dissolution, whereby a mixing process between the infiltrating groundwater and dissolving calcium carbonate generates an enriched $\delta^{13}C$ signature in the groundwater, or iii) a combination of i) and ii). The temporal variation of $\delta^{13}C$ in Figure 6.18 is believed to originate from a combination of dissolved soil CO_2 from C_4 plant types, and dissolution of bedrock carbon, depending on the time of year.

Table 6.8 $\delta^{13}C$, DOC (*mg/L*), and nitrate (*mg/L*) values of selected bedrock wells (nd=not determined).

Date	Rain (mm)	G2 (‰)	G3 (‰)	G8 (‰)	Avg. $\delta^{13}C$ (‰)	G2 DOC	G3 DOC	G8 DOC	G9 DOC	G2 NO_3
7-May-94	61.2	-14.58	-13.36	-13.67	-13.87	133.4	76.4	48.2	27.9	30.4
3-Jun.-94	44.6	-14.12	-13.67	-13.86	-13.88	14.9	9.6	26.8	12.1	45.2
1-Jul.-94	65.9	-12.46	-9.49	-9.65	-10.53	9.3	3.9	11.9	5.0	32.6
29-Jul.-94	13.3	-13.35	-11.36	-10.90	-11.54	64.7	3.7	7.1	3.7	16.4
12-Aug.-95	20.2	-11.29	-10.97	-10.28	-10.85	5.5	15.1	6.5	6.6	8.8
23-Sept.-94	22.8	-10.97	-10.16	-9.30	-10.14	nd	nd	nd	nd	5.0
14-Oct.-94	44.4	-9.99	-8.80	-8.90	-9.23	nd	nd	nd	nd	4.7
15-Nov.-94	51.7	-10.93	-11.46	-10.40	-10.93	nd	nd	nd	nd	19.3
14-Dec.-94	21.6	-13.38	-12.80	-13.35	-13.18	nd	nd	nd	nd	12.8
16-Jan.-95	40.9	-13.79	-13.43	-13.88	-13.70	13.4	2.2	9.2	17.1	7.5
16-Feb.-95	3.0	-8.28	-7.39	-9.12	-8.26	4.9	nd	nd	11.0	9.7
15-Mar.-95	13.4	-11.83	-11.53	-11.13	-11.50	nd	nd	nd	nd	3.6
12-Apr.-95	26.6	-12.31	-11.09	-13.39	-12.26	10.0	nd	nd	nd	9.5
15-May-95	21.2	-14.44	-13.32	-13.71	-13.82	nd	nd	nd	nd	21.2
13-Jun.-95	51.0	-14.45	-12.88	-13.37	-13.57	nd	nd	nd	nd	23.1

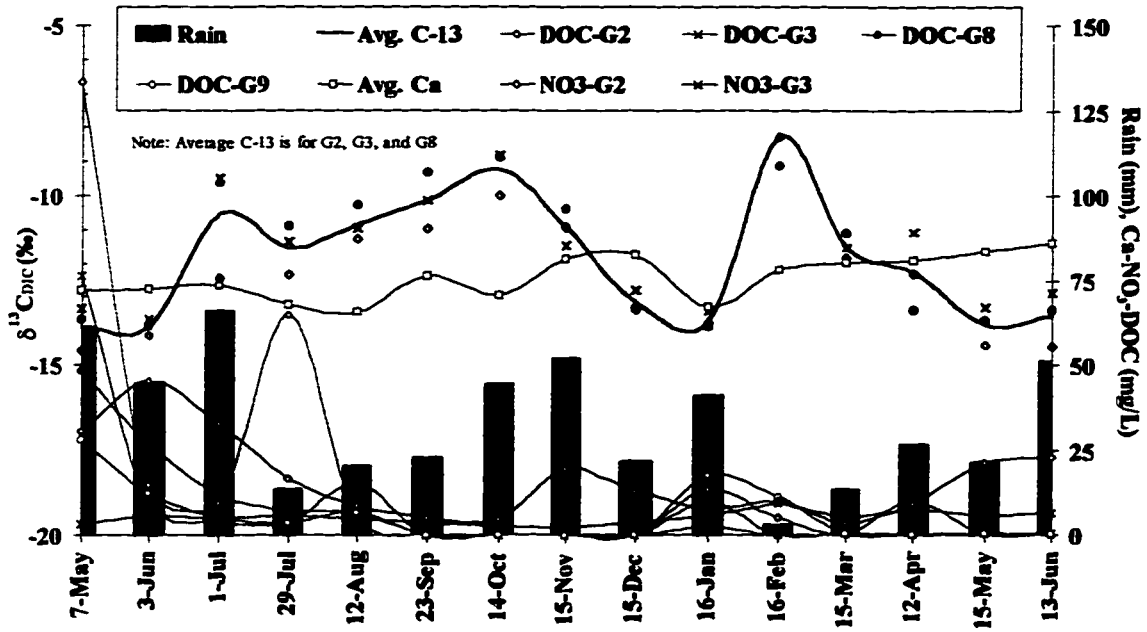


Figure 6.18. Temporal variation of $\delta^{13}C_{DIC}$ in bedrock wells compared to dissolved organic carbon (DOC) and nitrate fluctuations.

The temporal variation of $\delta^{13}C$ in bedrock wells displayed isotopically light values in the spring of 1994, corresponding to rapid groundwater movement through the bedrock aquifer (Table 6.8; Fig. 6.18). Partial carbonate dissolution from microfractures in the

bedrock contributed carbonate DIC to the flow of groundwater as $\delta^{13}C$ values became more enriched (-13‰ to -14‰) compared to infiltrating groundwaters (-17‰ to -21‰). The effect of soil CO_2 was minimal in the final $\delta^{13}C$ signature imparted by the groundwater as DOC was flushed through the system without having been oxidized by microorganisms. However, C_4 floral degradation over the winter added to the depleted nature of springtime $\delta^{13}C$ values as increased groundwater infiltration carried the ^{13}C signature into the bedrock aquifer. The onset of prolific microorganic and plant growth in June brought an increase in the production of soil CO_2. Soil biota oxidized most of the organic carbon as DOC values diminished into July 1994. In addition, nitrate reduction in well G2 showed decreasing nitrate levels throughout the summer. In July 1994, $\delta^{13}C$ values increased rapidly despite minimal DIC contributions from the bedrock as calcium concentrations remained constant. This sudden ^{13}C addition is attributed to increased fractionation of soil carbon produced by plant and microorganic growth. Since the saturated zone would have been lower than during the spring, oxidation by plant growth was enhanced as these tended to bind with the lighter ^{12}C molecule. A new influx of DOC from wells G2 and G3 occurred in July and August 1994, suggesting organic carbon from C_4 plants infiltrated the bedrock system depleting $\delta^{13}C$ values to approximately -11‰. Renewed oxidation of organic carbon increased the $\delta^{13}C$ signature to approximately -9‰ resulting from increased fractionation of the carbon system. The onset of fall showed $\delta^{13}C$ values were becoming increasingly depleted. Cooler temperatures during this time may have slowed the production of soil microorganisms capable of fractionating (and oxidizing) soil carbon. The result was an increase in nitrate and a decrease in ^{13}C levels (despite the absence of DOC) as groundwater $\delta^{13}C$ was influenced more by soil CO_2 than dissolution of bedrock. Groundwater contributions from the surficial aquifer were again evident in January of 1995 as the mid-winter thaw affected the entire watershed. DOC and nitrate concentrations were elevated, corresponding to maximum water levels during the field season. The dormancy of microorganisms in the soil zone fueled the DOC migration from surficial sediments into the bedrock aquifer. In addition, $\delta^{13}C$ values were highly depleted corresponding to the inclusion of ^{13}C within infiltrating groundwaters from decaying C_4

plants. Thus, it is unlikely that the $\delta^{13}C$ signature imparted by bedrock groundwaters in January 1995 was governed by even minimal dissolution of the limestone as calcium showed dilute concentrations within domestic wells. More seasonal conditions returned in February as the watershed sustained decreased groundwater flow ensuing a restoration of enriched $\delta^{13}C$ values. During this time, the bedrock aquifer suffered increased dissolution as shown by higher calcium concentrations where the groundwater $\delta^{13}C$ signature was governed solely by the incorporation of bedrock carbon. Renewed infiltration in the spring of 1995 showed an increase in nitrate levels and a regenerated interaction between the surficial and bedrock aquifers as depleted ^{13}C molecules from reduced C_4 plants replenished the bedrock aquifer.

The crosscorrelation between groundwater $\delta^{13}C$ values and DOC for domestic wells displays a negative correlation with no lag effect (Fig. 6.19). This suggests that periods of DOC infiltration are accompanied by an immediate decrease in groundwater $\delta^{13}C$ concentrations resulting from infiltration of ^{13}C molecules from C_4 plant decay.

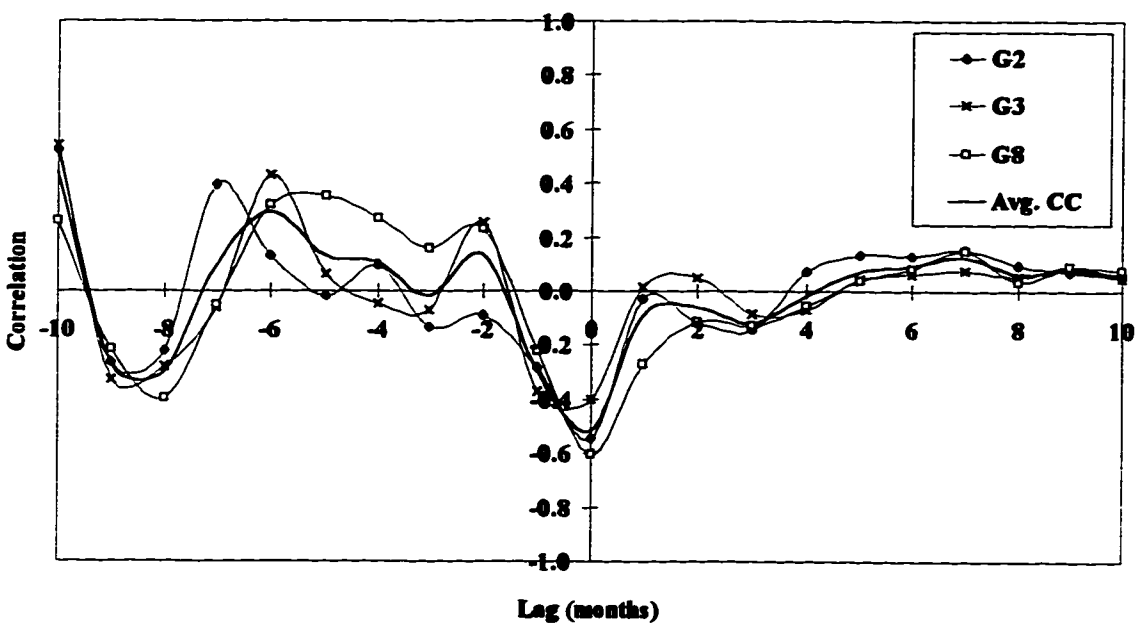


Figure 6.19. Crosscorrelation of ^{13}C and dissolved organic carbon for bedrock wells (*statistics in Appendix F6*).

6.4 Groundwater Contamination Zones

The identification of groundwater contamination zones addresses the presence of regional contaminant sources in high bedrock areas, which could eventually pollute domestic wells or aquatic systems lying within the groundwater flow path.

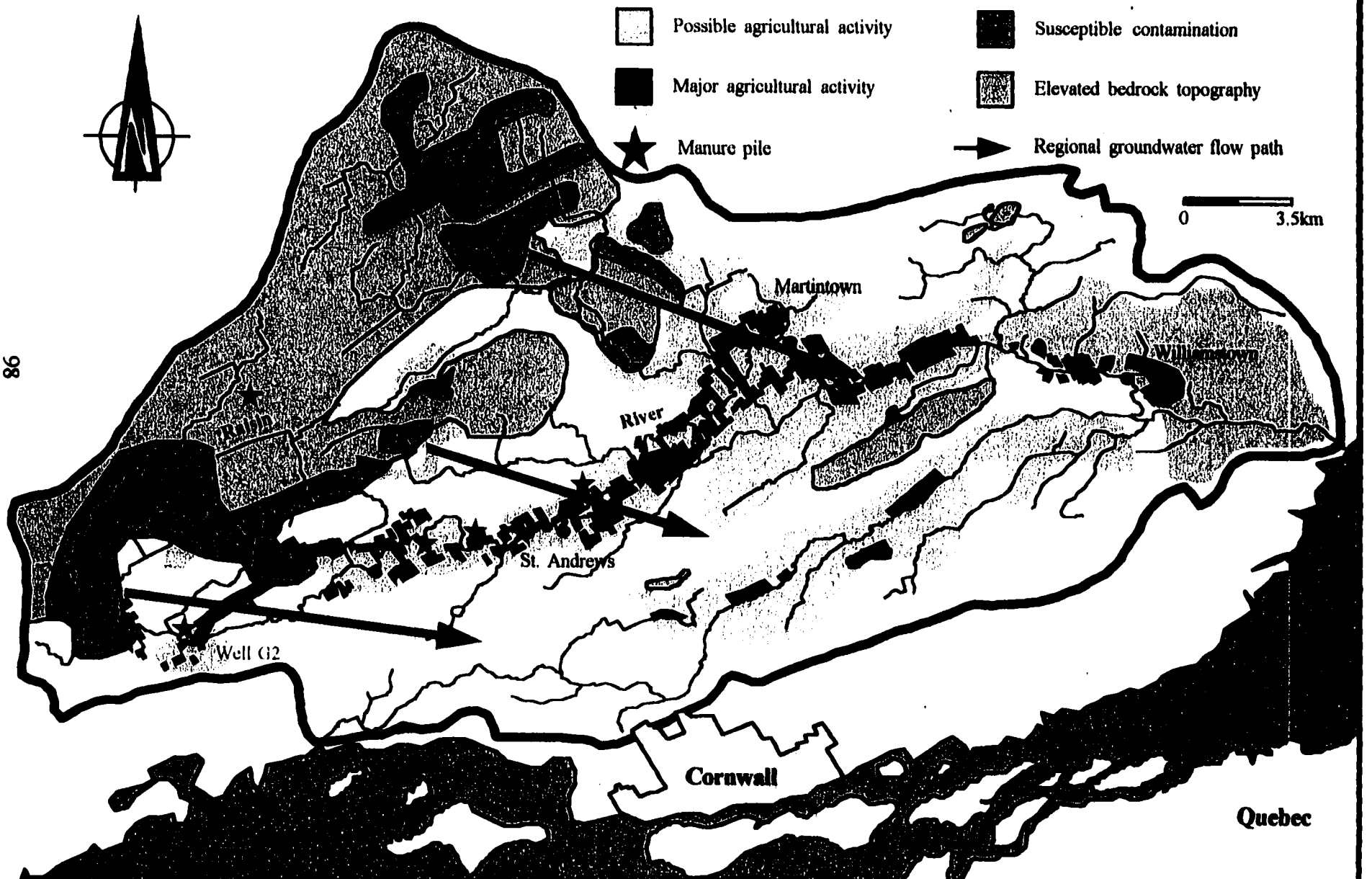
6.4.1 Regional Contamination Zones

The agriculture industry is the dominant practice on the Raisin River basin, posing a potentially major threat of groundwater contamination on a regional scale. The areal extent of agricultural activity is restricted along the main branch of the Raisin River, possibly due to the fertile nature of alluvium along its length (Fig. 1.5). However, the watershed contains several large areas which may be used for agricultural purposes (Fig. 1.5).

The Raisin River watershed has shown elevated sensitivity to periods of high groundwater flow. Crosscorrelations of air temperature and δ^2H for Raisin River water (Fig. 6.14) suggest that meteoric waters in the study area have an approximate shortest possible residence time of three months. Areas of high bedrock topography with little surficial deposits act as recharge areas, which are the potential zones of initial contaminant migration into the bedrock aquifer. However, these initial contamination zones are dependent on the distribution of land use practices. In addition, groundwater infiltration through surficial sediments has shown to be a major source of recharge to the bedrock aquifer. Thus, contaminant migration on a local scale must also be addressed.

The intersection of high bedrock topography (Fig. 3.1) with areas of potential or known agricultural activity (Fig. 1.5) shows that on a regional scale, initial contamination of the bedrock aquifer is restricted to the north and west of the study area (Fig. 6.20).

Figure 6.20. Agricultural areas susceptible to initial groundwater contamination.



Thus, groundwater infiltrating these areas is prone to contamination by pesticides and fertilizers within the basin. From there, agro-contaminants would follow the southeast trajectory of regional groundwater flow and contaminate wells along this path.

On a local scale, manure piles in the eastern portion of the study area act as potential contaminant sources during periods of increased groundwater flow such as the spring and periods of winter thaw.

Chapter 7: Groundwater Quality & Contaminant Pathways

Since watersheds are linked to the hydrological cycle, agro-contaminants infiltrating the Raisin River basin could ultimately discharge into the river and be transported to the St. Lawrence. Establishing groundwater quality in domestic wells and tile drains in the Raisin River basin is of prime importance in order to assess the presence or absence of contaminant migration through the system.

Table 7.1 displays environmental limits of contaminants used in the study area. Focus will be centered on nitrate and pesticides, including atrazine, metolachlor, and dicamba.

Table 7.1 Water quality objectives of contaminants for drinking water and aquatic life.

	Drinking Water	Aquatic Life	Reference
Temperature (^{0}C)	15 (max.)	-	ODWO,1994; McNeely *et al.*, 1979
pH	6.5-8.3	6.5-9.0	ODWO,1994; McNeely *et al.*, 1979
DOC (mg/L)	5.0	-	ODWO,1994
Nitrate (mg/L)	45.0	-	ODWO,1994; CWQG, 1987
Phosphate (mg/L)	0.2	0.1	McNeely *et al.*, 1979
		Metals	
Aluminum (mg/L)	0.10	0.10	ODWO,1994; McNeely *et al.*, 1979
Manganese (mg/L)	0.05	0.02	ODWO,1994; McNeely *et al.*, 1979
Iron (mg/L)	0.30	0.30	ODWO,1994; McNeely *et al.*, 1979
Cadmium (mg/L)	0.005	0.0002	ODWO,1994; McNeely *et al.*, 1979
Chromium (mg/L)	0.05	0.05	ODWO,1994; McNeely *et al.*, 1979
Copper (mg/L)	1.0	0.005	ODWO,1994; McNeely *et al.*, 1979
Lead (mg/L)	0.01	0.03	ODWO,1994; McNeely *et al.*, 1979
Zinc (mg/L)	5.0	0.03	ODWO,1994; McNeely *et al.*, 1979
		Pesticides	
Atrazine (mg/L)	0.005	0.002	ODWO,1994; CWQG, 1989
Metolachlor (mg/L)	0.05	0.008	ODWO,1994; CWQG, 1991
Dicamba (mg/L)	0.12	0.01	ODWO,1994; CWQG, 1993
Glyphosate (mg/L)	0.28	0.065	ODWO,1994; CWQG, 1989
Bromoxynil (mg/L)	0.005	0.005	ODWO,1994; CWQG, 1993
Butylate (mg/L)	-	-	
Permethrine (mg/L)	0.001	-	
Carbaryl (mg/L)	0.09	0.02	ODWO,1994; McNeely *et al.*, 1979
MCPA (mg/L)	0.1	0.0026	ODWO, 1994; CWQG, 1995
2-4DB (mg/L)	0.1	-	ODWO,1994
Metribuzin (mg/L)	0.08	0.001	ODWO,1994; CWQG, 1990

7.1 Groundwater Quality: Bedrock Wells

7.1.1 Nitrate

Nitrate was detected in 61% of domestic wells (8 of 13), although it was well below the maximum acceptable concentration (MAC) of 45 *mg/L* in 88% (7 of 8) of those wells (Table 7.2). Only well G2 shows appreciable quantities that exceed water quality standards for potable water. This well is located in the eastern part of the study area where bedrock is susceptible to initial groundwater contamination (Fig. 6.20). The contamination from this well is believed to originate from two manure piles located west of the well in the vicinity of a groundwater recharge zone. Groundwater flow towards the southeast may be contributing nitrate from these manure piles to well G2. The remaining wells showing presence of nitrate display concentrations that vary from 0.1 to 10 *mg/L*.

Table 7.2 Maximum nitrate concentrations in bedrock wells (MAC is 45*mg/L* NO_3).

Site	Date Collected	Value (*mg/L*)
G2	June 3, 1994	45.2
G3	February 16, 1995	9.4
G4	June 17, 1994	2.3
G7	February 16, 1995	3.0
G8	March 15, 1995	3.6
G10	May 7, 1994	1.2
G11	November 15, 1994	4.2
G11A	September 23, 1994	10.1

7.1.2 Phosphate

Phosphate was detected in 9 of the 13 domestic wells, however concentrations were well below the MAC for potable water. Table 7.3 displays phosphate levels found in domestic wells for spring 1995 samples.

Table 7.3 Maximum phosphorus (as PO_4^{3-}) concentration found in bedrock wells.

Site	Date collected	Concentration (*mg/L*)	times below MAC (potable water)	times below MAC (aquatic life)
G2	15-May-95	0.00	-	-
G3	15-May-95	0.01	20	10
G4	15-May-95	0.03	6.7	3.3
G5	15-May-95	0.01	20	10
G6	15-May-95	0.03	6.7	3.3
G7	3-June-94	0.03	6.7	3.3
G7	15-May-95	0.04	5.0	2.5
G7	13-June-95	0.03	6.7	3.3
G8	15-May-95	0.01	20	10
G9	15-May-95	0.01	20	10
G10	15-May-95	0.02	10	5.0
G11	15-May-95	0.01	20	10

7.1.3 Dissolved Organic Carbon (DOC)

DOC results show that values are extremely high, ranging from 3.7 to 133.4 *mg/L* (Fig. 7.1). Concentrations are highest during the springtime where values are 26, 15, 10, and 5 times over the MAC for potable water in wells G2, G3, G8, and G9, respectively (Table 7.4).

Table 7.4 Maximum DOC concentrations in bedrock wells (MAC for potable water is 5 *mg/L*).

Site	Date Collected	Value (*mg/L*)
G2	May 7, 1994	133.4
G3	May 7, 1994	76.4
G8	May 7, 1994	48.2
G9	May 7, 1994	27.9

The elevated DOC values in spring correspond to the inactivity of microorganisms which are unable to oxidize organic carbon in the soil zone. Groundwater infiltrating the surficial sediment acquires large amounts of DOC in early spring. Values subsequently

decline further into the summer as biological activity increases and reduction of organic carbon takes place.

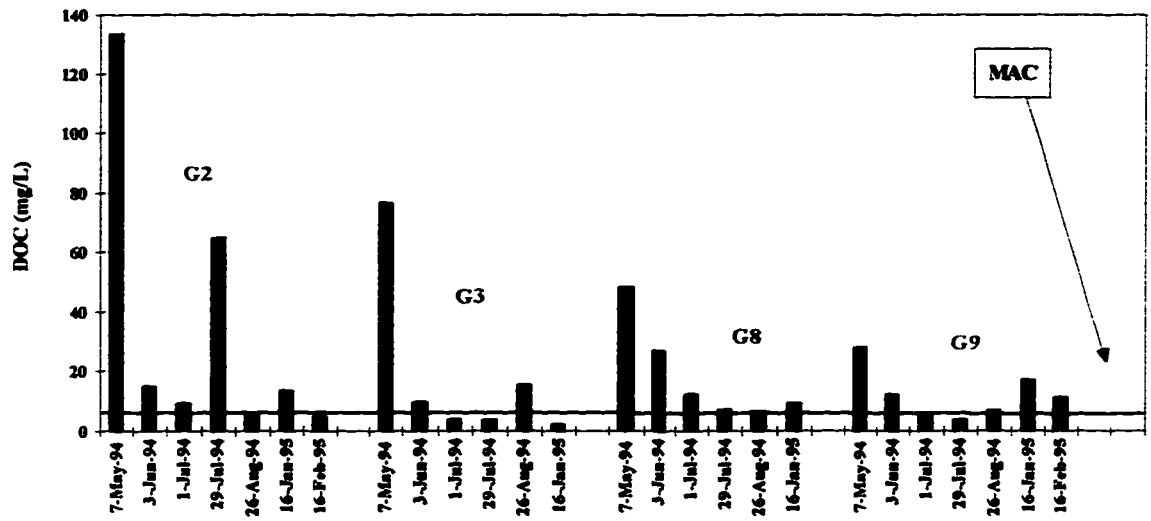


Figure 7.1. DOC concentrations in bedrock wells (MAC for drinking water=5mg/L).

7.1.4 Pesticides

Groundwater samples were collected for 8 wells during the spring of 1994 and 2 wells for the spring of 1995 during maximum groundwater flow periods following spring thaw (Fig. 5.7, p. 67). Pesticides selected for analysis included metolachlor, atrazine, dicamba, and glyphosate. These were selected based upon a survey conducted by the Department of Geography, University of Ottawa, and an informal survey by the author. No detectable levels of agricultural pesticides were found within the study area (*Appendix E5*).

7.1.5 Trace Metals

Only one well shows elevated trace metal concentrations. Site G4 displays iron levels up to three times above the MAC for potable water. The well owner reported a rusty looking film in the water, indicative of iron. The presence of iron in only one well would suggest a local effect possibly due to the dissolution of iron bearing carbonate minerals such as siderite.

Table 7.5 Trace metal detections in well G4 (all values in *mg/L*).

Site	Date Collected	Contaminant	Detection Limit	Value	MAC potable water
G4	21-May-94	Fe	0.005	0.945	0.30
	17-June-94	Fe	0.005	0.578	0.30
	15-July-94	Fe	0.005	0.722	0.30
	12-Aug.-94	Fe	0.005	0.307	0.30

7.2 Contaminant Pathway

The watershed's response to seasonality of recharge events displays the increased potential of groundwater contamination in bedrock wells. Despite this observation, groundwater quality in domestic wells remains good, showing no appreciable quantity of nitrate, pesticides, or trace metals. Pesticides and nitrate have been shown to occur in shallow aquifers similar to the Raisin River basin in several studies (Kolpin *et al.*, 1991; Rudolph & Goss, 1993). The lack of agro-contaminants in bedrock wells raises the question as to the fate of these agents once applied on fields. Focus will now be turned to the examination of pesticides and nitrate in soils, tile drainage effluent, and sediment, in order to determine their migration pathway in the subsystem.

7.2.1 Contaminants in Soils: Pesticides

Three sampling sessions were undertaken for soils during the 1994-95 field season in order to establish persistence and movement of agricultural pesticides through the soil horizon (Fig. 5.3 & 5.4, p. 60 & 61). Sampling trips were timed to follow the spring 1995 pesticide application period and again during the mid-growing season. The fall 1994 sampling session was undertaken to monitor pesticide persistence well after the cropping season. Table 7.6 presents the summer 1995 pesticide results.

Table 7.6 Pesticide concentrations (μg/g) for field soils collected during the summer of 1995 (Detection limits are; Atrazine=0.05, Dicamba=0.05, Metolachlor=0.05).

		June 15, 1995			July 1995		
Application date		Atrazine	Dicamba	Metolachlor	Atrazine	Dicamba	Metolachlor
G7F	Apr. 27	0.12	-	0.05	ND	-	0.30
G9F1	May 30	-	-	ND	-	-	0.30
G9F2	May 30	-	-	ND	-	-	0.20
P4F	June 5	-	0.57	ND	-	0.10	0.10
T3F	Apr. 24	0.16	-	0.22	ND	-	0.20
T4F	May 23	ND	0.082	ND	ND	ND	0.20

Soil samples were collected at a depth of 30 cm. While most samples had no detectable pesticide residues, some temporal variation is apparent. Between 10 and 49 days after application, atrazine and dicamba are present more often in the first sampling round than metolachlor (2 of 6 fields). More than one month after application, the second sampling session shows the absence of atrazine and dicamba in three cases (G7F, T3F, T4F). Dicamba is found at more than five times below its previous detection for P4F, thus showing the positive downward migration. However, metolachlor begins to reach the 30 cm depth more than two months after application for all 6 fields. An inverse proportionality exists between metolachlor and atrazine-dicamba. For fields sprayed with a combination of metolachlor and atrazine/dicamba, the first sampling round shows the presence of atrazine/dicamba at higher concentrations compared to the second sampling

round, whereas one month later the presence of metolachlor is at higher concentrations. Thus, the leaching potential of metolachlor is much lower than atrazine or dicamba.

In November 1994, six fields on the Raisin River watershed were sampled for pesticides applied during the previous spring (1994) (Table 7.7; Fig. 5.2, p. 58).

Table 7.7 Pesticide results for field soils collected on November 30th, 1994.

Site	Atrazine (µg/g) Detect. Limit=0.05	Metolachlor (µg/g) Detect. Limit=0.10	Application date
G2F	0.50	-	June 1994
G3F	0.31	ND	May 27, 1994 June 17, 1994
G8F	0.50	-	June 11, 1994
G9F1	0.13	ND	May 11, 1994 June 2, 1994
P4F	-	0.15	June 1, 1994

Of the six sampled fields, five register the presence of either atrazine or metolachlor at a depth of 30 cm six months after application. The presence of atrazine and absence of metolachlor is contrary to leaching potentials determined from Table 7.6. Under similar conditions, residual metolachlor should be found more often than atrazine at such a late time of year. The loss of metolachlor can be related to its degradation.

Metolachlor's soil half-life is approximately 30-50 days. With a concentration of 0.6 µg/g during application periods (May), the metolachlor concentration in July would be approximately 0.3 µg/g and would decrease to approximately 0.075 µg/g at the end of November, which is below detection. Atrazine persistence is variable and has been shown to remain in the soil system years after application (Smith, 1982).

7.2.2 Contaminants in Tile Drainage Effluent

7.2.2.1 Nitrate

Nitrate levels in all five tile drain sites exceeded maximum nitrate concentrations in bedrock wells (Table 7.2), in some cases by as much as 100 times (Table 7.8). Canadian Water Quality Guidelines (CWQG) (1987) does not state a recommended limit for aquatic life. However, reports of as little as 5 *mg/L* NO_3 can harm fish in freshwater environments (CWQG, 1987).

Nitrate is present in tile drainage effluent in increasing amounts during the spring where concentrations gradually rise from April and peak in June (Table 7.8; Fig. 7.2). However, fall fertilizer applications are practiced which is reflected in the elevated nitrate levels during November 1994.

Table 7.8 Nitrate levels (*mg/L*) in tile drainage effluent (Note; rain is a cumulative reading of the last 7 days prior to sampling).

Date	Rain (mm)	T1	T2	T3	T4	G7T	Avg.	Cumulative
3-Jun.-94	11.6	3.6	41.8	-	-	-	22.7	45.4
17-Jun.-94	20.4	7.3	43.4	-	-	-	25.4	50.7
1-Jul.-94	35.3	3.0	58.9	-	-	-	31.0	61.9
23-Sept.-94	4.2	-	11.1	30.0	-	-	20.6	41.1
7-Nov.-94	47.1	-	-	68.2	-	-	68.2	68.1
15-Nov.-94	2.4	1.89	-	55.7	4.0	-	20.5	61.6
16-Jan.-95	40.9	-	25.3	-	-	-	25.3	25.3
12-Apr.-95	21	4.1	36.2	41.6	1.7	-	21.0	83.5
15-May-95	21.2	7.7	-	62.1	6.0	-	25.3	75.8
13-Jun.-95	8.9	15.1	-	109.7	12.0	52.7	47.4	189.5

Rainfall appears to govern the amount of nitrate found in tile drainage effluent as the first six readings show a positive correlation of r^2=0.68 based on cumulative readings. Concentrations in the spring of 1995 show no correlation with rainfall amounts, since nitrate is inherently soluble given the slightest precipitation. Nevertheless, nitrate rises

substantially into June (1995) as a result of rainfall persistence. Since nitrogen fertilizers are applied in early to late April, the increases shown in Figure 7.2 are a reflection of the high solubility and mobility of this contaminant.

Despite the high nitrate levels being diverted into the Raisin River, surface water studies indicate dilution is taking place, as rates rarely exceed 7 *mg/L* NO_3^- (Watelet, 1996).

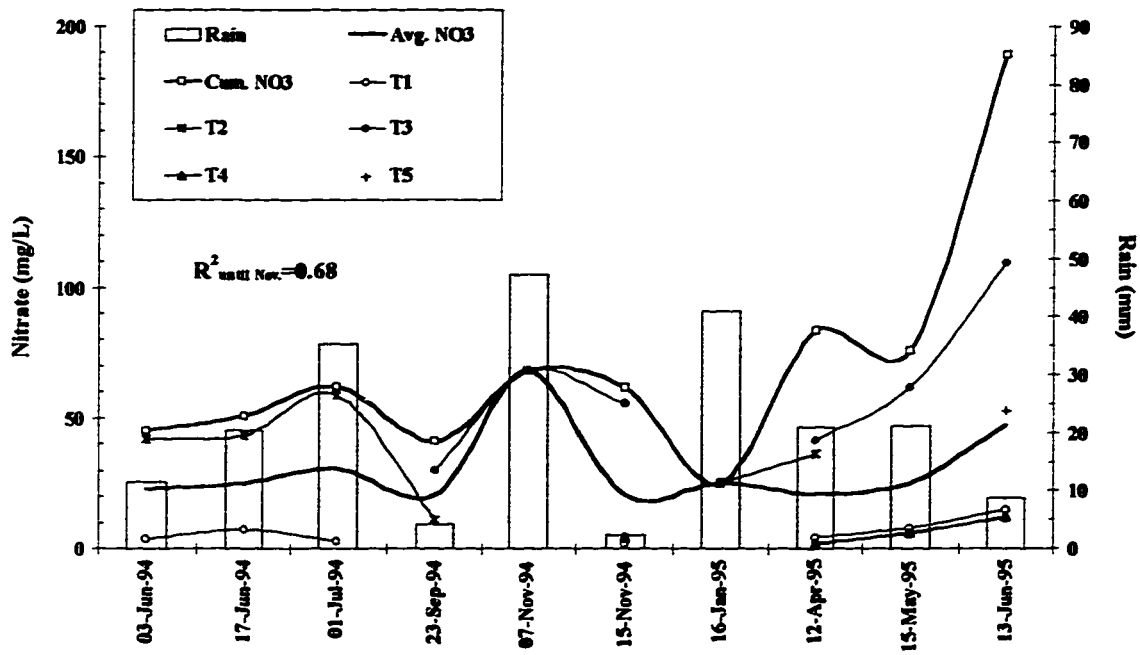


Figure 7.2. Average and cumulative nitrate levels in tile drainage effluent for the 1994-95 field season.

7.2.2.2 Phosphate

Dissolved hypophosphate (HPO_4^{2-}) was found to be below the detection limit of 0.3 *mg/L* using liquid chromatography. However, a lower detection limit of 0.01 *mg/L* was achieved for phosphate analyzed using a Hach DR2000 direct reading spectrophotometer. Concentrations in tile drains T1, T3 and T4 ranged from 0.01 to 0.04 *mg/L* PO_4^{3-} for May 1995 samples, and 0.01 to 0.02 *mg/L* for June samples. These concentrations are at least one order of magnitude below the MAC for aquatic life. However, actual phosphate levels in the system may be higher since it preferentially adheres to suspended sediment rather than being incorporated in the aqueous phase.

7.2.2.3 Dissolved Organic Carbon

DOC levels in tile drain T1 are elevated in the spring of 1994, whereas site T2 shows a partial increase into the summer (Table 7.9). Increasing DOC concentrations at site T1 are attributed to the flushing of organic carbon through the soil zone prior to organic reduction. Site T2 was agriculturally active as corn was planted during the spring (Plate 5-2, p. 48). Prior to this, the field was tilled and the addition of fertilizers was delayed allowing for more organic carbon to infiltrate the soil zone later in the season. However, microorganic activity was stimulated and DOC levels dropped into the fall. DOC levels compared to bedrock groundwaters also exceed the MAC for potable waters. However, no groundwater quality objectives have been set for aquatic life.

Table 7.9 DOC results (*mg/L*) in tile drainage effluent (detection limit=0.2 *mg/L*).

Date	T1	T2	T3
3-June-94	20.1	6.2	-
17-June-94	21.6	10.0	-
1-July-94	8.3	24.4	-
23-Sept.-94	<0.2	8.3	9.1
15-Nov.-94	<0.2	-	-

7.2.2.4 Pesticides

Several pesticides were selected for analysis in the tile drainage effluent, including atrazine, metolachlor, and dicamba (*Appendix E4*). Of the five sites selected for monitoring (Fig. 5.1, p. 47), site T3 was found to be draining dicamba on May 30th, 1995 at 2.7 ppm, and June 13th, 1995 at 2.3 ppm. The levels are over 270 times the MAC for aquatic life. Surface water samples collected during runoff and low flow periods indicate the presence of metolachlor below water quality objectives in 3 of 130 samples (Watelet, 1996). Thus, pesticides entering the Raisin River were strongly diluted.

7.2.2.5 Trace Metals

Zinc is the only trace metal found with any regularity in tile drainage effluent (Table 7.10; Fig. 7.3). It is found in pesticides and fertilizers (McNeely *et al.*, 1979), but may also be contributed from the alloy in tile drain pipe itself. Zinc solubility is extremely low, however increases with groundwater acidity. Concentrations are most common in the fall and spring due to increased groundwater flow (Fig. 7.3). Levels surpass up to 14 times the acceptable concentration for aquatic life between September and November 1994, and up to 30 times the MAC in April 1995.

Table 7.10 Zinc concentrations (*mg/L*) in tile drainage effluent. Detection limit is 0.006 *mg/L* and MAC for aquatic life is 0.03 *mg/L*.

Date Collected	T1	T2	T3	T4
3-Jun-94	<0.006	<0.006	-	-
17-Jun-94	<0.006	0.010	-	-
1-Jul-94	<0.006	<0.006	-	-
23-Sep-94	0.153	0.172	0.424	-
15-Nov-94	0.250	-	0.247	0.262
16-Jan-95	-	0.749	-	-
12-Apr-95	0.539	-	0.936	0.605
15-May-95	<0.006	-	<0.006	<0.006
13-Jun-95	<0.006	-	<0.006	<0.006

Site T2 also shows appreciable quantities in January corresponding to an increase in groundwater flow during the mid-winter thaw. Levels attain up to 25 times those permitted for aquatic life. Despite the high levels of zinc in tile drainage effluent, concentrations show diluted levels in the Raisin River, ranging from 0.007 *mg/L* to 0.025 *mg/L* (Watelet, 1996).

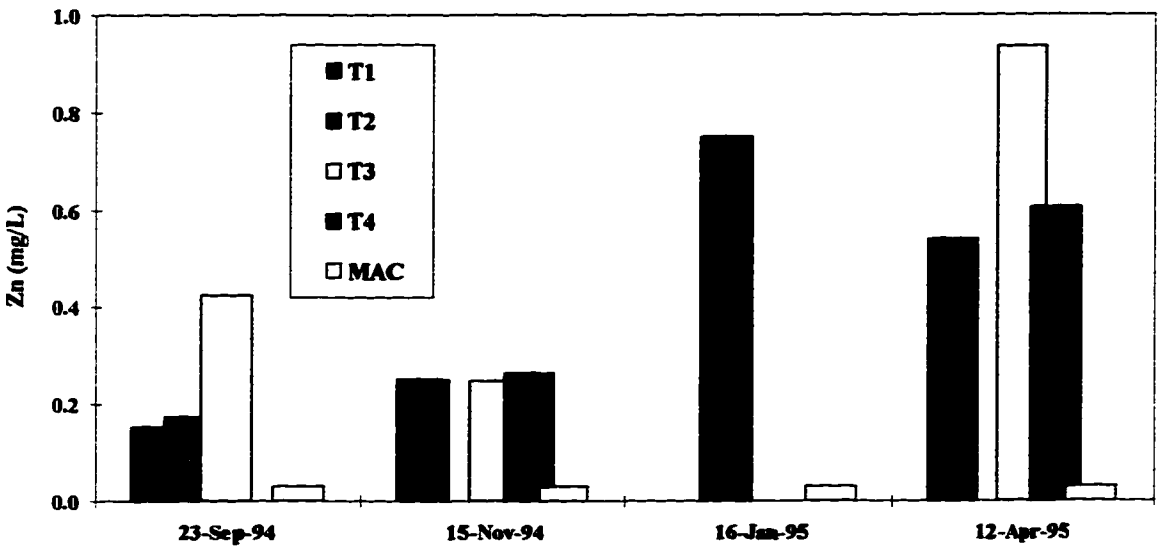


Figure 7.3. Zinc concentrations in tile drainage effluent. MAC for aquatic life is 0.03 *mg/L*.

