

DENITRIFICATION IN THE ABBOTSFORD AQUIFER AND THE INFLUENCE OF A
STREAM ENVIRONMENT

by

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ABSTRACT

The Abbotsford aquifer has an area of approximately 200 km², half of which lies in British Columbia. The general groundwater flow is southerly, and thus, issues surrounding the aquifer, such as nitrate contamination have gained interest due to their transboundary nature. The protection of groundwater as a resource is a concern in both Canada and the United States.

This study investigated the nitrate reduction occurring in an area just north of the border. The study site was chosen due to the presence of Fishtrap Creek and its unique surrounding geology. Due to a highly variable water table in the aquifer, an intimate relationship exists between the groundwater and surface water in Fishtrap Creek.

The conditions which support denitrification were found to be present at the site during the 11-month sampling period. Nitrate concentrations have been monitored over the entire aquifer for decades, and were found to exceed safe water drinking levels (10 mg N/l) in several areas. In general, nitrates are present over the entire aquifer. Within the study area, nitrate-N was found to exceed the safe limit in only three wells. Several wells contained trace amounts of nitrate, as well as low dissolved oxygen levels. Thus, in these areas, which are along Fishtrap Creek, nitrate reduction has occurred.

The water chemistry of both Fishtrap Creek and the surrounding groundwater was monitored bi-weekly over the 11-month period. Stiff diagrams and piper plots were employed to group different water types present within the aquifer. Results from this study were similar to those found from studies performed over the entire aquifer. Water chemistry at Zero Avenue is representative of a mixture of water from Huntingdon Avenue, the culvert, and infiltrating groundwater. The comparison of ratios of nitrate and chloride present at various locations provided insight to the amount of dilution occurring. These results suggested that nitrate reduction was occurring.

A flow balance performed on Fishtrap Creek revealed that flow was typically lost between Huntingdon Avenue and the bridge at FT5, but gained over the entire reach. During lower flows, groundwater seeps were visible along the stream, especially in the lower section of the reach. The flow in Fishtrap Creek was calculated to be approximately 25 percent of the flow through the aquifer. Thus, the potential for Fishtrap Creek to play a significant role in denitrification exists. The amount of uncertainty associated with flow measurements is dependent on the accuracy of the equipment used. Flow measurements were taken accurately to 0.005 m³/s, and thus mass balance results should be adequately reliable.

Local groundwater flow is influenced by Fishtrap Creek since this is an area of significant discharge. Nitrate fluctuations coincided with fluctuations of the amount of flow gained by the creek. As well, the amount of flow gained by the creek was influenced by the gradient between the ground and surface water.

An average annual loss of 1.06 mg N/l occurred between upstream and downstream locations. Comparing the loss of nitrate to that of chloride, a conservative tracer, the nitrate reduction occurring due to dilution can be observed. On several occasions, the proportionate amount of nitrate reduction exceeded that of chloride reduction, and thus means of reduction besides dilution exist.

By considering water levels, along with water chemistry, it is apparent that an intimate relationship exists between the surface and ground water. Nitrate reduction is occurring along Fishtrap Creek and this area serves as a significant nitrogen sink. However, these results are unique to this study area, and may not be applicable south of the border. Thus, further studies are required to better understand the application of these results to basin management.

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1.0 INTRODUCTION

Nitrate contamination of groundwater has become a global issue over the past few decades and continues to be a major concern in Canada (Zebarth, 1996). The Abbotsford aquifer, located in southwestern British Columbia, is the largest aquifer in the Lower Fraser River Valley. The aquifer is largely unconfined and thus is susceptible to contamination from activities on the land surface.

Detailed studies have been carried out which examine the water quality and quantity within the Abbotsford aquifer. The concentration of nitrate has generally increased during the last thirty years over the entire aquifer (Liebscher et al., 1992). The source of nitrate in the Abbotsford aquifer is largely attributed to long-term agricultural land use practices (Wassenaar, 1995).

The Abbotsford aquifer has an area of approximately 200 km², half of which lies in Washington State. The general groundwater flow is southerly, with some local easterly and westerly flows. Thus, issues surrounding the aquifer, such as nitrate contamination have gained interest due to their transboundary nature.

The protection of groundwater as a resource is a concern both in Canada and the United States. Agricultural techniques which support basin management are being continuously studied and implemented through educating the farmers. In order to fully understand the severity of the problem, in situ nitrate reduction must be determined. By assessing the amount of nitrate that is reduced due to processes such as denitrification, the extent to which farming practices must be altered will be better understood.

This study is aimed at investigating the amount of nitrate reduction occurring in an area just north of the border. This area was chosen for the investigation of natural denitrification due to the unique geology present. The section of the aquifer chosen lies in the southwestern portion of the Canadian side. The aquifer is composed of a succession of stratified, permeable, glaciofluvial sands and gravel interspersed with minor till and clayey silt lenses, collectively

called the Sumas Drift (Liebscher et al., 1992). Surficial geology along Fishtrap Creek is quite unique to the aquifer, containing disseminated organic material.

Fishtrap Creek drains part of the clay upland and flows south across the aquifer and into the United States. The creek's water level is reported to lie above local groundwater for six months of the year, allowing the creek to recharge the aquifer. During the other six months, the creek level lies below groundwater levels and the groundwater recharges the creek (Liebscher et al., 1992). Thus, an intimate relationship between the groundwater and stream water exists.

This study will focus on the relationship between ground and surface water, examining the impact that the presence of Fishtrap Creek has on nitrate reduction. It is important to determine if the creek is a nitrogen source or sink. As well, the influence of the creek will be determined by how large a component the surface water is relative to the groundwater. In other words, the role that the creek plays in nitrate reduction will depend on how flows through the creek relate to the overall flow through the aquifer.

Denitrification is the reduction of nitrate to nitrite, nitrous oxide, nitric oxide, or nitrogen. The conditions that support denitrification include the presence of nitrate concentrations, a labile carbon source, denitrifying bacteria, and reducing conditions. Denitrifying bacteria require a carbon source for respiration and growth, and low dissolved oxygen levels are generally required so that nitrate becomes the preferred electron acceptor.

Denitrification within the Abbotsford aquifer has not previously been fully studied, although conditions that support this process have been identified.

2.0 LITERATURE REVIEW AND AQUIFER BACKGROUND

An extensive number of studies have been carried out which focus on the presence of nitrates in the environment. Several experiments have been performed which investigate the potential for denitrification both in situ and in laboratory column tests. The relationship between nitrate reduction and stream environments has also been explored.

The objective of this Chapter is to present a review of recent findings in the area of nitrate contamination and reduction. As well, site background will be provided including a discussion of studies that have been carried out for this area.

2.1 The Threat of Nitrates

Nitrate is a soluble form of nitrogen, is highly mobile, and is far more persistent in groundwater than surface water. The maximum allowable concentration (MAC) of nitrate in public drinking water supplies recommended by the World Health Organisation is 10 mg-N/L, which corresponds to 50 mg/l NO_3^- (Starr and Gillham, 1993). This limit was imposed to prevent methemoglobinemia, also known as blue baby syndrome, in which ingestion of excessive nitrate by infants impairs oxygen transport in the bloodstream. The risks are greatest for babies since the pH typically present in their stomach is ideal for the conversion of nitrate to nitrite. Evidence from animal studies indicates that nitrate in drinking water contributes to the formation of nitrosamines in the body, many of which are carcinogenic, mutagenic, or teratogenic (Starr and Gillham, 1993).

Camargo and Ward (1995) conducted toxicity studies on two species of freshwater invertebrates. Safe concentrations of nitrate for early and last instar larvae, *Cheumatopsyche pettiti* and *Hydropsyche occidentalis*, were estimated from short-term bioassays. The lowest safe concentration was found to be 1.4 mg N/L. The results suggest that invertebrate larvae may be much more sensitive to nitrate pollution than fish, which have been found to tolerate 96 mg N/L, during long exposures (Camargo and Ward, 1995).

Streams which contain excessive nutrients are prone to becoming eutrophic with increased algae blooms. Excess nitrogen in streams has led to excessive plankton production, the demise of submerged aquatic vegetation, an increase in the extent of hypoxic water, and seasonal depletion of dissolved silica (Jordan et al., 1997).

2.2 Sources of Nitrate Contamination in Groundwater

The chief sources of groundwater contamination in farming areas are characterized as both point sources and diffuse sources. Possible point sources are feedlots, poorly-sited manure piles, septic sewage-treatment systems and sites of chemical spills (Goss and Barry, 1995).

Agricultural activities, because they involve large land areas, are often cited as a major contributor of groundwater contaminants. This is especially a problem where precipitation exceeds evapotranspiration. Several studies have linked the usage of fertilizer and manure with high concentrations of nitrate. Zhang, Tian and Li (1996) investigated nitrate pollution in northern China and found that in over half of the 69 sites studied, ground and drinking water exceeded the 50 mg/L limit. In all locations with high nitrate content in the water, N-fertilizer was applied in large quantities, ranging from 500 to 1900 kg N/ ha and the percentage of applied N taken up by crops was below 40 % (Zhang, Tian and Li, 1996). However, in most cases, the relationship between agricultural activities and groundwater contamination is not necessarily direct, as is the case for point sources of contamination.

The types of fertilizers used in agriculture are both organic and mineral. Organic fertilizers include solid and liquid manure, slurry, and compost. Mineral fertilizers are more commonly used than organic fertilizers. Commonly applied mineral fertilizers are urea (nitrogen=46.6 %), superphosphate, and potash (Pawar and Shaikh, 1995).

Nitrate transfer in a groundwater system involves two steps: (1) the nitrogen cycle in soils, and (2) nitrate migration in aquifers (Geng, Girard, and Ledoux, 1996). In general, the

extent of contamination due to each specific source of nitrate is dependent on surrounding conditions. The influences of geological setting, climate, and land use have each been the focus of several studies.

2.3 Occurrence of Nitrate in Groundwater-Global Synopsis

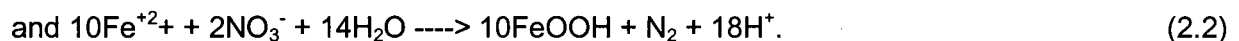
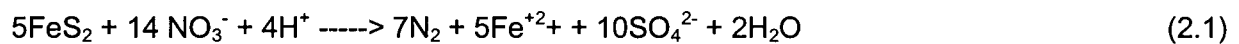
Nitrate is the most ubiquitous chemical contaminant in the world's aquifers and the levels of contamination are increasing (Spalding and Exner, 1993). Nitrate-nitrogen concentrations range from 5-11 mg/L in Belgium where agriculture has adversely affected the quality of the groundwater. Approximately 20 percent of the French population will drink water exceeding the European Community limit of 11.3 mg/L $\text{NO}_3\text{-N}$. In both Denmark and Germany, the public waterworks supply groundwater that exceeds the limit. The problem is also advancing in the Netherlands, England, Africa, the Middle East, New Zealand and Canada (Spalding and Exner, 1993).

Extensive surveys have been performed on aquifers in the United States and the results demonstrate a growing occurrence of nitrates in groundwater. A survey utilising the U.S. Geological Survey's Data Storage and Retrieval System examined the aerial distribution of nitrate in more than 87,000 wells. The survey found a number of factors which dictate the distribution of nitrate in groundwater. They include source availability, thickness and composition of the vadose zone, precipitation, irrigation, vertical flow, aquifer heterogeneity, dissolved oxygen concentrations and electron donor availability, dispersion, and saturated thickness. The USEPA (1992) estimates 4.5 million people including 66,000 infants under 12 months of age are served by community water systems or rural domestic wells that exceed the 10 mg/L $\text{NO}_3\text{-N}$ MCL (Spalding and Exner, 1993).