7.2.3 Contaminants in Sediment: Pesticides

Two sampling trips were performed for sediment from the Raisin River riverbed along zones of agricultural activity. The first involved sampling four sites (G2S, G9S, G13S, T4S) for deep sediment and two sites (P4S, T3S) for shallow sediment (~5 cm) in July 1995 (Fig. 5.5, p. 63). These were analyzed for pesticides including atrazine, metolachlor, glyphosate, dicamba, and MCPA. The second sampling round was

performed for sediment from a shallow standpoint (~10 cm) for 10 sites in October 1995 (Fig. 5.6, p. 64). Metolachlor was selected for analysis in these samples.

Results for the July sampling round indicate the presence of metolachlor in one of four deep sites (G13S), and one shallow site (P4S) (Table 7.11). No other detectable traces of pesticides were observed both in the July and October trips.

Table 7.11 Pesticide levels (µg/g or ppm) in Raisin River sediment for July and October 1995 sampling rounds (nd=below detection).

	July 1995									
	G2S	G9S	G13S	G14S	G15S	G16S	G17S	T3S	T4S	P4S
Atrazine	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Metolachlor	nd	nd	0.2	nd	nd	nd	nd	nd	nd	0.1
Glyphosate	nd	nd	nd	nd	nd	nd	nd	nd	-	-
Dicamba	-	nd	nd	nd	nd	nd	nd	nd	nd	nd
MCPA	-	nd	nd	-	-	-	-	-	-	-
	October 1995									
Metolachlor	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd

Pesticide levels at site P4S (deep sediment) were 12 times over the MAC for aquatic life, indicating metolachlor was discharging into the river. Site T3 (shallow sediment) displayed levels that were 25 times over the MAC for aquatic life.

The presence of metolachlor at these two sites may be the effect of contaminant loading in the watershed. Gradients are steep between the fields and Raisin River elevation, contributing to increased groundwater flow in the spring (Plate 7-1, 7-2).

The presence of tile drains (G13F) confirmed by the owner may preclude any contaminant migration to depth. However, the use of this pesticide during previous cropping seasons is possibly leading to a long-term contaminant burden in the basin.

Plate 7-1. Site G13S & P4S (Plate 7-2) showing the steep gradient between the Raisin River and adjacent field. Note the corn above the river at both sites.

Plate 7-2. Site P4S is viewed from a bridge ~5 m high overlooking the Raisin River. Cornfield is sloping towards the River (Cemetary Road, North Branch of Raisin River).

Chapter 8: Conclusions

8.1 Groundwater Geochemistry

The geochemical evolution of groundwaters in the Raisin River basin can be traced from the early stages of meteoric infiltration to the later stages of bedrock interaction. Rainwaters show pH values of approximately 5.5 to 6.0 with major element concentrations below 20 *ppm* with the exception of bicarbonate which is close to 50 *ppm*. Tile drainage effluent shows that meteoric infiltration within the upper few metres of the soil horizon becomes enriched in major chemical species as carbonic acid (H_2CO_3) reacts with soil carbonate. Field pH values rise to approximately 6.5. Groundwaters in the limestone aquifer are buffered by further dissolution of calcite from bedrock. Here, pH values rise to approximately 7.5 and groundwater geochemistry is enriched in calcium, bicarbonate, and magnesium. All groundwaters are at saturation with respect to calcite. Only groundwaters in the southeastern portion of the basin have reached dolomite saturation, reflecting geochemical evolution within the dolomite bearing St. Martin formation.

8.2 Groundwater Recharge & Rates of Circulation

The surficial aquifer is responsive to individual recharge events as well as seasonal fluctuations placing it at high risk for pollution during spring melt and storm events.

Bedrock groundwaters originate from a combination of regional recharge in topographically elevated bedrock areas and local recharge from the infiltration of meteoric waters through surficial sediments. Local recharge is supported by an altitude effect in

deuterium values where higher elevated wells receive depleted δ^2H values from meteoric waters and lower elevated wells receive enriched δ^2H values. In addition, watershed deuterium values are enriched during the summer and more depleted during the spring, showing the seasonality of meteoric recharge. Bedrock aquifer groundwaters show no response in water level or δ^2H following storm events. This reflects the regional extent of this aquifer and that infiltration is through a thick unsaturated zone.

The variation in $\delta^{13}C_{DIC}$ shows that during the spring and summer, the dissolved inorganic carbon (DIC) pool is influenced by agricultural sources or the action of root respiration during corn growth. During winter months, the groundwaters are characterized by DIC of regional input. A dramatic shift in $\delta^{13}C$ was observed in February 1995 following a warm and rainy period. These fluctuations (positive shifts) in $\delta^{13}C_{DIC}$ are interpreted as evidence for periods of high rates of direct infiltration to the bedrock groundwaters where DOC from cultivated areas is oxidized and dissolves the bedrock medium.

Events such as spring runoff and winter thaws, which induce this increased groundwater movement through the surficial aquifer, place the bedrock aquifer at high risk for contamination during these periods. This strong seasonal variation in $\delta^{13}C_{DIC}$ is displayed by a parallel response in all wells.

8.3 Bedrock Aquifer Contamination Zones and Pathways

Areas of high groundwater contamination potential are situated in the northern and western zones of the watershed. These areas are characterized by agricultural activity overlying high bedrock topography, where the contaminant pathway would be shortened

given the shallow nature of surficial sediments. Although agricultural activity is limited on the north branch of the Raisin River, it is extensive along the main branch. This activity and the high susceptibility to contamination along the western part of the main branch is reflected by the presence of elevated nitrate concentrations in well G2 throughout the study period. Thus, zones of high bedrock topography intersecting major agricultural areas pose a direct threat to groundwater quality in bedrock wells. In addition, $\delta^{13}C$ provides evidence for seasonal inputs to the bedrock aquifer by direct infiltration through cultivated fields. This represents a diffuse source of agricultural contamination in bedrock groundwater.

8.4 Bedrock Groundwater Quality

The absence of agricultural pesticides, nitrate, and trace metals at contaminated levels in domestic wells shows that bedrock groundwaters have good overall quality. Atrazine, metolachlor, and several other pesticides were selected for analysis based on their use in the watershed. The lack of pesticides at detection limits 2.5 times below the MAC for potable water indicates the clear absence of pesticides in the bedrock aquifer.

Only one of 13 domestic wells showed the presence of elevated nitrate levels, varying between 3.6 and 45.2 *mg/L* NO_3^-. Concentrations were highest during the spring and fall corresponding to increased groundwater flow rates. Several other wells displayed the presence of nitrate, however concentrations remained well below the MAC of 45 *mg/L* NO_3^-, ranging between 0.1 and 10 *mg/L* as $N\text{-}NO_3^-$.

Maximum phosphorous concentrations were at least 5 times below the MAC for potable water. Levels ranged between 0.01 and 0.04 *mg/L* as PO_4^{3-}. These data represent groundwaters collected during the spring of 1995 which is assumed to be the likely time of year phosphorous would appear in domestic wells.

Trace metals such as cadmium, lead, and aluminum were found to be below analytical detection limits, although the limits available were above the MAC for potable water.

Dissolved organic carbon (DOC) was found at concentrations exceeding the aesthetic objective for drinking water by as much as 26 times, although most levels were below detection. The presence of elevated DOC in the spring of 1994 corresponded with increased infiltration rates, whereas lower concentrations were registered in the summer and fall. Winter values were below the 0.5 *mg/L* detection limit. The presence of DOC in the spring is attributed to the infiltration of agricultural by-products through the soil zone as inactive microorganisms were unable to oxidize the organic matter passing though surficial sediments. Despite the absence of pesticides, nitrate, and metals in the bedrock aquifer, the elevated presence of DOC during the spring of 1994 may be interpreted as demonstrating a potential pathway for pesticide infiltration to bedrock groundwaters.

8.5 Agricultural Drainage & Contaminant Fate

The absence of agro-contaminants in bedrock groundwaters is contrary to the findings in other watershed studies. Changes in agricultural practices over the past few years have included the installation of tile drains in fields to improve spring runoff and allow an earlier planting season. During the springtime and storm events when the water table is high and tile drains are functioning, agro-contaminants migrating through the soil column are intercepted by the tile drainage network and discharged directly into the Raisin River.

Pesticides were detected in tile drainage effluent only in the early summer, following late spring applications. Values were as high as 2.7 ppm or 270 times above the MAC for aquatic life. In addition, nitrate detections were most frequent and at highest

concentrations in the early summer, following fertilizer application periods. Concentrations were as high as 10 times (110 ppm) over the acceptable concentration for aquatic life. Trace concentrations of zinc, believed to originate from the tile drain alloy, were found throughout the year, with increases in concentration observed for high runoff periods in the winter and spring of 1995. Zinc levels attained up to 25 times above the MAC for aquatic life.

Despite the observed tile drain effluent data, dilution in the Raisin River maintains levels of pesticides, phosphate, nitrate, and trace metals below limits established for water quality objectives.

The relatively high quality of bedrock groundwater can be attributed to tile drains diverting agro-contaminants into the Raisin River during periods of high infiltration following spring melt and storm events. Nonetheless, a component of bedrock groundwater is recharged through the cultivated areas and represents a potential contaminant pathway.

The presence of pesticides in the Raisin River sediments may reflect contaminant loading from surface runoff and via tile drainage networks. Since pesticides are used throughout this intensively cultivated watershed, and crop rotation is practiced every two to three years, the system could be suffering from an overload of several years of pesticide use.

Chapter 9: Future Research

The previous research has attempted to answer a specific set of objectives based on the contamination potential and groundwater quality of the Raisin River Watershed. In dealing with these objectives, the following recommendations have been proposed for future work related to this watershed.

9.1 Punctual Contaminant Discharges to the Raisin River

The paucity of measurable pesticide levels for this study is possibly due to the flushing of contaminants from cultivated fields during spring melt in March. The Raisin River overflowed its banks during this time of year inundating tile drain spouts and preventing the sampling of effluent. Pesticide concentrations have been shown to rise dramatically in river waters during the first few days of spring thaw, only to decline as rapidly (Buttle & Harris, 1991; Richards & Baker, 1993). Thus, the 'window' for contaminant monitoring is approximately two weeks. Since tile drains are direct contributors of agro-contaminants to the Raisin River, they should be monitored more closely for actual nitrate, phosphate, and pesticide levels.

9.2 Raisin River Sediment

The detection of metolachlor in Raisin River sediments raises an additional question as to the actual source of the contaminant. Since one site found metolachlor at shallow levels, and the other from a deep source, actual identification on the method of transport is difficult. Several shallow sediment samples taken in the fall of 1995 showed

no detectable quantities of metolachlor. Thus, the possibility of a loading effect taking place, especially with a higher adsorptive pesticide, is a possibility. More detailed work is needed on the confirmation of widespread detections and actual depths from surface.

9.3 Trace Metal Source

Detection limits available for lead and cadmium in groundwater were above the maximum acceptable concentration standards imposed by Canadian Water Quality Guidelines. Future analyses should include analytical detection limits that are lower than water quality guidelines, in order to assess the presence of a metals contamination problem.

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Appendices

Appendix A1.1. Groundwater temperature values (° C)

Site	7-May-94	21-May-94	3-Jun-94	17-Jun-94	1-Jul-94	15-Jul-94	29-Jul-94	12-Aug-94	26-Aug-94	10-Sep-94
G1	4.4	3.9	2.5	-	4	4.8	5.1	7.3	9.7	9.5
G2	6.8	3.9	3.6	3.7	4	6.2	5.8	6.4	10.5	10.7
G3	6	3.9	3.8	3.7	3.7	3.7	3.9	4.1	9.8	9.9
G4	5.6	3.6	4	4.8	4	5	5.9	6.3	11.6	10.8
G5	10.6	3.8	3.8	4.3	3.9	3.8	3.7	3.0	9.3	9.3
G6	9.9	5.4	5.3	6.6	4	6.2	6.4	6.2	10.7	10.8
G7	3	3.2	4.1	4.7	3.7	4.7	-	6.4	11.6	12.0
G8	3.9	3.9	4.2	4.6	3.7	4.5	4.6	4.5	9.4	9.5
G9	5.7	4.3	4.8	5.1	3.7	4.6	5.2	5.2	11.1	11.6
G10	5.6	3.6	3.9	4.3	4	4.8	4.0	-	10.1	10.3
G11	-	-	-	4.8	3.7	7.2	8.2	7.0	12.4	10.5
G11a	-	-	-	11.2	3.7	9.3	11.3	10.0	15.3	13.7
G12	-	-	-	-	-	-	5.7	4.9	10.5	10.1
T1	-	-	2.8	4.9	6.8	dried up	-	-	-	-
T2	-	-	3.2	5.6	3.7	dried up	-	-	-	-
T3	-	-	-	-	-	-	-	-	-	-
T4	-	-	-	-	-	-	-	-	-	-
P1	-	-	-	-	-	6.2	7.2	-	13.1	-
P2	-	-	-	-	-	14.5	14.8	-	21.3	-
P3	-	-	-	-	-	17.4	-	-	26.5	-
P4	-	-	-	-	-	14.5	14.0	-	22.8	-

Appendix A1.1 (continued)

Site	23-Sep-94	15-Oct-94	15-Nov-94	15-Dec-94	15-Jan-95	15-Feb-95	15-Mar-95	12-Apr-95	15-May-95	13-Jun-95
G1	12.0	9.8	8.9	-	-	-	-	-	-	-
G2	12.5	11.9	10.3	8.1	7.6	8.6	7.3	18.2	17.7	17.4
G3	11.4	11.1	10.5	8.8	10.1	8.4	7.9	18.0	17.6	17.5
G4	12.2	11.8	11.3	8.3	9.9	8.4	7.3	18.2	17.6	17.5
G5	11.3	10.1	9.3	9.1	11.9	8.4	7.9	18.2	17.5	17.4
G6	12.2	12.2	11.3	8.7	7.7	9.7	7.6	18.1	17.6	17.5
G7	10.9	9.9	10.1	7.3	8.1	9.8	5.5	18.4	17.5	17.4
G8	10.6	9.3	9.0	7.7	10.5	10.4	5.6	18.2	17.5	17.4
G9	13.0	12.2	11.6	8.6	10.4	11.2	5.4	18.3	17.6	17.4
G10	12.5	10.0	10.2	8.4	10.0	10.9	4.2	18.2	17.3	17.4
G11	13.0	11.4	10.0	9.3	12.3	11.4	4.2	18.2	17.6	17.2
G11a	15.3	sealed well	-	-	-	-	-	-	-	-
G12	10.6	10.0	10.1	10.0	11.1	11.6	6.2	18.2	17.4	17.0
T1	15.5	dried up	9.9	-	-	-	-	17.8	17.1	17.6
T2	-	-	-	-	9.1	-	-	17.9	-	-
T3	15.6	dried up	8.7	-	-	-	-	18.0	17.2	17.3
T4	-	dried up	10.2	-	-	-	-	17.7	17.4	17.3
P1	14.4	12.2	10.7	-	-	-	-	-	17.5	17.4
P2	-	12.4	6.3	-	-	-	-	-	17.4	17.7
P3	16.0	8.8	10.1	-	-	-	-	-	-	-
P4	-	7.7	10.3	-	-	-	-	-	17.8	-

Appendix A1.2. Groundwater pH values

Site	7-May-94	21-May-94	3-Jun-94	17-Jun-94	1-Jul-94	15-Jul-94	29-Jul-94	12-Aug-94	26-Aug-94	10-Sep-94
G1	6.91	7.10	7.15	-	7.54	7.09	7.72	-	7.69	7.56
G2	7.90	7.18	7.47	7.30	7.37	7.08	7.90	-	7.40	7.34
G3	7.16	7.21	7.08	7.20	7.46	6.80	7.69	-	7.44	7.23
G4	7.06	7.04	6.98	7.01	7.17	6.77	7.58	-	7.25	7.09
G5	7.50	7.48	7.54	7.45	7.20	7.22	8.02	-	7.69	7.46
G6	8.25	8.30	8.53	8.62	8.59	8.08	9.05	-	8.67	8.42
G7	7.12	7.56	7.55	7.62	7.63	7.33	-	-	7.82	7.71
G8	7.10	7.32	7.00	7.37	7.26	6.93	7.55	-	7.41	7.41
G9	7.41	7.60	7.75	7.41	7.58	7.26	7.61	-	7.72	7.56
G10	7.09	7.79	7.32	7.60	7.49	7.65	8.11	-	7.75	7.54
G11	-	-	-	6.95	7.01	6.69	7.47	-	7.28	7.30
G11a	-	-	-	7.41	7.44	7.15	7.78	-	7.46	7.29
G12	-	-	-	-	-	-	8.05	-	7.41	7.33
T1	-	-	7.04	6.95	6.53	dried up	dried up	-	-	-
T2	-	-	7.12	6.70	6.82	dried up	dried up	-	-	-
T3	-	-	-	-	-	-	-	-	-	-
T4	-	-	-	-	-	-	-	-	-	-
P1	-	-	-	-	7.10	6.46	7.72	-	7.03	-
P2	-	-	-	-	-	7.10	8.14	-	7.45	-
P3	-	-	-	-	-	6.99	7.10	-	7.27	-
P4	-	-	-	-	-	7.04	7.82	-	7.20	-

Appendix A1.2 (continued)

Site	23-Sep-94	15-Oct-94	15-Nov-94	15-Dec-94	15-Jan-95	15-Feb-95	15-Mar-95	15-Apr-95	15-May-95	13-Jun-95
G1	7.94	7.50	7.50	-	-	-	-	-	-	-
G2	7.55	7.48	7.48	7.56	7.46	7.60	7.77	7.41	7.76	7.80
G3	7.66	7.33	7.33	7.46	7.45	7.32	7.57	7.34	7.77	7.91
G4	7.33	7.03	7.03	7.21	7.65	7.05	7.37	7.09	7.73	7.70
G5	7.86	7.47	7.47	7.63	7.49	7.50	7.83	7.61	7.95	8.02
G6	8.79	8.83	8.83	7.77	8.73	8.63	8.77	8.35	8.17	8.16
G7	7.92	7.70	7.70	7.62	7.74	7.63	7.97	7.66	7.87	8.03
G8	7.47	7.16	7.16	7.42	7.38	7.22	7.59	7.38	7.76	8.09
G9	7.81	7.44	7.44	7.73	7.93	7.30	7.64	7.74	8.34	8.30
G10	7.92	7.65	7.65	8.03	8.21	8.28	7.91	7.50	7.86	8.08
G11	7.85	7.31	7.31	7.34	7.00	7.12	7.55	7.16	7.65	7.68
G11a	7.64	-	-	-	-	-	-	-	-	-
G12	7.63	7.56	7.61	7.57	7.33	7.23	7.68	7.42	7.91	7.90
T1	7.85	-	7.04	-	-	-	-	7.23	7.60	7.65
T2	-	-	-	-	7.41	-	-	7.42	-	-
T3	7.92	-	8.12	-	-	-	-	7.81	7.59	7.80
T4	-	-	8.04	-	-	-	-	7.50	7.49	7.98
P1	7.19	7.12	7.00	-	-	-	-	7.64	7.36	7.36
P2	-	8.47	8.06	-	-	-	-	-	8.68	8.00
P3	7.58	7.31	7.24	-	-	-	-	-	-	-
P4	-	8.00	7.55	-	-	-	-	-	7.79	-

Appendix A2.1. Titrating sulphuric acid preparation

Two solutions are needed in the actual titration of the sulphuric acid titrating cartridge. The first solution is reducing a concentrated volume of sulphuric acid (36N) into a dilute concentration of sulphuric acid such as 1.938N, which will actually be our titrating acid during the bicarbonate alkalinity tests of our sampled groundwater. However, the purpose of the acid titration is to accurately assess the concentration of the sulphuric acid, which we have stated here to be 1.938N. In order to do this, we need a second solution consisting of sodium bicarbonate ($NaHCO_3$), which will be the titrated solution.

A2.1.1 Sulphuric acid titrating solution preparation

The preparation of the titrating sulphuric acid solution involves diluting a concentrated volume of sulphuric acid (36N) to a desired acid concentration, which we have stated would be 1.938N. Going back to our standard chemistry, we can use the relation the following relation to determine the total volume of concentrated acid we should use;

$$M_1V_1 = M_2V_2$$

where; M_1 =the concentration of concentrated acid (36N)
V_1=the volume of concentrated acid
M_2=the concentration of the dilute acid (1.938N)
V_2=the volume of dilute acid

For example, if we want to make the total volume of dilute acid 1000 *mL* (V_2), we would need 53.8 *mL* (V_1) of concentrated H_2SO_4 poured into a 1*L* volumetric flask, topped up to 1*L* with deionized water to give a concentration of 1.938N to our diluted sulfuric acid solution.

A2.1.2 Sodium Bicarbonate solution preparation

-add 13.7706 g of $NaHCO_3$ to a 1*L* volumetric flask
-top up flask with deionized water to 1*L* mark
-concentration of $NaHCO_3$ solution is now 0.164 *mole/L* or 0.164N through the following conversion

$$(NaHCO_3) = \frac{13.77g/LNaHCO_3}{84.01g/moleNaHCO_3}$$

$$(NaHCO_3) = 0.164mole/L$$

A2.1.3 Sulphuric Acid Titration

The titration of the "1.938N" sulphuric acid involves filling a 50 *mL* burette with the titrating sulphuric acid. The burette is held approximately 10cm above the surface area. Beneath the burette is placed a magnetic stirrer upon which is placed a 50 *mL* beaker containing 10ml of the prepared $NaHCO_3$ solution and a magnetic teflon bar. The stirrer is turned on so that the $NaHCO_3$ begins to swirl enough so that mixing occurs but no splashing. The end of the burette is adjusted so that it is placed a centimeter or two above the top of the beaker. Two drops of bromecresol green methyl red indicator are added to the $NaHCO_3$ solution. The initial volume on the burette is noted, and it is subsequently opened so that sulphuric acid is ejected into the beaker while the magnetic stirrer swirls the contents. Eventually, the color of the solution changes from green to pink, at which time the endpoint is reached and the burette is clamped shut. The final volume is noted on the burette, and the difference with the initial volume gives the amount of sulphuric acid used to reach the titrating endpoint. Table A1 displays the results of the titration experiment.

Table A1. Results of Sulphuric acid titration using $NaHCO_3$ as the titrated solution.

	V_1	M_1	V_2	M_2
Assay	Vol. $NaHCO_3$ (*mL*)	[$NaHCO_3$] N	Vol. H_2SO_4 (*mL*)	[H_2SO_4] N
1	10	0.164	8.4	1.952
2	10	0.164	8.5	1.941
3	10	0.164	8.5	1.941
4	10	0.164	8.8	1.864

The concentration of the titrating sulphuric acid is measured using the relationship,

$$M_1V_1 = M_2V_2$$

In Table A1, we see that the concentration of the titrating acid varies between 1.864N and 1.952N. The average of these results gives 1.925N H_2SO_4, which is close to the stated objective of 1.938N. Thus, the concentration of the sulphuric acid that we made up for the bicarbonate alkalinity measurement of our groundwater samples will be 1.925N.

Appendix A2.2. Bicarbonate Standard Check

In order to verify that our titration and the acid are functioning well, we do a bicarbonate standard verification much in the same way as *Appendix A2.1*. The process involves the preparation of a bicarbonate standard solution which can be readily prepared following *Appendix A2.1.2*. A 108.2 mg/l standard bicarbonate solution was prepared for this work's convenience. Using the 1.925N sulphuric acid cartridge and the Hach titration, 50ml of bicarbonate standard was placed into a beaker with bromecresol green methyl red indicator, and titrated. Table A2 displays the results for 3 assays tried on April 18, 1995.

Table A2. Background check of bicarbonate standard performed to establish error on sulphuric acid, April 18, 1995.

Assay	Vol. H_2SO_4 (ml)	$[H_2SO_4]N$	Vol. HCO_3^- (ml)	$[HCO_3^-]$ mg/l
1	0.045	1.925	50	105.7
2	0.0475	1.925	50	111.6
3	0.04625	1.925	50	108.6

Taking the average bicarbonate value gives 108.6mg/l. The standard deviation between assay 1, 2, and 3 is 4.4mg/l. Thus, the error attributed to each groundwater sample can be ±4.4mg/l.

Appendix A2.3. Groundwater alkalinity values (mg/L HCO_3^-)

Site	7-May-94	21-May-94	3-Jun-94	17-Jun-94	1-Jul-94	15-Jul-94	29-Jul-94	12-Aug-94	26-Aug-94	10-Sep-94
G1	366.0	359.9	329.4	-	294.0	291.6	270.8	281.8	294.5	282.7
G2	331.8	366.0	394.1	386.7	389.2	400.2	355.0	351.4	340.0	349.3
G3	335.5	331.8	355.0	386.7	358.7	369.7	369.7	355.0	346.3	336.0
G4	501.4	461.2	481.9	459.9	508.7	427.0	440.4	457.5	457.3	436.6
G5	242.8	245.0	242.8	262.3	279.4	262.3	258.6	256.2	273.8	266.4
G6	228.1	209.8	206.2	211.1	212.3	205.0	214.7	215.9	225.0	217.6
G7	336.7	345.3	341.6	340.4	336.7	342.8	350.1	331.8	415.9	324.1
G8	313.5	292.8	290.4	295.2	298.9	285.5	308.7	287.9	287.9	300.4
G9	345.3	372.1	345.3	356.2	363.6	350.1	357.5	356.2	358.2	361.1
G10	397.7	361.1	365.2	324.5	366.0	314.8	316.0	307.4	318.2	297.5
G11	-	-	-	623.0	644.2	541.7	549.0	500.2	479.5	432.2
G11a	-	-	-	324.5	505.1	416.0	406.3	381.9	403.8	482.5
G12	-	-	-	-	-	-	346.5	350.1	341.9	349.3
T1	-	-	307.4	359.9	363.6	dried up	-	-	-	-
T2	-	-	239.1	228.1	244.0	dried up	-	-	-	-
T3	-	-	-	-	-	-	-	-	-	-
T4	-	-	-	-	-	-	-	-	-	-
P1	-	-	-	-	417.0	402.6	394.1	407.5	433.6	398.1
P2	-	-	-	-	-	392.8	392.8	-	-	-
P3	-	-	-	-	383.1	402.6	316.0	329.4	313.8	322.6
P4	-	-	-	-	-	-	200.0	183.0	236.8	219.7

Appendix A2.3 (continued)

Site	23-Sep-94	15-Oct-94	15-Nov-94	15-Dec-94	15-Jan-95	15-Feb-95	15-Mar-95	15-Apr-95	15-May-95	13-Jun-95
G1	284.2	272.3	281.2	-	-	-	-	-	-	-
G2	378.9	352.2	398.1	361.1	375.9	364.1	343.4	349.3	374.1	274.5
G3	322.6	353.7	355.2	337.4	373.0	328.6	343.4	328.6	351.4	306.7
G4	426.2	449.9	583.1	589.0	449.9	444.0	447.0	500.2	463.6	442.1
G5	247.2	260.5	315.2	278.2	278.2	293.0	248.6	281.2	239.1	270.8
G6	213.1	201.3	222.0	251.6	207.2	219.0	204.2	219.0	217.6	194.7
G7	325.6	340.4	352.2	331.5	346.3	325.6	307.8	337.4	336.7	329.6
G8	293.0	319.7	325.6	301.9	313.8	293.0	278.2	304.9	285.5	284.0
G9	368.5	378.9	368.5	361.1	266.4	322.6	340.4	378.9	307.4	330.9
G10	307.8	330.0	340.4	230.9	254.6	219.0	310.8	381.8	341.6	300.1
G11	449.9	367.0	482.5	532.8	74.0	447.0	400.0	497.3	497.8	466.0
G11a	316.7	-	-	-	-	-	-	-	-	-
G12	356.7	384.8	386.3	349.3	337.4	331.5	322.6	358.2	322.1	348.6
T1	321.2	-	390.7	-	-	-	-	322.6	329.4	292.8
T2	122.8	-	-	-	65.1	-	-	233.8	-	-
T3	296.0	-	312.3	-	-	-	-	316.7	278.2	205.0
T4	-	-	420.3	-	-	-	-	393.7	397.2	380.6
P1	402.6	430.7	461.8	-	-	-	-	393.9	348.9	424.6
P2	296.0	278.2	278.2	-	-	-	-	259.0	234.0	266.4
P3	330.0	370.0	358.2	-	-	-	-	-	-	-
P4	220.0	198.3	389.2	-	-	-	-	-	492.9	-

Appendix A3. Groundwater conductivity values (ms/cm)

Total dissolved solids (TDS)=conductivity*0.5/1000

Site	7-May-94	21-May-94	3-Jun-94	17-Jun-94	1-Jul-94	15-Jul-94	29-Jul-94	12-Aug-94	26-Aug-94	10-Sep-94
G1	-	-	-	-	0.500	-	0.480	-	0.481	0.473
G2	0.685	-	0.503	-	0.932	-	0.741	-	0.652	-
G3	0.553	0.544	0.523	0.580	0.534	0.578	0.573	0.569	0.564	-
G4	1.15	-	0.987	-	1.053	-	0.996	-	1.034	-
G5	0.412	-	0.428	-	0.463	-	0.437	-	0.422	-
G6	0.398	-	0.397	-	0.387	-	0.410	-	0.396	-
G7	-	-	-	-	-	-	-	-	-	-
G8	0.469	-	0.481	-	0.471	-	0.459	-	0.483	-
G9	-	0.932	-	0.906	-	0.920	-	0.922	-	0.929
G10	-	0.635	-	0.514	-	0.633	-	0.597	-	0.595
G11	-	-	-	0.522	-	0.697	-	0.708	-	0.706
G11a	-	-	-	-	-	-	-	-	-	-
G12	-	-	-	-	-	-	-	-	-	-
T1	-	-	-	-	-	-	-	-	-	-
T2	-	-	-	-	-	-	-	-	-	-
T3	-	-	-	-	-	-	-	-	-	-
T4	-	-	-	-	-	-	-	-	-	-
P1P	-	-	-	-	-	-	-	-	-	-
P2P	-	-	-	-	-	-	-	-	-	-
P3P	-	-	-	-	-	-	-	-	-	-
P4P	-	-	-	-	-	-	-	-	-	-

Appendix A3 (continued)

Site	23-Sep-94	15-Oct-94	15-Nov-94	15-Dec-94	15-Jan-95	15-Feb-95	15-Mar-95	15-Apr-95	15-May-95	13-Jun-95
G1	0.56	0.55	0.56	-	-	-	-	-	-	-
G2	0.76	0.75	0.80	0.77	0.69	0.80	0.80	0.81	0.829	0.817
G3	0.64	0.66	0.65	0.64	0.60	0.67	0.76	0.67	0.681	0.664
G4	1.06	1.11	1.32	1.30	0.98	1.24	1.20	1.22	1.213	1.262
G5	0.47	0.46	0.54	0.50	0.49	0.51	0.51	0.47	0.466	0.494
G6	0.41	0.40	0.41	0.39	0.38	0.42	0.44	0.41	0.4	0.386
G7	0.58	0.57	0.58	0.60	0.57	0.66	0.59	0.65	0.61	0.62
G8	0.55	0.55	0.57	0.58	0.57	0.60	0.62	0.59	0.56	0.556
G9	0.92	0.93	0.91	0.98	0.67	0.94	0.99	1.01	0.79	0.972
G10	0.59	0.59	0.62	0.63	0.48	0.64	0.68	0.75	0.69	0.631
G11	0.86	0.75	0.91	1.06	0.14	1.04	1.04	1.02	1.02	1.03
G11a	0.81	-	-	-	-	-	-	-	-	-
G12	0.77	0.76	0.77	0.77	0.74	0.82	0.84	0.82	0.80	0.765
T1	1.05	-	1.21	-	-	-	-	0.75	0.99	1.022
T2	-	-	-	-	0.20	-	-	0.58	-	-
T3	0.57	-	0.61	-	-	-	-	0.60	0.61	0.646
T4	-	-	0.88	-	-	-	-	0.99	0.97	0.831
P1P	0.78	0.77	0.79	-	-	-	-	0.38	0.76	0.739
P2P	-	0.44	0.45	-	-	-	-	-	-	-
P3P	0.59	0.62	0.74	-	-	-	-	-	-	-
P4P	-	0.86	0.90	-	-	-	-	-	-	-

Appendix A4. Water level values (m.a.s.l)

Site	15-Jul-94	29-Jul-94	12-Aug-94	26-Aug-94	10-Sep-94	23-Sep-94	15-Oct-94	15-Nov-94	15-Dec-94	15-Jan-95	15-Feb-95	15-Mar-95
G2	58.06	57.70	57.22	56.82	56.52	56.63	56.44	57.10	57.80	57.85	57.72	57.81
G4	64.35	64.27	64.69	64.68	64.70	66.00	66.05	66.65	67.01	67.57	66.58	67.23
G5	85.55	85.20	85.16	84.41	82.75	85.24	85.28	85.79	85.91	85.88	85.58	86.06
G8	47.70	47.38	47.30	47.22	47.08	46.06	47.17	47.25	47.26	47.27	47.71	48.77
G9	58.64	58.16	58.34	58.10	58.21	58.49	58.40	60.18	60.45	60.97	59.01	60.80
G10	50.40	50.21	49.98	50.10	50.00	49.96	49.91	50.12	50.40	51.60	50.31	51.13
G11	89.53	89.60	89.12	88.95	87.84	87.80	88.28	89.99	90.25	90.60	89.55	89.90
G11a	90.56	90.80	90.38	90.20	89.98	90.23	sealed well	-	-	-	-	-

Site	12-Apr-95	15-May-95	13-Jun-95	11-Jul-95
G2	58.34	58.47	57.94	57.48
G4	66.89	66.64	66.78	65.74
G5	85.67	85.63	85.44	85.14
G8	48.18	47.93	47.93	47.37
G9	60.73	60.62	59.17	59.97
G10	50.53	50.48	50.38	49.93
G11	90.30	90.55	89.79	88.20
G11a	-	-	-	-

Appendix B1. High pressure liquid chromatography results of selected anions (mg/L or ppm)

	Well G1								Well G2							
	F^-	Cl^-	NO_2^-	Br^-	NO_3^-	HPO_4^-	SO_4^{2-}	HCO_3^-	F^-	Cl^-	NO_2^-	Br^-	NO_3^-	HPO_4^-	SO_4^{2-}	HCO_3^-
detection limit=	0.07	0.2	0.3	0.2	0.3	0.3	0.4		0.07	0.2	0.3	0.2	0.3	0.3	0.4	
7-May-94	<0.07	54.0	<0.3	<0.2	<0.3	<0.3	28.4	366.0	<0.07	35.7	<0.3	<0.2	30.4	<0.3	42.4	331.8
21-May-94	<0.07	161.1	<0.3	<0.2	<0.3	<0.3	28.0	359.9	0.15	42.1	<0.3	<0.2	38.2	<0.3	39.1	366.0
3-Jun-94	<0.07	253.2	<0.3	<0.2	<0.3	<0.3	27.1	329.4	0.15	45.2	0.6	<0.2	45.2	<0.3	38.6	394.1
17-Jun-94	-	-	-	-	-	-	-	-	<0.07	46.7	<0.3	<0.2	41.9	<0.3	42.1	386.7
1-Jul-94	<0.07	15.3	<0.3	<0.2	<0.3	<0.3	43.8	294.0	<0.07	46.9	<0.3	<0.2	32.6	<0.3	53.7	389.2
15-Jul-94	<0.07	14.6	<0.3	<0.2	<0.3	<0.3	41.8	291.6	<0.07	49.3	<0.3	<0.2	41.0	<0.3	43.5	400.2
29-Jul-94	<0.07	15.9	<0.3	<0.2	<0.3	<0.3	43.8	270.8	<0.07	36.4	<0.3	<0.2	16.4	<0.3	56.5	355.0
12-Aug-94	<0.07	14.2	<0.3	<0.2	<0.3	<0.3	42.4	281.8	<0.07	31.9	<0.3	<0.2	8.8	<0.3	63.0	351.4
26-Aug-94	0.28	15.5	<0.3	<0.2	<0.3	<0.3	43.8	294.5	<0.07	30.9	<0.3	<0.2	5.3	<0.3	63.8	340.0
10-Sep-94	<0.07	15.5	<0.3	<0.2	<0.3	<0.3	42.0	282.7	<0.07	31.9	<0.3	<0.2	5.1	<0.3	64.9	349.3
23-Sep-94	0.25	13.3	<0.05	<0.05	<0.05	<0.3	42.2	284.2	0.21	30.4	<0.05	<0.05	5.0	<0.3	70.9	378.9
15-Oct-94	0.15	13.8	<0.3	<0.2	<0.3	<0.3	42.5	272.3	<0.07	31.8	<0.3	<0.2	4.7	<0.3	76.1	352.2
15-Nov-94	0.25	12.9	<0.05	<0.05	<0.05	<0.3	43.5	281.2	0.22	40.0	<0.05	<0.05	19.3	<0.3	55.8	398.1
15-Dec-94	-	-	-	-	-	-	-	-	<0.07	33.8	<0.3	<0.2	12.8	<0.3	65.0	361.1
16-Jan-95	-	-	-	-	-	-	-	-	<0.07	28.7	<0.3	<0.2	7.5	<0.3	64.0	375.9
16-Feb-95	-	-	-	-	-	-	-	-	0.21	30.2	<0.05	<0.05	9.65	<0.3	56.2	364.1
15-Mar-95	-	-	-	-	-	-	-	-	<0.05	29.2	<0.05	<0.05	3.64	<0.3	64.6	343.4
12-Apr-95	-	-	-	-	-	-	-	-	<0.05	35.6	<0.05	<0.05	9.48	<0.3	65.3	349.3
15-May-95	-	-	-	-	-	-	-	-	<0.05	38.0	<0.05	<0.05	21.23	<0.3	55.2	374.1
13-Jun-95	-	-	-	-	-	-	-	-	<0.05	37.5	<0.05	<0.05	23.14	<0.3	49.8	274.5

	Well G3								Well G4							
	F^-	Cl^-	NO_2^-	Br^-	NO_3^-	HPO_4^-	SO_4^{2-}	HCO_3^-	F^-	Cl^-	NO_2^-	Br^-	NO_3^-	HPO_4^-	SO_4^{2-}	HCO_3^-
detection limit=	0.07	0.2	0.3	0.2	0.3	0.3	0.4		0.07	0.2	0.3	0.2	0.3	0.3	0.4	
7-May-94	<0.07	12.8	<0.3	<0.2	3.4	<0.3	56.4	335.5	<0.07	66.1	<0.3	<0.2	0.0	<0.3	144.6	501.4
21-May-94	<0.07	11.4	0.7	<0.2	5.9	<0.3	48.2	331.8	<0.07	62.7	<0.3	<0.2	0.0	<0.3	131.0	461.2
3-Jun-94	<0.07	12.8	0.2	<0.2	5.8	<0.3	56.6	355.0	<0.07	65.0	<0.3	0.2	0.0	<0.3	134.9	481.9
17-Jun-94	<0.07	15.0	<0.3	<0.2	4.4	<0.3	58.5	386.7	<0.07	62.7	<0.3	0.2	2.3	<0.3	133.6	459.9
1-Jul-94	<0.07	15.3	<0.3	<0.2	4.8	<0.3	53.9	358.7	<0.07	67.8	<0.3	<0.2	0.0	<0.3	149.0	508.7
15-Jul-94	<0.07	15.2	<0.3	<0.2	5.0	<0.3	58.8	369.7	<0.07	59.1	<0.3	<0.2	0.0	<0.3	122.5	427.0
29-Jul-94	<0.07	14.6	<0.3	<0.2	5.6	<0.3	56.7	369.7	<0.07	61.3	<0.3	<0.2	0.1	<0.3	129.1	440.4
12-Aug-94	<0.07	14.4	<0.3	<0.2	4.7	<0.3	58.9	355.0	<0.07	61.8	<0.3	<0.2	0.1	<0.3	131.1	457.5
26-Aug-94	<0.07	12.1	<0.3	<0.2	5.0	<0.3	60.7	346.3	<0.07	62.3	<0.3	0.2	0.2	<0.3	131.5	457.3
10-Sep-94	<0.07	12.4	<0.3	<0.2	3.8	<0.3	59.7	336.0	<0.07	59.1	<0.3	0.6	0.2	<0.3	121.0	436.6
23-Sep-94	0.21	8.76	<0.05	<0.05	3.50	<0.3	57.6	322.6	<0.05	67.64	<0.05	<0.05	0.09	<0.3	121.4	426.2
15-Oct-94	0.14	12.0	<0.3	<0.2	2.6	<0.3	62.6	353.7	<0.07	59.0	<0.3	0.1	0.2	<0.3	136.5	449.9
15-Nov-94	0.25	9.1	<0.05	<0.05	2.05	<0.3	60.4	355.2	<0.05	67.65	<0.05	<0.05	<0.05	<0.3	154.7	583.1
15-Dec-94	<0.07	9.3	<0.3	<0.2	3.7	<0.3	59.4	337.4	<0.07	68.8	<0.3	<0.2	<0.3	<0.3	164.8	589.0
16-Jan-95	<0.07	11.0	<0.3	<0.2	5.4	<0.3	57.2	373.0	<0.07	58.7	<0.3	0.1	0.0	<0.3	120.5	449.9
16-Feb-95	0.23	9.4	<0.05	<0.05	9.36	<0.3	56.6	328.6	<0.05	57.88	<0.05	<0.05	<0.05	<0.3	138.0	444
15-Mar-95	<0.05	14.5	<0.05	<0.05	4.70	<0.3	55.0	343.4	<0.05	56.84	<0.05	<0.05	0.30	<0.3	133.8	447
12-Apr-95	<0.05	9.6	<0.05	<0.05	7.98	<0.3	58.3	328.6	<0.05	60.13	<0.05	<0.05	<0.05	<0.3	140.3	500.2
15-May-95	<0.05	12.0	<0.05	<0.05	5.39	<0.3	58.8	351.4	<0.05	60.1	<0.05	0.07	0.23	<0.3	142.5	463.6
13-Jun-95	<0.05	10.5	<0.05	<0.05	6.31	<0.3	59.9	306.7	<0.05	64.2	<0.05	<0.05	<0.05	<0.3	152.4	442.1

Appendix B1 (continued)

	Well G5								Well G6							
	F^-	Cl^-	NO_2^-	Br^-	NO_3^-	HPO_4^-	SO_4^{2-}	HCO_3^-	F^-	Cl^-	NO_2^-	Br^-	NO_3^-	HPO_4^-	SO_4^{2-}	HCO_3^-
detection limit=	0.07	0.2	0.3	0.2	0.3	0.3	0.4		0.07	0.2	0.3	0.2	0.3	0.3	0.4	
7-May-94	0.30	4.9	<0.3	<0.2	<0.3	<0.3	31.6	242.8	0.85	9.3	<0.3	<0.2	<0.3	<0.3	23.9	228.1
21-May-94	<0.07	4.7	<0.3	<0.2	<0.3	<0.3	28.5	245.0	0.81	8.0	<0.3	<0.2	<0.3	<0.3	23.4	209.8
3-Jun-94	0.27	4.5	<0.3	<0.2	<0.3	<0.3	30.5	242.8	0.87	8.8	<0.3	<0.2	<0.3	<0.3	24.0	206.2
17-Jun-94	0.28	4.2	<0.3	<0.2	<0.3	<0.3	35.1	262.3	0.74	5.9	<0.3	<0.2	<0.3	<0.3	23.8	211.1
1-Jul-94	0.22	4.9	<0.3	<0.2	<0.3	<0.3	32.1	279.4	0.79	6.7	<0.3	<0.2	<0.3	<0.3	22.5	212.3
15-Jul-94	0.34	4.9	<0.3	<0.2	<0.3	<0.3	31.2	262.3	0.86	8.5	<0.3	<0.2	<0.3	<0.3	22.7	205.0
29-Jul-94	0.31	5.3	<0.3	<0.2	<0.3	<0.3	30.7	258.6	0.84	11.0	<0.3	<0.2	<0.3	<0.3	22.7	214.7
12-Aug-94	0.32	5.5	<0.3	<0.2	<0.3	<0.3	30.2	256.2	0.79	9.1	<0.3	<0.2	<0.3	<0.3	22.5	215.9
26-Aug-94	0.31	5.5	<0.3	<0.2	<0.3	<0.3	30.2	273.8	0.74	8.0	<0.3	<0.2	<0.3	<0.3	24.0	225.0
10-Sep-94	0.35	6.0	<0.3	<0.2	<0.3	<0.3	29.2	266.4	0.80	9.6	<0.3	<0.2	<0.3	<0.3	22.2	217.6
23-Sep-94	0.37	4.51	<0.05	<0.05	<0.05	<0.3	28.9	247.2	1.37	9.80	<0.05	<0.05	<0.05	<0.3	24.0	213.1
15-Oct-94	0.22	5.3	<0.3	<0.2	<0.3	<0.3	29.7	260.5	0.86	10.4	<0.3	<0.2	<0.3	<0.3	24.4	201.3
15-Nov-94	0.41	8.64	<0.05	<0.05	<0.05	<0.3	31.6	315.2	1.41	8.81	<0.05	<0.05	<0.05	<0.3	23.2	222
15-Dec-94	0.22	6.7	<0.3	<0.2	<0.3	<0.3	33.2	278.2	0.77	6.1	<0.3	<0.2	<0.3	<0.3	25.2	251.6
16-Jan-95	0.25	10.2	<0.3	<0.2	<0.3	<0.3	32.3	278.2	0.92	10.8	<0.3	<0.2	<0.3	<0.3	23.9	207.2
16-Feb-95	0.41	5.69	<0.05	<0.05	<0.05	<0.3	30.2	293	1.43	8.39	<0.05	<0.05	<0.05	<0.3	22.9	219
15-Mar-95	0.42	5.64	<0.05	<0.05	<0.05	<0.3	30.6	248.6	0.94	6.14	<0.05	<0.05	<0.05	<0.3	23.7	204.2
12-Apr-95	0.39	4.94	<0.05	<0.05	<0.05	<0.3	31.1	281.2	1.52	8.63	<0.05	<0.05	<0.05	<0.3	24.2	219
15-May-95	0.31	4.3	<0.05	<0.05	<0.05	<0.3	31.2	239.1	0.84	6.5	<0.05	<0.05	<0.05	<0.3	24.7	219.6
13-Jun-95	0.29	5.7	<0.05	<0.05	<0.05	<0.3	33.5	270.8	1.11	5.4	<0.05	<0.05	<0.05	<0.3	24.6	194.7

Appendix B1 (continued)

	Well G7								Well G8							
	F^-	Cl^-	NO_2^-	Br^-	NO_3^-	HPO_4^-	SO_4^{2-}	HCO_3^-	F^-	Cl^-	NO_2^-	Br^-	NO_3^-	HPO_4^-	SO_4^{2-}	HCO_3^-
detection limit=	0.07	0.2	0.3	0.2	0.3	0.3	0.4		0.07	0.2	0.3	0.2	0.3	0.3	0.4	
7-May-94	<0.07	14.8	1.3	<0.2	0.6	<0.3	32.1	336.7	<0.07	12.7	<0.3	<0.2	2.4	<0.3	31.6	313.5
21-May-94	<0.07	16.0	<0.3	0.1	<0.3	<0.3	33.2	345.3	<0.07	12.8	<0.3	<0.2	2.3	<0.3	31.0	292.8
3-Jun-94	0.32	16.4	1.0	<0.2	<0.3	<0.3	34.4	341.6	0.16	12.3	<0.3	<0.2	1.1	<0.3	32.7	290.4
17-Jun-94	0.33	16.6	<0.3	<0.2	<0.3	<0.3	34.4	340.4	0.28	12.3	<0.3	<0.2	1.3	<0.3	34.9	295.2
1-Jul-94	0.51	15.5	<0.3	<0.2	<0.3	<0.3	33.1	336.7	0.24	12.5	<0.3	<0.2	0.9	<0.3	34.6	298.9
15-Jul-94	0.53	15.7	<0.3	<0.2	<0.3	0.3	33.2	342.8	0.26	13.1	<0.3	<0.2	3.6	<0.3	34.7	285.5
29-Jul-94	0.56	14.3	<0.3	<0.2	<0.3	<0.3	30.6	350.1	0.26	14.1	<0.3	<0.2	3.3	<0.3	34.6	308.7
12-Aug-94	0.56	13.7	<0.3	<0.2	<0.3	<0.3	29.1	331.8	0.25	13.7	<0.3	<0.2	3.4	<0.3	34.2	287.9
26-Aug-94	0.55	13.6	<0.3	<0.2	<0.3	<0.3	29.2	415.9	0.20	14.4	<0.3	<0.2	4.4	<0.3	35.8	287.9
10-Sep-94	0.56	13.4	<0.3	<0.2	<0.3	<0.3	28.1	324.1	0.18	14.3	<0.3	<0.2	3.3	<0.3	36.2	300.4
23-Sep-94	0.46	12.16	<0.05	<0.05	<0.05	<0.3	27.9	325.6	0.30	12.70	<0.05	<0.05	1.51	<0.3	36.7	293
15-Oct-94	0.33	12.5	<0.3	<0.2	<0.3	<0.3	29.3	340.4	0.11	12.6	<0.3	<0.2	<0.3	<0.3	38.6	319.7
15-Nov-94	0.47	11.81	<0.05	0.73	<0.05	<0.3	27.9	352.2	0.29	11.77	<0.05	<0.05	<0.05	<0.3	38.2	325.6
15-Dec-94	0.34	12.7	<0.3	<0.2	2.0	<0.3	30.3	331.5	0.12	11.9	<0.3	<0.2	<0.3	<0.3	39.5	301.9
16-Jan-95	0.31	12.8	<0.3	<0.2	0.1	<0.3	29.7	346.3	0.11	15.2	<0.3	<0.2	1.0	<0.3	39.9	313.8
16-Feb-95	0.47	14.60	<0.05	0.38	2.99	<0.3	33.8	325.6	0.30	11.77	<0.05	<0.05	1.86	<0.3	39.6	293
15-Mar-95	0.46	14.14	<0.05	0.39	0.19	<0.3	32.2	307.8	0.32	12.94	<0.05	<0.05	3.63	<0.3	43.0	278.2
12-Apr-95	0.47	14.13	<0.05	<0.05	<0.05	<0.3	32.9	337.4	0.29	11.49	<0.05	<0.05	<0.05	<0.3	38.1	304.9
15-May-95	0.38	13.2	0.74	<0.05	1.88	<0.3	30.7	336.7	0.23	10.4	<0.05	<0.05	1.48	<0.3	40.9	285.5
13-Jun-95	0.40	13.2	<0.05	0.02	<0.05	<0.3	31.6	329.6	0.23	10.6	<0.05	<0.05	2.79	<0.3	37.1	284.0

	Well G9								Well G10							
	F^-	Cl^-	NO_2^-	Br^-	NO_3^-	HPO_4^-	SO_4^{2-}	HCO_3^-	F^-	Cl^-	NO_2^-	Br^-	NO_3^-	HPO_4^-	SO_4^{2-}	HCO_3^-
detection limit=	0.07	0.2	0.3	0.2	0.3	0.3	0.4		0.07	0.2	0.3	0.2	0.3	0.3	0.4	
7-May-94	0.56	84.3	<0.3	<0.2	<0.3	<0.3	47.1	345.3	<0.07	36.0	<0.3	<0.2	1.2	<0.3	42.3	397.7
21-May-94	<0.07	91.1	<0.3	<0.2	<0.3	<0.3	47.6	372.1	0.01	25.1	<0.3	<0.2	<0.3	<0.3	36.1	361.1
3-Jun-94	0.56	90.0	<0.3	<0.2	<0.3	<0.3	42.6	345.3	0.05	27.6	<0.3	<0.2	<0.3	<0.3	39.7	365.2
17-Jun-94	0.56	91.0	<0.3	<0.2	<0.3	<0.3	45.3	356.2	0.07	24.8	<0.3	<0.2	<0.3	<0.3	37.4	324.5
1-Jul-94	0.56	91.4	<0.3	<0.2	<0.3	<0.3	46.3	363.6	0.07	29.9	<0.3	<0.2	<0.3	<0.3	40.6	366.0
15-Jul-94	0.59	85.9	<0.3	<0.2	<0.3	<0.3	50.8	350.1	<0.07	27.4	<0.3	<0.2	<0.3	<0.3	37.5	314.8
29-Jul-94	0.47	84.5	<0.3	<0.2	<0.3	<0.3	51.3	357.5	<0.07	25.5	<0.3	<0.2	<0.3	<0.3	36.3	316.0
12-Aug-94	0.57	85.4	<0.3	<0.2	<0.3	<0.3	50.4	356.2	<0.07	25.6	<0.3	<0.2	<0.3	<0.3	35.9	307.4
26-Aug-94	0.49	86.2	<0.3	<0.2	<0.3	<0.3	48.1	358.2	<0.07	22.8	<0.3	<0.2	<0.3	<0.3	36.2	318.2
10-Sep-94	<0.07	85.6	<0.3	<0.2	<0.3	<0.3	50.4	361.1	<0.07	21.4	<0.3	<0.2	<0.3	<0.3	36.3	297.5
23-Sep-94	<0.05	76.53	<0.05	<0.05	<0.05	<0.3	48.5	368.5	0.35	19.23	<0.05	0.47	<0.05	<0.3	36.8	307.8
15-Oct-94	<0.07	81.2	<0.3	<0.2	<0.3	<0.3	50.0	378.9	0.20	21.7	<0.3	0.1	<0.3	<0.3	39.4	330.0
15-Nov-94	<0.05	79.05	<0.05	<0.05	<0.05	<0.3	45.3	368.5	0.37	19.52	<0.05	0.46	<0.05	<0.3	37.4	340.4
15-Dec-94	<0.07	82.3	<0.3	<0.2	<0.3	<0.3	53.9	361.1	0.16	23.6	<0.3	<0.2	<0.3	<0.3	1.8	325.0
16-Jan-95	<0.07	87.7	<0.3	<0.2	<0.3	<0.3	11.5	266.4	1.05	25.9	<0.3	0.2	<0.3	<0.3	1.0	300.0
16-Feb-95	<0.05	82.56	<0.05	<0.05	<0.05	<0.3	43.8	322.6	0.35	21.78	<0.05	0.41	<0.05	<0.3	2.0	320
15-Mar-95	<0.05	81.56	<0.05	<0.05	<0.05	<0.3	51.9	340.4	<0.05	24.00	<0.05	0.44	0.11	<0.3	38.5	310.8
12-Apr-95	<0.05	82.27	<0.05	<0.05	<0.05	<0.3	48.1	378.9	<0.05	31.45	<0.05	0.42	0.18	<0.3	44.5	381.8
15-May-95	<0.05	83.3	<0.05	<0.05	<0.05	<0.3	11.5	307.4	<0.05	28.1	<0.05	0.09	1.23	<0.3	42.4	341.6
13-Jun-95	<0.05	82.2	<0.05	<0.05	<0.05	<0.3	51.8	330.9	0.30	24.8	<0.05	0.06	<0.05	<0.3	39.9	287.9

	Well G11								Well G11A							
	F^-	Cl^-	NO_2^-	Br^-	NO_3^-	HPO_4^-	SO_4^{2-}	HCO_3^-	F^-	Cl^-	NO_2^-	Br^-	NO_3^-	HPO_4^-	SO_4^{2-}	HCO_3
detection limit=	0.07	0.2	0.3	0.2	0.3	0.3	0.4		0.07	0.2	0.3	0.2	0.3	0.3	0.4	
7-May-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21-May-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3-Jun-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17-Jun-94	<0.07	56.9	<0.3	<0.2	0.1	<0.3	36.4	623.0	0.09	12.1	<0.3	<0.2	4.0	1.4	29.5	324.5
1-Jul-94	<0.07	60.2	<0.3	<0.2	<0.05	<0.3	31.9	644.2	0.08	22.6	<0.3	<0.2	10.0	0.3	39.1	505.1
15-Jul-94	<0.07	70.8	<0.3	<0.2	0.9	<0.3	34.4	541.7	<0.07	14.5	<0.3	<0.2	3.7	0.4	41.1	416.0
29-Jul-94	<0.07	71.4	<0.3	<0.2	0.1	<0.3	38.2	549.0	<0.07	16.2	1.1	<0.2	3.9	1.9	44.9	406.3
12-Aug-94	<0.07	72.4	<0.3	<0.2	0.8	<0.3	39.6	500.2	<0.07	14.4	<0.3	<0.2	5.2	1.1	44.1	381.9
26-Aug-94	<0.07	65.3	<0.3	<0.2	2.3	<0.3	44.0	479.5	<0.07	15.9	<0.3	<0.2	8.2	0.6	56.5	403.8
10-Sep-94	<0.07	63.1	<0.3	<0.2	3.8	<0.3	50.9	432.2	<0.07	19.6	<0.3	<0.2	7.4	0.3	61.6	482.5
23-Sep-94	0.29	40.96	<0.05	<0.05	1.86	<0.3	60.8	449.9	<0.05	15.0	<0.05	<0.05	10.1	0.6	121.8	316.7
15-Oct-94	<0.07	54.0	<0.3	<0.2	2.8	<0.3	40.1	367.0	-	-	-	-	-	-	-	-
15-Nov-94	<0.05	39.56	<0.05	<0.05	4.24	<0.3	65.9	482.5	-	-	-	-	-	-	-	-
15-Dec-94	<0.07	30.0	<0.3	<0.2	2.2	<0.3	68.5	532.8	-	-	-	-	-	-	-	-
16-Jan-95	0.11	9.2	<0.3	<0.2	<0.05	<0.3	5.5	74.0	-	-	-	-	-	-	-	-
16-Feb-95	<0.05	46.11	<0.05	<0.05	<0.05	<0.3	50.2	447	-	-	-	-	-	-	-	-
15-Mar-95	<0.05	45.12	<0.05	<0.05	1.11	<0.3	55.5	400	-	-	-	-	-	-	-	-
12-Apr-95	<0.05	39.86	<0.05	<0.05	<0.05	<0.3	49.8	497.3	-	-	-	-	-	-	-	-
15-May-95	<0.05	38.9	<0.05	<0.05	1.47	<0.3	54.5	497.8	-	-	-	-	-	-	-	-
13-Jun-95	<0.05	39.6	<0.05	<0.05	0.56	<0.3	49.0	466.0	-	-	-	-	-	-	-	-

Well G12									Piezometre P1							
	F^-	Cl^-	NO_2^-	Br^-	NO_3^-	HPO_4^-	SO_4^{2-}	HCO_3^-	F^-	Cl^-	NO_2^-	Br^-	NO_3^-	HPO_4^-	SO_4^{2-}	HCO_3^-
detection limit=	0.07	0.2	0.3	0.2	0.3	0.3	0.4		0.07	0.2	0.3	0.2	0.3	0.3	0.4	
7-May-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21-May-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3-Jun-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17-Jun-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1-Jul-94	-	-	-	-	-	-	-	-	<0.07	28.7	<0.3	<0.2	<0.3	<0.3	43.9	417.0
15-Jul-94	-	-	-	-	-	-	-	-	<0.07	29.1	<0.3	<0.2	<0.3	<0.3	44.5	402.6
29-Jul-94	<0.07	56.7	<0.3	<0.2	<0.3	0.0	60.1	346.5	<0.07	30.0	<0.3	<0.2	<0.3	<0.3	43.4	394.1
12-Aug-94	<0.07	59.5	<0.3	<0.2	<0.3	0.0	60.1	350.1	<0.07	29.9	<0.3	<0.2	<0.3	<0.3	42.6	407.5
26-Aug-94	-	-	-	-	-	-	-	-	<0.07	30.1	<0.3	<0.2	<0.3	<0.3	45.1	433.6
10-Sep-94	<0.07	46.2	<0.3	<0.2	<0.3	0.0	59.9	349.3	<0.08	29.7	<0.3	<0.2	<0.3	<0.3	36.2	398.1
23-Sep-94	0.20	40.5	<0.05	<0.05	<0.05	<0.3	58.8	356.7	<0.05	28.23	<0.05	<0.05	5.15	<0.3	48.2	402.6
15-Oct-94	<0.07	42.3	<0.3	<0.2	<0.3	0.0	61.2	384.8	<0.07	27.0	3.3	<0.2	0.3	<0.3	49.6	430.7
15-Nov-94	0.21	39.3	<0.05	<0.05	<0.05	<0.3	58.9	386.3	<0.05	27.83	<0.05	<0.05	<0.05	<0.3	48.7	461.8
15-Dec-94	<0.07	40.7	<0.3	<0.2	<0.3	<0.3	60.6	349.3	-	-	-	-	-	-	-	-
16-Jan-95	<0.07	48.8	<0.3	<0.2	<0.3	0.0	55.3	337.4	-	-	-	-	-	-	-	-
16-Feb-95	0.24	40.4	<0.05	<0.05	<0.05	<0.3	59.6	331.5	-	-	-	-	-	-	-	-
15-Mar-95	0.22	43.3	<0.05	<0.05	<0.05	<0.3	60.6	322.6	-	-	-	-	-	-	-	-
12-Apr-95	<0.05	41.6	<0.05	<0.05	<0.05	<0.3	60.2	358.2	<0.05	31.03	<0.05	<0.05	<0.05	<0.3	42.7	393.9
15-May-95	<0.05	44.9	<0.05	<0.05	<0.05	<0.3	61.3	322.1	<0.05	32.0	<0.05	<0.05	<0.05	<0.3	41.0	348.9
13-Jun-95	<0.05	38.6	<0.05	<0.05	<0.05	<0.3	60.8	348.6	<0.05	32.1	<0.05	<0.05	<0.05	<0.3	37.5	424.6

Appendix B1 (continued)

	Piezometre P2								Piezometre P3							
	F^-	Cl^-	NO_2^-	Br^-	NO_3^-	HPO_4^-	SO_4^{2-}	HCO_3^-	F^-	Cl^-	NO_2^-	Br^-	NO_3^-	HPO_4^-	SO_4^{2-}	HCO_3^-
detection limit=	0.07	0.2	0.3	0.2	0.3	0.3	0.4		0.07	0.2	0.3	0.2	0.3	0.3	0.4	
7-May-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21-May-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3-Jun-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17-Jun-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1-Jul-94	-	-	-	-	-	-	-	-	0.29	8.1	<0.3	<0.2	<0.3	<0.3	11.4	383.1
15-Jul-94	<0.07	4.8	<0.3	<0.2	<0.3	<0.3	4.3	392.8	<0.07	6.8	<0.3	<0.2	<0.3	<0.3	120.1	402.6
29-Jul-94	0.33	5.0	<0.3	<0.2	<0.4	<0.3	10.1	300.0	0.33	5.9	<0.3	<0.2	<0.3	<0.3	40.9	316.0
12-Aug-94	0.30	5.4	<0.3	<0.2	<0.5	<0.3	6.3	229.4	0.29	5.4	<0.3	<0.2	<0.3	<0.3	60.2	329.4
26-Aug-94	0.32	7.0	<0.3	<0.2	<0.6	<0.3	5.4	219.0	0.32	6.9	<0.3	<0.2	<0.3	<0.3	60.6	313.8
10-Sep-94	0.35	7.9	<0.3	<0.2	<0.7	<0.3	2.3	236.8	0.32	9.7	<0.3	<0.2	<0.3	<0.3	53.8	322.6
23-Sep-94	0.56	6.79	<0.05	<0.05	0.18	<0.3	10.1	296.0	0.31	7.08	<0.05	<0.05	<0.05	<0.3	34.5	330.0
15-Oct-94	0.38	7.9	0.4	<0.2	0.1	<0.3	13.7	278.2	0.13	8.8	<0.3	<0.2	<0.3	<0.3	37.7	370.0
15-Nov-94	0.82	15.88	<0.05	<0.05	0.57	<0.3	13.9	278.2	<0.05	8.97	<0.05	<0.05	<0.05	<0.3	126.4	358.2
15-Dec-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16-Jan-95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16-Feb-95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15-Mar-95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12-Apr-95	0.57	7.9	<0.05	<0.05	0.64	<0.3	23.6	259.0	-	-	-	-	-	-	-	-
15-May-95	0.43	8.2	0.90	<0.05	0.70	<0.3	28.3	234.0	-	-	-	-	-	-	-	-
13-Jun-95	0.43	6.3	<0.05	<0.05	<0.05	20.8	23.7	266.4	-	-	-	-	-	-	-	-

Appendix B1 (continued)

	Piezometre P4								Tile Drain T1							
	F^-	Cl^-	NO_2^-	Br^-	NO_3^-	HPO_4^-	SO_4^{2-}	HCO_3^-	F^-	Cl^-	NO_2^-	Br^-	NO_3^-	HPO_4^-	SO_4^{2-}	HCO_3^-
detection limit=	0.07	0.2	0.3	0.2	0.3	0.3	0.4		0.07	0.2	0.3	0.2	0.3	0.3	0.4	
7-May-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21-May-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3-Jun-94	-	-	-	-	-	-	-	-	<0.07	134.8	0.7	<0.2	3.6	<0.3	18.0	307.4
17-Jun-94	-	-	-	-	-	-	-	-	<0.07	145.0	<0.3	<0.2	7.3	<0.3	18.9	359.9
1-Jul-94	-	-	-	-	-	-	-	-	<0.07	101.5	<0.3	<0.2	3.0	<0.3	19.8	363.6
15-Jul-94	<0.07	14.3	<0.3	<0.2	<0.3	<0.3	2.7	313.5	-	-	-	-	-	-	-	-
29-Jul-94	0.40	16.2	<0.3	<0.2	<0.3	<0.3	18.9	183.0	-	-	-	-	-	-	-	-
12-Aug-94	0.40	6.4	<0.3	<0.2	<0.3	<0.3	31.0	183.0	-	-	-	-	-	-	-	-
26-Aug-94	0.35	6.3	<0.3	<0.2	<0.3	<0.3	42.8	236.8	-	-	-	-	-	-	-	-
10-Sep-94	0.44	6.8	<0.3	<0.2	<0.3	<0.3	33.7	219.7	-	-	-	-	-	-	-	-
23-Sep-94	0.39	37.47	<0.05	<0.05	0.14	<0.3	3.9	220	<0.05	172.52	<0.05	<0.05	<0.05	<0.3	40.1	321.2
15-Oct-94	<0.05	65.65	<0.05	<0.05	3.76	<0.3	18.7	198.3	-	-	-	-	-	-	-	-
15-Nov-94	<0.05	82.17	<0.05	<0.05	<0.05	<0.3	23.6	389.2	<0.05	219.55	<0.05	<0.05	1.89	<0.3	27.0	390.7
15-Dec-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16-Jan-95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16-Feb-95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15-Mar-95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12-Apr-95	<0.05	55.32	<0.05	<0.05	3.32	<0.3	36.6	300.0	<0.05	64.02	1.00	<0.05	4.05	<0.3	24.2	322.6
15-May-95	<0.05	21.7	0.76	<0.05	0.27	<0.3	2.8	492.9	<0.05	105.0	<0.05	<0.05	7.72	<0.3	28.7	329.4
13-Jun-95	0.24	12.4	<0.05	<0.05	<0.05	<0.3	23.4	300.0	<0.05	104.6	<0.05	<0.05	15.06	<0.3	28.8	292.8

	Tile Drain T2								Tile Drain G7T							
	F^-	Cl^-	NO_2^-	Br^-	NO_3^-	HPO_4^-	SO_4^{2-}	HCO_3^-	F^-	Cl^-	NO_2^-	Br^-	NO_3^-	HPO_4^-	SO_4^{2-}	HCO_3^-
detection limit=	0.07	0.2	0.3	0.2	0.3	0.3	0.4		0.07	0.2	0.3	0.2	0.3	0.3	0.4	
7-May-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21-May-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3-Jun-94	<0.07	35.3	0.5	<0.2	41.8	<0.3	15.3	239.1	-	-	-	-	-	-	-	-
17-Jun-94	0.27	32.8	<0.3	<0.2	43.4	<0.5	16.9	228.1	-	-	-	-	-	-	-	-
1-Jul-94	0.19	46.6	<0.3	<0.2	58.9	<0.3	13.7	244.0	-	-	-	-	-	-	-	-
15-Jul-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
29-Jul-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12-Aug-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
26-Aug-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10-Sep-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
23-Sep-94	0.34	6.45	<0.05	<0.05	11.14	<0.3	11.0	122.8	-	-	-	-	-	-	-	-
15-Oct-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15-Nov-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15-Dec-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16-Jan-95	0.11	13.9	<0.3	<0.2	25.3	<0.3	6.6	65.1	-	-	-	-	-	-	-	-
16-Feb-95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15-Mar-95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12-Apr-95	0.34	30.14	<0.05	<0.05	36.15	<0.3	23.0	233.8	-	-	-	-	-	-	-	-
15-May-95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13-Jun-95	-	-	-	-	-	-	-	-	0.36	27.3	<0.05	<0.05	52.67	<0.3	25.0	380.0

Tile Drain T4									Tile Drain T3							
	F^-	Cl^-	NO_2^-	Br^-	NO_3^-	HPO_4^-	SO_4^{2-}	HCO_3^-	F^-	Cl^-	NO_2^-	Br^-	NO_3^-	HPO_4^-	SO_4^{2-}	HCO_3
detection limit=	0.07	0.2	0.3	0.2	0.3	0.3	0.4		0.07	0.2	0.3	0.2	0.3	0.3	0.4	
7-May-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21-May-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3-Jun-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17-Jun-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1-Jul-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15-Jul-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
29-Jul-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12-Aug-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
26-Aug-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10-Sep-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
23-Sep-94	-	-	-	-	-	-	-	-	0.42	18.09	<0.05	<0.05	29.98	<0.3	18.4	296
15-Oct-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7-Nov-94	<0.05	179.64	<0.05	<0.05	<0.05	<0.3	59.2	377.4	0.33	13.20	<0.05	<0.05	68.15	<0.3	16.4	290.1
15-Nov-94	<0.05	54.38	<0.05	<0.05	4.04	<0.3	37.4	420.3	0.37	13.31	<0.05	<0.05	55.66	<0.3	18.2	312.3
15-Dec-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16-Jan-95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16-Feb-95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15-Mar-95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12-Apr-95	<0.05	80.36	<0.05	<0.05	1.74	<0.3	40.7	393.7	0.36	11.01	<0.05	<0.05	41.59	<0.3	19.9	316.7
15-May-95	<0.05	81.5	<0.05	<0.05	5.98	<0.3	39.6	397.2	0.29	11.5	<0.05	<0.05	62.07	<0.3	20.1	278.2
13-Jun-95	<0.05	40.9	<0.05	<0.05	12.04	<0.3	32.8	380.6	0.30	9.8	<0.05	<0.05	109.70	<0.3	18.6	205.0

Appendix B2. Atomic emission spectrometry results of selected cations (mg/L or ppm)

Well G1

	Al	B	Be	Ca	Fe	K	Li	Mg	Mn	Na	P	S	Si	Sr	Na+K
Detection Limit	0.01	0.01	0.002	0.01	0.01	0.05	0.005	0.01	0.002	0.01	0.1	0.05	0.01	0.002	
7-May-94	0.09	0.00	0.038	145.21	0.00	2.25	0.000	12.07	0.000	14.02	0.1	10.72	3.09	0.241	16.27
21-May-94	0.09	0.00	0.052	186.30	0.00	2.85	0.000	14.80	0.000	25.13	0.0	12.67	3.27	0.318	27.98
3-Jun-94	0.10	0.00	0.067	217.15	0.01	3.17	0.000	16.83	0.000	31.49	0.0	15.13	3.43	0.372	34.66
17-Jun-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1-Jul-94	0.14	0.02	0.227	69.10	0.70	3.54	0.010	27.08	0.026	7.87	0.0	18.45	10.14	0.840	11.41
15-Jul-94	0.00	0.02	0.224	67.28	0.78	3.56	0.009	26.12	0.029	8.00	0.2	18.69	10.01	0.829	11.56
29-Jul-94	0.15	0.02	0.225	66.63	0.32	3.74	0.011	27.29	0.020	8.40	0.0	19.19	9.60	0.866	12.14
12-Aug-94	0.06	0.01	0.214	70.46	1.53	3.54	0.009	25.42	0.048	7.77	0.1	18.44	9.76	0.789	11.32
26-Aug-94	0.04	0.01	0.214	69.07	0.92	3.29	0.010	26.01	0.029	7.66	0.3	18.42	9.70	0.798	10.95
10-Sep-94	0.04	0.01	0.177	62.08	0.40	3.47	0.010	24.55	0.036	7.77	0.0	17.65	7.79	0.755	11.24
23-Sep-94	0.38	0.03	0.170	67.10	<0.01	2.7	0.007	24.24	0.037	7.70	N.A.	14.8	6.84	0.819	10.44
15-Oct-94	0.10	0.02	0.190	60.70	<0.01	2.8	0.008	25.27	0.040	9.42	<0.1	26.99	7.35	0.693	12.26
15-Nov-94	0.07	0.03	0.182	69.37	0.02	2.8	0.008	23.93	0.019	7.80	N.A.	15.9	7.33	0.839	10.58
15-Dec-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16-Jan-95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16-Feb-95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15-Mar-95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12-Apr-95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15-May-95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13-Jun-95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Well G2

	Al	B	Ba	Ca	Fe	K	Li	Mg	Mn	Na	P	S	Si	Sr	Na+K
Detection Limit	0.01	0.01	0.002	0.01	0.01	0.05	0.005	0.01	0.002	0.01	0.1	0.05	0.01	0.002	
7-May-94	0.22	0.07	0.081	78.15	0.01	22.97	0.008	20.47	0.003	21.26	0.1	13.82	4.97	0.462	44.23
21-May-94	0.20	0.07	0.083	83.02	0.00	28.51	0.007	19.74	0.000	26.79	0.0	13.82	4.88	0.424	55.29
3-Jun-94	0.22	0.07	0.091	84.68	0.01	30.06	0.005	21.09	0.000	28.44	0.1	15.14	5.08	0.433	58.49
17-Jun-94	0.20	0.08	0.092	84.26	0.01	31.63	0.000	21.65	0.003	28.72	0.0	15.90	5.32	0.427	60.35
1-Jul-94	0.26	0.07	0.093	82.55	0.02	32.14	0.009	23.69	0.004	26.72	0.1	17.68	5.66	0.433	58.86
15-Jul-94	0.18	0.09	0.100	83.58	0.01	38.77	0.000	21.00	0.003	30.77	0.1	14.80	5.54	0.415	69.53
29-Jul-94	0.25	0.06	0.090	78.92	0.00	25.79	0.009	24.34	0.008	19.56	0.0	19.08	5.89	0.483	45.35
12-Aug-94	0.30	0.04	0.078	77.83	0.00	13.25	0.014	26.13	0.011	14.38	0.3	20.64	5.68	0.519	27.62
26-Aug-94	0.23	0.04	0.077	75.81	0.02	8.71	0.014	24.60	0.015	12.84	0.0	20.62	5.77	0.581	21.55
10-Sep-94	0.24	0.04	0.075	74.16	0.02	8.46	0.012	24.14	0.014	12.20	0.3	19.64	5.56	0.567	20.66
23-Sep-94	<0.05	0.04	0.088	105.52	0.02	6.1	0.006	26.83	0.018	11.36	N.A.	22.6	4.51	0.556	17.48
15-Oct-94	<0.05	0.03	0.100	95.42	<0.01	5.6	0.006	29.00	0.015	14.42	<0.1	46.53	4.80	0.507	20.01
15-Nov-94	0.43	0.05	0.107	102.00	0.31	16.3	0.006	22.45	0.008	19.96	N.A.	18.5	4.66	0.569	36.28
15-Dec-94	0.10	0.05	0.104	104.10	0.15	14.2	0.005	25.35	0.013	14.21	N.A.	21.0	4.77	0.573	28.41
16-Jan-95	0.20	0.03	0.116	87.33	<0.01	14.1	0.005	24.53	0.009	12.72	<0.1	35.93	4.22	0.503	26.78
16-Feb-95	0.27	0.04	0.104	101.52	<0.01	14.0	0.005	22.38	0.006	12.38	N.A.	18.6	4.48	0.551	26.33
15-Mar-95	0.33	0.03	0.098	102.31	0.018	7.3	0.005	23.78	0.008	10.29	N.A.	14.0	4.46	0.605	17.55
12-Apr-95	0.05	0.04	0.103	107.88	0.008	12.3	0.004	24.66	0.008	13.09	N.A.	14.1	4.36	0.545	25.39
15-May-95	<0.02	0.05	0.115	107.50	<0.005	18.0	<0.002	23.43	<0.002	16.99	N.A.	12.1	4.20	0.482	35.02
13-Jun-95	0.10	0.06	0.120	110.38	<0.005	22.3	0.002	21.77	0.009	19.15	N.A.	11.7	4.53	0.478	41.44