A survey performed on drinking water in Ontario revealed that one well in seven contained nitrate in excess of the maximum acceptable concentration. In Iowa, 18 percent of 686 rural domestic wells had $\text{NO}_3\text{-N}$ concentrations over 10 mg/L (Goss and Barry, 1995). As

well, in a study of drinking water wells in New Jersey, 6 percent of 343 wells sampled in 1990 were contaminated with nitrate (Murphy, 1992). The USEPA's national survey of drinking water wells, in 1990, indicated that nitrate was the most commonly found contaminant with 57 and 52 percent of the rural wells and community water supplies, respectively, containing detectable concentrations, and with 2.4 and 1.2 percent of those water sources exceeding the drinking water standard of 10 mg/L nitrate-N (Jemison and Fox, 1994).

Nitrate distribution and reduction processes were investigated by Postma et al. (1991) in an unconfined sandy aquifer. The aquifer was subdivided into an upper 10 to 15 m thick oxic zone that contains oxygen and nitrate, and a lower anoxic zone characterised by Fe^{+2} rich waters. One explanation of the persistence of a high content of total dissolved ions in the nitrate free anoxic zone is the downward migration of contaminants and that active nitrate reduction is taking place. However, vertical migration is unusual, and is generally not considered to be a contributing factor in nitrate reduction. Since both nitrite and ammonia were absent or found at very low concentrations, it appeared as though nitrate was reduced to nitrogen gas (Postma et al., 1991). Electron donors in the reduced zone of the aquifer were identified as organic matter, and pyrite. The oxidation of pyrite, Fe(II) to Fe(III) , coupled with the reduction of nitrate has been reported to have occurred in several aquifers (Appelo and Postma, 1994). This process involves the oxidation of both sulphur and Fe(II) and is described by the reactions:



The oxidation of pyrite is reflected by increases in sulphate and Fe(II) and is in good agreement with the distribution of pyrite in the sediment (Appelo and Postma, 1994).

2.4 Nitrate in Streams

Due to anthropogenic inputs over the past few decades, riverine discharges of plant nutrients have increased. Discharge of nitrogen from rivers throughout the United States and

Europe correlates with the sum of anthropogenic inputs from fertilizer application, cultivation of nitrogen-fixing crops, net imports of agricultural products and fossil fuel combustion (Jordan et al., 1997). The discharge of nitrate in streams has been related to a groundwater delivery factor that reflects the leaching potential of soils in the watersheds and the hydraulic conductivity of the aquifers.

The hydrological properties of the watershed strongly influence the proportion of the anthropogenic input that is discharged. The general pathway for nitrate is downward leaching into the groundwater that later emerges in streams. Thus, in watersheds having higher base flow indices, an indication of a greater predominance of infiltration over surface runoff, more nitrate will be leached from the surface soils and carried to the stream in shallow groundwater (Jordan et al., 1997). The amount of nitrate transported through the groundwater to streams may be reduced by interception in riparian forests, or by denitrification.

Denitrification potential was studied in a coastal plain riparian forest by Lowrance (1992), through the examination of both nitrate removal and limiting factors. The denitrification potential in the saturated zone was found to be very low, except when the saturated zone was within about 60 cm of the surface. Denitrification occurred near the stream when nitrate levels in groundwater had already been reduced. The findings of the investigation supported the hypothesis that the entire riparian forest ecosystem rather than just a poorly drained soil is essential to the N filtering and retention capacity of these areas (Lowrance, 1992).

Grischek et al. (1998) studied the factors which affect denitrification during infiltration of river water into a sand and gravel aquifer. The mass balance performed indicated that solid organic carbon in river water served as an additional source of organic carbon. Denitrification was observed in the upper layer of the aquifer, but the rates were lower than those calculated during laboratory column testing (Grischek et al., 1998).

Burns (1998) investigated the retention of nitrate in an upland stream environment using a mass balance approach. Stream nitrate concentrations showed diurnal fluctuations,

indicating that uptake by aquatic photoautotrophs has a significant effect on nitrate concentrations (Burns, 1998). The results of the study demonstrate that nitrate is generally not transported conservatively at base flow within an upland stream environment in which nitrate is the dominant dissolved N species (Burns, 1998). Moreover, results indicated that the aquatic and hyporheic processing of N is dependent on physical characteristics of the stream environment.

McMahon and Bohlke (1996) studied denitrification and mixing in a stream-aquifer system focusing on the effects on nitrate loading to surface water. Results showed that denitrification and mixing between river water and groundwater in the floodplain deposits and riverbed sediments substantially reduces nitrate concentrations between the recharge area and discharge area of groundwater (McMahon and Bohlke, 1996). As well, the results suggested that the net load of nitrate to the river was reduced in part by the exchange of water between the river and aquifer, which subjected nitrate in the river to further denitrification and removed some of the gas products of the reaction.

2.5 Denitrification

Denitrification is the reduction of nitrate occurring in both soil and water systems containing readily oxidizable organic matter. Nitrate is reduced to nitrite, nitrous oxide, nitric oxide, or nitrogen. The conditions supporting denitrification include the presence of a carbon source, generally low available dissolved oxygen, high water content of soil, pH level of 7 to 8.2, temperature of approximately 30°C (although not necessary), and an available source of nitrate at the same location as the carbon source. Most microbes capable of denitrification are heterotrophic facultative anaerobes. Thus organic carbon is the preferred electron donor. The presence of oxygen deters the process of denitrification since it is the preferred electron acceptor for the oxidation of organic compounds. When the soil is saturated, a reduction of oxygen transport to zones of high microbial activity occurs. This enhances the ability for

denitrification (Fujikawa and Hendry, 1991).

Three methods of nitrate reduction demonstrate potential for full-scale application including ion exchange, reverse osmosis, and biological denitrification (Mateju et al., 1992). Ion exchange may be limited by two factors. A resin of high selectivity for nitrates over ions that are commonly present in groundwater does not exist and secondly, the ability to provide an adequate resin regenerant is a problem (Mateju et al., 1992). However, Clifford and Liu (1993) developed a bench-scale ion exchange process for nitrate removal which demonstrated some potential, achieving high denitrification rates. Reverse osmosis is not favourable since the membranes used do not exhibit high selectivity for nitrates. Thus the most promising and versatile approach studied is biological denitrification.

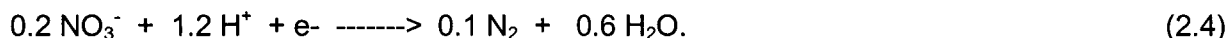
Biological denitrification has been used in wastewater treatment for years, and has been proven to be very efficient (Mateju et al., 1992). The process is highly selective for nitrate removal. Unfortunately, the potential bacterial contamination of treated water is a major risk.

Many bacteria exist which are capable of growing anoxically by reducing ionic nitrogenous oxides to gaseous products. Nitrates or nitrites serve as terminal electron acceptors instead of oxygen, which results in the generation of ATP (Mateju et al., 1992). Most investigations into denitrification have involved a limited group of specialized bacteria, resulting in a view that denitrification can only occur under anoxic conditions. However, denitrification has been shown to occur in the presence of oxygen in certain species (Griseck et al, 1998). The reduction of nitrate to nitrogen gas proceeds in four steps as shown in the following scheme:

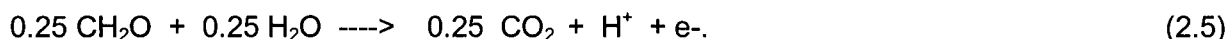


Each step is catalysed by an enzyme system. Dissimilatory reduction of nitrate to nitrite is important to a number of bacteria, since the process involves energy conservation through generation of a proton motive force (Mateju et al., 1992). This step is catalyzed by membrane-bound nitrate reductases. An oxidizable substrate or electron donor is required as an energy

source in order for denitrification to occur. Denitrifying bacteria are typically heterotrophic, however some are autotrophic and utilise hydrogen and carbon dioxide. Nitrate, which is an electron acceptor, is reduced to gaseous nitrogen during denitrification according to the following equation:



The oxidation of reduced organic carbon can be represented as:



Heterotrophic denitrifying bacteria require an organic carbon source for respiration and growth. Many organic compounds have been used including methanol, ethanol, glucose, acetate, aspartate or formic acid (Mateju et al., 1992).

2.5.1 Mechanisms of Denitrification

Denitrification in natural systems, without the addition of an electron donor, proceeds very slowly and is not significant for lowering of nitrate concentrations in aquifers (Mateju et al., 1992). Several studies have been done which investigate the effect of injecting various substrates and nutrients into aquifers. Denitrification rates in aquifers depend somewhat on the dispersion of the aquifer and its geological type. The four conditions required for denitrification to proceed are generally taken to be the presence of (1) nitrate, (2) labile organic carbon, (3) denitrifying bacteria, and (4) reducing conditions (Starr and Gillham, 1993).

The extensive occurrence of nitrate in aquifers is highly documented and has been previously discussed.

The availability of an oxidizable source of organic carbon is paramount for heterotrophic denitrification. The dissolved organic carbon of groundwater comes from either surface organic matter or originates in the action of bacteria on kerogen, the fossilized organic matter present in geologic material (Hiscock et al., 1991). The concentration of organic carbon is limited by the oxidation of the organic matter to carbon dioxide before reaching the water

table, and the general lack of soluble organic carbon contained in aquifer solids (Hiscock et al., 1991). Clay et al. (1996) observed temporal variability of organic carbon and nitrate in a shallow aquifer. They found that seasonally driven processes, such as freezing and thawing, influence organic substrate transport from surface to subsurface environments.

Starr et al. (1996), used a forced-gradient cluster-well technique to assess in situ movement and losses of nitrate in groundwater. They found that nitrate loss rates under in situ levels of carbon substrate were about one third those under the near optimal C/N (enriched C) conditions (Starr et al., 1996).

Whitelaw and Rees (as referenced in Starr and Gillham, 1993) observed denitrifying bacteria in the vadose zone of the Chalk formation of England. As well, Elrich et al. (as referenced in Starr and Gillham, 1993) identified denitrifiers in core samples from a Minnesota aquifer. Several other studies have identified bacteria in water or core samples collected from aquifers and thus it is reasonable to assume that denitrifying bacteria are widespread in aquifers (Starr and Gillham, 1993).

Oxygen, which competes with nitrate as an electron acceptor in the energy metabolism of cells, is an important inhibitor. Frequently, intra-aggregate water filled pores become virtually anaerobic and permit denitrification to occur. These anaerobic zones can be about 200 μm in diameter (Hiscock et al., 1991). Experimental evidence demonstrates that nitrate reduction is not observed at an oxygen concentration above 0.2 mg/L (Hiscock et al., 1991). This is due to the fact that most denitrifying bacteria are facultative anaerobes (Starr and Gillham, 1993). More recent evidence does suggest that aerobic denitrifiers do exist in wastewater treatment (Fujikawa and Hendry, 1991).

Pawar and Shaikh related the depth of the water table to denitrification, concluding that it occurs where the water table depth is less than 2-3 m from the ground surface.

According to Hiscock et al. (1991), the optimum pH range is 7.0-8.0. Temperature is also a controlling factor, denitrifiers favouring increased temperatures.

2.5.2 Evidence of Denitrification In Aquifers

The occurrence of denitrification in the natural groundwater environment has been documented in a number of experiments. Several studies have observed a decline in the groundwater redox potential from a highly oxidised state in upland recharge areas to a reduced state after migration to lowland discharge areas under confined flow conditions (Hiscock et al., 1991). A sequential reduction in dissolved groundwater species often accompanies a change in redox potential, beginning with oxygen and nitrate, and is often cited as evidence for denitrification. However, due to spatial and temporal variability of the sources of nitrate and the frequent mixing of groundwater of different origins, this evidence is not conclusive in isolation. The Chalk aquifer study found a reduction in nitrate concentration in the direction of decreasing redox potential which was primarily a result of mixing between waters of different origins (Hiscock et al., 1991).

Trudell et al. (as referenced in Hiscock et al, 1991) observed denitrification in a shallow, unconfined aquifer in Ontario. The aquifer consisted of fine brown and grey sands with a water table at a depth of 1 m, and was situated in an organic rich wetland environment. The use of bromide and nitrate tracer experiments demonstrated that a reduction in nitrate was occurring at a faster rate than could be explained by dilution alone. Both aerobic heterotrophs and denitrifiers were found below the water table, maintaining a rate of denitrification between 0.2 and 3.1 mg N/l/d (Hiscock et al. 1991).

Bang et al. (1995) conducted experiments on aerobic denitrification with polyvinyl alcohol as a carbon source in biofilms. The study found that aerobic denitrification was possible in a wastewater system containing polyvinyl alcohol and ammonia nitrogen. Dissolved oxygen concentrations higher than 3.0 mg/L did not prevent denitrification from occurring in the treatment system (Bang et al., 1995).

Todellsperger (as referenced in Hiscock et al., 1991) reported the occurrence of denitrification in a shallow aquifer system catalysed by autotrophic bacteria. Experiments

performed over a period of a few months showed that nearly all the nitrate was consumed and sulphate was produced. The increase in sulphate was a result of the oxidation of pyrite by autotrophic bacteria during denitrification.

At a similar site in Ontario, Starr and Gillham (as referenced by Hiscock et al., 1991), found that the upper 8 meters of the saturated zone below the water table was aerobic with nitrate concentrations up to 35 mg N/L. The amount of carbon below a depth of 2-3 m was found to be insufficient to support denitrification. In this case, the residence time of infiltrating water in the vadose zone was important since it is related to the amount of organic carbon available for oxidation.

Fujikawa and Hendry (1991) studied denitrification in core samples from oxidised and unoxidized clayey till by analysing N_2O production with time. Higher denitrifying activity appeared to be localised in diverse microsites along fractures and adjacent to organic matter (Fujikawa and Hendry, 1991).

Dahab and Lee (1992) investigated the potential of using in-situ denitrification to reduce nitrate concentration in contaminated groundwater. The relative stability of denitrification performance was observed at high carbon concentration (C:N=1.5), providing a maximum nitrate removal efficiency of 80% (Dahab and Lee, 1992). The presence of excess biological solids in the immediate vicinity of the wells caused severe clogging problems and created high head-loss in the aquifer system. The study found that the presence of dissolved oxygen must be eliminated to ensure anoxic conditions in the aquifer system and thus increase the nitrate removal efficiency (Dahab and Lee, 1992).

2.6 Site Geography and Geology

The Abbotsford aquifer is the largest of 200 aquifers in the Lower Fraser River valley. Its area is approximately 100 square km in British Columbia and about 100 square km in Washington State. The aquifer is an extensive sand and gravel deposit and is largely

unconfined with most of the water extracted from it coming from relatively shallow depths (Liebscher et al., 1992). The aquifer, as shown in Figure 2.6.1, extends south of Abbotsford into Washington State, west of Sumas, Washington, and north of the Nooksack River. The topography over most of the aquifer is primarily flat, with an escarpment formed on the west edge of the aquifer (Liebscher et al., 1992).

During the winter months, precipitation is the major source of ground water recharge. Winters tend to be cool and wet, while summers have frequent long periods of sunny weather. Average annual precipitation is approximately 1500 mm per year, with 75 percent falling between October and March (Zebarth, 1992).

The Abbotsford aquifer is composed of a succession of stratified, permeable, glaciofluvial sands and gravels interspersed with minor till and clayey silt lenses, collectively called the Sumas Drift (Liebscher et al., 1992). The glacial till and clay components are prevalent in the eastern portion of the aquifer while the western portion is characterised by cleaner sands and gravels (Liebscher et al., 1992). Thus the ability to transport contaminants is greater in the western portion of the aquifer.

Former meltwater streams that issued from stagnant melting ice masses in the vicinity of Sumas Mountain have built up a plain of very permeable sand and gravel to the south of Abbotsford (Atwater et al., 1993). The base of the aquifer is known to reach 70 m in thickness and is underlain by low permeability glaciomarine and marine clays (Liebscher et al., 1992).

Surficial geology surrounding Fishtrap Creek is very unique compared to that over the entire aquifer. Stream deposits include channel till, floodplain and overbank sediments. The lowland stream channel fill and overbank sandy loam contain disseminated organic material up to 8 m thick (Armstrong, 1976). Thus the geology along Fishtrap Creek is quite different from the surrounding sands and gravel. Cross sections of the lithology encountered during the drilling of two wells in close proximity to the creek are shown in Figure 2.6.2.

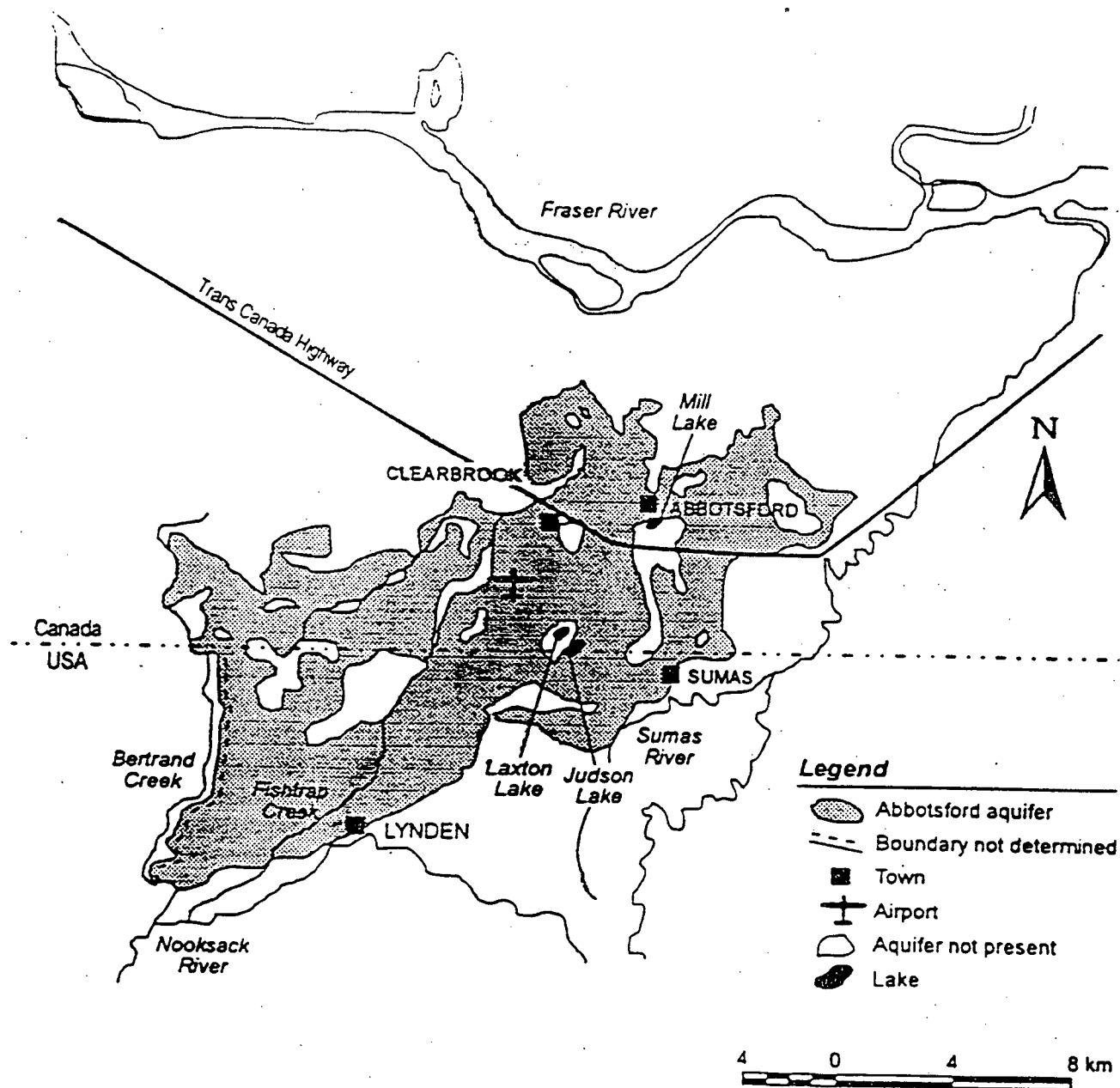


Figure 2.6.1: Map View of the Abbotsford Aquifer (ESSA Technologies Ltd., 1996)

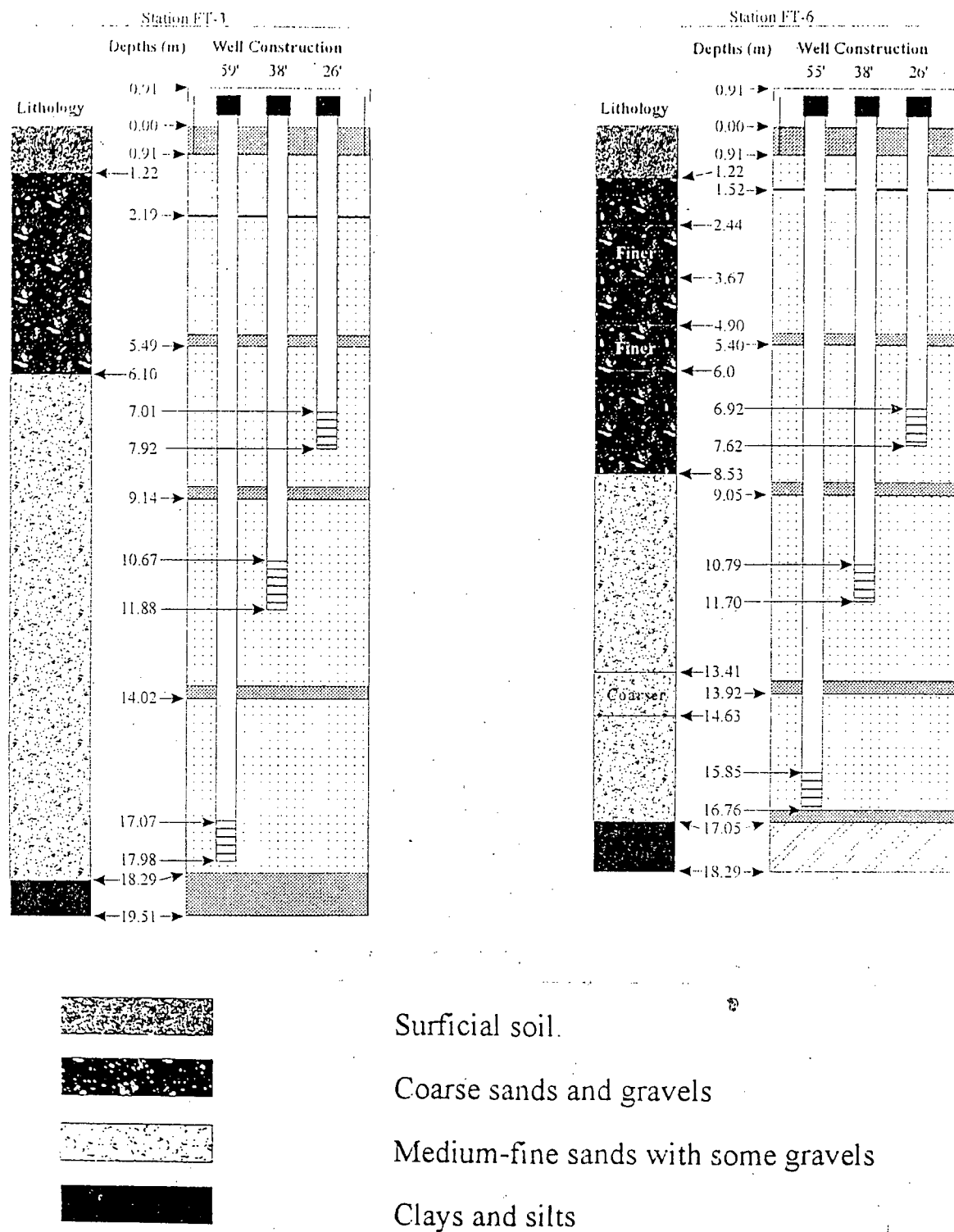


Figure 2.6.2: Bore Hole Lithologies for FT3 and FT6

2.7 Site Hydrogeology

Fishtrap Creek drains part of the clay upland and flows south across the aquifer and into Washington State. The creek's water level is reported to lie above local ground waters for six months of the year during which the creek recharges the aquifer. During the other six months, when the creek level lies below local ground water levels, the ground waters flow into or under the creek (Liebscher et al., 1992). The water table is highest in March and lowest in late October with an average 3 m seasonal fluctuation reported over the entire aquifer (Liebscher et al., 1992).