Well G3

	Al	B	Be	Ca	Fe	K	Li	Mg	Mn	Na	P	S	Si	Sr	Na+K
Detection Limit	0.01	0.01	0.002	0.01	0.01	0.05	0.005	0.01	0.002	0.01	0.1	0.05	0.01	0.002	
7-May-94	0.30	0.02	0.096	71.33	0.05	2.76	0.020	27.21	0.005	9.03	0.0	19.46	7.61	0.675	11.79
21-May-94	0.26	0.02	0.089	71.08	0.02	2.89	0.016	25.91	0.004	9.22	0.1	19.68	7.43	0.652	12.11
3-Jun-94	0.31	0.02	0.093	72.41	0.07	2.83	0.019	27.30	0.004	9.32	0.0	19.60	7.38	0.677	12.15
17-Jun-94	0.35	0.02	0.097	73.61	0.07	3.10	0.021	28.78	0.006	9.86	0.0	20.80	7.62	0.701	12.95
1-Jul-94	0.36	0.02	0.100	74.43	0.07	3.63	0.021	27.84	0.005	9.86	0.1	19.97	7.80	0.729	13.49
15-Jul-94	0.37	0.02	0.098	72.48	0.06	3.77	0.021	27.11	0.007	10.14	0.0	19.74	7.48	0.704	13.91
29-Jul-94	0.34	0.02	0.099	73.50	0.07	3.28	0.022	28.38	0.005	9.75	0.0	19.92	7.64	0.706	13.03
12-Aug-94	0.33	0.02	0.097	72.01	0.08	3.33	0.020	26.74	0.007	10.03	0.0	20.46	7.60	0.690	13.36
26-Aug-94	0.30	0.01	0.092	69.61	0.11	3.03	0.018	25.58	0.006	9.67	0.2	20.46	7.38	0.654	12.70
10-Sep-94	0.28	0.01	0.094	68.55	0.06	2.75	0.022	24.68	0.006	8.95	0.2	19.35	7.10	0.648	11.70
23-Sep-94	0.29	0.02	0.114	89.59	0.02	2.3	0.007	24.14	0.009	7.78	N.A.	17.4	5.59	0.657	10.12
15-Oct-94	0.00	0.01	0.146	85.90	<0.01	2.4	0.007	27.41	0.011	10.42	<0.1	39.73	6.15	0.626	12.83
15-Nov-94	0.30	0.02	0.116	92.33	0.02	2.5	0.007	24.88	0.016	8.33	N.A.	18.1	5.86	0.650	10.87
15-Dec-94	0.27	0.02	0.116	90.44	0.03	2.5	0.008	25.08	0.008	8.45	N.A.	18.7	6.00	0.658	10.94
16-Jan-95	0.00	0.02	0.131	78.54	<0.01	3.8	0.006	25.12	0.003	8.53	0.7	32.14	5.34	0.585	12.33
16-Feb-95	0.32	0.02	0.111	90.10	0.01	2.3	0.007	24.44	0.004	7.66	N.A.	18.4	5.71	0.655	9.92
15-Mar-95	0.17	0.01	0.137	100.00	0.006	2.3	0.006	26.99	0.007	7.40	N.A.	12.5	6.20	0.758	9.67
12-Apr-95	0.31	0.02	0.116	88.69	0.010	2.1	0.007	23.32	0.003	7.15	N.A.	13.0	5.45	0.675	9.26
15-May-95	<0.02	0.01	0.130	96.35	<0.005	2.2	0.007	26.31	0.003	7.41	N.A.	13.4	5.94	0.743	9.63
13-Jun-95	<0.02	0.02	0.123	97.12	<0.005	2.3	0.006	26.04	0.004	7.59	N.A.	13.6	5.98	0.732	9.85

Well G4

	Al	B	Ba	Ca	Fe	K	Li	Mg	Mn	Na	P	S	Si	Sr	Na+K
Detection Limit	0.01	0.01	0.002	0.01	0.01	0.05	0.005	0.01	0.002	0.01	0.1	0.05	0.01	0.002	
7-May-94	1.23	0.05	0.028	80.80	0.20	39.90	0.071	56.79	0.056	34.68	0.0	52.71	8.37	1.113	74.58
21-May-94	1.18	0.06	0.028	77.94	1.09	32.93	0.073	54.20	0.061	33.81	0.0	49.58	8.63	1.161	66.74
3-Jun-94	1.21	0.05	0.028	80.22	1.79	37.92	0.078	56.19	0.066	32.75	0.0	50.58	8.10	1.111	70.67
17-Jun-94	1.18	0.05	0.027	77.52	0.66	32.02	0.068	53.46	0.053	32.86	0.2	49.51	8.57	1.128	64.88
1-Jul-94	1.27	0.05	0.028	83.93	0.64	42.25	0.084	60.20	0.058	36.39	0.0	54.22	8.14	1.123	78.64
15-Jul-94	1.06	0.06	0.027	72.50	0.78	31.55	0.070	52.90	0.054	29.78	0.2	44.18	8.19	1.141	61.33
29-Jul-94	1.10	0.06	0.027	75.65	0.33	31.85	0.077	52.24	0.057	32.70	0.1	47.62	8.31	1.109	64.55
12-Aug-94	1.11	0.05	0.027	75.86	0.33	35.44	0.071	53.48	0.055	31.48	0.1	45.34	7.96	1.123	66.92
26-Aug-94	1.08	0.06	0.028	77.26	0.32	33.77	0.073	52.35	0.052	32.03	0.0	46.23	8.13	1.113	65.81
10-Sep-94	0.95	0.06	0.027	71.33	0.19	32.47	0.069	49.09	0.048	28.92	0.0	40.77	7.94	1.093	61.39
23-Sep-94	<0.05	0.06	0.037	100.29	<0.01	24.3	0.020	49.38	0.046	26.33	N.A.	41.5	6.64	1.208	50.67
15-Oct-94	<0.05	0.05	0.045	94.83	<0.01	30.3	0.025	52.93	0.045	35.60	<0.1	84.19	6.86	1.075	65.88
15-Nov-94	0.08	0.06	0.043	129.52	<0.01	43.0	0.023	54.48	0.095	33.62	N.A.	53.4	6.75	1.183	76.60
15-Dec-94	<0.05	0.06	0.041	129.71	<0.01	43.3	0.023	54.56	0.048	33.83	N.A.	53.7	6.97	1.187	77.15
16-Jan-95	<0.05	0.04	0.034	79.78	<0.01	24.2	0.018	50.74	<0.002	27.22	<0.1	65.61	4.94	0.955	51.39
16-Feb-95	<0.05	0.06	0.039	110.38	<0.01	28.9	0.021	51.19	0.045	27.64	N.A.	47.0	6.59	1.184	56.55
15-Mar-95	0.20	0.05	0.041	109.04	0.054	26.1	0.017	48.54	0.039	25.96	N.A.	30.7	6.36	1.197	52.02
12-Apr-95	0.07	0.05	0.040	111.06	0.010	27.0	0.018	49.41	0.047	25.51	N.A.	31.5	6.03	1.191	52.55
15-May-95	0.02	0.05	0.040	120.00	<0.005	28.5	0.018	52.33	0.045	25.84	N.A.	33.8	5.96	1.209	54.38
13-Jun-95	<0.02	0.05	0.038	129.13	0.010	35.7	0.021	52.20	0.053	30.10	N.A.	36.1	6.48	1.178	65.77

Well G5

	Al	B	Ba	Ca	Fe	K	Li	Mg	Mn	Na	P	S	Si	Sr	Na+K
Detection Limit	0.01	0.01	0.002	0.01	0.01	0.05	0.005	0.01	0.002	0.01	0.1	0.05	0.01	0.002	
7-May-94	0.17	0.02	0.107	57.11	0.07	2.52	0.009	20.25	0.017	12.39	0.0	10.76	7.33	0.730	14.92
21-May-94	0.16	0.02	0.109	58.46	0.18	2.84	0.009	20.51	0.019	12.25	0.2	12.01	7.70	0.727	15.09
3-Jun-94	0.14	0.02	0.107	58.76	0.13	2.53	0.009	20.45	0.017	11.44	0.1	12.50	7.78	0.709	13.97
17-Jun-94	0.16	0.01	0.115	63.39	0.11	2.47	0.009	22.00	0.014	9.37	0.0	15.10	8.18	0.724	11.84
1-Jul-94	0.14	0.01	0.114	66.19	0.09	2.32	0.008	21.03	0.016	8.22	0.0	14.67	7.97	0.662	10.55
15-Jul-94	0.16	0.01	0.108	56.80	0.21	2.47	0.008	20.16	0.018	13.14	0.0	13.74	7.66	0.735	15.62
29-Jul-94	0.15	0.01	0.113	57.70	0.17	2.73	0.009	20.14	0.017	12.74	0.1	13.70	7.87	0.760	15.46
12-Aug-94	0.15	0.02	0.115	55.72	0.19	2.62	0.009	20.53	0.017	13.39	0.0	13.77	7.47	0.777	16.01
26-Aug-94	0.14	0.01	0.110	55.15	0.17	2.28	0.009	19.60	0.015	12.10	0.0	13.05	7.45	0.739	14.38
10-Sep-94	0.16	0.01	0.115	52.16	0.18	2.74	0.009	19.20	0.016	13.85	0.2	12.93	7.51	0.804	16.59
23-Sep-94	0.23	0.03	0.097	52.88	<0.01	2.0	0.007	18.69	0.013	13.08	N.A.	10.2	5.68	0.784	15.04
15-Oct-94	0.14	0.03	0.121	47.85	<0.01	2.4	0.009	19.55	0.011	16.32	<0.1	19.38	5.90	0.757	18.74
15-Nov-94	0.25	0.04	0.111	59.34	0.01	2.7	0.009	20.87	0.014	15.96	N.A.	11.1	5.75	1.009	18.68
15-Dec-94	0.24	0.04	0.108	59.69	0.02	2.2	0.010	20.93	0.016	14.63	N.A.	11.7	5.84	0.906	16.82
16-Jan-95	0.14	0.03	0.122	51.10	<0.01	6.9	0.007	20.65	0.013	16.06	<0.1	19.82	5.49	0.780	22.92
16-Feb-95	0.23	0.04	0.100	54.11	<0.01	2.3	0.007	19.66	0.014	14.63	N.A.	10.8	5.48	0.864	16.91
15-Mar-95	0.27	0.04	0.104	53.00	0.009	2.0	0.007	18.49	0.013	14.21	N.A.	7.4	5.28	0.908	16.25
12-Apr-95	0.25	0.04	0.103	56.15	0.017	1.9	0.006	18.30	0.015	12.58	N.A.	7.6	5.41	0.839	14.53
15-May-95	0.21	0.03	0.102	56.86	<0.005	2.0	0.004	18.84	0.013	11.87	N.A.	7.5	5.51	0.837	13.83
13-Jun-95	0.22	0.03	0.111	64.29	0.029	1.9	0.006	20.29	<0.002	11.10	N.A.	8.3	5.71	0.858	12.95

Well G6

	Al	B	Ba	Ca	Fe	K	Li	Mg	Mn	Na	P	S	Si	Sr	Na+K
Detection Limit	0.01	0.01	0.002	0.01	0.01	0.05	0.005	0.01	0.002	0.01	0.1	0.05	0.01	0.002	
7-May-94	0.04	0.09	0.029	9.90	0.02	3.00	0.013	6.57	0.004	68.07	0.0	11.22	4.81	0.761	71.08
21-May-94	0.04	0.09	0.031	10.31	0.02	2.81	0.013	7.06	0.004	62.87	0.2	12.08	4.94	0.780	65.68
3-Jun-94	0.02	0.09	0.028	9.62	0.02	2.64	0.011	6.46	0.004	66.03	0.0	16.34	4.86	0.727	68.67
17-Jun-94	0.03	0.08	0.032	10.10	0.02	2.64	0.009	7.26	0.004	61.21	0.5	15.02	4.89	0.786	63.85
1-Jul-94	0.01	0.08	0.027	8.65	0.01	2.25	0.010	5.92	0.003	65.67	0.0	18.18	4.68	0.668	67.92
15-Jul-94	0.03	0.09	0.031	10.33	0.02	2.94	0.011	6.68	0.005	64.14	0.1	24.08	4.72	0.794	67.08
29-Jul-94	0.03	0.09	0.032	11.85	0.02	3.00	0.014	7.91	0.005	63.95	0.1	19.05	4.93	0.908	66.95
12-Aug-94	0.03	0.08	0.032	11.55	0.02	2.63	0.012	7.55	0.005	65.22	0.0	17.85	4.88	0.910	67.85
26-Aug-94	0.03	0.08	0.033	11.53	0.01	2.84	0.009	7.72	0.004	61.10	0.2	19.68	4.81	0.906	63.94
10-Sep-94	0.04	0.08	0.034	13.19	0.02	3.09	0.012	8.08	0.006	62.03	0.3	22.29	4.80	1.011	65.12
23-Sep-94	<0.05	0.21	0.032	12.34	0.05	2.5	0.010	8.50	0.006	58.20	N.A.	8.3	3.81	1.103	60.71
15-Oct-94	<0.05	0.18	0.036	10.37	<0.01	2.6	0.011	8.54	<0.002	77.85	<0.1	15.49	3.89	0.961	80.44
15-Nov-94	0.11	0.20	0.028	9.55	0.01	2.4	0.009	6.54	0.004	62.18	N.A.	8.3	3.49	0.862	64.61
15-Dec-94	0.09	0.18	0.028	9.25	<0.01	2.1	0.007	6.73	0.002	64.60	N.A.	8.9	3.62	0.841	66.72
16-Jan-95	<0.05	0.17	0.031	7.36	<0.01	5.3	0.009	6.17	0.002	72.57	<0.1	14.32	3.29	0.689	77.91
16-Feb-95	0.16	0.21	0.027	9.44	0.03	2.3	0.011	6.19	0.004	63.21	N.A.	8.6	3.50	0.824	65.51
15-Mar-95	0.13	0.18	0.026	8.45	0.021	2.0	0.007	5.62	0.004	59.77	N.A.	6.0	3.38	0.758	61.75
12-Apr-95	0.14	0.22	0.026	8.33	0.029	2.2	0.010	5.55	0.002	60.34	N.A.	5.9	3.29	0.779	62.53
15-May-95	0.07	0.20	0.028	9.19	0.012	2.0	0.006	6.41	0.005	59.66	N.A.	5.8	3.51	0.847	61.66
13-Jun-95	0.03	0.18	0.030	8.69	<0.005	2.1	0.006	6.66	<0.002	59.72	N.A.	6.5	3.55	0.841	61.81

Well G7

	Al	B	Ba	Ca	Fe	K	Li	Mg	Mn	Na	P	S	Si	Sr	Na+K
Detection Limit	0.01	0.01	0.002	0.01	0.01	0.05	0.005	0.01	0.002	0.01	0.1	0.05	0.01	0.002	
7-May-94	0.17	0.25	0.138	39.28	0.02	7.62	0.043	19.18	0.014	60.40	0.2	12.18	6.98	1.228	68.03
21-May-94	0.17	0.24	0.143	41.72	0.00	7.39	0.042	21.22	0.009	60.83	0.2	13.85	6.98	1.288	68.22
3-Jun-94	0.18	0.25	0.146	42.51	0.12	8.18	0.044	21.14	0.009	58.53	0.3	14.13	6.79	1.276	66.71
17-Jun-94	0.16	0.25	0.151	41.59	0.15	8.71	0.044	20.40	0.009	62.61	0.3	14.92	6.97	1.303	71.32
1-Jul-94	0.20	0.26	0.150	41.15	0.24	8.68	0.049	20.13	0.010	62.84	0.3	13.73	6.92	1.310	71.52
15-Jul-94	0.19	0.25	0.143	41.11	0.16	7.88	0.046	20.30	0.009	60.91	0.2	14.26	6.88	1.284	68.79
29-Jul-94	0.20	0.25	0.140	39.82	0.35	8.05	0.045	20.32	0.014	62.62	0.2	12.58	6.86	1.256	70.68
12-Aug-94	0.17	0.24	0.135	38.53	0.40	7.83	0.048	19.44	0.012	63.16	0.2	12.65	6.81	1.263	70.99
26-Aug-94	0.17	0.24	0.132	37.31	0.29	8.22	0.045	18.76	0.010	62.25	0.3	12.88	6.51	1.231	70.47
10-Sep-94	0.17	0.24	0.129	35.90	0.33	7.50	0.040	17.44	0.011	58.03	0.3	12.48	6.31	1.163	65.52
23-Sep-94	0.23	0.23	0.175	41.75	0.05	5.8	0.013	18.33	0.008	53.04	N.A.	8.1	5.28	1.297	58.85
15-Oct-94	0.12	0.20	0.196	37.01	0.02	6.2	0.017	18.99	0.007	64.65	<0.1	19.08	5.32	1.115	70.85
15-Nov-94	0.23	0.23	0.167	39.44	0.03	5.5	0.013	18.02	0.010	51.99	N.A.	8.3	5.22	1.269	57.44
15-Dec-94	0.23	0.23	0.179	41.75	0.50	6.0	0.015	18.40	0.006	53.25	N.A.	8.8	5.33	1.284	59.24
16-Jan-95	0.12	0.20	0.193	36.03	<0.01	5.3	0.013	18.89	0.009	55.52	0.3	17.71	4.90	1.105	60.78
16-Feb-95	0.26	0.22	0.187	46.19	0.01	6.6	0.013	19.20	0.009	53.24	N.A.	10.3	5.51	1.306	59.87
15-Mar-95	0.23	0.24	0.183	44.78	0.021	5.9	0.014	19.01	0.011	48.95	N.A.	9.1	5.18	1.298	54.86
12-Apr-95	0.25	0.23	0.184	47.23	0.015	6.0	0.014	19.56	0.014	49.24	N.A.	9.7	5.27	1.321	55.24
15-May-95	0.19	0.22	0.185	45.82	<0.005	5.8	0.014	20.08	0.007	48.76	N.A.	9.9	5.22	1.371	54.56
13-Jun-95	0.17	0.23	0.190	46.38	<0.005	6.0	0.014	19.83	0.006	51.19	N.A.	10.9	5.57	1.374	57.24

Well G8

	Al	B	Ba	Ca	Fe	K	Li	Mg	Mn	Na	P	S	Si	Sr	Na+K
Detection Limit	0.01	0.01	0.002	0.01	0.01	0.05	0.005	0.01	0.002	0.01	0.1	0.05	0.01	0.002	
7-May-94	0.12	0.00	0.086	94.54	0.00	2.47	0.006	14.20	0.000	8.17	0.0	13.57	5.85	0.312	10.63
21-May-94	0.10	0.00	0.083	95.31	0.00	2.32	0.008	14.23	0.000	8.14	0.0	14.14	5.90	0.303	10.46
3-Jun-94	0.10	0.00	0.083	94.00	0.00	2.18	0.006	14.20	0.000	8.18	0.0	14.50	5.93	0.304	10.35
17-Jun-94	0.09	0.00	0.083	94.13	0.00	2.34	0.006	14.24	0.000	8.18	0.0	15.26	5.90	0.308	10.52
1-Jul-94	0.08	0.00	0.082	92.23	0.00	2.16	0.007	13.93	0.000	8.28	0.2	15.42	5.72	0.304	10.44
15-Jul-94	0.11	0.00	0.087	93.50	0.00	2.25	0.000	13.85	0.000	8.28	0.0	15.61	5.54	0.316	10.53
29-Jul-94	0.07	0.00	0.087	89.54	0.00	2.18	0.006	13.79	0.000	8.55	0.2	15.59	5.57	0.319	10.73
12-Aug-94	0.08	0.00	0.086	93.56	0.00	2.38	0.007	13.70	0.000	8.70	0.2	16.24	5.59	0.322	11.09
26-Aug-94	0.08	0.00	0.082	91.29	0.00	1.92	0.006	13.34	0.000	8.48	0.0	16.05	5.52	0.310	10.40
10-Sep-94	0.07	0.00	0.083	91.17	0.00	2.02	0.000	13.40	0.000	8.33	0.1	16.24	5.42	0.311	10.35
23-Sep-94	0.19	0.02	0.076	90.51	<0.01	1.8	0.003	12.74	<0.002	8.67	N.A.	11.0	4.14	0.334	10.51
15-Oct-94	0.06	<0.01	0.087	83.63	<0.01	1.8	0.005	13.41	<0.002	10.98	<0.1	25.18	4.40	0.297	12.77
15-Nov-94	0.19	0.02	0.076	92.15	<0.01	1.5	0.004	13.02	<0.002	8.62	N.A.	11.7	4.15	0.335	10.16
15-Dec-94	0.17	0.02	0.078	94.97	0.01	1.9	0.006	13.18	0.007	8.78	N.A.	12.1	4.32	0.341	10.71
16-Jan-95	0.08	0.01	0.088	81.86	<0.01	3.9	0.004	13.11	<0.002	9.97	<0.1	23.53	3.87	0.296	13.84
16-Feb-95	0.21	0.01	0.080	91.01	<0.01	2.1	0.005	13.27	<0.002	8.54	N.A.	12.2	4.22	0.334	10.59
15-Mar-95	0.21	0.02	0.077	93.37	0.038	1.9	0.004	13.17	<0.002	7.97	N.A.	14.8	4.09	0.335	9.85
12-Apr-95	0.21	0.02	0.077	88.27	0.010	1.7	0.004	12.88	<0.002	7.71	N.A.	14.0	4.05	0.328	9.40
15-May-95	0.11	0.01	0.073	92.54	<0.005	1.7	0.004	13.49	<0.002	7.61	N.A.	15.0	4.06	0.339	9.35
13-Jun-95	0.13	0.02	0.076	91.02	<0.005	1.9	0.005	13.49	<0.002	7.92	N.A.	17.0	4.40	0.330	9.78

Well G9

	Al	B	Ba	Ca	Fe	K	Li	Mg	Mn	Na	P	S	Si	Sr	Na+K
Detection Limit	0.01	0.01	0.002	0.01	0.01	0.05	0.005	0.01	0.002	0.01	0.1	0.05	0.01	0.002	
7-May-94	0.00	0.02	0.003	2.32	0.04	0.76	0.000	0.07	0.003	191.42	0.0	16.27	13.56	0.011	192.18
21-May-94	0.00	0.02	0.003	4.64	0.03	0.70	0.024	0.16	0.004	187.34	0.1	18.80	13.39	0.019	188.04
3-Jun-94	0.00	0.02	0.003	2.47	0.05	0.65	0.000	0.07	0.002	184.26	0.0	16.75	11.53	0.011	184.91
17-Jun-94	0.00	0.02	0.002	2.31	0.03	0.80	0.022	0.09	0.003	181.34	0.0	17.85	11.97	0.010	182.14
1-Jul-94	0.00	0.02	0.003	2.67	0.03	0.71	0.000	0.08	0.003	185.67	0.0	19.11	12.12	0.012	186.39
15-Jul-94	0.00	0.02	0.003	2.84	0.03	1.05	0.022	0.24	0.004	195.50	0.0	20.90	12.98	0.014	196.55
29-Jul-94	0.00	0.01	0.002	2.26	0.02	0.37	0.008	0.07	0.003	191.09	0.0	21.44	12.86	0.010	191.46
12-Aug-94	0.00	0.01	0.002	2.18	0.02	0.81	0.021	0.08	0.003	192.34	0.2	20.88	12.74	0.010	193.14
26-Aug-94	0.00	0.02	0.003	2.60	0.03	0.59	0.020	0.08	0.003	190.09	0.0	19.93	12.35	0.012	190.68
10-Sep-94	0.00	0.01	0.003	2.19	0.03	0.55	0.000	0.06	0.002	172.35	0.2	20.13	12.64	0.009	172.90
23-Sep-94	<0.05	0.03	0.003	2.19	0.06	0.4	<0.002	0.08	<0.002	186.29	N.A.	16.9	9.51	0.011	186.69
15-Oct-94	<0.05	0.03	0.003	1.49	0.03	0.6	<0.005	0.08	<0.002	230.90	<0.1	30.70	9.84	0.010	231.46
15-Nov-94	<0.05	0.03	0.291	112.57	0.01	3.8	0.011	27.88	0.068	20.74	N.A.	17.0	9.00	1.859	24.56
15-Dec-94	<0.05	0.04	0.005	2.68	0.12	0.5	<0.002	0.12	0.002	196.17	N.A.	18.5	9.56	0.019	196.64
16-Jan-95	0.13	0.02	0.193	55.13	0.02	10.3	0.010	28.08	0.060	25.20	0.3	7.05	3.25	1.285	35.51
16-Feb-95	<0.05	0.04	0.293	105.43	<0.01	6.6	0.012	28.14	0.067	23.50	N.A.	16.6	8.24	1.870	30.13
15-Mar-95	0.01	0.04	0.262	99.81	0.014	4.1	0.010	26.18	0.047	36.64	N.A.	22.7	9.09	1.669	40.70
12-Apr-95	0.11	0.03	0.004	1.81	0.075	0.8	0.004	0.08	<0.002	174.73	N.A.	20.6	8.84	0.012	175.49
15-May-95	<0.02	0.03	<0.002	1.00	0.009	0.3	0.012	0.02	<0.002	152.63	N.A.	5.7	5.24	0.007	152.96
13-Jun-95	<0.02	0.04	0.002	1.82	<0.005	0.5	<0.002	0.04	0.002	193.14	N.A.	24.9	9.90	0.010	193.67

Well G10

	Al	B	Ba	Ca	Fe	K	Li	Mg	Mn	Na	P	S	Si	Sr	Na+K
Detection Limit	0.01	0.01	0.002	0.01	0.01	0.05	0.005	0.01	0.002	0.01	0.1	0.05	0.01	0.002	
7-May-94	0.03	0.04	0.180	82.20	0.07	6.10	0.018	35.82	0.039	28.21	0.0	17.38	8.79	2.078	34.31
21-May-94	0.08	0.04	0.168	69.83	0.27	6.34	0.016	31.86	0.033	23.87	0.3	16.32	8.62	2.226	30.21
3-Jun-94	0.00	0.04	0.183	73.72	0.20	6.78	0.016	32.51	0.031	22.73	0.2	17.45	8.36	2.243	29.51
17-Jun-94	0.07	0.05	0.149	61.62	0.17	6.36	0.016	29.34	0.024	24.45	0.2	16.81	8.47	2.217	30.81
1-Jul-94	0.00	0.04	0.188	72.91	0.16	6.47	0.016	32.94	0.034	25.91	0.2	18.90	8.74	2.279	32.37
15-Jul-94	0.07	0.04	0.156	59.63	0.08	5.62	0.018	29.34	0.026	27.56	0.0	17.18	8.70	2.202	33.18
29-Jul-94	0.13	0.04	0.151	57.43	0.14	5.31	0.019	29.21	0.022	26.26	0.2	16.84	9.11	2.172	31.57
12-Aug-94	0.12	0.04	0.145	54.77	0.26	5.20	0.019	28.38	0.022	26.31	0.1	16.48	9.35	2.144	31.50
26-Aug-94	0.09	0.04	0.148	52.15	0.11	5.04	0.019	28.21	0.018	27.33	0.0	16.78	9.26	2.273	32.37
10-Sep-94	0.22	0.04	0.142	51.34	0.10	4.96	0.018	27.63	0.016	25.36	0.1	16.12	8.90	2.214	30.32
23-Sep-94	<0.05	0.10	0.125	52.24	0.09	4.2	0.016	31.59	0.020	26.25	N.A.	9.3	6.87	2.369	30.41
15-Oct-94	0.15	0.08	0.146	49.06	<0.01	4.1	0.018	28.87	0.015	31.40	<0.1	25.11	7.23	2.073	35.47
15-Nov-94	<0.05	0.10	0.126	54.23	0.01	4.1	0.015	27.75	0.026	26.22	N.A.	9.7	6.90	2.369	30.35
15-Dec-94	<0.05	0.10	0.032	54.00	0.03	4.5	0.014	25.75	0.065	26.44	N.A.	0.5	0.98	2.232	30.96
16-Jan-95	<0.05	0.07	0.041	53.00	0.01	7.2	0.015	27.27	0.102	30.16	0.1	0.48	0.96	1.521	37.38
16-Feb-95	0.45	0.09	0.031	55.00	0.01	4.5	0.014	26.32	0.094	26.70	N.A.	0.7	1.03	2.662	31.20
15-Mar-95	0.36	0.09	0.135	58.30	0.008	4.0	0.015	28.97	0.022	24.24	N.A.	19.1	6.68	2.363	28.22
12-Apr-95	0.10	0.09	0.146	66.40	0.022	4.1	0.015	29.93	0.037	24.09	N.A.	21.3	6.10	2.151	28.17
15-May-95	<0.02	0.09	0.145	64.45	<0.005	4.5	0.014	29.97	0.022	24.32	N.A.	20.9	6.81	2.306	28.78
13-Jun-95	<0.02	0.11	0.137	62.89	<0.005	4.9	0.014	28.50	0.025	23.94	N.A.	20.5	6.39	2.407	28.81

Well G11

	Al	B	Ba	Ca	Fe	K	Li	Mg	Mn	Na	P	S	Si	Sr	Na+K
Detection Limit	0.01	0.01	0.002	0.01	0.01	0.05	0.005	0.01	0.002	0.01	0.1	0.05	0.01	0.002	
7-May-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21-May-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3-Jun-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17-Jun-94	0.11	0.02	0.084	192.49	0.00	6.51	0.000	26.65	0.002	12.39	0.3	18.11	6.22	0.587	18.91
1-Jul-94	0.15	0.03	0.085	201.10	0.00	5.28	0.000	25.94	0.003	14.95	0.0	17.34	6.83	0.574	20.23
15-Jul-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
29-Jul-94	0.13	0.02	0.080	166.43	0.00	5.88	0.000	28.90	0.000	14.20	0.0	19.47	8.46	0.471	20.08
12-Aug-94	<0.05	0.03	0.087	150.52	n.s.	5.6	0.005	34.53	<0.002	15.98	0.4	27.38	7.41	0.481	21.57
26-Aug-94	0.14	0.03	0.081	141.16	n.s.	5.7	<0.005	36.24	<0.002	16.62	<0.1	28.92	7.78	0.471	22.34
10-Sep-94	0.15	0.02	0.076	128.20	n.s.	6.8	0.006	36.41	<0.002	17.51	0.3	32.48	7.34	0.468	24.33
23-Sep-94	<0.05	0.03	0.049	108.48	<0.01	4.9	0.005	33.34	<0.002	14.38	N.A.	21.5	6.47	0.530	19.27
15-Oct-94	<0.05	0.02	0.051	90.87	<0.01	4.1	<0.005	32.25	<0.002	15.37	<0.1	26.23	6.65	0.398	19.46
15-Nov-94	<0.05	0.04	0.073	123.43	0.04	8.6	0.005	32.81	<0.002	16.65	N.A.	24.0	5.69	0.634	25.29
15-Dec-94	<0.05	0.05	0.077	160.10	0.02	6.8	0.003	31.66	<0.002	16.24	N.A.	24.4	4.97	0.688	23.05
16-Jan-95	<0.05	0.01	0.009	17.36	0.01	11.3	<0.005	2.43	<0.002	1.60	0.4	4.04	0.85	0.059	12.89
16-Feb-95	<0.05	0.03	0.063	157.24	0.02	4.5	0.003	24.73	0.014	12.89	N.A.	18.9	4.19	0.556	17.38
15-Mar-95	0.17	0.03	0.070	145.48	0.010	5.3	0.004	28.33	<0.002	12.31	N.A.	27.4	4.48	0.604	17.58
12-Apr-95	0.15	0.03	0.065	150.77	0.009	4.3	0.004	23.77	<0.002	10.73	N.A.	25.0	3.74	0.545	15.01
15-May-95	0.11	0.04	0.071	166.25	<0.005	5.0	<0.002	24.66	<0.002	10.91	N.A.	27.4	4.19	0.588	15.91
13-Jun-95	<0.02	0.05	0.073	178.75	<0.005	4.6	0.003	24.79	<0.002	11.83	N.A.	25.7	4.53	0.584	16.44

Well G11A

	Al	B	Ba	Ca	Fe	K	Li	Mg	Mn	Na	P	S	Si	Sr	Na+K
Detection Limit	0.01	0.01	0.002	0.01	0.01	0.05	0.005	0.01	0.002	0.01	0.1	0.05	0.01	0.002	
7-May-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21-May-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3-Jun-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17-Jun-94	0.12	0.03	0.055	81.51	0.54	56.29	0.000	14.59	0.430	7.01	1.1	12.94	10.40	0.317	63.30
1-Jul-94	0.07	0.04	0.078	115.99	0.66	76.53	0.000	23.71	0.575	16.21	1.4	18.59	9.09	0.560	92.73
15-Jul-94	0.10	0.04	0.059	96.39	0.24	66.04	0.000	18.01	0.253	9.26	0.8	20.55	9.62	0.392	75.30
29-Jul-94	0.10	0.04	0.060	95.08	0.57	65.32	0.000	18.13	0.437	9.71	1.7	23.32	8.28	0.420	75.03
12-Aug-94	0.15	0.09	0.032	89.09	1.81	59.6	<0.005	0.92	0.040	10.39	6.8	31.78	7.75	0.394	69.98
26-Aug-94	0.19	0.09	0.063	101.31	<0.01	69.6	<0.005	20.39	0.363	13.40	3.3	37.96	7.46	0.460	82.97
10-Sep-94	0.21	0.10	0.072	113.02	<0.01	77.9	<0.005	24.23	0.453	16.07	2.0	40.13	7.45	0.550	93.96
23-Sep-94	0.17	0.12	0.058	89.96	0.07	71.1	0.002	16.50	0.028	13.62	N.A.	39.8	5.27	0.424	84.71
15-Oct-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15-Nov-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15-Dec-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16-Jan-95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16-Feb-95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15-Mar-95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12-Apr-95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15-May-95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13-Jun-95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Well G12

	Al	B	Ba	Ca	Fe	K	Li	Mg	Mn	Na	P	S	Si	Sr	Na+K
Detection Limit	0.01	0.01	0.002	0.01	0.01	0.05	0.005	0.01	0.002	0.01	0.1	0.05	0.01	0.002	
7-May-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21-May-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3-Jun-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17-Jun-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1-Jul-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15-Jul-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
29-Jul-94	0.00	0.01	0.002	1.50	0.00	1.96	0.000	0.49	0.000	172.35	0.0	26.69	6.34	0.017	174.31
12-Aug-94	<0.05	0.03	<0.005	0.17	0.01	0.7	<0.005	0.09	<0.002	201.20	<0.1	37.28	5.12	0.007	201.92
26-Aug-94	<0.05	0.03	0.168	95.36	0.66	2.8	0.006	26.01	0.031	25.94	<0.1	37.89	5.03	1.561	28.70
10-Sep-94	<0.05	0.02	0.166	95.19	0.69	2.8	0.006	25.82	0.032	25.55	<0.1	37.07	5.12	1.561	28.31
23-Sep-94	0.31	0.03	0.142	100.67	0.03	2.7	0.007	23.73	0.033	21.24	N.A.	20.7	4.82	1.749	23.97
15-Oct-94	<0.05	0.03	0.165	88.01	<0.01	2.9	0.006	25.28	0.033	27.08	<0.1	38.18	5.00	1.554	29.98
15-Nov-94	0.28	0.03	0.143	101.43	<0.01	2.5	0.006	23.74	0.038	21.01	N.A.	20.8	4.77	1.731	23.53
15-Dec-94	0.29	0.04	0.138	98.57	0.05	2.5	0.006	24.08	0.028	20.64	N.A.	20.5	4.82	1.701	23.17
16-Jan-95	0.20	0.03	0.153	76.86	<0.01	11.0	0.007	23.38	0.025	26.93	<0.1	30.99	4.54	1.504	37.93
16-Feb-95	0.31	0.03	0.139	100.57	0.02	2.6	0.006	23.96	0.030	19.02	N.A.	20.7	4.72	1.725	21.61
15-Mar-95	0.15	0.03	0.145	97.50	0.008	2.4	0.006	24.01	0.031	19.79	N.A.	28.9	4.75	1.770	22.20
12-Apr-95	0.35	0.03	0.143	100.00	0.009	2.3	0.006	23.47	0.033	18.69	N.A.	29.3	4.51	1.747	21.03
15-May-95	0.09	0.03	0.146	101.83	<0.005	2.3	0.006	24.58	0.033	19.75	N.A.	29.2	4.55	1.811	22.02
13-Jun-95	<0.02	0.04	0.145	106.92	<0.005	2.6	0.006	25.42	0.036	18.40	N.A.	31.1	4.96	1.806	20.96

Piezometre P1

	Al	B	Ba	Ca	Fe	K	Li	Mg	Mn	Na	P	S	Si	Sr	Na+K
Detection Limit	0.01	0.01	0.002	0.01	0.01	0.05	0.005	0.01	0.002	0.01	0.1	0.05	0.01	0.002	
7-May-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21-May-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3-Jun-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17-Jun-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1-Jul-94	0.17	0.02	0.217	117.83	0.63	3.11	0.009	28.01	0.263	16.03	0.1	20.65	10.56	0.987	19.14
15-Jul-94	0.09	0.02	0.209	111.89	0.68	3.11	0.008	27.99	0.257	16.52	0.2	20.72	11.40	0.965	19.62
29-Jul-94	0.21	0.02	0.202	109.84	0.63	3.43	0.009	27.50	0.252	15.79	0.1	22.24	11.17	0.916	19.22
12-Aug-94	<0.05	0.03	0.237	113.38	1.60	2.8	0.011	30.18	0.220	18.60	0.4	31.51	9.43	0.923	21.37
26-Aug-94	<0.05	0.04	0.249	113.78	1.34	3.1	0.012	30.70	0.226	18.31	<0.1	32.48	9.38	0.997	21.41
10-Sep-94	0.09	0.04	0.226	107.51	1.24	2.8	0.011	28.57	0.208	18.57	0.8	26.16	9.45	0.941	21.33
23-Sep-94	<0.02	0.03	0.160	118.08	0.775	2.2	0.009	22.26	0.215	12.30	N.A.	26.1	7.29	0.798	14.49
15-Oct-94	0.16	0.03	0.187	108.86	1.48	2.6	0.009	24.10	0.203	15.98	0.1	33.47	7.68	0.716	18.55
15-Nov-94	0.23	0.04	0.153	119.04	0.533	2.2	0.008	23.00	0.214	12.15	N.A.	27.1	7.14	0.799	14.38
15-Dec-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16-Jan-95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16-Feb-95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15-Mar-95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12-Apr-95	0.17	0.04	0.183	95.76	0.050	2.8	0.007	25.56	0.203	14.57	N.A.	22.7	8.13	1.079	17.38
15-May-95	0.10	0.04	0.198	98.27	0.021	2.4	0.007	26.21	0.230	14.16	N.A.	22.4	8.17	1.145	16.55
13-Jun-95	<0.02	0.05	0.199	101.54	0.081	2.7	0.007	26.85	0.209	15.44	N.A.	9.7	8.54	1.121	18.10

Piezometre P2

	Al	B	Ba	Ca	Fe	K	Li	Mg	Mn	Na	P	S	Si	Sr	Na+K
Detection Limit	0.01	0.01	0.002	0.01	0.01	0.05	0.005	0.01	0.002	0.01	0.1	0.05	0.01	0.002	
7-May-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21-May-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3-Jun-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17-Jun-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1-Jul-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15-Jul-94	0.16	0.09	0.082	59.72	0.02	4.72	0.007	20.04	0.000	32.07	0.2	2.79	18.25	1.081	36.79
29-Jul-94	0.12	0.08	0.072	49.98	0.04	4.14	0.000	14.73	0.151	29.62	0.2	5.51	12.04	0.755	33.76
12-Aug-94	<0.05	<0.01	0.033	56.15	1.96	1.7	<0.005	7.50	0.901	3.72	<0.1	3.64	3.81	0.155	5.39
26-Aug-94	0.06	0.02	0.058	58.26	1.77	2.5	<0.005	9.19	1.038	6.57	<0.1	3.41	4.19	0.262	9.04
10-Sep-94	0.15	0.02	0.065	66.29	2.10	2.4	0.005	10.05	1.224	5.97	<0.1	1.91	4.22	0.253	8.42
23-Sep-94	0.15	0.22	0.073	39.64	0.018	5.7	0.004	13.29	<0.002	32.28	N.A.	3.2	5.65	0.975	37.95
15-Oct-94	0.65	0.20	0.056	30.27	0.06	7.6	<0.005	12.38	<0.002	41.20	<0.1	9.31	7.16	0.628	48.78
15-Nov-94	0.13	0.22	0.048	35.19	<0.005	16.0	0.004	13.71	<0.002	33.87	N.A.	4.5	5.78	1.075	49.90
15-Dec-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16-Jan-95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16-Feb-95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15-Mar-95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12-Apr-95	0.20	0.21	0.082	39.04	0.026	4.0	0.004	15.62	0.130	33.16	N.A.	8.2	4.46	1.265	37.12
15-May-95	0.11	0.18	0.044	35.75	0.009	4.1	0.003	14.98	0.008	33.53	N.A.	10.2	4.75	1.210	37.64
13-Jun-95	0.12	0.20	0.042	38.85	<0.005	3.7	0.003	14.73	<0.002	33.60	N.A.	7.6	4.91	1.221	37.33