Fishtrap Creek is fairly flat with a maximum slope of 2-3 percent, and ranges from 3-5 meters in width. The stream provides habitat for coho salmon, cutthroat trout and Pacific lamprey. The temperature in the creek ranges from 5 to 13°C, and flows range from 0.12 to 1.2 m³/s (Mike Pearson, Personal Communication).

Recharge to the groundwater comes from infiltrating precipitation, runoff from the uplands, and Fishtrap Creek. The regional groundwater flow is southwards, with a south-westerly influence in the southwest portion of the aquifer north of the international boundary.

Wassenaar (1995) conducted an evaluation of the origin and fate of nitrate in the Abbotsford Aquifer using the isotopes of ¹⁵N and ¹⁸O in NO₃⁻. The stable isotope data confirmed that groundwater in the Abbotsford aquifer is primarily recharged from the late fall rains. Tritium samples were collected from three multi-level piezometers, and all were titrated, indicating groundwater in the aquifer was recharged since 1953 (Wassenaar, 1995). The residence time of groundwater in the entire aquifer system from north to south was estimated from horizontal Darcy flow velocities of up to 450 m/year.

2.8 Land Use

The main agricultural activities on the Canadian part of the aquifer are row crops (intensive raspberry farming), poultry breeding and production, and pasture (Liebscher et al.,

1992). The major source of nitrate contamination in the Abbotsford aquifer is primarily attributed to long-term agricultural land use practices, such as poultry manure stockpiling and spreading of poultry manure and fertilizer directly above the permeable sands and gravels of the aquifer (Wassenaar, 1995).

2.9 Water Quality

The study performed by Wassenaar (1995) included some water chemical analysis. Groundwaters are a Ca-HCO_3 type, with total dissolved solids ranging from 70 to 300 mg/L. The pH of groundwater ranged from 6-8 and the chemistry data showed that water in the aquifer was undersaturated with respect to major mineral phases such as calcite, dolomite, silicates, and sulphates (Wassenaar, 1995).

Nitrate was found to be the predominant N form in the aquifer, with ammonia at or below, the limit of detection (Wassenaar, 1995). Nitrate concentrations within the aquifer ranged from below detection to 30 mg N/L. Of a total of 117 wells studied, 54% of the wells had nitrate concentrations exceeding accepted drinking water limit of 10 mg N/L (Wassenaar, 1995). Groundwater with no nitrate came from wells along the uncultivated flood plain of Fishtrap Creek. No relationship between nitrate concentration and depth in the Abbotsford aquifer was found.

Long term monitoring of nitrate concentrations demonstrated that there has been an overall increase throughout the aquifer (Liebscher et al., 1992). A study performed by Zebarth et al. (1996) found that although there is some evidence of annual cycling in nitrate concentration, the variation does not relate to annual precipitation patterns. Hydraulic head potentials were essentially the same for piezometers within a piezometer nest, indicating that the vertical hydraulic head was small (Zebarth, 1996). As a result, water sampled from piezometers at different depths may have come from different spatial locations.

Several wells demonstrate seasonal variation in water table nitrate concentrations

with the highest concentrations occurring during the fall and winter recharge period (Wassenaar, 1995). Chemical N fertilizers are typically applied in April and May at rates of 50 to 70 kg N/ha with additional poultry manure spread between raspberry rows (Wassenaar, 1995). A N budget for a section of the aquifer performed by Zebarth et al. (1996) suggested a seven-fold excess of N is applied to the fields in the forms of manure and fertilizer.

Comparisons of nitrate and chloride distribution aids in the evaluation of dilution and nitrate removal processes (Altman and Parizek, 1995). Chloride concentrations are high in the Abbotsford aquifer, which suggests additional chloride in the aquifer was derived from animal waste sources or from potash used in fertilizers (Wassenaar, 1995). The ratio of nitrate to some other less reactive constituent known to have originated with the nitrate can be used to determine if denitrification is occurring. Chloride is commonly used since it is associated with anthropogenic pollution (Altman and Parizek, 1995). The nitrogen to chloride ratios decreased along with inorganic carbon over depth suggesting that heterotrophic denitrification may be occurring beneath the water table (Dasika, 1996). However, the variable and temporal input of chloride to the aquifer either from manure, potash or precipitation suggest that nitrate to chloride ratios cannot be reliably used as an indicator of denitrification (Wassenaar, 1995).

The surrounding vegetation suggests that an ample source of carbon is provided for denitrification. More evidence of conditions which support denitrification was found in unpublished data which showed dissolved oxygen levels less than 1 mg/L (Dasika, 1996).

2.10 Conclusions

The maximum allowable concentration of nitrate in public drinking water supplies recommended by the World Health Organisation is 10 mg N/L. High nitrate concentrations in drinking water are harmful to humans and may also lead to eutrophication of estuaries.

Nitrate enters groundwater systems through direct infiltration and from stream discharge. There are several sources of nitrate including septic systems, manure stockpiling,

and the use of fertilizer and manure in farming practices. The extent of contamination is dependent on various factors including well depth, aquifer depth, irrigation and geological setting.

It is apparent from the extensive number of studies which have been performed that nitrate contamination is widespread. Nitrate levels in streams are typically much lower than in groundwater. The importance of riparian vegetation in the removal of nitrate during the mixing of ground and stream water has been noted.

The occurrence of denitrification has been demonstrated by both in situ and laboratory testing. Studies generally concluded that the presence of oxygen eliminated the potential for denitrification, although some studies identified the existence of aerobic denitrifiers. The conditions which favour denitrification include the presence of nitrate, a carbon source, denitrifying bacteria, and reducing conditions.

The Abbotsford aquifer is an extensive sand and gravel deposit and is largely unconfined, rendering it susceptible to contamination due to land use activities. Disseminated organic material is present along Fishtrap Creek, which is an area that possesses a unique geology. There has been a steady increase in the intensity of various agricultural and animal husbandry activities in the area which has resulted in a gradual but steady decline locally in the ground water quality (Liebscher et al., 1992). The presence of nitrate over the entire aquifer has been confirmed and studies indicate that concentrations have continued to increase over the past twenty years.

3.0 RESEARCH OBJECTIVES AND SCOPE

3.1 General

This thesis discusses the results obtained during research that began with the aim of investigating the occurrence of denitrification in the Abbotsford aquifer. The specific objectives consisted of:

- determining if the conditions that support denitrification are present over the segment of the aquifer studied,
- determining if denitrification is occurring in the segment of Abbotsford aquifer in the area surrounding Fish Trap Creek as it crosses the border,
- quantifying the amount of nitrate that is transported by Fish Trap Creek. In other words, to determine if the creek adds or takes away nitrate from the groundwater, and
- defining the flux of nitrate into and out of the segment defined by performing a nitrogen balance.

Sampling of both groundwater and Fishtrap Creek over an 11 month period allows for the observation of both spatial and temporal variations in water quality conditions. Sediment sampling and total organic carbon testing on the water aid in determining if the conditions which support denitrification are present in the aquifer. Monitoring water levels and stream flow provides the information required to determine the recharge relationship between the stream and the groundwater and to better understand the transport of nitrate. The general characterization of the water in the aquifer is achieved through the analysis of basic water chemistry. A mass balance on the system allows for an assessment of overall nitrate loss or gain. Analyzing the water levels, flows, and water chemistry for each sampling event will provide the necessary evidence of the occurrence of nitrate removal.

3.2 Hypothesis

The study area was chosen due to the unique geology present along the creek, which indicates the presence of organic materials. The existence of an intimate relationship between the ground and surface water is known. Due to this relationship, along with the unique geology present, it is hypothesized that nitrate reduction is occurring in the study area along Fishtrap Creek. Due to the nature of the discharge/recharge relationship of Fishtrap Creek with the groundwater, it is hypothesized that the creek may be a considerable nitrogen sink within the aquifer.

4.0 SITE DESCRIPTION AND METHODOLOGY

In all cases, procedures recommended by Standard Methods (1997) were followed as closely as possible. Table 4.1.1 presents a summary of the analyses performed on the monitoring well samples and on Fishtrap Creek.

4.1 Site Boundaries

The site chosen for study is located in the southwestern portion of the Abbotsford aquifer north of the international boundary. The total area of the site is approximately 1 mile², or 2.6 km². The northern, eastern and southern boundaries, as seen in Figure 4.1.1, are Huntingdon Avenue, Ross Road, and Zero Avenue, respectively. The western boundary was determined by examining drainage patterns and the groundwater divide, with an overall effort made to account for all contributions of groundwater flow into the segment.

The land use is primarily raspberry and blueberry farming, which is sustained through the use nitrogen fertilizer and manure. A large greenhouse is situated on Ross Road, the eastern boundary.

Fishtrap Creek enters the segment at the intersection of Huntingdon Road and Ross Road, which is the upstream sampling location. The downstream sampling location is along Zero Avenue, approximately 0.2 km west of Ross Road. A large culvert which drains agricultural areas to the northeast of the site enters the segment approximately 0.6 km north of Zero Avenue and discharges directly into the creek. A ditch running parallel Zero Avenue carries runoff directly into the creek at Zero Avenue. As shown in Figure 4.1.1, a total of three surface water stations were monitored including Fishtrap creek at both Huntingdon Avenue and Zero avenue, and the culvert at Ross Road.

Nine wells over the site were monitored and are shown in Figure 4.1.1. Table 4.1.2 provides a summary of information related to the groundwater wells sampled:

[illegible]

Table 4.1.2: Summary of Well Log

Well Name	Location of Well (X,Y)	Well Depth (m)	Geology encountered
FT1	543477.165, 5427693.894	11.89	coarse-medium sands and gravel
FT3	543552.028, 5428412.726	7.92	loamy sand, fine-medium sand
FT5	543642.61, 5429055.315	7.62	coarse sand and gravel
FT6	543527.835, 5428414.15	7.83	coarse-fine sand and gravel
FT8	542936.126, 5427693.610	24.08	coarse-fine sand and gravel
91-11	543738.789, 5428222.746	20.70	coarse sand and gravel
91-12	543735.973, 5428222.686	12.50	coarse sand and gravel
ABB1	543665.811, 5428349.295	7.92	coarse-medium sands and gravel
ABB5	544471.424, 5427708.938	8.84	coarse sand and gravel

4.2 Methods of Collection

Stream water was collected directly into the nalgene bottles at the three locations. In the event of high flows, a bucket was lowered from the bridge to collect stream water.

All groundwater well sites were previously developed. In the event that the well had been unused for a period exceeding one month, the well was purged using a peristaltic pump for up to one hour prior to sampling. Groundwater wells were purged each sampling event using Watera pumping tubes to remove three standing volumes of water prior to sampling. The depth to water measurement allowed for a standing water volume to be calculated. After purging the well, the water was directly pumped into nalgene bottles. The bottles were consistently filled to capacity in order to avoid air bubbles. In most cases, acid washed nalgene bottles were used to collect the samples. In the case of dissolved oxygen, Biochemical Oxygen Demand (BOD) bottles were used.