Piezometre P3

	Al	B	Ba	Ca	Fe	K	Li	Mg	Mn	Na	P	S	Si	Sr	Na+K
Detection Limit	0.01	0.01	0.002	0.01	0.01	0.05	0.005	0.01	0.002	0.01	0.1	0.05	0.01	0.002	
7-May-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21-May-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3-Jun-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17-Jun-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1-Jul-94	0.15	0.00	0.065	108.54	0.17	2.62	0.000	12.56	0.653	5.91	0.0	5.28	7.32	0.329	8.53
15-Jul-94	0.17	0.02	0.113	137.59	0.16	3.46	0.000	18.29	0.211	6.67	0.0	39.44	5.11	0.529	10.13
29-Jul-94	0.07	0.00	0.061	98.28	0.06	2.09	0.000	11.56	0.289	3.98	0.0	15.24	3.86	0.283	6.07
12-Aug-94	0.16	<0.01	0.081	127.12	0.15	1.7	<0.005	15.09	0.174	4.72	<0.1	36.08	3.31	0.318	6.39
26-Aug-94	0.19	<0.01	0.083	130.00	0.30	1.5	<0.005	15.21	0.108	4.86	<0.1	33.13	3.37	0.307	6.39
10-Sep-94	0.37	<0.01	0.089	132.52	0.52	1.5	<0.005	15.23	0.068	5.51	<0.1	28.56	3.68	0.311	7.06
23-Sep-94	0.08	<0.01	0.072	107.79	0.016	1.3	0.003	11.56	0.047	4.31	N.A.	18.5	2.74	0.329	5.59
15-Oct-94	0.05	<0.01	0.072	98.74	0.01	1.4	<0.005	12.33	0.013	6.32	<0.1	24.97	2.60	0.293	7.72
15-Nov-94	0.14	<0.01	0.069	127.40	0.035	1.3	<0.002	13.79	0.055	5.26	N.A.	59.1	2.54	0.387	6.51
15-Dec-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16-Jan-95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16-Feb-95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15-Mar-95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12-Apr-95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15-May-95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13-Jun-95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Piezometre P4

	Al	B	Ba	Ca	Fe	K	Li	Mg	Mn	Na	P	S	Si	Sr	Na+K
Detection Limit	0.01	0.01	0.002	0.01	0.01	0.05	0.005	0.01	0.002	0.01	0.1	0.05	0.01	0.002	
7-May-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21-May-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3-Jun-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17-Jun-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1-Jul-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15-Jul-94	0.05	0.00	0.035	92.37	1.02	3.84	0.000	9.24	0.854	7.59	0.0	1.87	4.58	0.231	11.43
29-Jul-94	0.36	0.02	0.146	57.74	0.22	3.76	0.006	23.78	0.240	12.25	0.0	7.17	11.36	0.638	16.00
12-Aug-94	<0.05	0.06	0.068	40.86	0.02	3.1	0.006	25.57	0.181	15.35	<0.1	16.26	8.42	0.674	18.40
26-Aug-94	0.41	0.06	0.151	36.48	0.66	3.3	0.006	3.26	0.078	15.06	<0.1	20.39	9.23	0.796	18.37
10-Sep-94	3.51	0.05	0.003	38.32	<0.01	4.3	0.007	0.06	<0.002	15.28	<0.1	20.18	9.28	0.790	19.61
23-Sep-94	0.27	0.06	0.062	108.75	0.046	3.2	0.003	21.30	0.324	12.71	N.A.	2.6	9.62	0.591	15.91
15-Oct-94	0.06	0.04	0.227	94.91	<0.01	3.5	0.008	32.02	0.018	16.71	<0.1	13.46	7.31	0.844	20.25
15-Nov-94	<0.02	0.04	0.234	110.10	0.007	2.5	0.008	31.20	0.277	14.41	N.A.	10.5	6.62	1.012	16.95
15-Dec-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16-Jan-95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16-Feb-95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15-Mar-95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12-Apr-95	0.35	0.04	0.083	97.02	0.054	2.6	0.003	20.71	0.003	11.98	N.A.	14.4	4.46	0.599	14.60
15-May-95	<0.02	0.10	0.093	100.38	0.005	4.2	0.013	32.45	<0.002	15.94	N.A.	1.7	14.41	1.073	20.14
13-Jun-95	0.43	0.02	0.051	86.65	0.311	1.7	0.004	10.02	0.005	8.00	N.A.	11.0	1.90	0.332	9.67

Tile Drain T1

	Al	B	Ba	Ca	Fe	K	Li	Mg	Mn	Na	P	S	Si	Sr	Na+K
Detection Limit	0.01	0.01	0.002	0.01	0.01	0.05	0.005	0.01	0.002	0.01	0.1	0.05	0.01	0.002	
7-May-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21-May-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3-Jun-94	0.09	0.00	0.034	129.79	0.00	0.85	0.000	14.45	0.000	48.26	0.0	10.44	5.87	0.376	49.11
17-Jun-94	0.09	0.00	0.038	133.28	0.00	1.19	0.000	14.54	0.000	55.24	0.1	10.90	6.37	0.385	56.42
1-Jul-94	0.12	0.00	0.038	124.61	0.00	1.20	0.006	16.18	0.000	39.10	0.0	11.07	7.38	0.418	40.30
15-Jul-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
29-Jul-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12-Aug-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
26-Aug-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10-Sep-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
23-Sep-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15-Oct-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15-Nov-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15-Dec-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16-Jan-95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16-Feb-95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15-Mar-95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12-Apr-95	0.24	<0.01	0.025	115.48	0.007	0.7	0.003	15.97	<0.002	23.56	N.A.	5.7	4.56	0.432	24.22
15-May-95	0.20	<0.01	0.029	129.52	<0.005	0.8	0.003	16.91	<0.002	29.86	N.A.	6.5	4.76	0.490	30.62
13-Jun-95	0.17	<0.01	0.035	150.19	<0.005	0.4	<0.002	15.90	<0.002	38.90	N.A.	6.8	4.90	0.488	39.26

Tile Drain T2

	Al	B	Ba	Ca	Fe	K	Li	Mg	Mn	Na	P	S	Si	Sr	Na+K
Detection Limit	0.01	0.01	0.002	0.01	0.01	0.05	0.005	0.01	0.002	0.01	0.1	0.05	0.01	0.002	
7-May-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21-May-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3-Jun-94	0.15	0.00	0.020	84.15	0.00	1.08	0.006	21.53	0.000	6.48	0.2	8.09	7.66	0.163	7.57
17-Jun-94	0.13	0.00	0.023	82.40	0.00	0.98	0.005	18.57	0.000	6.19	0.0	7.76	7.91	0.170	7.16
1-Jul-94	0.11	0.00	0.024	77.92	0.00	0.84	0.000	24.80	0.000	8.60	0.0	7.64	9.31	0.162	9.45
15-Jul-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
29-Jul-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12-Aug-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
26-Aug-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10-Sep-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
23-Sep-94	<0.05	<0.01	0.010	19.96	0.01	2.2	<0.005	6.88	<0.002	3.21	<0.1	4.32	1.89	0.056	5.42
15-Oct-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15-Nov-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15-Dec-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16-Jan-95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16-Feb-95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15-Mar-95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12-Apr-95	0.28	<0.01	0.017	77.55	0.009	0.5	0.002	18.90	<0.002	5.57	N.A.	5.3	4.66	0.170	6.03
15-May-95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13-Jun-95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Tile Drain T3

	Al	B	Ba	Ca	Fe	K	Li	Mg	Mn	Na	P	S	Si	Sr	Na+K
Detection Limit	0.01	0.01	0.002	0.01	0.01	0.05	0.005	0.01	0.002	0.01	0.1	0.05	0.01	0.002	
7-May-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21-May-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3-Jun-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17-Jun-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1-Jul-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15-Jul-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
29-Jul-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12-Aug-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
26-Aug-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10-Sep-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
23-Sep-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15-Oct-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15-Nov-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15-Dec-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16-Jan-95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16-Feb-95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15-Mar-95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12-Apr-95	0.24	<0.01	0.021	92.54	0.006	0.3	0.002	13.15	<0.002	7.35	N.A.	4.9	4.12	0.228	7.62
15-May-95	0.15	<0.01	0.023	103.17	<0.005	0.3	0.002	13.48	<0.002	7.19	N.A.	4.8	4.65	0.237	7.50
13-Jun-95	0.16	<0.01	0.026	108.17	<0.005	0.5	0.003	13.89	<0.002	8.13	N.A.	4.7	5.47	0.256	8.67

Tile Drain T4

	Al	B	Ba	Ca	Fe	K	Li	Mg	Mn	Na	P	S	Si	Sr	Na+K
Detection Limit	0.01	0.01	0.002	0.01	0.01	0.05	0.005	0.01	0.002	0.01	0.1	0.05	0.01	0.002	
7-May-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21-May-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3-Jun-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17-Jun-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1-Jul-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15-Jul-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
29-Jul-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12-Aug-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
26-Aug-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10-Sep-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
23-Sep-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15-Oct-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15-Nov-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15-Dec-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16-Jan-95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16-Feb-95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15-Mar-95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12-Apr-95	<0.02	0.03	0.026	118.08	0.010	1.7	0.008	37.36	<0.002	18.58	N.A.	9.3	5.45	0.643	20.24
15-May-95	0.17	0.03	0.026	113.56	<0.005	1.7	0.008	35.76	<0.002	18.12	N.A.	8.5	5.79	0.621	19.81
13-Jun-95	<0.02	0.05	0.025	106.92	0.006	1.8	0.012	33.26	<0.002	21.84	N.A.	7.7	6.88	0.581	23.64

Appendix B3. Atomic emission spectrometry results of selected trace metals (mg/L or ppm)

Well G1	Al	Cd	Co	Cr	Cu	Fe	Mo	Pb	Zn	Be	Ni
detection limit=	<0.04	<0.009	<0.007	<0.008	<0.008	<0.005	<0.015	<0.05	0.015	<0.002	<0.01
7-May-94	0.04	0.009	0.009	<0.008	0.087	0.015	<.015	<0.05	0.052	<0.002	<0.01
21-May-94	<0.04	<0.009	0.007	<0.008	0.073	0.009	<.015	<0.05	0.054	<0.002	<0.01
3-Jun-94	<0.04	<0.009	0.007	<0.008	0.051	0.020	<.015	<0.05	0.072	<0.002	<0.01

Well G2	Al	Cd	Co	Cr	Cu	Fe	Mo	Pb	Zn	Be	Ni
detection limit=	<0.04	<0.009	<0.007	<0.008	<0.008	<0.005	<0.015	<0.05	0.015	<0.002	<0.01
7-May-94	<0.04	0.014	<0.007	<0.008	<0.008	<0.005	<.015	<0.05	0.070	<0.002	<0.01
21-May-94	0.06	<0.009	0.009	<0.008	0.009	0.012	<.015	<0.05	0.119	<0.002	<0.01
3-Jun-94	<0.04	0.010	0.010	<0.008	0.039	0.007	<.015	<0.05	0.047	<0.002	<0.01
17-Jun-94	<0.04	<0.009	0.007	<0.008	0.018	<0.005	<.015	<0.05	0.032	<0.002	<0.01
1-Jul-94	<0.04	<0.009	<0.007	<0.008	0.017	0.010	<.015	<0.05	0.130	<0.002	0.010
15-Jul-94	<0.04	<0.009	<0.007	<0.008	0.025	0.009	<.015	<0.05	0.141	<0.002	<0.01
29-Jul-94	<0.04	<0.009	<0.007	<0.008	0.034	<0.005	<.015	<0.05	0.059	<0.002	<0.01
12-Aug-94	0.06	<0.009	<0.007	<0.008	0.021	0.007	<.015	<0.05	0.084	<0.002	<0.01
26-Aug-94	0.05	0.011	<0.007	<0.008	<0.008	0.006	<.015	<0.05	0.015	<0.002	<0.01
10-Sep-94	<0.04	<0.009	<0.007	<0.008	<0.008	0.007	<.015	<0.05	0.018	<0.002	<0.01
23-Sep-94	<0.04	<0.009	<0.007	<0.008	0.012	0.016	<.015	0.05	0.097	<0.002	<0.01
15-Oct-94	<0.04	<0.009	<0.007	<0.008	<0.008	<0.005	<.015	<0.05	0.075	<0.002	<0.01
15-Nov-94	0.23	<0.009	<0.007	<0.008	0.015	0.211	<.015	<0.05	0.214	<0.002	<0.01
15-Dec-94	<0.04	<0.009	0.010	<0.008	<0.008	0.121	<.015	<0.05	0.209	<0.002	<0.01
16-Jan-95	0.05	0.011	0.008	<0.008	<0.008	0.007	<.015	<0.05	0.161	<0.002	<0.01
16-Feb-95	<0.04	0.001	<0.007	<0.008	<0.008	0.008	<.015	<0.05	0.339	<0.002	<0.01
15-Mar-95	0.04	<0.009	<0.007	<0.008	<0.008	<0.005	<.015	<0.05	0.033	<0.002	<0.01
12-Apr-95	-	<0.01	<0.015	<0.015	<0.002	-	-	<0.06	0.972	<0.001	<0.01
15-May-95	-	<0.01	<0.015	<0.015	<0.002	-	-	<0.06	0.126	<0.001	<0.01
13-Jun-95	-	<0.01	<0.015	<0.015	0.003	-	-	<0.06	0.052	<0.001	<0.01

Appendix B3 (continued)

Well G3	Al	Cd	Co	Cr	Cu	Fe	Mo	Pb	Zn	Be	Ni
detection limit=	<0.04	<0.009	<0.007	<0.008	<0.008	<0.005	<0.015	<0.05	0.015	<0.002	<0.01
7-May-94	0.05	<0.009	0.008	<0.008	0.021	0.042	<.015	<0.05	0.046	0.004	0.016
3-Jun-94	<0.04	0.009	<0.007	<0.008	<0.008	0.034	<.015	<0.05	0.041	<0.002	<0.01
1-Jul-94	0.12	<0.009	<0.007	<0.008	<0.008	0.035	<.015	<0.05	0.034	<0.002	<0.01
29-Jul-94	0.05	<0.009	0.008	<0.008	<0.008	0.039	<.015	<0.05	0.039	<0.002	0.011
26-Aug-94	0.05	<0.009	<0.007	<0.008	<0.008	0.049	<.015	<0.05	0.052	<0.002	<0.01
23-Sep-94	0.06	<0.009	0.010	<0.008	0.003	0.018	<.015	0.06	0.148	<0.002	<0.01
15-Oct-94	0.11	<0.009	0.008	<0.008	<0.008	0.007	<.015	<0.05	0.072	<0.002	<0.01
15-Nov-94	0.10	<0.009	<0.007	<0.008	<0.008	0.016	<.015	0.08	0.359	<0.002	<0.01
15-Dec-94	<0.04	0.009	<0.007	<0.008	0.009	0.020	<.015	<0.05	0.260	<0.002	<0.01
16-Jan-95	0.11	<0.009	0.007	<0.008	0.010	0.010	<.015	<0.05	0.249	0.003	0.025
16-Feb-95	0.14	0.009	0.007	<0.008	0.008	0.015	<.015	<0.05	0.452	<0.002	<0.01
15-Mar-95	0.10	<0.009	<0.007	<0.008	<0.008	<0.005	<.015	<0.05	0.184	<0.002	<0.01
12-Apr-95	-	<0.01	<0.015	<0.015	<0.002	-	-	<0.06	0.745	<0.001	<0.01
15-May-95	-	<0.01	<0.015	<0.015	<0.002	-	-	<0.06	0.020	<0.001	<0.01
13-Jun-95	-	<0.01	<0.015	<0.015	<0.002	-	-	<0.06	0.042	<0.001	<0.01

Well G4	Al	Cd	Co	Cr	Cu	Fe	Mo	Pb	Zn	Be	Ni
detection limit=	<0.04	<0.009	<0.007	<0.008	<0.008	<0.005	<0.015	<0.05	0.015	<0.002	<0.01
21-May-94	0.04	<0.009	<0.007	<0.008	<0.008	0.945	<.015	<0.05	0.044	<0.002	<0.01
17-Jun-94	0.06	<0.009	<0.007	<0.008	<0.008	0.578	<.015	<0.05	0.022	<0.002	<0.01
15-Jul-94	<0.04	<0.009	0.008	<0.008	<0.008	0.722	<.015	<0.05	0.025	<0.002	<0.01
12-Aug-94	<0.04	<0.009	<0.007	<0.008	<0.008	0.307	<.015	<0.05	0.149	<0.002	<0.01
10-Sep-94	<0.04	<0.009	<0.007	<0.008	<0.008	0.163	<.015	<0.05	0.123	<0.002	<0.01
23-Sep-94	0.05	<0.009	0.009	<0.008	<0.008	0.011	<.015	<0.05	0.417	<0.002	<0.01
15-Oct-94	0.07	<0.009	0.014	<0.008	0.009	0.008	<.015	<0.05	0.055	<0.002	<0.01
15-Nov-94	0.21	<0.009	0.007	<0.008	<0.008	0.018	<.015	<0.05	1.725	<0.002	<0.01
15-Dec-94	0.11	<0.009	0.011	<0.008	<0.008	0.008	<.015	<0.05	0.517	<0.002	<0.01
16-Jan-95	<0.04	<0.009	<0.007	<0.008	<0.008	0.023	<.015	<0.05	0.345	<0.002	<0.01
16-Feb-95	<0.04	<0.009	<0.007	<0.008	<0.008	<0.005	<.015	<0.05	0.595	<0.002	<0.01
15-Mar-95	0.11	<0.009	<0.007	<0.008	<0.008	<0.005	<.015	0.05	0.341	<0.002	<0.01

Appendix B3 (continued)

Well G6	Al	Cd	Co	Cr	Cu	Fe	Mo	Pb	Zn	Be	Ni
detection limit=	<0.04	<0.009	<0.007	<0.008	<0.008	<0.005	<0.015	<0.05	0.015	<0.002	<0.01
7-May-94	0.12	0.009	<0.007	<0.008	<0.008	0.024	<.015	<0.05	<0.008	<0.002	<0.01
3-Jun-94	0.05	<0.009	0.008	<0.008	<0.008	0.017	<.015	<0.05	<0.008	<0.002	<0.01
1-Jul-94	<0.04	<0.009	<0.007	<0.008	<0.008	0.020	<.015	0.05	<0.008	<0.002	<0.01
29-Jul-94	0.08	<0.009	0.013	<0.008	<0.008	0.016	<.015	<0.05	<0.008	<0.002	<0.01
26-Aug-94	0.06	<0.009	<0.007	<0.008	<0.008	0.015	<.015	<0.05	<0.008	<0.002	<0.01
23-Sep-94	<0.04	<0.009	<0.007	<0.008	<0.008	0.042	<.015	<0.05	0.143	<0.002	<0.01
15-Oct-94	0.10	<0.009	0.012	<0.008	<0.008	<0.005	<.015	<0.05	0.046	<0.002	<0.01
15-Nov-94	<0.04	<0.009	<0.007	<0.008	<0.008	0.009	<.015	<0.05	0.363	<0.002	<0.01
15-Dec-94	0.05	<0.009	0.008	<0.008	<0.008	0.009	<.015	<0.05	0.162	<0.002	<0.01
16-Jan-95	0.08	<0.009	0.007	<0.008	<0.008	0.008	<.015	<0.05	0.188	<0.002	<0.01
16-Feb-95	0.17	<0.009	0.006	<0.008	<0.008	0.019	<.015	<0.05	0.392	<0.002	<0.01
15-Mar-95	0.09	<0.009	<0.007	<0.008	<0.008	0.008	<.015	<0.05	<0.008	<0.002	<0.01
12-Apr-95	-	<0.01	<0.015	<0.015	<0.002	-	-	<0.06	0.960	<0.001	<0.01
15-May-95	-	<0.01	<0.015	<0.015	<0.002	-	-	<0.06	0.016	<0.001	<0.01
13-Jun-95	-	<0.01	<0.015	<0.015	<0.002	-	-	<0.06	<0.006	<0.001	<0.01

Well G7	Al	Cd	Co	Cr	Cu	Fe	Mo	Pb	Zn	Be	Ni
detection limit=	<0.04	<0.009	<0.007	<0.008	<0.008	<0.005	<0.015	<0.05	0.015	<0.002	<0.01
7-May-94	<0.04	<0.009	<0.007	<0.008	0.011	0.020	<.015	<0.05	0.015	<0.002	<0.01
21-May-94	<0.04	<0.009	<0.007	<0.008	0.009	0.006	<.015	<0.05	0.018	<0.002	<0.01
3-Jun-94	<0.04	<0.009	<0.007	<0.008	<0.008	0.104	<.015	<0.05	<0.008	<0.002	<0.01
17-Jun-94	0.08	<0.009	<0.007	<0.008	<0.008	0.078	<.015	0.06	<0.008	<0.002	<0.01
1-Jul-94	0.05	<0.009	<0.007	<0.008	<0.008	0.210	<.015	<0.05	<0.008	<0.002	<0.01
15-Jul-94	0.05	0.009	<0.007	<0.008	<0.008	0.090	<.015	<0.05	0.010	0.002	<0.01
29-Jul-94	0.06	<0.009	<0.007	<0.008	<0.008	0.289	<.015	<0.05	0.009	<0.002	<0.01
12-Aug-94	<0.04	<0.009	0.012	<0.008	<0.008	0.188	<.015	<0.05	<0.008	<0.002	<0.01
26-Aug-94	<0.04	<0.009	0.009	<0.008	<0.008	0.140	<.015	<0.05	<0.008	<0.002	<0.01
10-Sep-94	0.10	<0.009	0.009	<0.008	<0.008	0.039	<.015	<0.05	<0.008	<0.002	<0.01
23-Sep-94	0.07	<0.009	<0.007	<0.008	<0.008	0.038	<.015	<0.05	<0.008	<0.002	<0.01
15-Oct-94	0.05	0.009	<0.007	<0.008	0.012	0.013	<.015	<0.05	0.050	<0.002	<0.01
15-Nov-94	0.09	<0.009	<0.007	<0.008	<0.008	0.020	<.015	<0.05	0.372	<0.002	<0.01
15-Dec-94	<0.04	<0.009	0.009	<0.008	0.015	0.279	<.015	<0.05	0.198	<0.002	<0.01
16-Jan-95	0.06	<0.009	<0.007	<0.008	0.009	<0.005	<.015	<0.05	0.167	<0.002	<0.01
16-Feb-95	<0.04	<0.009	<0.007	<0.008	<0.008	<0.005	<.015	0.06	0.254	<0.002	<0.01
15-Mar-95	<0.04	0.010	<0.007	<0.008	<0.008	<0.005	<.015	<0.05	0.015	<0.002	<0.01
12-Apr-95	-	<0.01	<0.015	<0.015	<0.002	-	-	<0.06	0.883	<0.001	<0.01
15-May-95	-	<0.01	<0.015	<0.015	<0.002	-	-	<0.06	<0.006	<0.001	<0.01
13-Jun-95	-	<0.01	<0.015	<0.015	<0.002	-	-	<0.06	<0.006	<0.001	<0.01

Appendix B3 (continued)

Well G8	Al	Cd	Co	Cr	Cu	Fe	Mo	Pb	Zn	Be	Ni
detection limit=	<0.04	<0.009	<0.007	<0.008	<0.008	<0.005	<0.015	<0.05	0.015	<0.002	<0.01
7-May-94	0.07	<0.009	0.010	<0.008	0.013	0.006	<.015	<0.05	0.013	<0.002	<0.01
21-May-94	<0.04	<0.009	<0.007	<0.008	0.008	0.007	<.015	<0.05	0.022	<0.002	<0.01
3-Jun-94	<0.04	<0.009	0.008	<0.008	0.011	<0.005	<.015	<0.05	<0.008	<0.002	<0.01
17-Jun-94	0.04	0.011	<0.007	<0.008	<0.008	0.007	<.015	<0.05	<0.008	<0.002	<0.01
1-Jul-94	<0.04	<0.009	<0.007	<0.008	0.010	<0.005	<.015	<0.05	<0.008	<0.002	<0.01
15-Jul-94	0.05	0.011	<0.007	<0.008	0.008	<0.005	<.015	<0.05	<0.008	<0.002	<0.01
29-Jul-94	0.07	<0.009	<0.007	<0.008	0.010	<0.005	<.015	<0.05	<0.008	<0.002	<0.01
12-Aug-94	0.05	<0.009	<0.007	<0.008	0.011	<0.005	<.015	<0.05	<0.008	<0.002	<0.01
26-Aug-94	<0.04	<0.009	<0.007	<0.008	0.009	<0.005	<.015	<0.05	<0.008	<0.002	<0.01
10-Sep-94	<0.04	<0.009	0.008	<0.008	0.010	<0.005	<.015	<0.05	<0.008	<0.002	<0.01
23-Sep-94	<0.04	<0.009	<0.007	<0.008	0.013	0.011	<.015	<0.05	0.173	<0.002	<0.01
15-Oct-94	<0.04	<0.009	0.010	<0.008	<0.008	0.006	<.015	<0.05	0.049	<0.002	<0.01
15-Nov-94	0.08	<0.009	<0.007	<0.008	0.009	0.006	<.015	<0.05	0.376	<0.002	<0.01
15-Dec-94	0.09	<0.009	<0.007	<0.008	0.019	0.011	<.015	<0.05	0.245	<0.002	<0.01
16-Jan-95	0.04	<0.009	<0.007	<0.008	0.014	<0.005	<.015	<0.05	0.179	<0.002	0.014
16-Feb-95	0.09	<0.009	<0.007	<0.008	0.112	0.008	<.015	<0.05	0.790	<0.002	<0.01
15-Mar-95	<0.04	<0.009	<0.007	<0.008	0.010	<0.005	<.015	<0.05	0.014	<0.002	<0.01
12-Apr-95	-	<0.01	<0.015	<0.015	<0.002	-	-	<0.06	1.086	<0.001	<0.01
15-May-95	-	<0.01	<0.015	<0.015	<0.002	-	-	<0.06	<0.006	<0.001	<0.01
13-Jun-95	-	<0.01	<0.015	<0.015	0.003	-	-	<0.06	0.007	<0.001	<0.01

Well G9	Al	Cd	Co	Cr	Cu	Fe	Mo	Pb	Zn	Be	Ni
7-May-94	<0.04	<0.009	<0.007	<0.008	0.012	0.059	<.015	<0.05	<0.008	0.002	0.027
3-Jun-94	<0.04	<0.009	<0.007	<0.008	<0.008	0.063	<.015	<0.05	<0.008	<0.002	0.033
1-Jul-94	<0.04	<0.009	<0.007	<0.008	<0.008	0.037	<.015	<0.05	<0.008	<0.002	0.033
29-Jul-94	0.06	<0.009	<0.007	<0.008	<0.008	0.021	<.015	<0.05	<0.008	<0.002	0.044
26-Aug-94	<0.04	<0.009	<0.007	<0.008	<0.008	0.029	<.015	<0.05	<0.008	<0.002	0.037
23-Sep-94	<0.04	<0.009	<0.007	<0.008	<0.008	0.051	<.015	<0.05	0.116	<0.002	<0.01
15-Oct-94	<0.04	<0.009	<0.007	<0.008	<0.008	0.023	<.015	<0.05	0.041	<0.002	0.068
15-Nov-94	<0.04	<0.009	<0.007	<0.008	<0.008	0.016	<.015	<0.05	0.151	<0.002	<0.01
15-Dec-94	<0.04	<0.009	<0.007	<0.008	<0.008	0.094	<.015	<0.05	0.257	<0.002	<0.01
16-Jan-95	<0.04	<0.009	<0.007	<0.008	<0.008	0.016	<.015	<0.05	0.056	<0.002	0.027
16-Feb-95	0.05	<0.009	<0.007	<0.008	<0.008	0.012	<.015	<0.05	0.355	<0.002	0.013
16-Feb-95	<0.04	<0.009	<0.007	<0.008	<0.008	0.012	<.015	<0.05	0.431	<0.002	<0.01
15-Mar-95	<0.04	<0.009	<0.007	<0.008	<0.008	0.196	<.015	<0.05	0.028	<0.002	0.019
12-Apr-95	-	<0.01	<0.015	<0.015	<0.002	-	-	<0.06	1.310	<0.001	<0.01
15-May-95	-	<0.01	<0.015	<0.015	0.017	-	-	<0.06	<0.006	<0.001	<0.01
13-Jun-95	-	<0.01	<0.015	<0.015	<0.002	-	-	<0.06	<0.006	<0.001	<0.01

Appendix B3 (continued)

Well G10	Al	Cd	Co	Cr	Cu	Fe	Mo	Pb	Zn	Be	Ni
detection limit=	<0.04	<0.009	<0.007	<0.008	<0.008	<0.005	<0.015	<0.05	0.015	<0.002	<0.01
21-May-94	<0.04	<0.009	<0.007	<0.008	<0.008	0.196	<.015	<0.05	0.030	<0.002	<0.01
17-Jun-94	<0.04	<0.009	0.010	<0.008	<0.008	0.248	<.015	<0.05	<0.008	<0.002	<0.01
15-Jul-94	0.08	<0.009	0.013	<0.008	<0.008	0.064	<.015	0.08	<0.008	<0.002	<0.01
12-Aug-94	<0.04	<0.009	0.007	<0.008	<0.008	0.196	<.015	<0.05	<0.008	<0.002	<0.01
10-Sep-94	0.06	<0.009	<0.007	<0.008	<0.008	0.077	<.015	<0.05	0.009	<0.002	<0.01
23-Sep-94	0.06	<0.009	<0.007	<0.008	<0.008	0.041	<.015	0.07	0.030	<0.002	<0.01
15-Oct-94	<0.04	<0.009	<0.007	<0.008	<0.008	0.008	<.015	<0.05	0.036	<0.002	<0.01
15-Nov-94	0.05	<0.009	<0.007	<0.008	<0.008	0.011	<.015	0.08	0.230	<0.002	<0.01
15-Dec-94	0.07	0.009	<0.007	<0.008	<0.008	0.019	<.015	<0.05	0.322	<0.002	<0.01
16-Jan-95	0.06	<0.009	<0.007	<0.008	<0.008	0.007	<.015	<0.05	0.112	<0.002	<0.01
16-Feb-95	0.12	<0.009	<0.007	<0.008	<0.008	0.010	<.015	<0.05	0.458	<0.002	<0.01
15-Mar-95	<0.04	<0.009	<0.007	<0.008	<0.008	<0.005	<.015	0.08	<0.008	<0.002	<0.01
12-Apr-95	-	<0.01	<0.015	<0.015	<0.002	-	-	<0.06	1.302	<0.001	<0.01
15-May-95	-	<0.01	<0.015	<0.015	<0.002	-	-	<0.06	<0.006	<0.001	<0.01
13-Jun-95	-	<0.01	<0.015	<0.015	<0.002	-	-	<0.06	<0.006	<0.001	<0.01

Tile Drain T1	Al	Cd	Co	Cr	Cu	Fe	Mo	Pb	Zn	Be	Ni
detection limit=	<0.04	<0.009	<0.007	<0.008	<0.008	<0.005	<0.015	<0.05	0.015	<0.002	<0.01
3-Jun-94	<0.04	<0.009	<0.007	<0.008	<0.008	<0.005	<.015	<0.05	<0.008	<0.002	<0.01
17-Jun-94	<0.04	<0.009	0.008	<0.008	<0.008	<0.005	<.015	<0.05	<0.008	<0.002	<0.01
1-Jul-94	0.05	<0.009	<0.007	<0.008	<0.008	<0.005	<.015	<0.05	<0.008	<0.002	<0.01
23-Sep-94	0.05	<0.009	<0.007	<0.008	<0.008	0.014	<.015	0.07	0.153	<0.002	<0.01
15-Nov-94	0.09	<0.009	<0.007	<0.008	<0.008	0.005	<.015	<0.05	0.250	<0.002	<0.01
12-Apr-95	-	<0.01	<0.015	<0.015	<0.002	-	-	<0.06	0.539	<0.001	<0.01
15-May-95	-	<0.01	<0.015	<0.015	<0.002	-	-	<0.06	<0.006	<0.001	<0.01
13-Jun-95	-	<0.01	<0.015	<0.015	<0.002	-	-	<0.06	<0.006	<0.001	<0.01

Tile Drain T2	Al	Cd	Co	Cr	Cu	Fe	Mo	Pb	Zn	Be	Ni
detection limit=	<0.04	<0.009	<0.007	<0.008	<0.008	<0.005	<0.015	<0.05	0.015	<0.002	<0.01
3-Jun-94	0.06	<0.009	<0.007	<0.008	<0.008	<0.005	<.015	<0.05	<0.008	<0.002	<0.01
17-Jun-94	<0.04	<0.009	0.010	<0.008	<0.008	0.008	<.015	<0.05	0.010	<0.002	<0.01
1-Jul-94	0.04	<0.009	0.008	<0.008	<0.008	<0.005	<.015	<0.05	<0.008	<0.002	<0.01
23-Sep-94	0.66	<0.009	<0.007	<0.008	<0.008	0.324	<.015	<0.05	0.172	<0.002	<0.01
16-Jan-95	0.07	<0.009	0.009	<0.008	<0.008	0.011	<.015	<0.05	0.172	<0.002	<0.01
16-Jan-95	-	<0.01	<0.015	<0.015	<0.002	-	-	<0.06	0.749	<0.001	<0.01

Appendix B3 (continued; note: T4, G7T, P2, and P4 analyses all have the same detection limits as T3)

Tile Drain T3	Al	Cd	Co	Cr	Cu	Fe	Mo	Pb	Zn	Be	Ni
detection limit=	<0.04	<0.009	<0.007	<0.008	<0.008	<0.005	<0.015	<0.05	0.015	<0.002	<0.01
23-Sep-94	0.36	0.009	<0.007	<0.008	<0.008	0.082	<.015	<0.05	0.424	<0.002	<0.01
7-Nov-94	0.07	<0.009	0.008	<0.008	<0.008	0.007	<.015	<0.05	0.269	<0.002	<0.01
15-Nov-94	<0.04	<0.009	<0.007	<0.008	<0.008	0.005	<.015	<0.05	0.247	<0.002	<0.01
12-Apr-95	-	<0.01	<0.015	<0.015	<0.002	-	-	<0.06	0.936	<0.001	<0.01
15-May-95	-	<0.01	<0.015	<0.015	<0.002	-	-	<0.06	<0.006	<0.001	<0.01
13-Jun-95	-	<0.01	<0.015	<0.015	<0.002	-	-	<0.06	<0.006	<0.001	<0.01

Tile Drain T4	Al	Cd	Co	Cr	Cu	Fe	Mo	Pb	Zn	Be	Ni
7-Nov-94	0.08	<0.009	<0.007	<0.008	<0.008	0.009	<.015	<0.05	0.230	<0.002	<0.01
15-Nov-94	0.11	0.012	<0.007	<0.008	<0.008	0.007	<.015	<0.05	0.262	<0.002	<0.01
12-Apr-95	-	<0.01	<0.015	<0.015	<0.002	-	-	<0.06	0.605	<0.001	<0.01
15-May-95	-	<0.01	<0.015	<0.015	<0.002	-	-	<0.06	<0.006	<0.001	<0.01
13-Jun-95	-	<0.01	0.02	<0.015	<0.002	-	-	<0.06	<0.006	<0.001	<0.01

Tile Drain G7T	Al	Cd	Co	Cr	Cu	Fe	Mo	Pb	Zn	Be	Ni
13-Jun-95	-	<0.01	<0.015	<0.015	<0.002	-	-	<0.06	<0.006	<0.001	<0.01

Piezometre P2	Al	Cd	Co	Cr	Cu	Fe	Mo	Pb	Zn	Be	Ni
23-Sep-94	-	<0.01	<0.015	<0.015	<0.002	-	-	<0.06	0.547	<0.001	<0.01
15-Nov-94	-	<0.01	<0.015	<0.015	<0.002	-	-	<0.06	0.176	<0.001	<0.01
12-Apr-95	-	<0.01	<0.015	<0.015	<0.002	-	-	<0.06	0.629	<0.001	<0.01
15-May-95	-	0.01	<0.015	<0.015	<0.002	-	-	<0.06	<0.006	<0.001	<0.01
13-Jun-95	-	<0.01	<0.015	<0.015	<0.002	-	-	<0.06	<0.006	<0.001	<0.01

Piezometre P4	Al	Cd	Co	Cr	Cu	Fe	Mo	Pb	Zn	Be	Ni
29-Jul-94	-	<0.01	<0.015	<0.015	<0.002	-	-	<0.06	0.010	<0.001	<0.01
26-Aug-94	-	<0.01	<0.015	<0.015	<0.002	-	-	<0.06	<0.006	<0.001	<0.01
23-Sep-94	-	<0.01	<0.015	<0.015	0.002	-	-	<0.06	0.664	<0.001	<0.01
15-Nov-94	-	<0.01	<0.015	<0.015	<0.002	-	-	<0.06	0.265	<0.001	<0.01
12-Apr-95	-	<0.01	<0.015	<0.015	<0.002	-	-	<0.06	1.311	<0.001	<0.01
15-May-95	-	<0.01	<0.015	<0.015	<0.002	-	-	<0.06	<0.006	<0.001	<0.01
13-Jun-95	-	<0.01	<0.015	<0.015	0.004	-	-	<0.06	0.259	<0.001	0.02

Appendix C1. Deuterium Extraction Procedure

The method used for the extraction of deuterium from water is taken from the Ottawa-Carleton Geoscience Center Stable Isotope Facility where the extractions were performed on a deuterium extraction line. The method is as follows:

At the Beginning of the Day:

-dump water that has collected in the liquid nitrogen trap from previous day's work
-fill liquid nitrogen (LN_2) trap with LN_2
-turn on power bar so heater is engaged
-turn on water tap so there's continuous flow
-open oxygen tank for blowtorch

Extraction Procedure:

-select 10 breakseals of approximately the same length
-take zinc vessel and check to see if the vacuum has been breached
-if vacuum gauge reads >100mT, warn lab technician. Zinc may be spoiled since moisture has been in contact with it for an extended period of time.
-weigh between 100 and 110mg of zinc on scale and dump into a breakseal. repeat for the other 9 breakseals.
-once this is done, reattach zinc vessel to a vacuum line for 5 minutes making sure atmospheric pressure is completely out of the vessel. After 5 minutes, store zinc vessel back in cupboard.
-attach breakseals to deuterium line and then open all ports (black valves on top of extraction line)
-wait for line to heat up to between 90 and 100°C. Once line is ≥ 90°C and vacuum gauge reads ≤30mT, heat zinc for each breakseal using blow torch (gas only, no oxygen) until zinc begins to sublimate. All ten breakseals should take approximately 30 minutes to complete.
-once all ten breakseals have been heated, wait 30 minutes.
-place styrofoam cups under 5 of the 10 breakseals, using ports 1,3,5,7, and 9. We can't use all ten ports at the same time because there isn't enough room for all ten styrofoam cups.
*-close vacuum valve for port 1, and fill styrofoam cup with LN_2.
-using 10µl syringe, inject 3µl of sample water quickly into port 1 and retract syringe.
-clean syringe by filling twice to 10µl mark and then twice to 6µl mark with high grade acetone ejecting acetone each time onto a kimwipe. Insert syringe into drier. Open plunger for 10 seconds, and then pump the plunger slowly two consecutive times, leaving

plunger open at 9µl at the end of the second time. Leave syringe in drier until vacuum gauge drops to 30mT or less. Pump plunger all the way to the 0µl mark and wait for vacuum gauge to read ≤15mT. Eject syringe from drier
-repeat from step * for ports 3,5,7, and 9.
-once odd number ports have been used up, open port 1 to evacuate non-condensable gases and note if gauge reads ≥5mT. Wait until gauge drops to base level before closing port again. Repeat for ports 3,5,7, and 9.
**-seal breakseals with blowtorch (using oxygen this time)
-place empty styrofoam cups under ports 2,4,6,8, and 10 and repeat from step * until step **.
-Once all ten breakseals have been sealed, repeat for next batch from the start of the **Extraction Procedure** section.

Meanwhile...
-for 10 extracted breakseals, mark them accordingly using high temperature marker and place them in the oven at 500^{0}C for 30 minutes. This procedure can be performed during the 30 minute wait (above) after zinc in second batch has been sublimated.
-place in freezer until ready to analyze on gas source mass spectrometer.

At the End of the Day,
-turn off power bar, water, and oxygen tank.
-lower LN_2 trap
-any breakseals that haven't been heated in oven should be placed in freezer until next day.
-clean up work area

Appendix C2. Groundwater and surface water $\delta^{2}H$ and $\delta^{18}O$ values (‰)

Well Water

G1		G2		G5		G9		G10		G12	
Date	$\delta^{2}H$	Date	$\delta^{2}H$	Date	$\delta^{2}H$	Date	$\delta^{2}H$	Date	$\delta^{2}H$	Date	$\delta^{2}H$
20-May-94	-	20-May-94	-67.9	20-May-94	-73.5	20-May-94	-71.1	20-May-94	-76.5	20-May-94	-
17-Jun-94	-	17-Jun-94	-67.4	17-Jun-94	-75.4	17-Jun-94	-73.8	17-Jun-94	-75.2	17-Jun-94	-
1-Jul-94	-71.6	15-Jul-94	-64.1	15-Jul-94	-73.8	15-Jul-94	-71.6	15-Jul-94	-70.7	15-Jul-94	-
29-Jul-94	-72.7	12-Aug-94	-71.3	12-Aug-94	-74.3	12-Aug-94	-73.0	12-Aug-94	-75	12-Aug-94	-72.9
26-Aug-94	-71.0	10-Sep-94	-72.6	10-Sep-94	-76.3	10-Sep-94	-72.8	10-Sep-94	-75.9	10-Sep-94	-74.3
10-Sep-94	-74.1	23-Sep-94	-71.6	23-Sep-94	-76.4	23-Sep-94	-73.0	23-Sep-94	-74.3	23-Sep-94	-75.9
23-Sep-94	-75.5	14-Oct-94	-71.9	14-Oct-94	-75.0	14-Oct-94	-72.3	14-Oct-94	-73.8	14-Oct-94	-76.3
14-Oct-94	-73.8	15-Nov-94	-70.0	15-Nov-94	-74.0	15-Nov-94	-73.3	15-Nov-94	-74.8	15-Nov-94	-73.4
15-Nov-94	-72.0	14-Dec-94	-70.3	14-Dec-94	-73.9	14-Dec-94	-72.1	14-Dec-94	-75.7	14-Dec-94	-75.6
14-Dec-94	-	16-Jan-95	-71.3	16-Jan-95	-73.2	16-Jan-95	-72.3	16-Jan-95	-73.7	16-Jan-95	-76.0
16-Jan-95	-	16-Feb-95	-71.5	16-Feb-95	-74.2	16-Feb-95	-69.3	16-Feb-95	-73.8	16-Feb-95	-75.4
16-Feb-95	-	15-Mar-95	-73.3	15-Mar-95	-76.6	15-Mar-95	-74.0	15-Mar-95	-71.5	15-Mar-95	-73.9
15-Mar-95	-	12-Apr-95	-69.0	12-Apr-95	-76.6	12-Apr-95	-72.4	12-Apr-95	-73.9	12-Apr-95	-75.2
12-Apr-95	-	15-May-95	-66.5	15-May-95	-77.1	15-May-95	-71.2	15-May-95	-71.2	15-May-95	-
15-May-95	-	13-Jun-95	-67.1	13-Jun-95	-73.5	13-Jun-95	-73.3	13-Jun-95	-71.6	13-Jun-95	-
13-Jun-95	-										

Tile Drainage Water

T1			T2	
Date	$\delta^{2}H$	$\delta^{18}O$	Date	$\delta^{2}H$
26-Apr-94	-80.1	-11.91	20-May-94	-
24-May-94	-84.4	-11.91	3-Jun-94	-79.8
3-Jun-94	-84.8	-	17-Jun-94	-80.7
17-Jun-94	-82.0	-	1-Jul-94	-79.3
1-Jul-94	-77.2		15-Jul-94	-
4-Jul-94	-77	-11.65	12-Aug-94	-
15-Jul-94	-	-	10-Sep-94	-
12-Aug-94	-	-	23-Sep-94	-95.8
10-Sep-94	-	-	14-Oct-94	-
28-Sep-94	-80.8	-11.69	15-Nov-94	-
14-Oct-94	-	-	14-Dec-94	-
3-Nov-94	-76.4	-11.44	16-Jan-95	-76.1
9-Nov-94	-72.5	-11.5	16-Feb-95	-
15-Nov-94	-79.1	-	15-Mar-95	-
1-Dec-94	-77.4	-11.49	12-Apr-94	-81.5
14-Dec-94	-	-	15-May-95	-
16-Jan-95	-	-	13-Jun-95	-
16-Feb-95	-	-		
15-Mar-95	-	-		
10-Apr-94	-75.8	-		
12-Apr-94	-78.4	-		
25-May-95	-78.9	-		
13-Jun-95	-	-		

Piezometric Water

P1			P2			P3			P4		
Date	$\delta^{2}H$	$\delta^{18}O$	Date	$\delta^{2}H$	$\delta^{18}O$	Date	$\delta^{2}H$	$\delta^{18}O$	Date	$\delta^{2}H$	$\delta^{18}O$
20-May-94	-	-	20-May-94	-	-	20-May-94	-	-	20-May-94	-	-
7-Jun-94	-75.2	-11.14	7-Jun-94	-	-	7-Jun-94	-	-	7-Jun-94	-	-
8-Jun-94	-74.9	-11.16	23-Jun-94	-71.3	-10.74	21-Jun-94	-79.3	-11.76	23-Jun-94	-	-
23-Jun-94	-71.4	-11.19	1-Jul-94	-	-	1-Jul-94	-80.6	-11.56	1-Jul-94	-	-
1-Jul-94	-75.0	-11.22	15-Jul-94	-	-	15-Jul-94	-78.1	-11.35	15-Jul-94	-72.0	-10.16
15-Jul-94	-74.1	-11.23	29-Jul-94	-74.6	-10.70	29-Jul-94	-78.1	-11.15	29-Jul-94	-70.6	-9.79
29-Jul-94	-73.5	-11.26	16-Aug-94	-72.9	-11.11	12-Aug-94	-79.7	-11.37	12-Aug-94	-78.9	-11.46
12-Aug-94	-75.1	-11.18	26-Aug-94	-	-	26-Aug-94	-79.1	-11.05	26-Aug-94	-79.9	-11.39
26-Aug-94	-75.3	-11.19	10-Sep-94	-77.6	-10.90	10-Sep-94	-76.1	-10.77	10-Sep-94	-79.1	-11.45
10-Sep-94	-76.3	-11.27	23-Sep-94	-74.7	-10.72	23-Sep-94	-75.9	-10.55	23-Sep-94	-73.0	-10.32
23-Sep-94	-75.8	-11.21	14-Oct-94	-76.4	-10.93	14-Oct-94	-73.7	-10.31	14-Oct-94	-73.2	-10.94
14-Oct-94	-74.0	-11.21	15-Nov-94	-77.0	-11.00	15-Nov-94	-71.3	-10.07	15-Nov-94	-73.7	-10.80
15-Nov-94	-74.5	-11.01	14-Dec-94	-	-	14-Dec-94	-	-	14-Dec-94	-	-
14-Dec-94	-	-	16-Jan-95	-	-	16-Jan-95	-	-	16-Jan-95	-	-
16-Jan-95	-	-	16-Feb-95	-	-	16-Feb-95	-	-	16-Feb-95	-	-
16-Feb-95	-	-	15-Mar-95	-	-	15-Mar-95	-	-	15-Mar-95	-	-
15-Mar-95	-	-	12-Apr-95	-	-	12-Apr-95	-	-	12-Apr-95	-	-
12-Apr-95	-	-	15-May-95	-	-	15-May-95	-	-	15-May-95	-	-
15-May-95	-	-	13-Jun-95	-	-	13-Jun-95	-	-	13-Jun-95	-	-
13-Jun-95	-	-									

Tile Drainage Water

T3			T4		
Date	$\delta^{2}H$	$\delta^{18}O$	Date	$\delta^{2}H$	$\delta^{18}O$
20-May-94	-	-	20-May-94	-	
17-Jun-94	-	-	17-Jun-94	-	
30-Jun-94	-62.3	-9.89	15-Jul-94	-	
15-Jul-94	-	-	12-Aug-94	-	
12-Aug-94	-	-	10-Sep-94	-	
10-Sep-94	-	-	23-Sep-94	-	
23-Sep-94	-69.3	-	14-Oct-94	-	
14-Oct-94	-	-	3-Nov-94	-66.8	-10.83
9-Nov-94	-75.4	-10.77	9-Nov-94	-71.7	-10.80
15-Nov-94	-74.5	-	15-Nov-94	-73.5	
14-Dec-94	-	-	23-Nov-94	-70.2	-10.76
16-Jan-95	-	-	1-Dec-94	-71.1	-10.94
16-Feb-95	-	-	14-Dec-94	-	-
15-Mar-95	-	-	16-Jan-95	-	-
12-Apr-95	-70.8	-	16-Feb-95	-	-
25-May-95	-70.1	-	15-Mar-95	-	-
13-Jun-95	-	-	10-Apr-95	-75.3	-
			12-Apr-95	-79.8	-
			23-May-95	-58.3	-
			13-Jun-95	-	-

River Water

P1			G2			P3			P4			G5		G9	
Date	$\delta^{2}H$	$\delta^{18}O$	Date	$\delta^{2}H$	$\delta^{18}O$	Date	$\delta^{2}H$	$\delta^{18}O$	Date	$\delta^{2}H$	$\delta^{18}O$	Date	$\delta^{2}H$	Date	$\delta^{2}H$
20-May-94	-	-	20-May-94	-	-	20-May-94	-	-	20-May-94	-	-	20-May-94	-	20-May-94	-
3-Jun-94	-82.2	-11.88	3-Jun-94	-81.5	-11.37	3-Jun-94	-	-	3-Jun-94	-72.9	-10.8	3-Jun-94	-78.1	3-Jun-94	-73.4
8-Jun-94	-76.3	-11.33	17-Jun-94	-72.4	-10.55	17-Jun-94	-	-	22-Jun-94	-75.1	-11.01	17-Jun-94	-65.3	17-Jun-94	-66.3
22-Jun-94	-71.8	-10.83	22-Jun-94	-70.4	-10.45	1-Jul-94	-68	-10.3	1-Jul-94	-71.8	-10.4	1-Jul-94	-64.5	1-Jul-94	-66.0
1-Jul-94	-72.9	-10.67	1-Jul-94	-68.2	-10.13	7-Jul-94	-68.6	-10.5	3-Aug-94	-64.9	-8.94	15-Jul-94	-	15-Jul-94	-
6-Jul-94	-70.5	-10.37	6-Jul-94	-71.8	-10.62	11-Aug-94	-65.4	-9.5	10-Sep-94	-59.3	-8.25	29-Jul-94	-	29-Jul-94	-
15-Jul-94	-	-	15-Jul-94	-	-	17-Aug-94	-73.5	-9.6	14-Oct-94	-62.5	-8.51	12-Aug-94	-	12-Aug-94	-
12-Aug-94	-	-	29-Jul-94	-	-	26-Aug-94	-61.3	-9.18	13-Oct-94	-61.6	-8.59	26-Aug-94	-	26-Aug-94	-
10-Sep-94	-69.2	-9.60	16-Aug-94	-	-	10-Sep-94	-65.9	-9.71	9-Nov-94	-69.6	-10.16	10-Sep-94	-	10-Sep-94	-
12-Sep-94	-69.2	-9.74	26-Aug-94	-	-	14-Oct-94	-63.8	-8.92	15-Nov-94	-68.6	-	23-Sep-94	-	23-Sep-94	-53.6
23-Sep-94	-	-	10-Sep-94	-64.1	-10.9	15-Nov-94	-67.3	-10.48	14-Dec-94	-	-	14-Oct-94	-61.0	14-Oct-94	-54.9
14-Oct-94	-70.8	-10.44	23-Sep-94	-	-	14-Dec-94	-	-	16-Jan-95	-	-	15-Nov-94	-67.4	15-Nov-94	-70.9
15-Nov-94	-70.4	-10.70	14-Oct-94	-64.0	-8.84	16-Jan-95	-	-	16-Feb-95	-	-	14-Dec-94	-70.4	14-Dec-94	-78.9
14-Dec-94	-74.7	-11.02	15-Nov-94	-69.1	-10.32	16-Feb-95	-	-	15-Mar-95	-	-	16-Jan-95	-75.6	16-Jan-95	-68.6
16-Jan-95	-73.1	-11.35	14-Dec-94	-74.1	-11.13	15-Mar-95	-	-	12-Apr-95	-81.1	-	16-Feb-95	-77.6	16-Feb-95	-77.8
16-Feb-95	-73.9	-	16-Jan-95	-75.5	-11.58	12-Apr-95	-	-	15-May-95	-67.5	-	15-Mar-95	-102.5	15-Mar-95	-103.7
15-Mar-95	-88.0	-	16-Feb-95	-76.3	-	15-May-95	-	-	13-Jun-95	-	-	12-Apr-95	-80.5	12-Apr-95	-77.4
12-Apr-95	-78.1	-	15-Mar-95	-101.7	-	13-Jun-95	-	-				15-May-95	-73.0	15-May-95	-68.9
15-May-95	-72.8	-	12-Apr-95	-79.4	-							13-Jun-95	-64.2	13-Jun-95	-64.9
13-Jun-95	-	-	15-May-95	-72.5	-										
			13-Jun-95	-66.8	-										

Appendix C3. Dissolved Inorganic Carbon Extraction Procedure

The DIC extraction procedure is taken from the Ottawa-Carleton Geoscience Center Stable Isotope laboratory where the extractions were performed. The procedure is as follows;

At the Beginning of the Day:

-fill pump trap with LN_2
-prepare two -80^{0}C ethanol baths: one in a medium-sized dewar, the other in a small dewar
-assemble sample vessel (with H_3PO_4 in neck) to vacuum line along with a new breakseal, then open valves for pumpdown
-for each sample, calculate the ml of water required to obtain 50μmol CO_2 as follows:
    -divide 3050 by the sample's alkalinity in mg/l bicarbonate
-fill out sample info in book
-open oxygen tank for blowtorch
-turn on drying oven to 150^{0}C
-when vacuum is good, check line for leaks
-place large -80^{0}C bath around large U trap
-close valve W1
-remove sample vessel from line

Extraction Procedure:

**-fill side-arm of sample vessel 1/3 full with 85% H_3PO_4
**-attach vessel to line, with its valve open
**-close P2 (P1 remains open)
**-open I1, W1 to evacuate sample vessel. A good vacuum may not be reached because the acid contains water; the goal is only to get rid of the air in the line.
✂-when the vacuum is good, or when the acid begins to boil, close P1 to check for leaks. If there are no leaks, reopen P1 and close the vessel valve
-inject sample using both hands-one to steady the vessel
-close W1
-remove vessel from line. Tilt to acidify the sample, shake well. Return to line.
-open W1 to evacuate the portion of the line that has been open to atmosphere. Wait until gauge C1 goes down to base level. Meanwhile, rinse syringe with distilled water, dry with Kimwipe
-install LN_2 bath on large U-trap so that only 1-2cm of the trap are covered
-close P1, open P2, B1 to evacuate the breakseal

-open vessel valve-gauge C1 will indicate near-atmospheric pressure. Watch for CO_2 ring to appear. Let transfer 2 minutes, covering ring by only 1cm after first minute
-when transfer is complete, close P2. Open PT to evacuate non-condensable gases through the trap. Another set of CO_2 and H_2O rings will form in the trap as the vacuum pulls any remaining gases from the reaction vessel. When gauge C1 slows down, close I1 and W1
-check temperature of large ethanol bath; add some LN_2 if necessary
-let gauge C1 go down to base level, then close I2, PT. Make sure that all the sample rings are covered
-install styrofoam cup under small U-trap and fill with LN_2
-open TD1 and let transfer 2 minutes covering ring after first minute. Meanwhile, remove sample vessel, degrease neck, rinse with hot water, then 3 times with distilled water. Shake well, place in 150^{0}C oven to dry.
-close TD1. Remove small ethanol bath from line and put back on Cryocool, or check temperature and add LN_2 if necessary. Warm up both U-traps with blowdrier. Note digital gauge reading and use table to determine yield
-close P2. check for leaks in breakseal. If O.K. open P1, I2
-place styrofoam cup under breakseal, fill with LN_2
-open TD2 and let CO_2 transfer for about 2 minutes, covering ring with LN_2 after first minute. Meanwhile, do **.
-close TD2. Seal off breakseal with blowtorch, close B1, and change breakseal.
-extract next sample beginning at ✕

At the End of the Day:

-turn off oxygen tank, gas and oxygen faucets, and cryocool
-cover ethanol baths
-remove water trap from line, degrease neck and pour out water

Appendix C4. Groundwater dissolved inorganic carbon results (‰)

Well Water

Date	$\delta^{13}C$ G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11	G11A	G12
7-May-94	-15.67	-14.58	-13.36	-12.93	-12.77	-11.30	-8.59	-13.67	-14.44	-15.41	-	-	-
20-May-94	-15.88	-14.98	-13.64	-11.75	-13.00	-11.45	-13.93	-13.43	-14.24	-15.27	-	-	-
3-Jun-94	-16.32	-14.12	-13.67	-13.02	-12.94	-10.94	-13.97	-13.86	-14.76	-14.96	-	-	-
17-Jun-94	-	-12.44	-14.44	-10.90	-9.19	-8.08	-11.57	-9.51	-11.67	-10.10	-11.45	-12.35	-
1-Jul-94	-9.45	-12.46	-9.49	-10.05	-10.70	-9.81	-10.01	-9.65	-12.78	-12.95	-13.79	-14.63	-
29-Jul-94	-10.33	-12.35	-11.36	-10.60	-11.11	-10.92	-11.82	-10.90	-12.81	-12.99	-13.25	-15.01	-12.11
12-Aug-94	-	-11.29	-10.97	-	-	-	-	-10.28	-	-	-	-	-
23-Sep-94	-7.87	-10.97	-10.16	-9.75	-8.17	-7.48	-9.04	-9.30	-10.88	-9.46	-8.04	-11.87	-10.19
14-Oct-94	-9.18	-9.99	-8.80	-8.83	-8.42	-7.39	-10.19	-8.90	-11.97	-10.15	-7.26	-	-10.68
15-Nov-94	-9.97	-10.93	-11.46	-11.26	-11.43	-7.96	-11.35	-10.40	-13.07	-12.20	-11.46	-	-11.94
14-Dec-94	-	-13.38	-12.80	-12.77	-13.50	-12.19	-13.60	-13.35	-14.45	-8.80	-14.25	-	-13.79
16-Jan-95	-	-13.79	-13.43	-11.92	-13.49	-11.66	-13.73	-13.88	-13.07	-7.32	-15.09	-	-14.50
16-Feb-95	-	-8.28	-7.39	-	-	-	-	-9.12	-	-	-	-	-
15-Mar-95	-	-11.83	-11.53	-	-	-	-	-11.13	-	-	-	-	-13.93
12-Apr-95	-	-12.31	-11.09	-	-	-	-	-13.39	-	-	-	-	-
15-May-95	-	-14.44	-13.32	-	-	-	-	-13.71	-	-	-	-	-
13-Jun-95	-	-14.45	-12.88	-	-	-	-	-13.37	-	-	-	-	-

	Piezometric Water				Tile Drainage Water			
	$\delta^{13}C$				$\delta^{13}C$			
Date	P1	P2	P3	P4	T1	T2	T3	T4
7-May-94	-	-	-	-	-	-	-	-
20-May-94	-	-	-	-	-	-	-	-
3-Jun-94	-	-	-	-	-12.76	-8.20	-	-
17-Jun-94	-	-	-	-	-11.17	-4.39	-	-
1-Jul-94	-12.76	-	-7.23	-	-14.25	-7.40	-	-
29-Jul-94	-13.13	-12.70	-10.99	-9.38	-	-	-	-
12-Aug-94	-	-	-	-	-	-	-	-
23-Sep-94	-11.31	-8.41	-8.68	-0.71	-13.53	-4.07	-8.69	-
14-Oct-94	-11.98	-10.20	-9.22	-8.28	-	-	-	-
15-Nov-94	-13.71	-13.04	-11.38	-12.00	-14.34	-	-9.12	-11.62
14-Dec-94	-	-	-	-	-	-	-	-
16-Jan-95	-	-	-	-	-	-11.28	-	-
16-Feb-95	-	-	-	-	-	-	-	-
15-Mar-95	-	-	-	-	-	-	-	-
12-Apr-95	-	-	-	-	-	-	-	-
15-May-95	-	-	-	-	-	-	-	-
13-Jun-95	-	-	-	-	-	-	-	-

Appendix D. Groundwater dissolved organic carbon results (mg/L)

Well Water					Piezometric Water			Tile Drainage Water			
	DOC					DOC			DOC		
Date	G2	G3	G8	G9	Date	P2	P4	Date	T1	T2	T3
7-May-94	133.40	76.40	48.20	27.90	7-May-94	-	-	7-May-94	-	-	-
20-May-94	-	-	-	-	20-May-94	-	-	20-May-94	-	-	-
3-Jun-94	14.90	9.60	26.80	12.10	3-Jun-94	-	-	3-Jun-94	20.10	6.20	-
17-Jun-94	-	-	-	-	17-Jun-94	-	-	17-Jun-94	21.60	10.00	-
1-Jul-94	9.30	3.90	11.90	5.00	1-Jul-94	-	-	1-Jul-94	8.30	24.40	-
29-Jul-94	64.70	3.70	7.10	3.70	29-Jul-94	18.20	40.20	29-Jul-94	-	-	-
12-Aug-94	-	-	-	-	12-Aug-94	-	-	12-Aug-94	-	-	-
26-Aug-94	5.50	15.10	6.50	6.60	26-Aug-94	67.2	14.4	26-Aug-94	-	-	-
23-Sep-94	ND	ND	ND	ND	23-Sep-94	9.70	16.40	23-Sep-94	ND	8.30	9.10
14-Oct-94	ND	ND	ND	ND	14-Oct-94	ND	ND	14-Oct-94	-	-	-
15-Nov-94	ND	ND	ND	ND	15-Nov-94	9.00	ND	15-Nov-94	ND	-	ND
14-Dec-94	ND	ND	ND	ND	14-Dec-94	-	-	14-Dec-94	-	-	-
16-Jan-95	13.40	2.20	9.20	17.10	16-Jan-95	-	-	16-Jan-95	-	5.40	-
16-Feb-95	4.90	ND	ND	11.00	16-Feb-95	-	-	16-Feb-95	-	-	-
15-Mar-95	ND	ND	ND	ND	15-Mar-95	-	-	15-Mar-95	-	-	-
12-Apr-95	10.00	ND	ND	ND	12-Apr-95	-	-	12-Apr-95	-	-	-
15-May-95	ND	ND	ND	ND	15-May-95	-	-	15-May-95	-	-	-
13-Jun-95	ND	ND	ND	-	13-Jun-95	-	-	13-Jun-95	-	-	-

Appendix E1. Pesticide Extraction Procedures for Soils & Sediments

Soil and sediment samples were collected and sent to Accutest Laboratories for herbicide analysis. Two extraction procedures were used depending on the analyte in question. They are described as i) conventional solvent extraction, and ii) soxhlet extraction.

Conventional Solvent Extraction

This has been the most widely used method for pesticide extraction from soils, however, is becoming phased out by many labs due to its extremely long procedure. The extraction process is as follows;

-30g of sample soil is weighed into a 250ml beaker
-Na_2SO_4 is added in copious amounts to the soil in order to absorb any moisture within the soil
-the two are mixed thoroughly and any large soil chunks are broken up using a spoon
-the beaker is set aside for 20 minutes to let any residual moisture absorb to the Na_2SO_4.

Meanwhile, the extraction column is set up as follows:

-using a glass rod, glass wool is inserted at the bottom of the extraction column
-20g of activated fluorosil is poured on top of the glass wool in the column
-1 inch of sodium sulphate (Na_2SO_4) is poured on top of the fluorosil
-a beaker is placed beneath the column and 100ml of methylene chloride is poured in the column with the valve open. This is to allow the column time to saturate itself
-when the solvent level reaches 1mm above the sodium sulphate, the valve is closed
-any solvent collected in the beaker is discarded as waste
-taking the 250ml beaker, the mixture is stirred again using the same spoon
-5µl of DBOB (Dibromooctafluorobiphenyl) and 5ml of DCAA (Dichlorophenylacetic acid) are added to the soil as surrogates, which will measure the amount of return when analyzed on the GCMS.
-a 500ml 50/50 solution of high grade acetone and methylene chloride is prepared
**-100ml of the 50/50 solution is added to the beaker where it is subsequently placed in an ultrasonic bath for 5 minutes
**-the solvent is then poured out of the beaker into a separatory funnel containing a Whatman no.41 filter paper under which is placed a round bottom flask.
-** is repeated two more times
-at the end of the third 50/50 solvent addition, the soil in the beaker is poured into the separatory funnel and another 100ml of 50/50 methylene chloride is added.

-once the remaining solvent has decanted, the round-bottom flask is placed on a roto-evaporator where the volume is reduced to approximately 5ml.
-using a glass pipette, empty the 5ml from the round-bottom flask into the already prepared extraction column. Keep the round-bottom flask near the extraction column.
-prepare 200ml solutions of 6%, 15%, 50%, and 100% ethyl ether in methylene chloride using 500ml graduated cylinders.

Ω -place a clean round-bottom flask under the extraction column. Label it "6%".
-take the 6% ethyl ether solution and rinse the round bottom flask previously used. Slowly pour the contents of the round-bottom flask into the extraction column opening the valve at the same time. Pour the remaining 6% ethyl ether solution into the extraction column.
-When the level reaches the top of the Na_2SO_4, close the valve, and remove the now almost full round-bottom flask.
-roto-evaporate the "6%" round-bottom flask until approximately 5ml of solvent remains.

-repeat for the 15%, 50%, and 100% ethyl ether solutions starting at Ω. Ignore the 'rinse the round-bottom flask previously used' caption.
-Once all four fractions have been roto-evaporated, copper cleaning is required

Copper Cleaning...

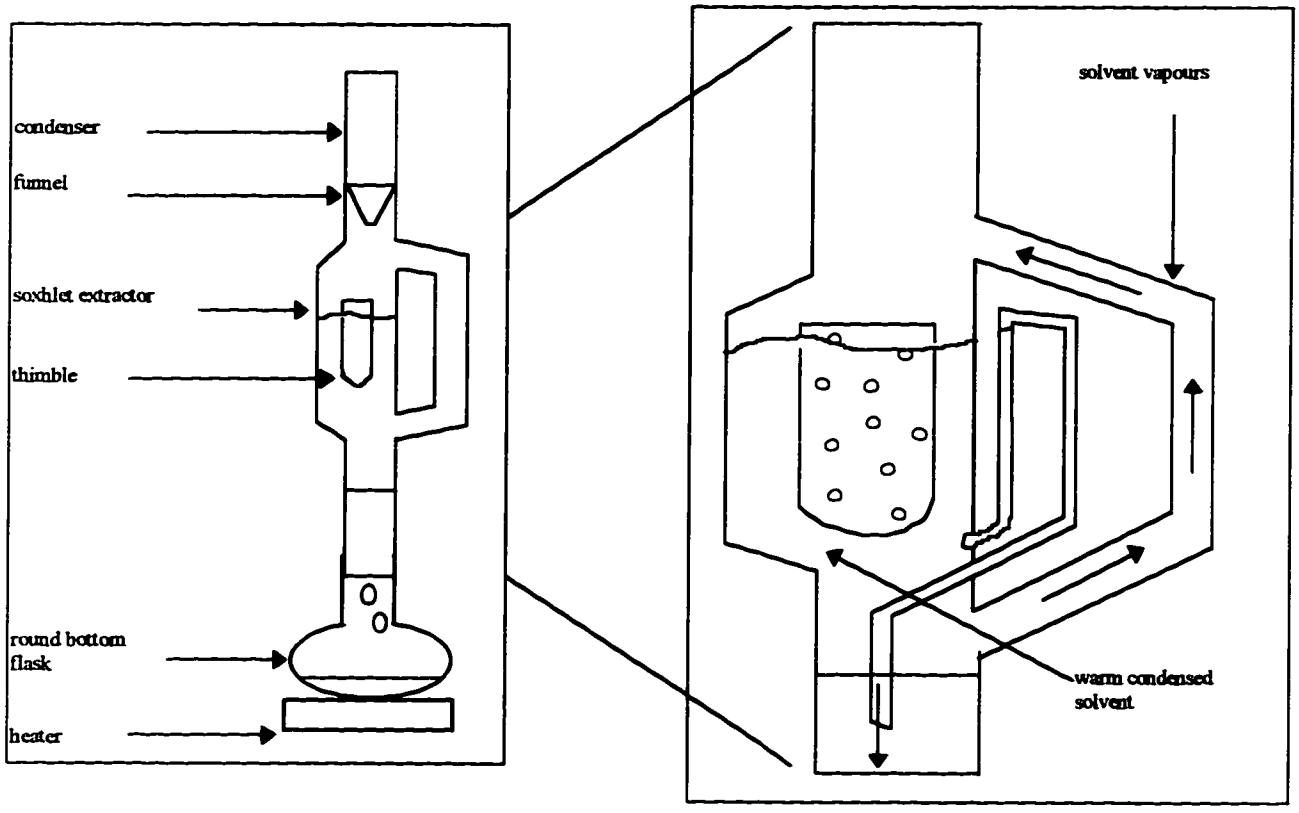
-clean the copper powder using a 1M solution of hydrochloric acid until the copper becomes very bright in colour. Discard the hydrochloric acid as waste, and rinse the copper with high grade acetone at least twice to remove any water present.
-transfer each of the four fractions to separate 10ml graduated cylinders using glass pipettes. Label them accordingly. Do not use the same glass pipette for the four fractions, otherwise contamination occurs.
-using a very small spoon, transfer some of the cleaned copper to each graduated cylinder and place in sonic bath for 2 minutes.
-roto-evaporate each fraction to below 5ml and then add methylene chloride to exactly the 5ml mark for each fraction. Transfer the contents of each fraction to small 5ml glass vials labeling each vial with the appropriate fraction.
-Sample is now ready for analysis on GCMS.

Soxhlet Extraction

This extraction procedure uses a condensation method where a Soxhlet column is used for analyte extraction. The column is divided into three sections (bottom figure); i) a condenser is situated at the top where the solvent originates, ii) the Soxhlet extractor is placed beneath the condenser where a porous glass thimble is incorporated, iii) at the

bottom of the column is situated a heater upon which is placed a round bottom flask where the analytes are collected.

The sample is placed in the glass thimble and a methylene chloride solvent originating from the condenser is passed through a funnel containing sodium sulfate. The Soxhlet extractor is filled with solvent, soaking the porous thimble. The heater is turned on and the solvent vapours begin to condense and drip from an inner tube into a round bottom flask. Analytes present within the soil are leached by the solvent where they are collected into the flask. When the solvent in the Soxhlet extractor has completely vapourized, the collected solvent-analyte solution is heated above the boiling point of the solvent to reduce the volume present. This remaining solution is then transferred to a secondary flask where it is concentrated down to a lower volume. The sample is then ready for analysis on the Varian GCMS.



Appendix E2. Pesticide values in soils (ug/g)

Collected on November 30, 1994

	Detection Limit (ug/g)	G2F	G3F	G4F	G8F	G9F	P4F
Atrazine	0.05	**0.5**	**0.31**		**0.50**	**0.13**	
Metolachlor	0.10		ND			ND	**0.15**
Bentazon	0.50		ND				
2,4-DB	10.0			ND			
Carbaryl	0.50					ND	
Permethrin	0.50					ND	
Dicamba	10.0						ND

Collected on June 15, 1995

	Detection Limit (ug/g)	G2F	G7F	G8F	G9F1	G9F2	P4F	T3F	T4F	G13F
Atrazine	0.05	ND	**0.12**	ND	ND	ND		**0.16**	ND	ND
Metolachlor	0.05	ND	**0.05**		ND	ND	ND	**0.22**	ND	ND
Glyphosate	1.0							ND		
Bromoxynil	0.50	ND			ND	ND				
Metribuzin	0.05			ND						
Lorox	0.50			ND						
Dicamba	0.05						**0.57**		**0.082**	ND
Butylate	1.0		ND							

Collected in July 1995

	Detection Limit (ppm)	P4F1	G7F	G8F	G9F1	G9F2	P4F	T3F	T4F	G13F
Atrazine	0.05	ND	ND	ND	ND	ND	ND	ND	ND	ND
Metolachlor	0.05	ND	**0.3**	ND	**0.3**	**0.2**	**0.1**	**0.2**	**0.2**	ND
Glyphosate	1.0									
Bromoxynil	0.50				ND	ND				
Metribuzin	0.20			ND						
Lorox	0.40			ND						
Dicamba	0.10	**Trace**					**0.1**	**0.1**	ND	**0.1**

Appendix E3. Pesticide values in sediment (u g/g)

Collected in July 1995

	Detection Limit (ug/g)	G2S	G9S	G13S	P4S	T4S	T3S	G9T	T3T	T4T
Atrazine	0.05	ND	ND	ND	ND	ND	ND	ND	ND	ND
Metolachlor	0.05	ND	ND	0.2	0.1	ND	ND	ND	ND	ND
Glyphosate	1.0	ND	ND	ND			ND	ND	ND	
Dicamba	0.10	ND	ND	ND	ND	ND	ND	ND	ND	ND
MCPA	0.10		ND	ND				ND		

Collected on October 19, 1995

	Detection Limit (ug/g)	G2S	G9S	G13S	P4S	T4S	G14S	G15S	G16S	G17S
Metolachlor	0.1	ND	ND	ND	ND	ND	ND	ND	ND	ND

Appendix E4. Pesticide values in tile drainage water (ppm or mg/L)

	Detection Limit (ppm)	3-Jun-94 T1	1-Jul-94 T1	23-Sep-94 T1	30-May-95 T2	15-Nov-94 T3	12-Apr-95 T3	30-May-95 T3	13-Jun-95 T3	23-Sep-94 T4
Bentazon	0.019	ND	ND	ND						
2,4-D	0.024	ND	ND	ND						
2,4-DB	0.0076	ND	ND	ND						
Dicamba	0.0005	ND	ND	ND		ND	ND	2.7	2.3	ND
2,4,5-T	0.0045	ND	ND	ND						
2,4,5-TP	0.0082	ND	ND	ND						
Metolachlor	0.00036	ND				ND	ND	ND	ND	
Alachlor	0.00046	ND								
Cyanazine	0.00066	ND								
Metribuzin	0.005	ND								
Atrazine	0.002				ND	ND	ND	ND	ND	ND
Glyphosate	0.01				ND	ND	ND	ND	ND	
Ultim	0.08									ND

	Detection Limit (ppm)	15-Nov-94 T4	12-Apr-95 T4	30-May-95 T4	13-Jun-95 T4	12-Apr-95 G7T	30-May-95 G7T	13-Jun-95 G7T
Atrazine	0.002	ND	ND	ND	ND	ND	ND	ND
Metolachlor	0.005			ND	ND	ND	ND	ND
Glyphosate	0.001							
Dicamba	0.001	ND	ND	ND	ND			
Ultim	0.080	ND	ND					
Bentazon	0.050							
Butylate	0.010					ND		

Appendix E5. Pesticide values in domestic well water (ppm or mg/L)

	Detection Limit (ppm)	3-Jun-94 G1	1-Jul-94 G1	3-Jun-94 G3	17-Jun-94 G3	1-Jul-94 G3	15-May-95 G3	3-Jun-94 G4	1-Jul-94 G4	3-Jun-94 G5	17-Jun-94 G5
Org. chlorines	variable			ND		ND		ND	ND		ND
Alachlor	0.0015	ND	ND							ND	
Cyanazine	0.0038	ND	ND							ND	
Metribuzin	0.000084	ND	ND							ND	
Permethrin	0.00045	ND	ND								
Metolachlor	0.00036		ND	ND			ND			ND	
Bentazon	0.05						ND				
Atrazine	0.002						ND				

	Detection Limit (ppm)	1-Jul-94 G5	15-May-95 G8	3-Jun-94 G9	17-Jun-94 G9	1-Jul-94 G9	15-Jul-94 G9	3-Jun-94 G10	17-Jun-94 G11	1-Jul-94 G11
Org. chlorines	variable							ND		ND
Alachlor	0.0015	ND							ND	
Cyanazine	0.0038	ND							ND	
Metribuzin	0.000084	ND							ND	
Permethrin	0.00045	ND		ND	ND	ND	ND			
Metolachlor	0.00036	ND	ND	ND	ND	ND	ND		ND	
Atrazine	0.002		ND							

Appendix F1. Autocorrelation statistics for water level.

Note: Biased function was used to construct Figure 6.2.