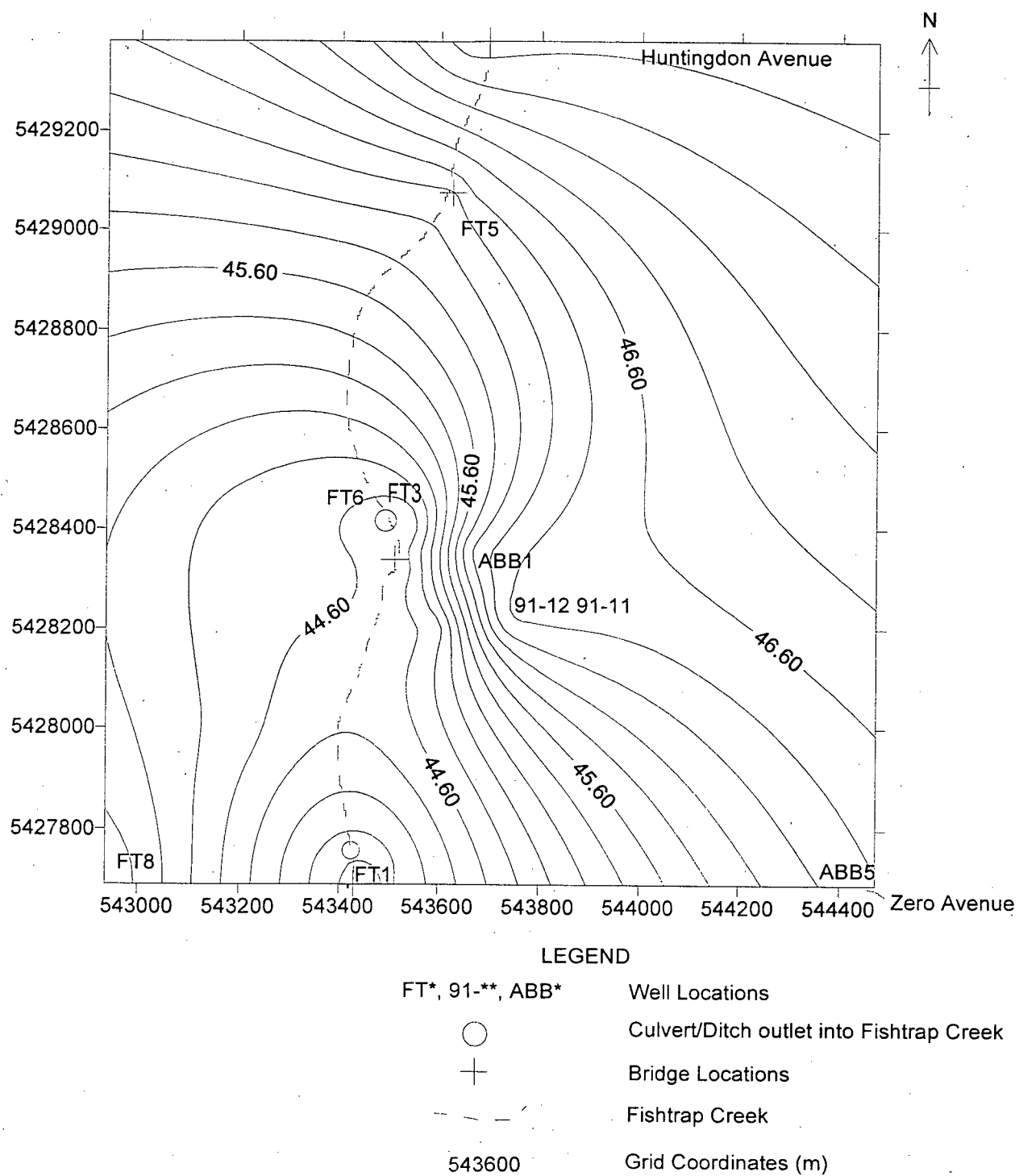


Figure 4.1.1: Site Map of Study Area within the Abbotsford Aquifer

4.3 Method of Storage

All samples were stored in an ice packed cooler while travelling between the site and the laboratory. After being preserved, the samples were stored in the cold room at 4°C. Most samples were analyzed immediately or within two days of collection. The samples collected for metal analysis were tested within six months which is the specified guideline for preserved samples.

4.4 QA/QC

Due to frequency of sampling, duplicate sampling was not always performed. The use of duplicate sampling was carried out on several occasions in order to provide controls on the quality of sampling and analysis.

Field blanks were used each sampling event in order to account for any entrainment of atmospheric nitrate. Laboratory blanks were used to account for the interference of preservation and acidification techniques. Spiked samples were also included in the analysis to ensure accuracy of the methodology.

4.5 Water Chemistry

The chemistry of both groundwater and stream water was monitored bi-weekly over a 11 month period. The various sites can be characterised by the water quality derived from their source. In order to complete a nitrogen balance on the segment, the major forms including nitrate, nitrite, Total Kjeldahl Nitrogen (TKN) and ammonia, were monitored. Major cations and anions were analyzed to complete the water balance and characterization. In order to develop a relationship between stream and ground water, indicators such as pH, temperature, and dissolved oxygen were observed.

4.5.1 Nitrogen Balance

The prevalent forms of nitrogen including nitrate, nitrite, organic nitrogen (TKN) and ammonia were continuously monitored. Each constituent was individually quantified using a LACHAT Instruments QuickChem Automated Ion Analyzer using the following colorimetric techniques (4500: NO_3^- -F, NO_2^- -B, NH_3^+ -G, N_{org} -B). Water samples collected for nitrate and nitrite analysis were preserved with "No_x Preservative" (0.1g phenyl mercuric acetate, 20 ml acetone, 280 ml H₂O). This preservative eliminates the interference of biological activity on nitrate and nitrite concentrations. For each 100 ml of sample, 5 drops of preservative were added. Samples collected for ammonia analysis were acidified to a pH 2 using sulphuric acid. Organic nitrogen samples were digested using Kjeldahl flasks as described in method 4500 N_{org} -B. All nitrogen samples were filtered using Porex Filter Samplers which were 16mm X 6".

The detection limits are 0.05 mg-N/L for NO_3^- and NO_2^- ; and 0.05 mg-N/L for NH_3^+ -N.

4.5.2 Cation-Anion Balance

In order to carry out a complete water balance, major cations and anions were monitored. The following major ions were analyzed: Na^+ , Ca^{2+} , Mg^{2+} , K^+ , Cl^- , SO_4^{2-} , and HCO_3^- . The metal analysis was performed using a Thermo Jarrell Ash IL VIDEO 22 AA/AE Spectrophotometer with an air/acetylene flame. Prior to analysis, nitric acid was used to maintain metals in solution. Approximately 3 drops were added to each 125 ml sample to acidify to pH 2. Lanthanum was used as a matrix modifier and was added to both the standards and the samples analyzed.

Chloride and sulphate concentrations were determined using a LACHAT Instruments QuickChem Automated Ion Analyzer using colorimetric techniques 4500: Cl^- -E and SO_4^{2-} -F. No preservation or acidification was required by this method. The detection limit for both ions is 0.5 mg/l.

Bicarbonate concentrations were determined using a Total Carbon/Inorganic Carbon

analysis which is explained in section 4.5.4.

4.5.3 Field Measurements

pH, dissolved oxygen, and temperature were each measured on site. pH and temperature were both measured using a portable Oakton pH/mV/°C meter RS-232. Dissolved oxygen of the groundwater samples was measured using two techniques. In-situ measurements were performed using a portable YSI Incorporated model 54A oxygen meter. A 13 litre bucket was used to create a "wet cell" where the water entering the bucket was equal to the water leaving the bucket. The dissolved oxygen probe was placed at the bottom of the bucket along with the end of the watera tubing from the well. Laboratory measurements of dissolved oxygen of the groundwater were performed using YSI Model 50B DO probe. Water samples from each well were collected into BOD bottles and preserved with a NOx preservative to inhibit biological activity. The preserved samples were then transported back to the lab where they were then analyzed for dissolved oxygen.

4.5.4 Total and Inorganic Carbon (TC/TIC)

Total Carbon (TC) and Inorganic Carbon (IC) determinations were made separately using a SHIMADZU TOC-500 Total Organic Carbon Analyses. The Total Organic Carbon (TOC) is computed as TC-IC.

The IC portion represents the combined concentration of bicarbonate and carbonate. The carbonate contribution is typically negligible (when pH<8.3) and thus the IC was accepted as the bicarbonate concentration of the water.

The detection limit for the TOC analyzer is 1 mg/l, however experience suggests that accuracy is reduced for TC/IC values less than 5 mg/l.

4.6 Water Levels

Groundwater levels were measured using a 45 meter water level tape. Water table

elevations were calculated using standard referenced co-ordinates. Water level measurements were accurate to 0.01 m.

4.7 Streamflow Measurements

The velocity-area method of flow measurements was employed. This method involves calculation a cross-sectional area of the stream by taking several measurements of depth across the width of the river bank. Several measurements of mean velocity across the section are required to complete the flow measurement. When the depth of the river exceeds 60 cm, velocity measurements are required at 0.2 and 0.8 times the water depth at that point (Maidment, 1993). Otherwise, the velocity measurements are taken at 0.4 times the water depth at that location. A portable Swoffer Model 2100 Series Current Velocity Meter was used to determine the velocity.

Creek flows and depths which were recorded at an existing data-logging station at Zero Avenue were obtained from Environment Canada. A relationship between this site and the cross section taken at Huntingdon Road was derived using the data from Environment Canada and flows taken using the portable velocity meter. Culvert flow measurements were performed at the upstream end using the portable velocity meter. The portable velocity meter reads to 0.001 +/- 0.0005 m/s.

4.8 Soil Sample Analyses

4.8.1 Carbon Content

The carbon content of soil retrieved from approximately 2 feet below the surface along Fishtrap Creek was analyzed by loss on ignition (LOI). Samples of soil were initially heated at 150°C to obtain a dry weight. Weighed samples were then combusted at 550°C and the amount of volatile matter (LOI) was calculated. The carbon content was calculated as a percentage of the total weight of the sample.

4.8.2 Jar Test

A jar test was carried out to determine the presence of denitrifying bacteria in the soil. A 500 ml jar was filled with sediment retrieved from 2 feet below the ground surface along Fishtrap Creek. In the laboratory, distilled water containing a known concentration of nitrate was added to the jar. The jar was shaken to mix the water and sediment continuously. Water from the jar was sampled daily for five days and was analyzed using a LACHAT Instruments QuickChem Automated Ion Analyzer using colourimetric techniques. The dissolved oxygen concentration of the water in the jar was monitored to determine the conditions present in the jar.

5.0 RESULTS AND DISCUSSION

This chapter presents the results of the analyses performed on samples of groundwater, surface water, and soil obtained from the study sites. A discussion of these results and comparisons to other related published findings is also presented. As well, a summary on QA/QC procedures has been included.

5.1 Conditions for Denitrification

A conducive environment for denitrification is characterized by four conditions, each of which was studied separately during this project. An available organic carbon source combined with the presence of nitrate and relative absence of oxygen is generally required in order for denitrification to occur. As well, the presence of denitrifying bacteria is of paramount importance. Each of these essential conditions were studied throughout the study and are discussed in the following sections.

5.1.1 *Jar Test for Denitrifying Bacteria*

Soil from approximately two feet below the surface along Fishtrap Creek was collected into 500 ml tightly sealed jars. Three different locations along the creek were chosen in order to determine both variation along the creek and also repeatability of the results. Distilled water with a known concentration of nitrate was added to the drained samples. The jars were stored at 11°C, which is the approximate temperature of the stream, and samples of the water were extracted daily for 6 days. The dissolved oxygen concentration in the water from the jars was monitored during a similar test in order to determine the conditions present in the jar. DO levels ranged over the period of one week between 1-3 mg/l. Thus it is likely that anaerobic conditions were not present during the original test, however, DO levels are fairly low.

Table 5.1.1 contains the results of the nitrate analyses, which indicate that an exponential reduction of nitrate occurred in the water. Nitrate-N in the samples was effectively reduced by approximately 50 percent within the first day, and by 99 percent within one week.

Results from the same location indicate good test repeatability. Since the presence of low concentrations of DO were confirmed during a second test, the amount of nitrate reduction occurring strictly due to denitrification cannot be accurately quantified. It is likely that some nitrate reduction occurred due to nitrate assimilation and reduction to ammonia.

Table 5.1.1: Denitrifying Bacteria Detection Using Jar Tests

	<i>Zero Avenue</i>		<i>FT3 Bridge</i>		<i>Huntingdon Ave</i>	
Time (days)	Concentration (mg NO ₃ -N/L)	% Removal	Concentration (mg NO ₃ -N/L)	% Removal	Concentration (mg NO ₃ -N/L)	% Removal
0	16.00		16.00		16.00	
1	8.33	48.0	7.81	51.2	6.00	62.5
2	0.31	98.1	3.50	78.1	4.59	71.3
3	0.20	98.7	1.01	93.7	2.34	85.4
4	0.04	99.8	0.06	99.7	1.23	92.3
6	0.03	99.8	0.03	99.8	0.33	97.9

5.1.2 Dissolved Oxygen Results

The dissolved oxygen (DO) in the stream and ground water was monitored over the eleven-month sampling period. Table 5.1.2 presents the average DO level for each monitoring location. The creek generally possesses DO levels around 8-12 mg/l, while the groundwater varies from less than 1 mg/l to 10 mg/l. In general, the deeper wells contained less dissolved oxygen.

Table 5.1.2: Average Dissolved Oxygen Concentrations

WATER	Dissolved Oxygen (mg/l)
<i>Creek</i>	
Huntingdon Ave	9.4
Culvert	7
Zero Ave	9
<i>Groundwater</i>	
FT1	1.6
FT3	1.3
FT5	5.8
FT6	1.4
FT8	0.8
91-11	1.2
91-12	1.5
ABB1	1.6
ABB5	8.5

5.1.3 Organic Carbon Results

The amount of total organic carbon (TOC) in both the water and soil were analyzed. Samples of stream and ground water, as well as soil samples were collected and tested during several sampling dates.

Table 5.1.3 presents the average TOC values obtained from the water analyses. Surface water consistently contained approximately 6-7 mg C/l. During all sampling events, the TOC value obtained at the downstream location (Zero Avenue) was lower than the value obtained at the upstream location (Huntingdon Avenue). The ground water contained varying levels (0.9-3.4 mg C/l) of TOC at various depths.

Soil samples were collected from various locations along the stream and were brought back to the lab in sealed containers to be immediately analyzed. The average loss on ignition varied from 0.83 to 1.96 percent.

Distilled water was added to drained soil samples in a jar and the jar was manually shaken over a 24-hour period. Each jar contained 0.5 kg of soil. Extracted water samples were analyzed for TOC. The average TOC obtained from the shake test was 16.5 mg C/l.

Table 5.1.3: Total Organic Carbon in Stream and Ground Water

WATER	TOC (mg/L)
<i>Creek</i>	
Huntingdon Ave	7.4
Culvert	6.4
FT3 Bridge	7.5
FT5 Bridge	7.1
Zero Ave	6.6
<i>Groundwater</i>	
FT1	1.5
FT3	2
FT5	1.3
FT6	2
FT8	3.1
91-11	0.9
91-12	3.4
ABB1	2
ABB5	1.5

5.1.4 Presence of Nitrate

The presence of nitrate in the Abbotsford aquifer has been monitored over the past 28 years by Environment Canada (Liebscher et al., 1992), and Agriculture and Agri-Food Canada (Zebarth et al., 1996). A general trend of an increasing nitrate concentration over the aquifer is shown in Figure 5.1.1: Nitrate Data 1970-1996. Recorded data from Environment Canada indicate that the nitrate-N concentration in several wells that were included in the current study have increased significantly over the past ten years. Table 5.1.4 is a summary of existing nitrate-N data for wells in the study area which have been identified in Figure 4.1.1.

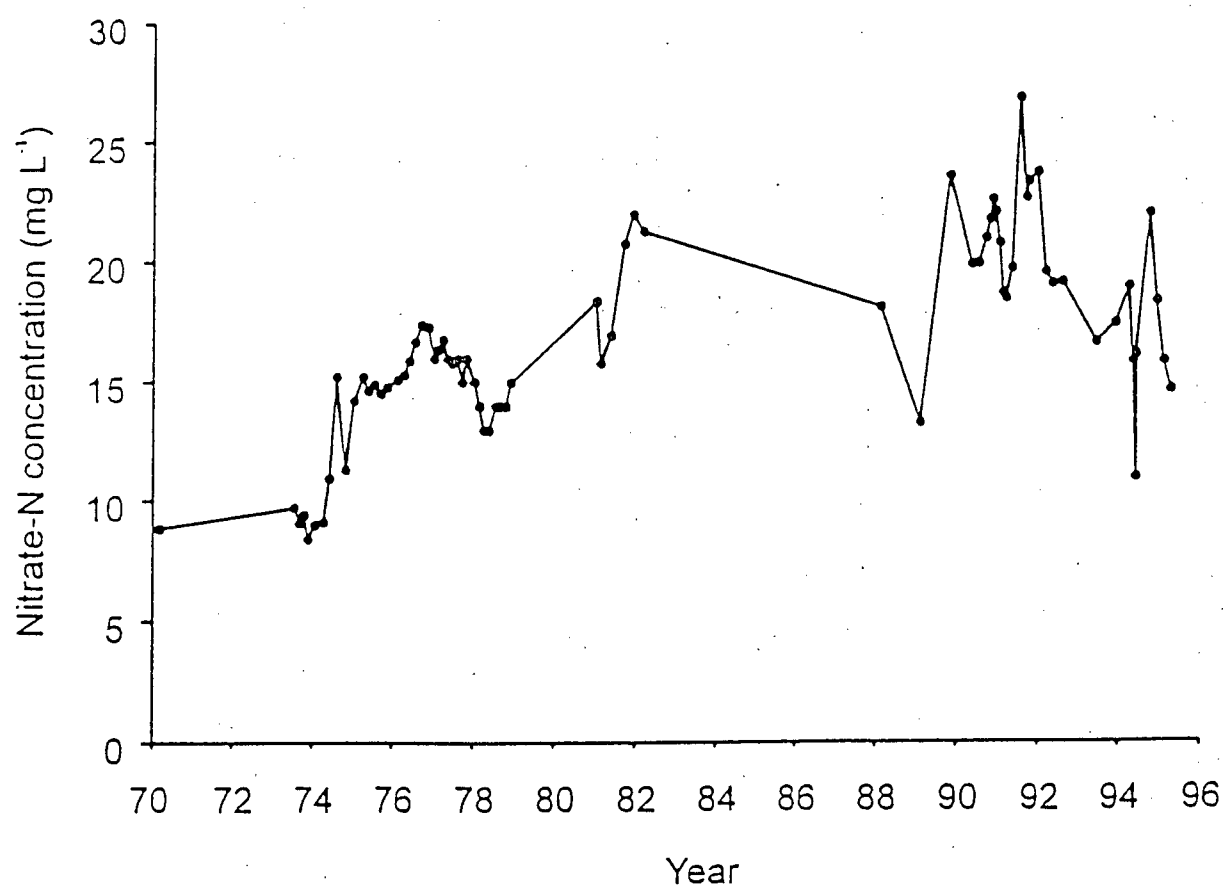


Figure 5.1.1: Nitrate Data 1970-1996 (Zebarth et al., 1996)

Table 5.1.4: Nitrate-N Concentrations in Well Water from the Abbotsford Aquifer (mg N/l)

Date	91-11	91-12	ABB1	ABB5	FT5-25'	FT8-79'
Nov/89			5.85	17.30		
March/90			15.15	15.50		
May/90			13.85	16.50		
July/90			9.90	16.20		
Sept/90			9.82	17.00		
Oct/90			11.40	22.75		
Dec/90			9.09	20.40		
June/91	0.00	0.00	11.25	26.45		
May/92	0.00	0.00	16.90	18.40		
June/93	0.00	0.00	11.30	15.40		
June/94	0.00	0.02	8.38	17.20		
April/95	0.53	0.00	20.70	17.50		
Jan/96	0.04	0.00	10.30	16.40		
Aug/96	0.01	0.00	12.30	30.10	17.0	0.13
May/97	0.00	0.05	25.40	18.60		

Over the 11-month sampling period, nitrate values for both Fish Trap Creek and surrounding groundwater were obtained. Table 5.1.5 presents average nitrate-N values for each sampling location. Nitrate concentrations in the stream water concentrations varied from 1.5-5.6 mg N/l. Groundwater nitrate concentrations ranged from less than 1 mg N/l to 22 mg N/l. Over the sampling period, nitrate concentrations in wells FT5, ABB1 and ABB5 exceeded 10 mg N/l, which is the safe drinking water limit.

Table 5.1.5: Average Nitrate-N Concentrations

WATER	Nitrate-N (mg N/l)
<i>Creek</i>	
Huntingdon Ave	2.92
Culvert	5.58
Zero Ave	3.65
<i>Groundwater</i>	
FT1	0.07
FT3	0.25
FT5	9.95
FT6	0.04
FT8	0.09
91-11	0.13
91-12	0.25
ABB1	22.62
ABB5	15.62

Groundwater nitrate levels are directly correlated with the depth of the piezometer sampled. Figure 5.1.2: Nitrate-N as a Function of Depth, demonstrates that the shallower wells are those that contain elevated levels of nitrate. Evidence from several other studies including Dasika (1996) and Liebscher (1992), indicate that elevated nitrate concentrations are present over the entire aquifer, and are especially prominent in shallow groundwater. Wells that are very close to Fishtrap Creek, including FT3 and FT6, contain negligible amounts of nitrate at shallow levels. This lack of nitrate present in groundwater near the creek coupled with low dissolved oxygen concentrations is indicative of the occurrence of nitrate reduction. The possibility of dilution due to precipitation exists, and may account partially for the decrease in nitrate levels.

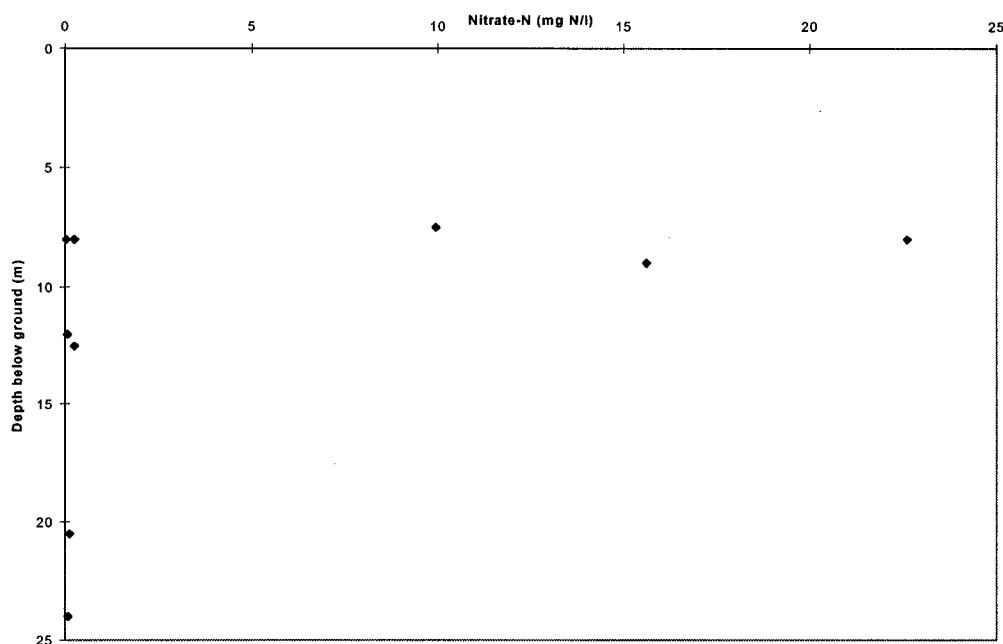


Figure 5.1.2: Nitrate-N as a Function of Depth of Well Water in the Abbotsford Aquifer

Nitrite, ammonia, and organic nitrogen concentrations were also monitored, but were found to be negligible compared to the nitrate-N values. A complete record of concentrations of all nitrogen components can be found in Appendix A.