Well G2

Observ.	Water L.	Perturbation	Lag#	#pairs	Autocovariance (unbiased)	Autocovariance (biased)	Autocorrelation (unbiased)	Autocorrelation (biased)
15-Jul-94	58.06	0.56533	0	15	0.40613	0.43514	0.9333	1.0000
29-Jul-94	57.70	0.20533	0.5	14	0.42098	0.42098	0.9674	0.9674
12-Aug-94	57.22	-0.27467	1	13	0.33105	0.30741	0.7608	0.7064
26-Aug-94	56.82	-0.67467	1.5	12	0.28993	0.24851	0.6663	0.5711
10-Sep-94	56.52	-0.97467	2	11	0.16687	0.13111	0.3835	0.3013
23-Sep-94	56.63	-0.86467	2.5	10	0.16451	0.11751	0.3781	0.2700
15-Oct-94	56.44	-1.05467	3	9	0.01342	0.00863	0.0308	0.0198
15-Nov-94	57.10	-0.39467	4	8	-0.14244	-0.08140	-0.3273	-0.1871
15-Dec-94	57.80	0.30533	5	7	-0.23953	-0.11976	-0.5505	-0.2752
15-Jan-95	57.85	0.35533	6	6	-0.24886	-0.10665	-0.5719	-0.2451
15-fev-95	57.72	0.22533	7	5	-0.14348	-0.05124	-0.3297	-0.1178
15-Mar-95	57.81	0.31533	8	4	-0.00727	-0.00208	-0.0167	-0.0048
12-Apr-95	58.34	0.84533	9	3	0.05351	0.01147	0.1230	0.0264
15-May-95	58.47	0.97533	10	2	0.09607	0.01372	0.2208	0.0315
13-Jun-95	57.94	0.44533	11	1	0.17827	0.01273	0.4097	0.0293

Well G4

Observ.	Water L.	Perturbation	Lag#	#pairs	Autocovariance (unbiased)	Autocovariance (biased)	Autocorrelation (unbiased)	Autocorrelation (biased)
15-Jul-94	64.35	-1.656	0	15	1.2289	1.3166	0.9334	1.0000
29-Jul-94	64.27	-1.736	0.5	14	1.2738	1.2738	0.9675	0.9675
12-Aug-94	64.69	-1.316	1	13	1.0871	1.0094	0.8257	0.7667
26-Aug-94	64.68	-1.326	1.5	12	1.1309	0.9694	0.8590	0.7363
10-Sep-94	64.70	-1.306	2	11	0.9269	0.7283	0.7040	0.5532
23-Sep-94	66.00	-0.006	2.5	10	0.9689	0.6920	0.7359	0.5256
15-Oct-94	66.05	0.044	3	9	0.5814	0.3738	0.4416	0.2839
15-Nov-94	66.65	0.644	4	8	0.0943	0.0539	0.0716	0.0409
15-Dec-94	67.01	1.004	5	7	-0.6053	-0.3027	-0.4598	-0.2299
15-Jan-95	67.57	1.564	6	6	-0.8905	-0.3816	-0.6764	-0.2899
15-fev-95	66.58	0.574	7	5	-1.4455	-0.5162	-1.0979	-0.3921
15-Mar-95	67.23	1.224	8	4	-1.6890	-0.4826	-1.2829	-0.3665
12-Apr-95	66.89	0.884	9	3	-1.7324	-0.3712	-1.3158	-0.2820
15-May-95	66.64	0.634	10	2	-1.5377	-0.2197	-1.1679	-0.1668
13-Jun-95	66.78	0.774	11	1	-2.0269	-0.1448	-1.5395	-0.1100

Well G5

Observ.	Water L.	Perturbation	Lag#	#pairs	Autocovariance (unbiased)	Autocovariance (biased)	Autocorrelation (unbiased)	Autocorrelation (biased)
15-Jul-94	85.55	0.25	0	15	0.6174	0.6615	0.9333	1.0000
29-Jul-94	85.20	-0.10	0.5	14	0.6601	0.6601	0.9980	0.9980
12-Aug-94	85.16	-0.14	1	13	0.3047	0.2830	0.4607	0.4278
26-Aug-94	84.41	-0.89	1.5	12	0.3201	0.2744	0.4840	0.4148
10-Sep-94	82.75	-2.55	2	11	0.1346	0.1057	0.2035	0.1599
23-Sep-94	85.24	-0.06	2.5	10	0.1379	0.0985	0.2085	0.1489
15-Oct-94	85.28	-0.02	3	9	-0.0697	-0.0448	-0.1054	-0.0678
15-Nov-94	85.79	0.49	4	8	-0.2848	-0.1627	-0.4306	-0.2460
15-Dec-94	85.91	0.61	5	7	-0.3046	-0.1523	-0.4606	-0.2303
15-Jan-95	85.88	0.58	6	6	-0.2354	-0.1009	-0.3559	-0.1525
15-fev-95	85.58	0.28	7	5	-0.4409	-0.1575	-0.6665	-0.2381
15-Mar-95	86.06	0.76	8	4	-0.1564	-0.0447	-0.2364	-0.0676
12-Apr-95	85.67	0.37	9	3	0.0017	0.0004	0.0026	0.0006
15-May-95	85.63	0.33	10	2	-0.0050	-0.0007	-0.0075	-0.0011
13-Jun-95	85.44	0.14	11	1	0.1866	0.0133	0.2822	0.0202

Well G8

Observ.	Water L.	Perturbation	Lag#	#pairs	Autocovariance (unbiased)	Autocovariance (biased)	Autocorrelation (unbiased)	Autocorrelation (biased)
15-Jul-94	47.70	0.22	0	15	0.3459	0.3706	0.9333	1.0000
29-Jul-94	47.38	-0.10	0.5	14	0.3562	0.3562	0.9611	0.9611
12-Aug-94	47.30	-0.18	1	13	0.2147	0.1993	0.5792	0.5379
26-Aug-94	47.22	-0.26	1.5	12	0.2064	0.1769	0.5568	0.4773
10-Sep-94	47.08	-0.40	2	11	0.0761	0.0598	0.2053	0.1613
23-Sep-94	46.06	-1.42	2.5	10	0.0676	0.0483	0.1825	0.1304
15-Oct-94	47.17	-0.31	3	9	0.0505	0.0325	0.1364	0.0877
15-Nov-94	47.25	-0.23	4	8	0.0238	0.0136	0.0642	0.0367
15-Dec-94	47.26	-0.22	5	7	-0.1176	-0.0588	-0.3173	-0.1586
15-Jan-95	47.27	-0.21	6	6	-0.3123	-0.1338	-0.8427	-0.3611
15-fev-95	47.71	0.23	7	5	-0.1133	-0.0405	-0.3058	-0.1092
15-Mar-95	48.77	1.29	8	4	-0.1012	-0.0289	-0.2730	-0.0780
12-Apr-95	48.18	0.70	9	3	-0.1007	-0.0216	-0.2718	-0.0583
15-May-95	47.93	0.45	10	2	-0.0397	-0.0057	-0.1073	-0.0153
13-Jun-95	47.93	0.45	11	1	0.2828	0.0202	0.7631	0.0545

Well G9

Observ.	Water L.	Perturbation	Lag#	#pairs	Autocovariance (unbiased)	Autocovariance (biased)	Autocorrelation (unbiased)	Autocorrelation (biased)
15-Jul-94	58.64	-0.71	0	15	1.1824	1.2668	0.9333	1.0000
29-Jul-94	58.16	-1.19	0.5	14	1.2645	1.2645	0.9981	0.9981
12-Aug-94	58.34	-1.01	1	13	0.8576	0.7963	0.6769	0.6286
26-Aug-94	58.10	-1.25	1.5	12	0.7833	0.6714	0.6183	0.5300
10-Sep-94	58.21	-1.14	2	11	0.6009	0.4721	0.4743	0.3727
23-Sep-94	58.49	-0.86	2.5	10	0.7080	0.5057	0.5589	0.3992
15-Oct-94	58.40	-0.95	3	9	0.2431	0.1563	0.1919	0.1234
15-Nov-94	60.18	0.83	4	8	0.0800	0.0457	0.0632	0.0361
15-Dec-94	60.45	1.10	5	7	-0.4855	-0.2427	-0.3832	-0.1916
15-Jan-95	60.97	1.62	6	6	-0.7176	-0.3075	-0.5664	-0.2428
15-fev-95	59.01	-0.34	7	5	-0.9523	-0.3401	-0.7517	-0.2685
15-Mar-95	60.80	1.45	8	4	-1.0444	-0.2984	-0.8244	-0.2355
12-Apr-95	60.73	1.38	9	3	-0.7366	-0.1578	-0.5815	-0.1246
15-May-95	60.62	1.27	10	2	-0.7415	-0.1059	-0.5853	-0.0836
13-Jun-95	59.17	-0.18	11	1	-1.0305	-0.0736	-0.8134	-0.0581

Well G10

Observ.	Water L.	Perturbation	Lag#	#pairs	Autocovariance (unbiased)	Autocovariance (biased)	Autocorrelation (unbiased)	Autocorrelation (biased)
15-Jul-94	50.40	0.03	0	15	0.1976	0.2117	0.9333	1.0000
29-Jul-94	50.21	-0.16	0.5	14	0.2117	0.2117	0.9999	0.9999
12-Aug-94	49.98	-0.39	1	13	0.0590	0.0548	0.2787	0.2587
26-Aug-94	50.10	-0.27	1.5	12	0.0624	0.0535	0.2947	0.2526
10-Sep-94	50.00	-0.37	2	11	0.1053	0.0827	0.4975	0.3909
23-Sep-94	49.96	-0.41	2.5	10	0.1168	0.0834	0.5517	0.3941
15-Oct-94	49.91	-0.46	3	9	-0.0131	-0.0084	-0.0619	-0.0398
15-Nov-94	50.12	-0.25	4	8	-0.0476	-0.0272	-0.2251	-0.1286
15-Dec-94	50.40	0.03	5	7	-0.0904	-0.0452	-0.4269	-0.2135
15-Jan-95	51.60	1.23	6	6	-0.1013	-0.0434	-0.4786	-0.2051
15-fev-95	50.31	-0.06	7	5	-0.1511	-0.0540	-0.7139	-0.2550
15-Mar-95	51.13	0.76	8	4	-0.0936	-0.0268	-0.4424	-0.1264
12-Apr-95	50.53	0.16	9	3	-0.0820	-0.0176	-0.3876	-0.0831
15-May-95	50.48	0.11	10	2	-0.0609	-0.0087	-0.2879	-0.0411
13-Jun-95	50.38	0.01	11	1	0.0249	0.0018	0.1177	0.0084

Appendix F2. Crosscorrelation stats. for water level and air temp.

Note: **Biased function was used to construct Figure 6.3.**

Well G2							Crosscovariance		Crosscorrelation	
Observ.	Temp.	Perturb.	Water L.	Perturb.	Lag #	# Pairs	Unbiased	Biased	Unbiased	Biased
15-Jul-94	26.5	12.7	58.06	0.76	-11	1	8.892	0.808	1.591	0.145
12-Aug-94	26.0	12.2	57.70	0.40	-10	2	2.986	0.543	0.534	0.097
10-Sep-94	17.5	3.7	57.22	-0.08	-9	3	-0.288	-0.079	-0.052	-0.014
15-Oct-94	12.5	-1.3	56.82	-0.48	-8	4	-1.860	-0.676	-0.333	-0.121
15-Nov-94	13.0	-0.8	56.52	-0.78	-7	5	-3.913	-1.779	-0.700	-0.318
15-Dec-94	-4.0	-17.8	56.63	-0.67	-6	6	-3.278	-1.788	-0.586	-0.320
15-Jan-95	5.5	-8.3	56.44	-0.86	-5	7	-3.660	-2.329	-0.655	-0.417
15-fev-95	2.0	-11.8	57.10	-0.20	-4	8	-0.408	-0.297	-0.073	-0.053
15-Mar-95	12.0	-1.8	57.80	0.50	-3	9	2.301	1.883	0.412	0.337
12-Apr-95	13.0	-0.8	57.85	0.55	-2	10	3.427	3.116	0.613	0.557
15-May-95	15.5	1.7	57.72	0.42	-1	11	4.240	4.240	0.759	0.759
13-Jun-95	25.5	11.7	57.81	0.51	0	12	3.521	3.841	0.630	0.687
					1	11	1.317	1.317	0.236	0.236
mean=	13.75	mean=	57.31		2	10	-1.644	-1.495	-0.294	-0.267
Std.dev=	9.51	std.dev.=	0.59		3	9	-4.017	-3.287	-0.719	-0.588
					4	8	-5.087	-3.700	-0.910	-0.662
					5	7	-4.649	-2.958	-0.832	-0.529
					6	6	-3.607	-1.967	-0.645	-0.352
					7	5	0.928	0.422	0.166	0.075
					8	4	3.488	1.268	0.624	0.227
					9	3	4.665	1.272	0.835	0.228
					10	2	5.778	1.051	1.034	0.188
					11	1	6.477	0.589	1.159	0.105

Well G4							Crosscovariance		Crosscorrelation	
Observ.	Temp.	Perturb.	Water L.	Perturb.	Lag #	# Pairs	Unbiased	Biased	Unbiased	Biased
15-Jul-94	26.5	12.7	64.35	-1.95	-11	1	-22.815	-2.074	-2.217	-0.202
12-Aug-94	26.0	12.2	64.69	-1.61	-10	2	-11.076	-2.014	-1.077	-0.196
10-Sep-94	17.5	3.7	64.70	-1.60	-9	3	-6.632	-1.809	-0.645	-0.176
15-Oct-94	12.5	-1.3	66.05	-0.25	-8	4	-0.212	-0.077	-0.021	-0.007
15-Nov-94	13.0	-0.8	66.65	0.35	-7	5	6.172	2.805	0.600	0.273
15-Dec-94	-4.0	-17.8	67.01	0.71	-6	6	7.861	4.288	0.764	0.417
15-Jan-95	5.5	-8.3	67.57	1.27	-5	7	11.884	7.563	1.155	0.735
15-fev-95	2.0	-11.8	66.58	0.28	-4	8	6.336	4.608	0.616	0.448
15-Mar-95	12.0	-1.8	67.23	0.93	-3	9	4.368	3.574	0.425	0.347
12-Apr-95	13.0	-0.8	66.89	0.59	-2	10	-0.470	-0.427	-0.046	-0.042
15-May-95	15.5	1.7	66.64	0.34	-1	11	-4.622	-4.622	-0.449	-0.449
13-Jun-95	25.5	11.7	66.78	0.48	0	12	-6.060	-6.611	-0.589	-0.643
					1	11	-7.122	-7.122	-0.692	-0.692
mean=	13.75	mean=	66.26		2	10	-4.468	-4.061	-0.434	-0.395
Std.dev=	9.51	std.dev.=	1.08		3	9	-2.720	-2.225	-0.264	-0.216
					4	8	-0.286	-0.208	-0.028	-0.020
					5	7	1.976	1.257	0.192	0.122
					6	6	2.234	1.218	0.217	0.118
					7	5	3.252	1.478	0.316	0.144
					8	4	4.911	1.786	0.477	0.174
					9	3	4.472	1.220	0.435	0.119
					10	2	5.087	0.925	0.494	0.090
					11	1	6.096	0.554	0.592	0.054

Well G5							Crosscovariance		Crosscorrelation	
Observ.	Temp.	Perturb.	Water L.	Perturb.	Lag #	# Pairs	Unbiased	Biased	Unbiased	Biased
15-Jul-94	26.5	12.7	85.55	0.16	-11	1	1.852	0.168	0.223	0.020
12-Aug-94	26.0	12.2	85.16	-0.23	-10	2	-1.221	-0.222	-0.147	-0.027
10-Sep-94	17.5	3.7	82.75	-2.64	-9	3	-10.476	-2.857	-1.264	-0.345
15-Oct-94	12.5	-1.3	85.28	-0.11	-8	4	-1.474	-0.536	-0.178	-0.065
15-Nov-94	13.0	-0.8	85.79	0.40	-7	5	1.027	0.467	0.124	0.056
15-Dec-94	-4.0	-17.8	85.91	0.52	-6	6	2.168	1.182	0.262	0.143
15-Jan-95	5.5	-8.3	85.88	0.49	-5	7	5.251	3.341	0.634	0.403
15-fev-95	2.0	-11.8	85.58	0.19	-4	8	3.643	2.649	0.440	0.320
15-Mar-95	12.0	-1.8	86.06	0.67	-3	9	5.561	4.550	0.671	0.549
12-Apr-95	13.0	-0.8	85.67	0.28	-2	10	-0.107	-0.097	-0.013	-0.012
15-May-95	15.5	1.7	85.63	0.24	-1	11	-0.924	-0.924	-0.112	-0.112
13-Jun-95	25.5	11.7	85.44	0.05	0	12	-2.227	-2.429	-0.269	-0.293
					1	11	-5.024	-5.024	-0.606	-0.606
mean=	13.75	mean=	85.39		2	10	-4.715	-4.287	-0.569	-0.517
Std.dev=	9.51	std.dev.=	0.87		3	9	-1.392	-1.139	-0.168	-0.137
					4	8	0.613	0.446	0.074	0.054
					5	7	1.072	0.682	0.129	0.082
					6	6	1.593	0.869	0.192	0.105
					7	5	2.245	1.021	0.271	0.123
					8	4	3.175	1.155	0.383	0.139
					9	3	2.207	0.602	0.266	0.073
					10	2	1.808	0.329	0.218	0.040
					11	1	0.613	0.056	0.074	0.007

Well G8							Crosscovariance		Crosscorrelation	
Observ.	Temp.	Perturb.	Water L.	Perturb.	Lag #	# Pairs	Unbiased	Biased	Unbiased	Biased
15-Jul-94	26.5	12.7	47.70	0.07	-11	1	0.828	0.075	0.172	0.016
12-Aug-94	26.0	12.2	47.30	-0.33	-10	2	-1.866	-0.339	-0.387	-0.070
10-Sep-94	17.5	3.7	47.08	-0.55	-9	3	-2.347	-0.640	-0.487	-0.133
15-Oct-94	12.5	-1.3	47.17	-0.46	-8	4	-1.543	-0.561	-0.320	-0.116
15-Nov-94	13.0	-0.8	47.25	-0.38	-7	5	-1.004	-0.456	-0.208	-0.095
15-Dec-94	-4.0	-17.8	47.26	-0.37	-6	6	-0.052	-0.028	-0.011	-0.006
15-Jan-95	5.5	-8.3	47.27	-0.36	-5	7	0.607	0.387	0.126	0.080
15-fev-95	2.0	-11.8	47.71	0.08	-4	8	2.137	1.554	0.443	0.322
15-Mar-95	12.0	-1.8	48.77	1.14	-3	9	3.630	2.970	0.753	0.616
12-Apr-95	13.0	-0.8	48.18	0.55	-2	10	2.577	2.343	0.535	0.486
15-May-95	15.5	1.7	47.93	0.30	-1	11	1.652	1.652	0.343	0.343
13-Jun-95	25.5	11.7	47.93	0.30	0	12	0.491	0.535	0.102	0.111
					1	11	-1.841	-1.841	-0.382	-0.382
mean=	13.75	mean=	47.63		2	10	-3.140	-2.855	-0.651	-0.592
Std.dev=	9.51	std.dev.=	0.51		3	9	-4.488	-3.672	-0.931	-0.762
					4	8	-3.440	-2.502	-0.713	-0.519
					5	7	-2.650	-1.686	-0.550	-0.350
					6	6	-0.944	-0.515	-0.196	-0.107
					7	5	3.270	1.486	0.678	0.308
					8	4	5.482	1.994	1.137	0.414
					9	3	3.926	1.071	0.814	0.222
					10	2	3.745	0.681	0.777	0.141
					11	1	3.820	0.347	0.792	0.072

Well G9							Crosscovariance		Crosscorrelation	
Observ.	Temp.	Perturb.	Water L.	Perturb.	Lag #	# Pairs	Unbiased	Biased	Unbiased	Biased
15-Jul-94	26.5	12.7	58.64	-0.99	-11	1	-11.544	-1.049	-1.112	-0.101
12-Aug-94	26.0	12.2	58.34	-1.29	-10	2	-8.366	-1.521	-0.806	-0.147
10-Sep-94	17.5	3.7	58.21	-1.42	-9	3	-5.991	-1.634	-0.577	-0.157
15-Oct-94	12.5	-1.3	58.40	-1.23	-8	4	-3.489	-1.269	-0.336	-0.122
15-Nov-94	13.0	-0.8	60.18	0.55	-7	5	3.896	1.771	0.375	0.171
15-Dec-94	-4.0	-17.8	60.45	0.82	-6	6	6.246	3.407	0.602	0.328
15-Jan-95	5.5	-8.3	60.97	1.34	-5	7	9.120	5.804	0.879	0.559
15-fev-95	2.0	-11.8	59.01	-0.62	-4	8	5.417	3.940	0.522	0.380
15-Mar-95	12.0	-1.8	60.80	1.17	-3	9	4.589	3.755	0.442	0.362
12-Apr-95	13.0	-0.8	60.73	1.10	-2	10	1.966	1.787	0.189	0.172
15-May-95	15.5	1.7	60.62	0.99	-1	11	-2.985	-2.985	-0.288	-0.288
13-Jun-95	25.5	11.7	59.17	-0.46	0	12	-4.791	-5.227	-0.462	-0.504
					1	11	-6.885	-6.885	-0.663	-0.663
mean=	13.75	mean=	59.63		2	10	-4.626	-4.205	-0.446	-0.405
Std.dev=	9.51	std.dev.=	1.09		3	9	-5.331	-4.362	-0.514	-0.420
					4	8	-0.074	-0.054	-0.007	-0.005
					5	7	1.181	0.751	0.114	0.072
					6	6	3.296	1.798	0.318	0.173
					7	5	1.928	0.876	0.186	0.084
					8	4	8.158	2.966	0.786	0.286
					9	3	8.147	2.222	0.785	0.214
					10	2	3.522	0.640	0.339	0.062
					11	1	-5.800	-0.527	-0.559	-0.051

Well G10							Crosscovariance		Crosscorrelation	
Observ.	Temp.	Perturb.	Water L.	Perturb.	Lag #	# Pairs	Unbiased	Biased	Unbiased	Biased
15-Jul-94	26.5	12.7	50.40	-0.04	-11	1	-0.429	-0.039	-0.092	-0.008
12-Aug-94	26.0	12.2	49.98	-0.46	-10	2	-2.703	-0.491	-0.580	-0.105
10-Sep-94	17.5	3.7	50.00	-0.44	-9	3	-1.952	-0.532	-0.419	-0.114
15-Oct-94	12.5	-1.3	49.91	-0.53	-8	4	-1.618	-0.588	-0.347	-0.126
15-Nov-94	13.0	-0.8	50.12	-0.32	-7	5	-0.599	-0.272	-0.129	-0.058
15-Dec-94	-4.0	-17.8	50.40	-0.04	-6	6	0.989	0.539	0.212	0.116
15-Jan-95	5.5	-8.3	51.60	1.16	-5	7	3.478	2.213	0.746	0.475
15-fev-95	2.0	-11.8	50.31	-0.13	-4	8	2.387	1.736	0.512	0.372
15-Mar-95	12.0	-1.8	51.13	0.69	-3	9	2.592	2.121	0.556	0.455
12-Apr-95	13.0	-0.8	50.53	0.09	-2	10	1.352	1.229	0.290	0.264
15-May-95	15.5	1.7	50.48	0.04	-1	11	-0.781	-0.781	-0.168	-0.168
13-Jun-95	25.5	11.7	50.38	-0.06	0	12	-1.345	-1.467	-0.288	-0.315
					1	11	-3.706	-3.706	-0.795	-0.795
mean=	13.75	mean=	50.44		2	10	-1.866	-1.696	-0.400	-0.364
Std.dev=	9.51	std.dev.=	0.49		3	9	-2.847	-2.329	-0.611	-0.500
					4	8	-0.238	-0.173	-0.051	-0.037
					5	7	1.712	1.089	0.367	0.234
					6	6	2.774	1.513	0.595	0.325
					7	5	1.437	0.653	0.308	0.140
					8	4	2.544	0.925	0.546	0.198
					9	3	0.501	0.137	0.107	0.029
					10	2	-0.071	-0.013	-0.015	-0.003
					11	1	-0.720	-0.065	-0.154	-0.014

Appendix F3. Autocorrelation statistics for Total Dissolved Solids.

Note: Biased function was used to construct Figure 6.10.

Well G2

Date	TDS	TDS'	Lag#	#pairs	Autocovariance (unbiased)	Autocovariance (biased)	Autocorrelation (unbiased)	Autocorrelation (biased)
7-May-94	342.5	-35.5	0	15	2224.1	2382.9	0.933	1.000
3-Jun-94	251.5	-126.5	1	14	-336.7	-336.7	-0.141	-0.141
1-Jul-94	466.0	88.0	2	13	-435.5	-404.4	-0.183	-0.170
29-Jul-94	370.5	-7.5	3	12	602.7	516.6	0.253	0.217
26-Aug-94	326.0	-52.0	4	11	73.3	57.6	0.031	0.024
23-Sep-94	380.0	2.0	5	10	372.9	266.3	0.156	0.112
15-Oct-94	375.0	-3.0	6	9	-219.6	-141.2	-0.092	-0.059
15-Nov-94	400.0	22.0	7	8	-657.9	-375.9	-0.276	-0.158
15-Dec-94	385.0	7.0	8	7	610.5	305.3	0.256	0.128
16-Jan-95	345.0	-33.0	9	6	-286.0	-122.6	-0.120	-0.051
15-Feb-95	400.0	22.0	10	5	-609.5	-217.7	-0.256	-0.091
15-Mar-95	400	22.0	11	4	-303.0	-86.6	-0.127	-0.036
12-Apr-95	405.00	27.0	12	3	-963.7	-206.5	-0.404	-0.087
15-May-95	414.50	36.5	13	2	-2578.6	-368.4	-1.082	-0.155
13-Jun-95	408.5	30.5	14	1	-1082.9	-77.4	-0.454	-0.032

Well G3

Date	TDS	TDS'	Lag#	#pairs	Autocovariance (unbiased)	Autocovariance (biased)	Autocorrelation (unbiased)	Autocorrelation (biased)
7-May-94	276.5	-36.2333	0	15	1002.5	1074.1	0.933	1.000
3-Jun-94	261.5	-51.2333	1	14	727.2	727.2	0.677	0.677
1-Jul-94	267	-45.7333	2	13	449.4	417.3	0.418	0.388
29-Jul-94	286.5	-26.2333	3	12	299.0	256.3	0.278	0.239
26-Aug-94	282	-30.733	4	11	69.2	54.3	0.064	0.051
23-Sep-94	320	7.2667	5	10	4.5	3.2	0.004	0.003
15-Oct-94	330	17.2667	6	9	-64.8	-41.6	-0.060	-0.039
15-Nov-94	325	12.2667	7	8	-251.0	-143.4	-0.234	-0.134
15-Dec-94	320	7.2667	8	7	-363.4	-181.7	-0.338	-0.169
16-Jan-95	300	-12.733	9	6	-842.2	-360.9	-0.784	-0.336
15-Feb-95	335	22.2667	10	5	-1318.4	-470.9	-1.227	-0.438
15-Mar-95	380	67.2667	11	4	-1338.3	-382.4	-1.246	-0.356
12-Apr-95	335	22.2667	12	3	-1036.8	-222.2	-0.965	-0.207
15-May-95	340.5	27.7667	13	2	-996.6	-142.4	-0.928	-0.133
13-Jun-95	332	19.2667	14	1	-698.1	-49.9	-0.650	-0.046

Well G4

Date	TDS	TDS'	Lag#	#pairs	Autocovariance (unbiased)	Autocovariance (biased)	Autocorrelation (unbiased)	Autocorrelation (biased)
7-May-94	575	4.2	0	15	3235.4	3466.5	0.933	1.000
3-Jun-94	493.5	-77.3	1	14	1035.3	1035.3	0.299	0.299
1-Jul-94	526.5	-44.3	2	13	493.5	458.3	0.142	0.132
29-Jul-94	498	-72.8	3	12	592.1	507.6	0.171	0.146
26-Aug-94	517	-53.8	4	11	107.1	84.1	0.031	0.024
23-Sep-94	530	-40.8	5	10	-533.0	-380.7	-0.154	-0.110
15-Oct-94	555	-15.8	6	9	-122.0	-78.5	-0.035	-0.023
15-Nov-94	660	89.2	7	8	-514.7	-294.1	-0.148	-0.085
15-Dec-94	650	79.2	8	7	-320.1	-160.0	-0.092	-0.046
16-Jan-95	490	-80.8	9	6	-2110.3	-904.4	-0.609	-0.261
15-Feb-95	620.0	49.2	10	5	-1924.8	-687.4	-0.555	-0.198
15-Mar-95	600.0	29.2	11	4	-2217.7	-633.6	-0.640	-0.183
12-Apr-95	610.0	39.2	12	3	-1754.1	-375.9	-0.506	-0.108
15-May-95	606.5	35.7	13	2	-2252.1	-321.7	-0.650	-0.093
13-Jun-95	631.0	60.2	14	1	250.7	17.9	0.072	0.005

Well G5

Date	TDS	TDS'	Lag#	#pairs	Autocovariance (unbiased)	Autocovariance (biased)	Autocorrelation (unbiased)	Autocorrelation (biased)
7-May-94	206.0	-29.7	0	15	310.5	332.7	0.933	1.000
3-Jun-94	214.0	-21.7	1	14	156.5	156.5	0.470	0.470
1-Jul-94	231.5	-4.2	2	13	103.7	96.3	0.312	0.290
29-Jul-94	218.5	-17.2	3	12	111.1	95.2	0.334	0.286
26-Aug-94	211.0	-24.7	4	11	50.6	39.7	0.152	0.119
23-Sep-94	235	-0.7	5	10	-55.8	-39.9	-0.168	-0.120
15-Oct-94	230	-5.7	6	9	-134.9	-86.7	-0.405	-0.261
15-Nov-94	270	34.3	7	8	-221.8	-126.7	-0.667	-0.381
15-Dec-94	250	14.3	8	7	-154.8	-77.4	-0.465	-0.233
16-Jan-95	245	9.3	9	6	-117.3	-50.3	-0.353	-0.151
15-Feb-95	255	19.3	10	5	-244.0	-87.1	-0.733	-0.262
15-Mar-95	255	19.3	11	4	-184.9	-52.8	-0.556	-0.159
12-Apr-95	235	-0.7	12	3	11.2	2.4	0.034	0.007
15-May-95	233	-2.7	13	2	-81.8	-11.7	-0.246	-0.035
13-Jun-95	247	11.3	14	1	-335.0	-23.9	-1.007	-0.072

Well G8

Date	TDS	TDS'	Lag#	#pairs	Autocovariance (unbiased)	Autocovariance (biased)	Autocorrelation (unbiased)	Autocorrelation (biased)
7-May-94	234.5	-35.8	0	15	664.1	711.5	0.933	1.000
3-Jun-94	240.5	-29.8	1	14	581.7	581.7	0.818	0.818
1-Jul-94	235.5	-34.8	2	13	460.9	428.0	0.648	0.602
29-Jul-94	229.5	-40.8	3	12	323.1	277.0	0.454	0.389
26-Aug-94	241.5	-28.8	4	11	110.0	86.5	0.155	0.122
23-Sep-94	275.0	4.7	5	10	-105.3	-75.2	-0.148	-0.106
15-Oct-94	275.0	4.7	6	9	-238.9	-153.6	-0.336	-0.216
15-Nov-94	285.0	14.7	7	8	-463.1	-264.7	-0.651	-0.372
15-Dec-94	290.0	19.7	8	7	-632.3	-316.2	-0.889	-0.444
16-Jan-95	285.0	14.7	9	6	-674.0	-288.8	-0.947	-0.406
15-Feb-95	300.0	29.7	10	5	-744.7	-266.0	-1.047	-0.374
15-Mar-95	310.0	39.7	11	4	-702.3	-200.6	-0.987	-0.282
12-Apr-95	295.0	24.7	12	3	-480.4	-102.9	-0.675	-0.145
15-May-95	280.0	9.7	13	2	-288.4	-41.2	-0.405	-0.058
13-Jun-95	278.0	7.7	14	1	-275.7	-19.7	-0.387	-0.028

Well G10

Date	TDS	TDS'	Lag#	#pairs	Autocovariance (unbiased)	Autocovariance (biased)	Autocorrelation (unbiased)	Autocorrelation (biased)
7-May-94	317.5	22.3	0	15	2016.7	2160.8	0.933	1.000
3-Jun-94	257	-38.2	1	14	985.3	985.3	0.456	0.456
1-Jul-94	316.5	21.3	2	13	-15.1	-14.1	-0.007	-0.007
29-Jul-94	298.5	3.3	3	12	-1071.3	-918.3	-0.496	-0.425
26-Aug-94	297.5	2.3	4	11	-987.7	-776.1	-0.457	-0.359
23-Sep-94	295	-0.2	5	10	-445.9	-318.5	-0.206	-0.147
15-Oct-94	295	-0.2	6	9	-399.4	-256.7	-0.185	-0.119
15-Nov-94	310	14.8	7	8	244.4	139.6	0.113	0.065
15-Dec-94	215	-80.2	8	7	1.8	0.9	0.001	0.000
16-Jan-95	220	-75.2	9	6	357.3	153.1	0.165	0.071
15-Feb-95	230	-65.2	10	5	-250.0	-89.3	-0.116	-0.041
15-Mar-95	340	44.8	11	4	-228.7	-65.3	-0.106	-0.030
12-Apr-95	375	79.8	12	3	104.9	22.5	0.049	0.010
15-May-95	345	49.8	13	2	168.4	24.1	0.078	0.011
13-Jun-95	315.5	20.3	14	1	454.1	32.4	0.210	0.015

Appendix F4. Crosscorrelation stats. between water level and TDS.

Note: biased function was used in the construction of Figure 6.11

Well G2

Date	Water L.	Water L'	TDS	TDS'	Lag #	# Pairs	Crosscovariance Unbiased	Crosscovariance Biased	Crosscorrelation Unbiased	Crosscorrelation Biased
1-Jul-94	58.06	0.47	466	75.58	-12	1	26.394	2.199	1.200	0.100
29-Jul-94	57.70	0.11	370.5	-19.92	-11	2	29.746	4.958	1.352	0.225
26-Aug-94	56.82	-0.77	326	-64.42	-10	3	5.536	1.384	0.252	0.063
23-Sep-94	56.63	-0.96	380	-10.42	-9	4	-14.660	-4.887	-0.666	-0.222
15-Oct-94	56.44	-1.15	375	-15.42	-8	5	-11.484	-4.785	-0.522	-0.217
15-Nov-94	57.10	-0.49	400	9.58	-7	6	-2.522	-1.261	-0.115	-0.057
15-Dec-94	57.80	0.21	385	-5.42	-6	7	-0.713	-0.416	-0.032	-0.019
15-Jan-95	57.85	0.26	345	-45.42	-5	8	-9.518	-6.345	-0.433	-0.288
15-fev-95	57.72	0.13	400	9.58	-4	9	-14.881	-11.160	-0.676	-0.507
15-Mar-95	57.81	0.22	400	9.58	-3	10	-4.647	-3.872	-0.211	-0.176
12-Apr-95	58.34	0.75	405	14.58	-2	11	4.493	4.119	0.204	0.187
15-May-95	58.47	0.88	414.5	24.08	-1	12	10.858	10.858	0.494	0.494
13-Jun-95	57.94	0.35	408.5	18.08	0	13	10.372	11.236	0.471	0.511
					1	12	2.454	2.454	0.112	0.112
mean=	57.6	mean=	390.42		2	11	2.277	2.087	0.103	0.095
std. dev.=	0.642	std. dev.=	34.269		3	10	5.168	4.307	0.235	0.196
					4	9	4.171	3.128	0.190	0.142
					5	8	2.657	1.772	0.121	0.081
					6	7	-6.985	-4.075	-0.317	-0.185
					7	6	-13.039	-6.519	-0.593	-0.296
					8	5	-9.926	-4.136	-0.451	-0.188
					9	4	-7.460	-2.487	-0.339	-0.113
					10	3	-1.488	-0.372	-0.068	-0.017
					11	2	6.636	1.106	0.302	0.050
					12	1	8.482	0.707	0.386	0.032

Well G4

Date	Water L.	Water L'	TDS	TDS'	Lag #	# Pairs	Crosscovariance Unbiased	Crosscovariance Biased	Crosscorrelation Unbiased	Crosscorrelation Biased
1-Jul-94	64.35	-1.86	526.5	-49.96	-12	1	-28.593	-2.383	-0.440	-0.037
29-Jul-94	64.27	-1.94	498	-78.46	-11	2	-33.251	-5.542	-0.511	-0.085
26-Aug-94	64.68	-1.53	517	-59.46	-10	3	-34.013	-8.503	-0.523	-0.131
23-Sep-94	66.00	-0.21	530	-46.46	-9	4	-39.227	-13.076	-0.603	-0.201
15-Oct-94	66.05	-0.16	555	-21.46	-8	5	-34.350	-14.313	-0.528	-0.220
15-Nov-94	66.65	0.44	660	83.54	-7	6	-25.205	-12.603	-0.387	-0.194
15-Dec-94	67.01	0.80	650	73.54	-6	7	-21.864	-12.754	-0.336	-0.196
15-Jan-95	67.57	1.36	490	-86.46	-5	8	-20.748	-13.832	-0.319	-0.213
15-fev-95	66.58	0.37	620	43.54	-4	9	-2.522	-1.892	-0.039	-0.029
15-Mar-95	67.23	1.02	600	23.54	-3	10	0.952	0.793	0.015	0.012
12-Apr-95	66.89	0.68	610	33.54	-2	11	16.009	14.675	0.246	0.226
15-May-95	66.64	0.43	606.5	30.04	-1	12	37.845	37.845	0.582	0.582
13-Jun-95	66.78	0.57	631	54.54	0	13	33.403	36.187	0.513	0.556
					1	12	36.069	36.069	0.554	0.554
Mean=	66.2077	Mean=	576.46		2	11	28.499	26.124	0.438	0.402
Std. Dev=	1.097969	Std. Dev=	59.2458		3	10	14.941	12.451	0.230	0.191
					4	9	-13.857	-10.392	-0.213	-0.160
					5	8	-8.140	-5.427	-0.125	-0.083
					6	7	1.611	0.940	0.025	0.014
					7	6	8.786	4.393	0.135	0.068
					8	5	-38.513	-16.047	-0.592	-0.247
					9	4	-41.483	-13.828	-0.638	-0.213
					10	3	-67.943	-16.986	-1.044	-0.261
					11	2	-80.741	-13.457	-1.241	-0.207
					12	1	-101.316	-8.443	-1.557	-0.130

Well G5

Date	Water L.	Water L'	TDS	TDS'	Lag #	# Pairs	Crosscovariance Unbiased	Crosscovariance Biased	Crosscorrelation Unbiased	Crosscorrelation Biased
1-Jul-94	85.6	0.0	231.5	-8.2	-12	1	0.580	0.048	0.085	0.007
29-Jul-94	85.2	-0.3	218.5	-21.2	-11	2	0.262	0.044	0.038	0.006
26-Aug-94	84.4	-1.1	211.0	-28.7	-10	3	-0.600	-0.150	-0.088	-0.022
23-Sep-94	85.2	-0.3	235.0	-4.7	-9	4	-2.740	-0.913	-0.402	-0.134
15-Oct-94	85.3	-0.2	230.0	-9.7	-8	5	-3.329	-1.387	-0.488	-0.203
15-Nov-94	85.8	0.3	270.0	30.3	-7	6	-4.050	-2.025	-0.594	-0.297
15-Dec-94	85.9	0.4	250.0	10.3	-6	7	-2.045	-1.193	-0.300	-0.175
15-Jan-95	85.9	0.4	245.0	5.3	-5	8	-2.664	-1.776	-0.391	-0.260
15-fev-95	85.6	0.1	255.0	15.3	-4	9	-0.005	-0.004	-0.001	-0.001
15-Mar-95	86.1	0.5	255.0	15.3	-3	10	0.299	0.249	0.044	0.037
12-Apr-95	85.7	0.2	235.0	-4.7	-2	11	3.237	2.968	0.475	0.435
15-May-95	85.6	0.1	233.0	-6.7	-1	12	4.921	4.921	0.722	0.722
13-Jun-95	85.4	-0.1	247.0	7.3	0	13	4.869	5.275	0.714	0.774
					1	12	1.485	1.485	0.218	0.218
Mean=	85.5108	Mean=	239.69		2	11	0.984	0.902	0.144	0.132
Std. Dev=	0.424371	Std. Dev=	16.0657		3	10	-2.235	-1.862	-0.328	-0.273
					4	9	-2.853	-2.140	-0.418	-0.314
					5	8	-2.103	-1.402	-0.308	-0.206
					6	7	-2.873	-1.676	-0.421	-0.246
					7	6	-2.757	-1.379	-0.404	-0.202
					8	5	0.227	0.094	0.033	0.014
					9	4	1.862	0.621	0.273	0.091
					10	3	-2.049	-0.512	-0.301	-0.075
					11	2	-1.267	-0.211	-0.186	-0.031
					12	1	0.286	0.024	0.042	0.004

Well G10

Date	Water L.	Water L'	TDS	TDS'	Lag #	# Pairs	Crosscovariance Unbiased	Crosscovariance Biased	Crosscorrelation Unbiased	Crosscorrelation Biased
1-Jul-94	50.40	0	316.5	3.9	-12	1	-0.078	-0.006	-0.005	0.000
29-Jul-94	49.98	-0.42	298.5	-14.1	-11	2	0.297	0.049	0.019	0.003
26-Aug-94	50.00	-0.4	297.5	-15.1	-10	3	-0.106	-0.027	-0.007	-0.002
23-Sep-94	49.96	-0.44	295	-17.6	-9	4	0.039	0.013	0.003	0.001
15-Oct-94	49.91	-0.49	295	-17.6	-8	5	-2.733	-1.139	-0.176	-0.074
15-Nov-94	50.12	-0.28	310	-2.6	-7	6	-1.453	-0.727	-0.094	-0.047
15-Dec-94	50.40	0.00	315	2.4	-6	7	-4.422	-2.579	-0.286	-0.167
15-Jan-95	51.60	1.20	240	-72.6	-5	8	-3.646	-2.431	-0.235	-0.157
15-fev-95	50.31	-0.09	320	7.4	-4	9	-2.782	-2.087	-0.180	-0.135
15-Mar-95	51.13	0.73	340	27.4	-3	10	-1.911	-1.592	-0.123	-0.103
12-Apr-95	50.53	0.13	375	62.4	-2	11	-3.405	-3.121	-0.220	-0.202
15-May-95	50.48	0.08	345	32.4	-1	12	3.910	3.910	0.253	0.253
13-Jun-95	50.38	-0.02	315.5	2.9	0	13	-2.160	-2.340	-0.139	-0.151
					1	12	6.512	6.512	0.421	0.421
Mean=	50.4	Mean=	312.54		2	11	7.820	7.168	0.505	0.463
Std. Dev=	0.487613	Std. Dev=	31.7572		3	10	11.496	9.580	0.742	0.619
					4	9	6.600	4.950	0.426	0.320
					5	8	-0.330	-0.220	-0.021	-0.014
					6	7	-3.453	-2.014	-0.223	-0.130
					7	6	-9.702	-4.851	-0.627	-0.313
					8	5	-10.429	-4.345	-0.674	-0.281
					9	4	-10.111	-3.370	-0.653	-0.218
					10	3	-4.923	-1.231	-0.318	-0.079
					11	2	-0.609	-0.102	-0.039	-0.007
					12	1	0.000	0.000	0.000	0.000

Appendix F5. Crosscorrelation stats. for $\delta^2 H$ and air temperature.