5.1.5 Potential for Denitrification

The presence of denitrifying bacteria was determined using a simple jar test on several soil samples taken from the creek area. Approximately 50 percent of the nitrate was removed after 24 hours, and 99 percent after 5-6 days. The data demonstrated that an exponential removal of nitrate occurs.

Dissolved oxygen levels were approximately 8-12 mg/l in the creek and ranged from less than 1 mg/l to 10 mg/l in the groundwater. The potential for denitrification requires that low dissolved oxygen levels are present so that nitrate becomes the preferred electron acceptor. In the shallow wells, where nitrate levels are significantly higher, dissolved oxygen levels are generally the highest. These conditions are indicative of no denitrification occurring since both

nitrate and oxygen levels are high. In several wells along Fishtrap Creek where nitrate is low, the DO is approximately 1 mg/l or less. These conditions are indicative of denitrification occurring.

A carbon source appears to be present not only from the geological setting, but also from the TOC analysis. Hiscock et al. (1991) reported a typical TOC level in groundwater to be 2.95 mg/l with 9.2 % volatile in the soil. The study also reported C:N ratios ranging from 1:1-3:1 required for 80-90 percent denitrification. Values obtained during this study were comparable and are typical for groundwater TOC levels. The TOC in the stream decreased from upstream to downstream as a result of the flow added from the culvert.

The results from the shake test indicate that the availability of organic carbon exists. The TOC values indicate that the potential for organic carbon to become available in solution and contribute to denitrification exists. Grischek et al. (1998) conducted a mass balance for denitrification and found that oxidizable organic carbon required for denitrification is derived from both the infiltrating river water and solid organic matter fixed in the river bed sediments and aquifer material. Thus, the presence of streambed material and mixing river water may enhance the potential for denitrification.

The nitrate data obtained by Environment Canada over the previous 30 years demonstrates an increasing overall concentration of nitrate in the groundwater. During the study period, only three of the nine wells surveyed exceeded the MAC. Thus, nitrate reduction appears to have occurred in the study area since nitrate levels are lower than those throughout the aquifer. Stream nitrate-N levels in Fishtrap Creek were higher than typical concentrations for surface water, probably as a result of groundwater infiltration.

5.2 Water Chemistry

A significant amount of fieldwork contributed to this research, including monitoring water chemistry of both Fishtrap Creek and surrounding wells. In order to make comparisons between locations, predict sub-surface processes, and conduct mass balances which include

the influences of groundwater, the various types of water present in the study area must be identified. Stiff diagrams are a useful tool for grouping various types of water because they display data graphically (Appelo and Postma, 1994). Different water types yield different shapes and the absolute concentrations are visualized by the width of the figure. Piper plots relate rock type and groundwater compositions by displaying relative compositions of cations and anions. Both stiff diagrams and piper plots are presented and discussed in the following sections. As well, tracers including sulfate, chloride, pH, and temperature were monitored for both surface and groundwater. By examining changes in tracers, mixing and changing water compositions can be identified.

5.2.1 *Inorganic Chemistry*

An effective means of determining the level of accuracy of chemical analyses is the use of electron balances. This is done by computing the electro neutrality, which is a function of the sum of cations and the sum of anions. Charge balances were performed for each sampling event at each location. The major cations included in the balance were calcium, magnesium, potassium, and sodium, while the major anions included were chloride, sulfate, bicarbonate, and nitrate. Table 5.2.1 contains a completed cation-anion balance for Fishtrap Creek at Zero Avenue. Remaining balances for all other sites have been included in Appendix A.

In general, charge balances conducted on surface water indicated reliable results with electro neutrality values ranging from 0.5-10 %. Charge balances performed for groundwater were not always as favourable, but for the most part had electro neutrality numbers between 0.5-12 %. Bicarbonate concentrations were estimated in some cases since this ion was not always analyzed, which may have led to a potential imbalance. As well, iron was not included in the balance, but it is not expected that this would significantly effect results. Overall, based on quality control of methodology, discrepancies found during the analyses are partially a result of analytical error. Most methods were accurate to at least 0.01 mg/l.

5.2.2 Stiff Diagrams

Stiff diagrams were constructed for each location and each sampling event. These graphical representations of water chemistry are a useful tool for grouping water types (Appelo and Postma, 1994). A complete set from the November 11, 1997 sampling has been included and are shown in Figure 5.2.2. The remaining sets of diagrams have been included in Appendix B. Predominant cations and anions are plotted on the horizontal axis in units of equivalents per liter as shown in the diagram. Each sampling location has been plotted separately on a diagram so that common shapes can be identified.

Surface water diagrams are similar, chemistry at Zero Avenue appears to result from a mixture of Huntingdon Avenue and the major culvert. Several diagrams of groundwater chemistry resemble surface water diagrams including FT5, ABB5, and 91-11. FT5 is located 3 meters from the stream, and at its location, groundwater levels exceed surface water elevations. However, north of this site, surface water is lost to groundwater and due to regional groundwater flow to the southwest, surface water is expected to return to the stream south of FT5. pH and temperature of the groundwater at FT5 is typically closer to that of surface water at Huntingdon than to background groundwater pH and temperature at ABB1. Nitrate concentrations at FT5 are high compared to surface water, but are significantly lower than levels at ABB1. As well, sulfate concentrations at FT5 were significantly higher than in the creek, but again lower than levels at ABB1. Thus it appears as though shallow groundwater (7 m) is influenced by surface water that is returning to the creek and also by groundwater from the east. Ideally, wells located along Huntingdon east of Ross would have been useful in determining increasingly accurate background levels in groundwater.

Chemistry of groundwater at ABB5 (8.5 m deep) and at 91-11 (20.5 m) are similar to that present at FT5. Nitrate concentrations are more elevated at ABB5, which is also a shallow piezometer, while at 91-11, which is much deeper, nitrate levels are less than 1 mg N/l.

Chemistry of groundwater at FT1 (12 m), FT3 (8m), and 91-12 (12.5m) appear related. Calcium is significantly higher at FT1 and 91-12. Sulfate and chloride concentrations are

extremely high at 91-12, probably as a result of depth. Water chemistry at ABB1 resembles that at 91-12, except that nitrate concentrations are high and sulfate levels are lower at ABB1.

91-11 (20.5m) and 91-12 (12.5m) are only 3 meters apart but differences in water chemistry are extreme. Concentrations of calcium, sulfate, chloride and magnesium are much higher in 91-12, which is the shallower of the two. As well, temperatures in the shallower 91-12 are approximately three degrees higher and pH is generally lower. These results suggest that little vertical mixing occurs since at the two depths, very different waters exist.

It was assumed that groundwater flows on the west side of Fishtrap Creek would mirror those occurring on the east side. Chemistry found at FT3 and FT6 does not completely support this assumption. Both piezometers represent water from approximately 8 meters deep. FT6 is slightly closer to the creek, FT3 is approximately 15 meters from the creek while the distance to FT6 is about 5 meters. FT3 appears to be influenced by groundwater flowing from the northeast since it resembles water at ABB1. Groundwater at FT3 is lower in calcium and nitrate than water at ABB1. Furthermore, groundwater at FT6 appears to be more influenced by surface water than groundwater at FT3. pH, temperature, as well as, concentrations of bicarbonate, sulfate, and chloride are similar to surface water at FT6. Fishtrap Creek curves dramatically around FT6, the location of the well is in the direct straight line path of flow. It is likely that groundwater passing under this point has mixed with surface water and influences groundwater at this location.

To the extreme west of the study area, water chemistry at FT8 appeared to be very different than at all other locations. This piezometer was the deepest (24 m) of all sampled locations. Concentrations of bicarbonate, chloride and sodium were very high, while calcium was very low. Data obtained from Environment Canada for a shallower piezometer (12m) at this location reveals that nitrate and calcium levels are higher closer to the surface. These results suggest that water at various depths at the same location differ greatly, probably as a result of various layers of impervious material.

Thus, relationships between stream and groundwater, as well as between groundwater