Note: Biased function was used in the construction of Figure 6.14

P1R

Obs #	Temp.	Temp.'	Deuter.	Deuter.'	Lag #	# Pairs	Crosscovariance Unbiased	Crosscovariance Biased	Crosscorrelation Unbiased	Crosscorrelation Biased
3-Jun-94	22.5	10.27	-82.2	-7.1	-10	1	-23.236	-2.324	-0.486	-0.049
1-Jul-94	25.0	12.77	-72.9	2.2	-9	2	0.857	0.171	0.018	0.004
10-Sep-94	17.5	5.27	-69.2	5.9	-8	3	7.541	2.262	0.158	0.047
14-Oct-94	12.5	0.27	-70.8	4.3	-7	4	22.686	9.075	0.474	0.190
15-Nov-94	13.0	0.77	-70.4	4.7	-6	5	8.525	4.263	0.178	0.089
14-Dec-94	-4.0	-16.23	-74.7	0.4	-5	6	7.339	4.404	0.153	0.092
16-Jan-95	5.5	-6.73	-73.1	2.0	-4	7	-17.010	-11.907	-0.356	-0.249
16-Feb-95	2.0	-10.23	-73.9	1.2	-3	8	-20.949	-16.759	-0.438	-0.350
15-Mar-95	12.0	-0.23	-88	-12.9	-2	9	-19.945	-17.951	-0.417	-0.375
12-Apr-95	13.0	0.77	-78.1	-3.0	-1	10	-19.363	-19.363	-0.405	-0.405
15-May-95	15.5	3.27	-72.8	2.3	0	11	-3.000	-3.300	-0.063	-0.069
					1	10	21.609	21.609	0.452	0.452
Mean=	12.227	Mean=	-75.1		2	9	26.604	23.944	0.556	0.501
Std Dev=	8.495	Std Dev=	5.62974		3	8	39.222	31.378	0.820	0.656
					4	7	12.501	8.750	0.261	0.183
					5	6	-1.196	-0.718	-0.025	-0.015
					6	5	-6.237	-3.119	-0.130	-0.065
					7	4	-41.908	-16.763	-0.876	-0.351
					8	3	-52.903	-15.871	-1.106	-0.332
					9	2	-0.720	-0.144	-0.015	-0.003
					10	1	23.627	2.363	0.494	0.049

G2R

Obs #	Temp.	Temp.'	Deuter.	Deuter.'	Lag #	# Pairs	Crosscovariance Unbiased	Crosscovariance Biased	Crosscorrelation Unbiased	Crosscorrelation Biased
3-Jun-94	22.5	9.17	-81.5	-7.38	-11	1	-89.754	-8.159	-0.949	-0.086
1-Jul-94	25.0	11.67	-64.5	9.63	-10	2	50.566	9.194	0.534	0.097
10-Sep-94	17.5	4.17	-64.1	10.03	-9	3	48.441	13.211	0.512	0.140
14-Oct-94	12.5	-0.83	-64	10.13	-8	4	37.902	13.783	0.401	0.146
15-Nov-94	13.0	-0.33	-69.1	5.03	-7	5	30.115	13.689	0.318	0.145
14-Dec-94	-4.0	-17.33	-74.1	0.03	-6	6	-9.462	-5.161	-0.100	-0.055
16-Jan-95	5.5	-7.83	-75.5	-1.38	-5	7	-13.277	-8.449	-0.140	-0.089
16-Feb-95	2.0	-11.33	-76.3	-2.18	-4	8	-49.216	-35.793	-0.520	-0.378
15-Mar-95	12.0	-1.33	-101.7	-27.58	-3	9	-71.876	-58.808	-0.760	-0.622
12-Apr-95	13.0	-0.33	-79.4	-5.28	-2	10	-37.863	-34.421	-0.400	-0.364
15-May-95	15.5	2.17	-72.5	1.63	-1	11	-9.906	-9.906	-0.105	-0.105
13-Jun-95	25.5	12.17	-66.8	7.33	0	12	20.208	22.045	0.214	0.233
					1	11	56.269	56.269	0.595	0.595
Mean=	13.333	Mean=	-74.125		2	10	54.027	49.115	0.571	0.519
Std Dev=	8.960	Std Dev=	10.559		3	9	71.608	58.589	0.757	0.619
					4	8	5.905	4.295	0.062	0.045
					5	7	-12.254	-7.798	-0.130	-0.082
					6	6	-46.013	-25.098	-0.486	-0.265
					7	5	-73.502	-33.410	-0.777	-0.353
					8	4	-78.431	-28.521	-0.829	-0.301
					9	3	0.379	0.103	0.004	0.001
					10	2	50.192	9.126	0.531	0.096
					11	1	67.170	6.106	0.710	0.065

G5R

Obs #	Temp.	Temp.'	Deuter.	Deuter.'	Lag #	# Pairs	Crosscovariance Unbiased	Crosscovariance Biased	Crosscorrelation Unbiased	Crosscorrelation Biased
3-Jun-94	22.5	9.55	-78.1	-4.03	-10	1	-50.524	-5.052	-0.477	-0.048
1-Jul-94	25.0	12.05	-64.5	9.57	-9	2	54.921	10.984	0.519	0.104
14-Oct-94	12.5	-0.45	-61.0	13.07	-8	3	62.729	18.819	0.592	0.178
15-Nov-94	13.0	0.05	-67.4	6.67	-7	4	30.317	12.127	0.286	0.115
14-Dec-94	-4.0	-16.95	-70.4	3.67	-6	5	19.727	9.863	0.186	0.093
16-Jan-95	5.5	-7.45	-75.6	-1.53	-5	6	-16.138	-9.683	-0.152	-0.091
16-Feb-95	2.0	-10.95	-77.6	-3.53	-4	7	-28.661	-20.063	-0.271	-0.189
15-Mar-95	12.0	-0.95	-102.5	-28.43	-3	8	-87.777	-70.222	-0.829	-0.663
12-Apr-95	13.0	0.05	-80.5	-6.43	-2	9	-51.228	-46.105	-0.484	-0.435
15-May-95	15.5	2.55	-73.0	1.07	-1	10	-17.688	-17.688	-0.167	-0.167
13-Jun-95	25.5	12.55	-64.2	9.87	0	11	19.310	21.241	0.182	0.201
					1	10	64.089	64.089	0.605	0.605
Mean=	12.955	Mean=	-74.073		2	9	60.552	54.497	0.572	0.515
Std Dev=	9.2964	Std Dev=	11.3999		3	8	77.147	61.718	0.728	0.583
					4	7	1.399	0.980	0.013	0.009
					5	6	-22.704	-13.622	-0.214	-0.129
					6	5	-108.101	-54.051	-1.021	-0.510
					7	4	-87.202	-34.881	-0.823	-0.329
					8	3	-17.639	-5.292	-0.167	-0.050
					9	2	64.581	12.916	0.610	0.122
					10	1	94.240	9.424	0.890	0.089

G9R

Obs #	Temp.	Temp.'	Deuter.	Deuter.'	Lag #	# Pairs	Crosscovariance Unbiased	Crosscovariance Biased	Crosscorrelation Unbiased	Crosscorrelation Biased
3-Jun-94	22.5	9.25	-73.4	-1.82	-11	1	-22.254	-2.023	-0.192	-0.017
1-Jul-94	25.0	11.75	-66.0	5.58	-10	2	32.154	5.846	0.278	0.050
23-Sep-94	16.5	3.25	-53.6	17.98	-9	3	77.771	21.210	0.671	0.183
14-Oct-94	12.5	-0.75	-54.9	16.68	-8	4	61.427	22.337	0.530	0.193
15-Nov-94	13.0	-0.25	-70.9	0.68	-7	5	10.974	4.988	0.095	0.043
14-Dec-94	-4.0	-17.25	-78.9	-7.32	-6	6	-27.246	-14.861	-0.235	-0.128
16-Jan-95	5.5	-7.75	-68.6	2.98	-5	7	-30.741	-19.563	-0.265	-0.169
16-Feb-95	2.0	-11.25	-77.8	-6.22	-4	8	-61.423	-44.671	-0.530	-0.386
15-Mar-95	12.0	-1.25	-103.7	-32.12	-3	9	-94.027	-76.931	-0.812	-0.664
12-Apr-95	13.0	-0.25	-77.4	-5.82	-2	10	-37.105	-33.732	-0.320	-0.291
15-May-95	15.5	2.25	-68.9	2.68	-1	11	2.371	2.371	0.020	0.020
13-Jun-95	25.5	12.25	-64.9	6.68	0	12	33.092	36.100	0.286	0.312
					1	11	63.469	63.469	0.548	0.548
Mean=	13.25	Mean=	-71.58		2	10	78.589	71.445	0.678	0.617
Std Dev=	8.923	Std Dev=	12.986		3	9	77.604	63.494	0.670	0.548
					4	8	-6.614	-4.810	-0.057	-0.042
					5	7	-17.910	-11.397	-0.155	-0.098
					6	6	-43.571	-23.766	-0.376	-0.205
					7	5	-91.493	-41.588	-0.790	-0.359
					8	4	-90.429	-32.883	-0.780	-0.284
					9	3	-0.185	-0.050	-0.002	0.000
					10	2	51.675	9.395	0.446	0.081
					11	1	61.821	5.620	0.534	0.049

Appendix F6. Crosscorrelation statistics for $\delta^{13}C$ and DOC.

Note: Biased function was used for the construction of Figure 6.19

Well G2

Date	C-13 G2	C-13 G2'	DOC-G2	DOC-G2'	Lag #	# Pairs	Crosscovariance Unbiased	Crosscovariance Biased	Crosscorrelation Unbiased	Crosscorrelation Biased
7-May-94	-14.58	-2.48	133.4	111	-10	1	424.020	42.402	5.223	0.522
3-Jun-94	-14.12	-2.02	14.9	-7.5	-9	2	-108.120	-21.624	-1.332	-0.266
1-Jul-94	-12.46	-0.36	9.3	-13.1	-8	3	-59.816	-17.945	-0.737	-0.221
29-Jul-94	-13.35	-1.25	64.7	42.3	-7	4	80.799	32.320	0.995	0.398
12-Aug-94	-11.29	0.81	5.5	-16.9	-6	5	21.232	10.616	0.262	0.131
23-Sep-94	-10.97	1.13	0.1	-22.3	-5	6	-2.749	-1.649	-0.034	-0.020
14-Oct-94	-9.99	2.11	0.1	-22.3	-4	7	11.060	7.742	0.136	0.095
15-Nov-94	-10.93	1.17	0.1	-22.3	-3	8	-13.638	-10.910	-0.168	-0.134
14-Dec-94	-13.38	-1.28	0.1	-22.3	-2	9	-8.234	-7.410	-0.101	-0.091
34715	-13.79	-1.69	13.4	-9	-1	10	-23.127	-23.127	-0.285	-0.285
34746	-8.28	3.82	4.900	-17.5	0	11	-40.311	-44.342	-0.497	-0.546
					1	10	-2.435	-2.435	-0.030	-0.030
					2	9	-10.827	-9.744	-0.133	-0.120
mean=	-12.104	mean=	22.409		3	8	-14.699	-11.759	-0.181	-0.145
std.dev.=	1.9688	std.dev.=	41.231		4	7	8.243	5.770	0.102	0.071
					5	6	18.198	10.919	0.224	0.135
					6	5	21.091	10.545	0.260	0.130
					7	4	31.366	12.547	0.386	0.155
					8	3	26.595	7.978	0.328	0.098
					9	2	28.835	5.767	0.355	0.071
					10	1	43.4	4.34	0.535	0.053

Well G3

Date	C-13 G3	C-13 G3'	DOC-G3	DOC-G3'	Lag #	# Pairs	Crosscovariance Unbiased	Crosscovariance Biased	Crosscorrelation Unbiased	Crosscorrelation Biased
7-May-94	-13.36	-2.19	76.40	66.30	-10	1	250.614	25.061	5.389	0.539
3-Jun-94	-13.67	-2.5	9.60	-0.50	-9	2	-75.864	-15.173	-1.631	-0.326
1-Jul-94	-9.49	1.68	3.90	-6.20	-8	3	-43.458	-13.038	-0.934	-0.280
29-Jul-94	-11.36	-0.19	3.70	-6.40	-7	4	-7.148	-2.859	-0.154	-0.061
12-Aug-94	-10.97	0.2	15.10	5.00	-6	5	40.149	20.075	0.863	0.432
23-Sep-94	-10.16	1.01	0.10	-10.00	-5	6	4.818	2.891	0.104	0.062
14-Oct-94	-8.80	2.37	0.10	-10.00	-4	7	-3.348	-2.343	-0.072	-0.050
15-Nov-94	-11.46	-0.29	0.10	-10.00	-3	8	-4.310	-3.448	-0.093	-0.074
14-Dec-94	-12.80	-1.63	0.10	-10.00	-2	9	13.292	11.963	0.286	0.257
16-Jan-95	-13.43	-2.26	2.20	-7.90	-1	10	-17.340	-17.340	-0.373	-0.373
16-Feb-95	-7.39	3.78	0.10	-10.00	0	11	-16.972	-18.669	-0.365	-0.401
					1	10	0.747	0.747	0.016	0.016
					2	9	2.519	2.267	0.054	0.049
mean=	-11.172	mean=	10.127		3	8	-5.163	-4.131	-0.111	-0.089
std.dev.=	2.067	std.dev.=	22.501		4	7	-4.933	-3.453	-0.106	-0.074
					5	6	3.387	2.032	0.073	0.044
					6	5	5.920	2.960	0.127	0.064
					7	4	8.882	3.553	0.191	0.076
					8	3	8.283	2.485	0.178	0.053
					9	2	21.151	4.230	0.455	0.091
					10	1	21.900	2.190	0.471	0.047

Well G8

Date	C-13 G8	C-13 G8'	DOC-G8	DOC-G8'	Lag #	# Pairs	Crosscovariance Unbiased	Crosscovariance Biased	Crosscorrelation Unbiased	Crosscorrelation Biased
7-May-94	-13.67	-2.46	48.2	38.2	-10	1	79.838	7.9838	2.588	0.259
3-Jun-94	-13.86	-2.65	26.8	16.8	-9	2	-33.441	-6.6882	-1.084	-0.217
1-Jul-94	-9.65	1.56	11.9	1.9	-8	3	-40.8777	-12.2633	-1.325	-0.397
29-Jul-94	-10.9	0.31	7.1	-2.9	-7	4	-4.036	-1.6144	-0.131	-0.052
12-Aug-94	-10.28	0.93	6.5	-3.5	-6	5	19.6424	9.8212	0.637	0.318
23-Sep-94	-9.3	1.91	0.1	-9.9	-5	6	18.02817	10.8169	0.584	0.351
14-Oct-94	-8.9	2.31	0.1	-9.9	-4	7	11.84086	8.2886	0.384	0.269
15-Nov-94	-10.4	0.81	0.1	-9.9	-3	8	6.061125	4.8489	0.196	0.157
14-Dec-94	-13.35	-2.14	0.1	-9.9	-2	9	7.983556	7.1852	0.259	0.233
16-Jan-95	-13.88	-2.67	9.2	-0.8	-1	10	-6.8756	-6.8756	-0.223	-0.223
16-Feb-95	-9.12	2.09	0.1	-9.9	0	11	-16.9862	-18.6848	-0.551	-0.606
					1	10	-8.2831	-8.2831	-0.268	-0.268
					2	9	-3.99611	-3.5965	-0.130	-0.117
mean=	-11.21	mean=	10.018		3	8	-5.01088	-4.0087	-0.162	-0.130
std.dev.=	2.0539	std.dev.=	15.021		4	7	-2.46743	-1.7272	-0.080	-0.056
					5	6	2.0705	1.2423	0.067	0.040
					6	5	5.138	2.569	0.167	0.083
					7	4	11.568	4.6272	0.375	0.150
					8	3	3.676667	1.103	0.119	0.036
					9	2	14.1015	2.8203	0.457	0.091
					10	1	24.354	2.4354	0.789	0.079

Appendix G. Saturation indices for different groundwaters

Well G1 1-Jul-94

Phase	Chemical Formula	Log (AP/KT) S.I.	Saturation
Microcline	$KAlSi_3O_8$	-0.32	undersaturated
Anorthite	$(Na,Ca)(Al,Si)_3O_8$	-4.55	undersaturated
Aragonite	$CaCO_3$	-0.11	saturated
Barite	$BaSO_4$	0.76	supersaturated
Calcite	$CaCO_3$	0.05	saturated
Chlorite	$(Mg,Fe,Al)_6(Si,Al)_4O_{10}(OH)_8$	-7.00	undersaturated
Clinoenstatite	$MgSiO_3$	-4.35	undersaturated
Dolomite	$CaMg(CO_3)_2$	-0.34	undersaturated
Kaolinite	$Al_2Si_2O_5(OH)_4$	2.61	supersaturated
Pyrophyllite	$Al_2(OH)_2Si_4O_{10}$	3.73	supersaturated
Quartz	SiO_2	0.58	supersaturated
Tremolite	$Ca_2Mg_5[(OH,F)Si_4O_{11}]_2$	-8.60	undersaturated
K-Mica		8.24	supersaturated

Well G2 15-Jul-94

Phase	Chemical Formula	Log (AP/KT) S.I.	Saturation
Microcline	$KAlSi_3O_8$	-0.36	undersaturated
Anorthite	$(Na,Ca)(Al,Si)_3O_8$	-5.27	undersaturated
Aragonite	$CaCO_3$	-0.34	undersaturated
Barite	$BaSO_4$	0.32	supersaturated
Calcite	$CaCO_3$	-0.19	undersaturated
Chlorite	$(Mg,Fe,Al)_6(Si,Al)_4O_{10}(OH)_8$	-11.93	undersaturated
Clinoenstatite	$MgSiO_3$	-5.52	undersaturated
Dolomite	$CaMg(CO_3)_2$	-0.96	undersaturated
Kaolinite	$Al_2Si_2O_5(OH)_4$	2.51	supersaturated
Pyrophyllite	$Al_2(OH)_2Si_4O_{10}$	3.41	supersaturated
Quartz	SiO_2	0.28	supersaturated
Tremolite	$Ca_2Mg_5[(OH,F)Si_4O_{11}]_2$	-16.97	undersaturated
K-Mica		8.67	supersaturated

Appendix G (continued)

Well G3 1-Jul-94

Phase	Chemical Formula	Log (AP/KT) S.I.	Saturation
Microcline	$KAlSi_3O_8$	-0.34	undersaturated
Anorthite	$(Na,Ca)(Al,Si)_3O_8$	-4.16	undersaturated
Aragonite	$CaCO_3$	-0.09	saturated
Barite	$BaSO_4$	0.472	supersaturated
Calcite	$CaCO_3$	0.068	saturated
Chlorite	$(Mg,Fe,Al)_6(Si,Al)_4O_{10}(OH)_8$	-11.04	undersaturated
Clinoenstatite	$MgSiO_3$	-4.64	undersaturated
Dolomite	$CaMg(CO_3)_2$	-0.32	undersaturated
Kaolinite	$Al_2Si_2O_5(OH)_4$	3.17	supersaturated
Pyrophyllite	$Al_2(OH)_2Si_4O_{10}$	4.02	supersaturated
Quartz	SiO_2	0.47	supersaturated
Tremolite	$Ca_2Mg_5[(OH,F)Si_4O_{11}]_2$	-10.68	undersaturated
K-Mica		9.00	supersaturated

Well G4 15-Jul-94

Phase	Chemical Formula	Log (AP/KT) S.I.	Saturation
Microcline	$KAlSi_3O_8$	0.44	supersaturated
Anorthite	$(Na,Ca)(Al,Si)_3O_8$	-4.42	undersaturated
Aragonite	$CaCO_3$	-0.75	undersaturated
Barite	$BaSO_4$	0.13	supersaturated
Calcite	$CaCO_3$	-0.59	undersaturated
Chlorite	$(Mg,Fe,Al)_6(Si,Al)_4O_{10}(OH)_8$	-11.69	undersaturated
Clinoenstatite	$MgSiO_3$	-5.68	undersaturated
Dolomite	$CaMg(CO_3)_2$	-1.32	undersaturated
Kaolinite	$Al_2Si_2O_5(OH)_4$	4.21	supersaturated
Pyrophyllite	$Al_2(OH)_2Si_4O_{10}$	5.28	supersaturated
Quartz	SiO_2	0.47	supersaturated
Tremolite	$Ca_2Mg_5[(OH,F)Si_4O_{11}]_2$	-19.67	undersaturated
K-Mica		10.80	supersaturated

Appendix G (continued)

Well G5 1-Jul-94

Phase	Chemical Formula	Log (AP/KT) S.I.	Saturation
Microcline	$KAlSi_3O_8$	-1.17	undersaturated
Anorthite	$(Na,Ca)(Al,Si)_3O_8$	-5.49	undersaturated
Aragonite	$CaCO_3$	-0.48	undersaturated
Barite	$BaSO_4$	0.35	supersaturated
Calcite	$CaCO_3$	-0.32	undersaturated
Chlorite	$(Mg,Fe,Al)_6(Si,Al)_4O_{10}(OH)_8$	-11.27	undersaturated
Clinoenstatite	$MgSiO_3$	-5.24	undersaturated
Dolomite	$CaMg(CO_3)_2$	-1.16	undersaturated
Kaolinite	$Al_2Si_2O_5(OH)_4$	2.37	supersaturated
Pyrophyllite	$Al_2(OH)_2Si_4O_{10}$	3.27	supersaturated
Quartz	SiO_2	0.48	supersaturated
Tremolite	$Ca_2Mg_5[(OH,F)Si_4O_{11}]_2$	-14.73	undersaturated
K-Mica		7.36	supersaturated

Well G6 1-Jul-94

Phase	Chemical Formula	Log (AP/KT) S.I.	Saturation
Microcline	$KAlSi_3O_8$	-1.68	undersaturated
Anorthite	$(Na,Ca)(Al,Si)_3O_8$	-6.39	undersaturated
Aragonite	$CaCO_3$	-0.07	saturated
Barite	$BaSO_4$	-0.3	undersaturated
Calcite	$CaCO_3$	0.09	saturated
Chlorite	$(Mg,Fe,Al)_6(Si,Al)_4O_{10}(OH)_8$	-3.02	undersaturated
Clinoenstatite	$MgSiO_3$	-3.21	undersaturated
Dolomite	$CaMg(CO_3)_2$	0.00	saturated
Kaolinite	$Al_2Si_2O_5(OH)_4$	-0.46	undersaturated
Pyrophyllite	$Al_2(OH)_2Si_4O_{10}$	-0.02	saturated
Quartz	SiO_2	0.24	supersaturated
Tremolite	$Ca_2Mg_5[(OH,F)Si_4O_{11}]_2$	-1.48	undersaturated
K-Mica		4.50	supersaturated

Appendix G (continued)

Well G7 15-Jul-94

Phase	Chemical Formula	Log (AP/KT) S.I.	Saturation
Microcline	$KAlSi_3O_8$	-0.54	undersaturated
Anorthite	$(Na,Ca)(Al,Si)_3O_8$	-5.12	undersaturated
Aragonite	$CaCO_3$	-0.46	undersaturated
Barite	$BaSO_4$	0.46	supersaturated
Calcite	$CaCO_3$	-0.30	undersaturated
Chlorite	$(Mg,Fe,Al)_6(Si,Al)_4O_{10}(OH)_8$	-9.67	undersaturated
Clinoenstatite	$MgSiO_3$	-5.02	undersaturated
Dolomite	$CaMg(CO_3)_2$	-0.93	undersaturated
Kaolinite	$Al_2Si_2O_5(OH)_4$	2.61	supersaturated
Pyrophyllite	$Al_2(OH)_2Si_4O_{10}$	3.49	supersaturated
Quartz	SiO_2	0.40	supersaturated
Tremolite	$Ca_2Mg_5[(OH,F)Si_4O_{11}]_2$	-13.72	undersaturated
K-Mica		8.37	supersaturated

Well G8 1-Jul-94

Phase	Chemical Formula	Log (AP/KT) S.I.	Saturation
Microcline	$KAlSi_3O_8$	-1.83	undersaturated
Anorthite	$(Na,Ca)(Al,Si)_3O_8$	-6.04	undersaturated
Aragonite	$CaCO_3$	-0.26	undersaturated
Barite	$BaSO_4$	0.22	supersaturated
Calcite	$CaCO_3$	-0.10	saturated
Chlorite	$(Mg,Fe,Al)_6(Si,Al)_4O_{10}(OH)_8$	-12.6	undersaturated
Clinoenstatite	$MgSiO_3$	-5.46	undersaturated
Dolomite	$CaMg(CO_3)_2$	-1.05	undersaturated
Kaolinite	$Al_2Si_2O_5(OH)_4$	1.58	supersaturated
Pyrophyllite	$Al_2(OH)_2Si_4O_{10}$	2.16	supersaturated
Quartz	SiO_2	0.34	supersaturated
Tremolite	$Ca_2Mg_5[(OH,F)Si_4O_{11}]_2$	-15.77	undersaturated
K-Mica		6.20	supersaturated

Appendix G (continued)

Well G9 15-Jan-95

Phase	Chemical Formula	Log (AP/KT) S.I.	Saturation
Microcline	$KAlSi_3O_8$	-0.82	undersaturated
Anorthite	$(Na,Ca)(Al,Si)_3O_8$	-3.7	undersaturated
Aragonite	$CaCO_3$	0.25	supersaturated
Barite	$BaSO_4$	0.02	saturated
Calcite	$CaCO_3$	0.40	supersaturated
Chlorite	$(Mg,Fe,Al)_6(Si,Al)_4O_{10}(OH)_8$	-1.99	undersaturated
Clinoenstatite	$MgSiO_3$	-3.65	undersaturated
Dolomite	$CaMg(CO_3)_2$	0.59	supersaturated
Kaolinite	$Al_2Si_2O_5(OH)_4$	2.11	supersaturated
Pyrophyllite	$Al_2(OH)_2Si_4O_{10}$	3.12	supersaturated
Quartz	SiO_2	0.03	saturated
Tremolite	$Ca_2Mg_5[(OH,F)Si_4O_{11}]_2$	-5.21	undersaturated
K-Mica		8.36	supersaturated

Well G10 15-Jul-94

Phase	Chemical Formula	Log (AP/KT) S.I.	Saturation
Microcline	$KAlSi_3O_8$	-0.49	undersaturated
Anorthite	$(Na,Ca)(Al,Si)_3O_8$	-4.96	undersaturated
Aragonite	$CaCO_3$	-0.03	saturated
Barite	$BaSO_4$	0.51	supersaturated
Calcite	$CaCO_3$	0.13	supersaturated
Chlorite	$(Mg,Fe,Al)_6(Si,Al)_4O_{10}(OH)_8$	-6.20	undersaturated
Clinoenstatite	$MgSiO_3$	-4.11	undersaturated
Dolomite	$CaMg(CO_3)_2$	-0.06	saturated
Kaolinite	$Al_2Si_2O_5(OH)_4$	1.96	supersaturated
Pyrophyllite	$Al_2(OH)_2Si_4O_{10}$	3.06	supersaturated
Quartz	SiO_2	0.50	supersaturated
Tremolite	$Ca_2Mg_5[(OH,F)Si_4O_{11}]_2$	-7.31	undersaturated
K-Mica		7.58	supersaturated

Appendix G (continued)

Well G11 1-Jul-94

Phase	Chemical Formula	Log (AP/KT) S.I.	Saturation
Microcline	$KAlSi_3O_8$	-1.21	undersaturated
Anorthite	$(Na,Ca)(Al,Si)_3O_8$	-5.59	undersaturated
Aragonite	$CaCO_3$	0.08	saturated
Barite	$BaSO_4$	0.05	saturated
Calcite	$CaCO_3$	0.24	supersaturated
Chlorite	$(Mg,Fe,Al)_6(Si,Al)_4O_{10}(OH)_8$	-13.32	undersaturated
Clinoenstatite	$MgSiO_3$	-5.68	undersaturated
Dolomite	$CaMg(CO_3)_2$	-0.44	undersaturated
Kaolinite	$Al_2Si_2O_5(OH)_4$	2.26	supersaturated
Pyrophyllite	$Al_2(OH)_2Si_4O_{10}$	3.00	supersaturated
Quartz	SiO_2	0.42	supersaturated
Tremolite	$Ca_2Mg_5[(OH,F)Si_4O_{11}]_2$	-17.06	undersaturated
K-Mica		7.33	supersaturated

Well G12 26-Aug-94

Phase	Chemical Formula	Log (AP/KT) S.I.	Saturation
Microcline	$KAlSi_3O_8$	-	
Anorthite	$(Na,Ca)(Al,Si)_3O_8$	-	
Aragonite	$CaCO_3$	0.05	saturated
Barite	$BaSO_4$	0.59	supersaturated
Calcite	$CaCO_3$	0.21	supersaturated
Chlorite	$(Mg,Fe,Al)_6(Si,Al)_4O_{10}(OH)_8$	-	
Clinoenstatite	$MgSiO_3$	-4.56	undersaturated
Dolomite	$CaMg(CO_3)_2$	0.07	saturated
Kaolinite	$Al_2Si_2O_5(OH)_4$	-	
Pyrophyllite	$Al_2(OH)_2Si_4O_{10}$	-	
Quartz	SiO_2	0.16	supersaturated
Tremolite	$Ca_2Mg_5[(OH,F)Si_4O_{11}]_2$	-10.83	undersaturated
K-Mica		-	

Appendix G (continued)

P1 1-Jul-94

Phase	Chemical Formula	Log (AP/KT) S.I.	Saturation
Microcline	$KAlSi_3O_8$	-0.66	undersaturated
Anorthite	$(Na,Ca)(Al,Si)_3O_8$	-4.79	undersaturated
Aragonite	$CaCO_3$	-0.18	undersaturated
Barite	$BaSO_4$	0.65	supersaturated
Calcite	$CaCO_3$	0.02	saturated
Chlorite	$(Mg,Fe,Al)_6(Si,Al)_4O_{10}(OH)_8$	-10.76	undersaturated
Clinoenstatite	$MgSiO_3$	-5.15	undersaturated
Dolomite	$CaMg(CO_3)_2$	-0.67	undersaturated
Kaolinite	$Al_2Si_2O_5(OH)_4$	2.92	supersaturated
Pyrophyllite	$Al_2(OH)_2Si_4O_{10}$	4.24	supersaturated
Quartz	SiO_2	0.58	supersaturated
Tremolite	$Ca_2Mg_5[(OH,F)Si_4O_{11}]_2$	-13.88	undersaturated
K-Mica		8.20	supersaturated

P2 15-Nov-94

Phase	Chemical Formula	Log (AP/KT) S.I.	Saturation
Microcline	$KAlSi_3O_8$	0.15	supersaturated
Anorthite	$(Na,Ca)(Al,Si)_3O_8$	-3.89	undersaturated
Aragonite	$CaCO_3$	0.16	supersaturated
Barite	$BaSO_4$	-0.36	undersaturated
Calcite	$CaCO_3$	0.32	supersaturated
Chlorite	$(Mg,Fe,Al)_6(Si,Al)_4O_{10}(OH)_8$	-3.02	undersaturated
Clinoenstatite	$MgSiO_3$	-3.68	undersaturated
Dolomite	$CaMg(CO_3)_2$	0.24	supersaturated
Kaolinite	$Al_2Si_2O_5(OH)_4$	2.26	supersaturated
Pyrophyllite	$Al_2(OH)_2Si_4O_{10}$	3.21	supersaturated
Quartz	SiO_2	0.29	supersaturated
Tremolite	$Ca_2Mg_5[(OH,F)Si_4O_{11}]_2$	-4.45	undersaturated
K-Mica		8.90	supersaturated

Appendix G (continued)

P3 15-Nov-94

Phase	Chemical Formula	Log (AP/KT) S.I.	Saturation
Microcline	$KAlSi_3O_8$	-2.66	undersaturated
Anorthite	$(Na,Ca)(Al,Si)_3O_8$	-4.87	undersaturated
Aragonite	$CaCO_3$	-0.01	saturated
Barite	$BaSO_4$	0.48	supersaturated
Calcite	$CaCO_3$	0.15	supersaturated
Chlorite	$(Mg,Fe,Al)_6(Si,Al)_4O_{10}(OH)_8$	-10.94	undersaturated
Clinoenstatite	$MgSiO_3$	-5.51	undersaturated
Dolomite	$CaMg(CO_3)_2$	-0.59	undersaturated
Kaolinite	$Al_2Si_2O_5(OH)_4$	2.03	supersaturated
Pyrophyllite	$Al_2(OH)_2Si_4O_{10}$	2.78	supersaturated
Quartz	SiO_2	-0.13	undersaturated
Tremolite	$Ca_2Mg_5[(OH,F)Si_4O_{11}]_2$	-16.95	undersaturated
K-Mica		6.64	supersaturated

P4 15-Nov-94

Phase	Chemical Formula	Log (AP/KT) S.I.	Saturation
Microcline	$KAlSi_3O_8$	-	
Anorthite	$(Na,Ca)(Al,Si)_3O_8$	-	
Aragonite	$CaCO_3$	0.29	supersaturated
Barite	$BaSO_4$	0.33	supersaturated
Calcite	$CaCO_3$	0.45	supersaturated
Chlorite	$(Mg,Fe,Al)_6(Si,Al)_4O_{10}(OH)_8$	-	
Clinoenstatite	$MgSiO_3$	-4.09	undersaturated
Dolomite	$CaMg(CO_3)_2$	0.43	supersaturated
Kaolinite	$Al_2Si_2O_5(OH)_4$	-	
Pyrophyllite	$Al_2(OH)_2Si_4O_{10}$	-	
Quartz	SiO_2	0.29	supersaturated
Tremolite	$Ca_2Mg_5[(OH,F)Si_4O_{11}]_2$	-7.45	undersaturated
K-Mica		-	

Appendix G (continued)

T1 1-Jul-94

Phase	Chemical Formula	Log (AP/KT) S.I.	Saturation
Microcline	$KAlSi_3O_8$	-2.42	undersaturated
Anorthite	$(Na,Ca)(Al,Si)_3O_8$	-6.30	undersaturated
Aragonite	$CaCO_3$	-0.74	undersaturated
Barite	$BaSO_4$	-0.47	undersaturated
Calcite	$CaCO_3$	-0.58	undersaturated
Chlorite	$(Mg,Fe,Al)_6(Si,Al)_4O_{10}(OH)_8$	-18.1	undersaturated
Clinoenstatite	$MgSiO_3$	-6.63	undersaturated
Dolomite	$CaMg(CO_3)_2$	-2.09	undersaturated
Kaolinite	$Al_2Si_2O_5(OH)_4$	2.34	supersaturated
Pyrophyllite	$Al_2(OH)_2Si_4O_{10}$	3.57	supersaturated
Quartz	SiO_2	0.39	supersaturated
Tremolite	$Ca_2Mg_5[(OH,F)Si_4O_{11}]_2$	-23.92	undersaturated
K-Mica		6.20	supersaturated

T2 1-Jul-94

Phase	Chemical Formula	Log (AP/KT) S.I.	Saturation
Microcline	$KAlSi_3O_8$	-2.08	undersaturated
Anorthite	$(Na,Ca)(Al,Si)_3O_8$	-6.21	undersaturated
Aragonite	$CaCO_3$	-0.94	undersaturated
Barite	$BaSO_4$	-0.66	undersaturated
Calcite	$CaCO_3$	-0.78	undersaturated
Chlorite	$(Mg,Fe,Al)_6(Si,Al)_4O_{10}(OH)_8$	-15.99	undersaturated
Clinoenstatite	$MgSiO_3$	-6.19	undersaturated
Dolomite	$CaMg(CO_3)_2$	-2.21	undersaturated
Kaolinite	$Al_2Si_2O_5(OH)_4$	2.37	supersaturated
Pyrophyllite	$Al_2(OH)_2Si_4O_{10}$	3.5	supersaturated
Quartz	SiO_2	0.44	supersaturated
Tremolite	$Ca_2Mg_5[(OH,F)Si_4O_{11}]_2$	-21.28	undersaturated
K-Mica		6.45	supersaturated

Appendix G (continued)

T3 15-May-95

T (°C)=6 pH=6.5	Phase	Chemical Formula	Log (AP/KT) S.I.	Saturation
	Microcline	$KAlSi_3O_8$	-3.48	undersaturated
	Anorthite	$(Na,Ca)(Al,Si)_3O_8$	-6.90	undersaturated
	Aragonite	$CaCO_3$	-0.96	undersaturated
	Barite	$BaSO_4$	-0.61	undersaturated
	Calcite	$CaCO_3$	-0.80	undersaturated
	Chlorite	$(Mg,Fe,Al)_6(Si,Al)_4O_{10}(OH)_8$	-19.27	undersaturated
	Clinoenstatite	$MgSiO_3$	-6.94	undersaturated
	Dolomite	$CaMg(CO_3)_2$	-2.48	undersaturated
	Kaolinite	$Al_2Si_2O_5(OH)_4$	1.94	supersaturated
	Pyrophyllite	$Al_2(OH)_2Si_4O_{10}$	2.66	supersaturated
	Quartz	SiO_2	0.21	supersaturated
	Tremolite	$Ca_2Mg_5[(OH,F)Si_4O_{11}]_2$	-26.36	undersaturated
	K-Mica		5.12	supersaturated

T4 15-May-95

T (°C)=6 pH=6.5	Phase	Chemical Formula	Log (AP/KT) S.I.	Saturation
	Microcline	$KAlSi_3O_8$	-2.35	undersaturated
	Anorthite	$(Na,Ca)(Al,Si)_3O_8$	-6.16	undersaturated
	Aragonite	$CaCO_3$	-0.81	undersaturated
	Barite	$BaSO_4$	-0.35	undersaturated
	Calcite	$CaCO_3$	-0.65	undersaturated
	Chlorite	$(Mg,Fe,Al)_6(Si,Al)_4O_{10}(OH)_8$	-16.84	undersaturated
	Clinoenstatite	$MgSiO_3$	-6.45	undersaturated
	Dolomite	$CaMg(CO_3)_2$	-1.80	undersaturated
	Kaolinite	$Al_2Si_2O_5(OH)_4$	2.33	supersaturated
	Pyrophyllite	$Al_2(OH)_2Si_4O_{10}$	3.24	supersaturated
	Quartz	SiO_2	0.30	supersaturated
	Tremolite	$Ca_2Mg_5[(OH,F)Si_4O_{11}]_2$	-23.63	undersaturated
	K-Mica		6.45	supersaturated