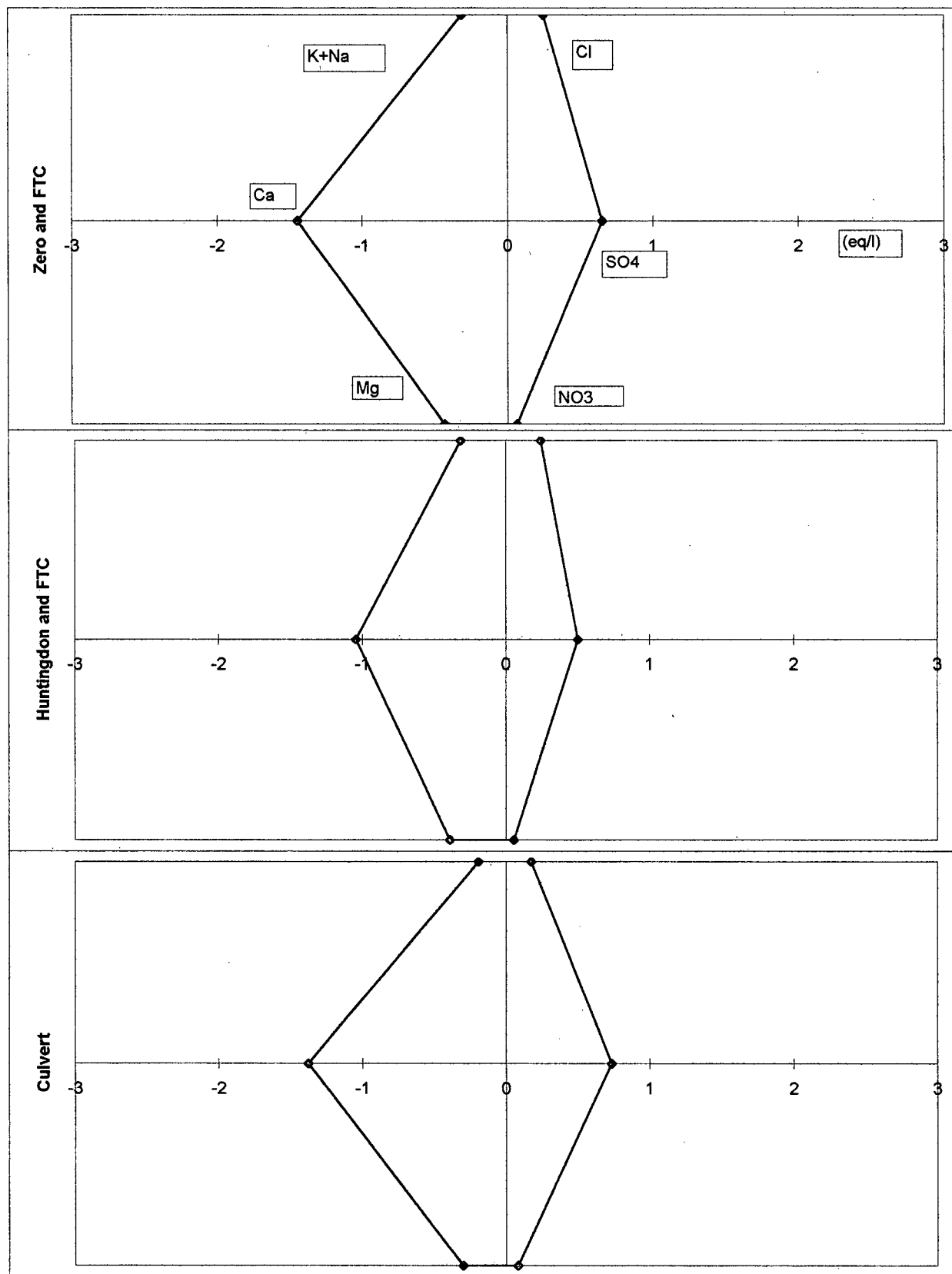


Figure 5.2.2: Stiff Diagrams for November 11, 1997

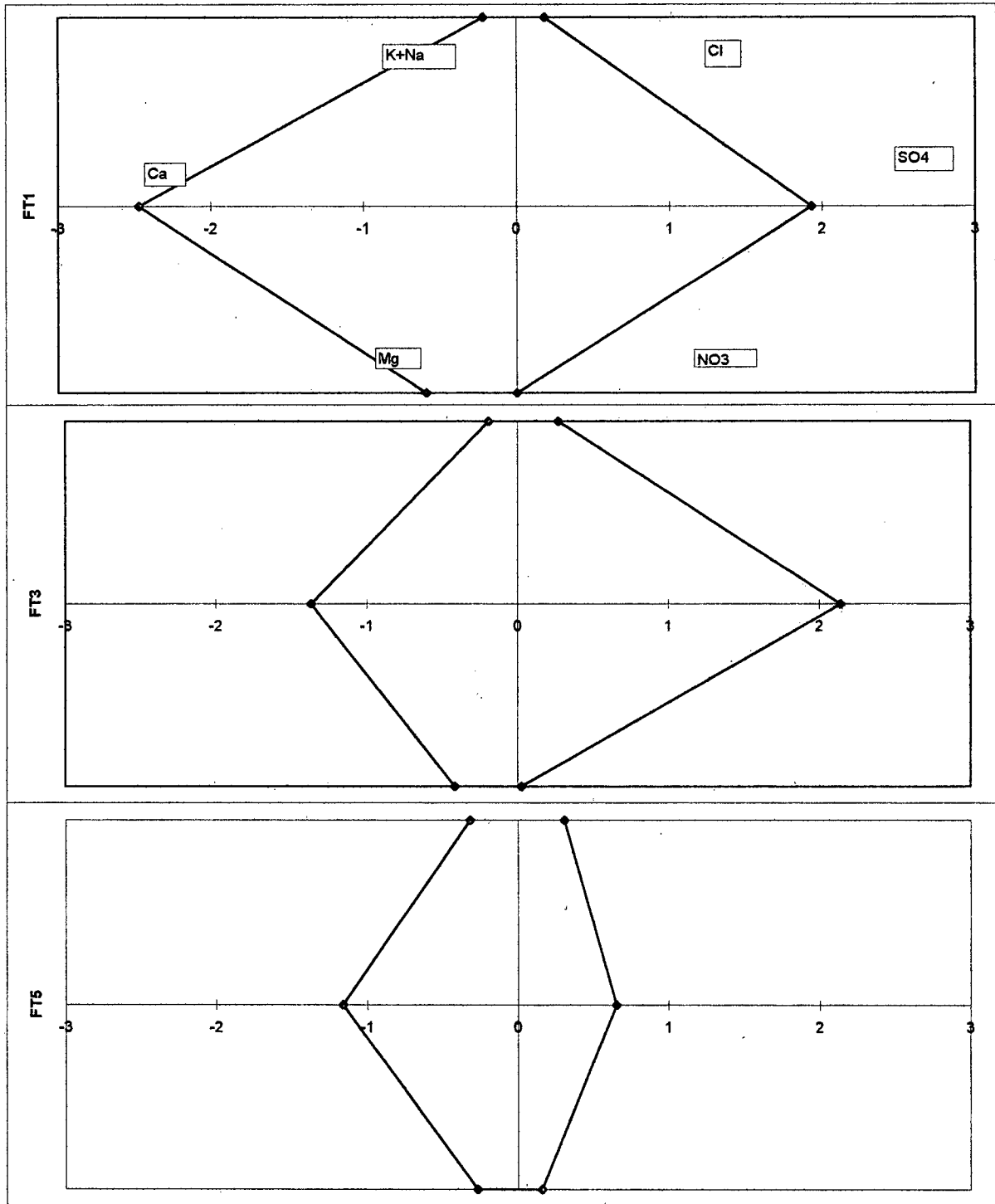


Figure 5.2.2: Stiff Diagrams for November 11, 1997

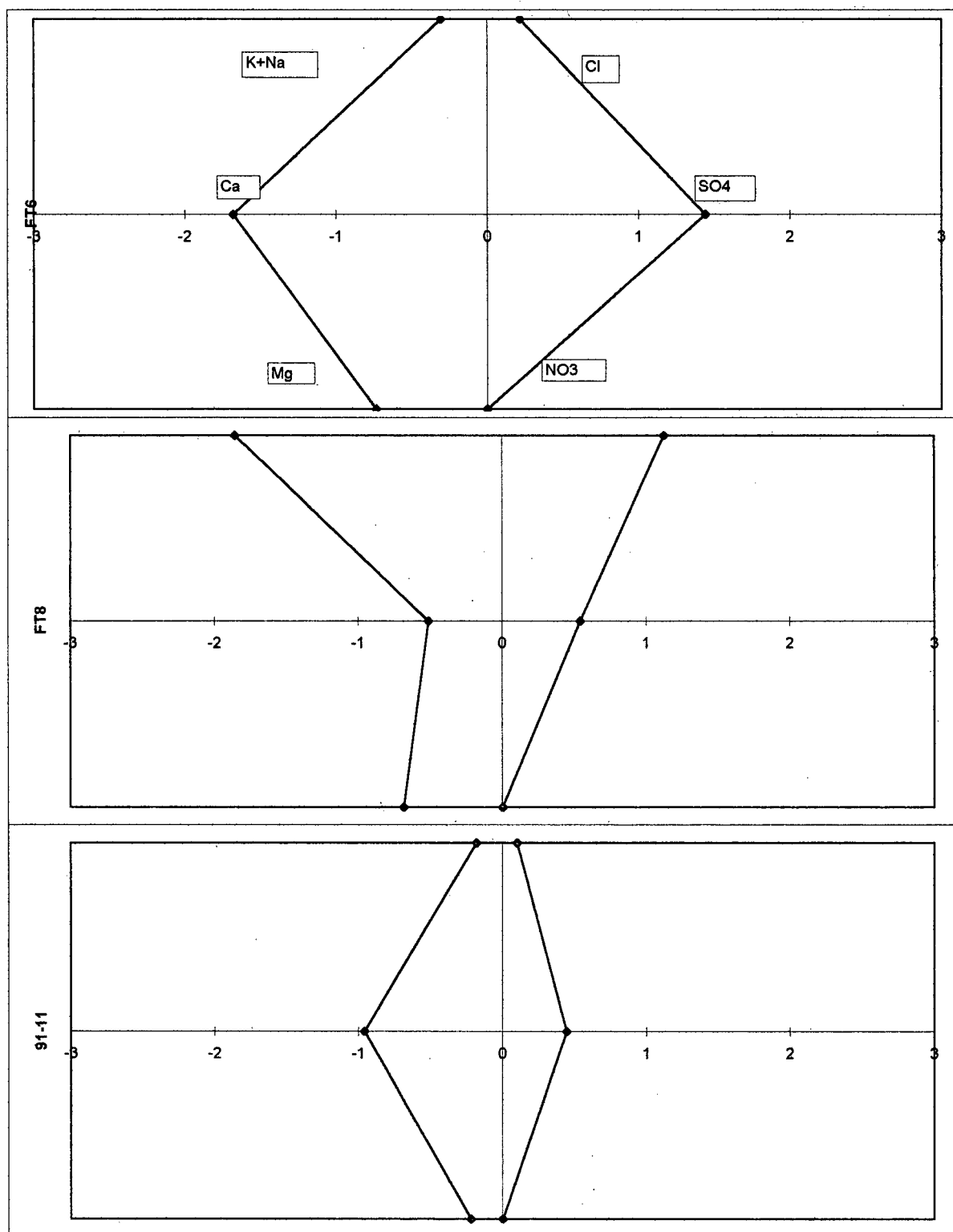


Figure 5.2.2: Stiff Diagrams for November 11, 1997

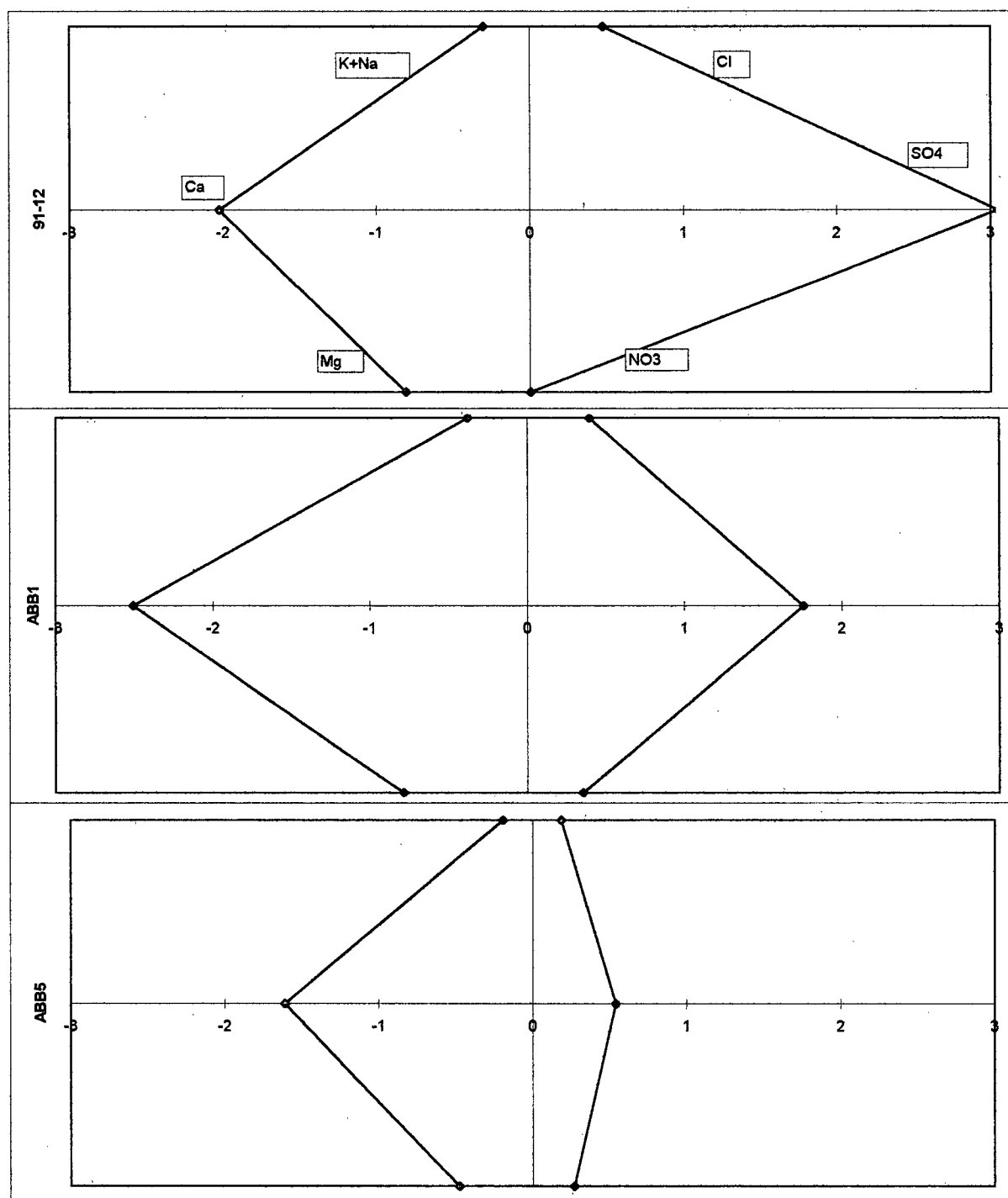


Figure 5.2.2: Stiff Diagrams for November 11, 1997

at various locations are better understood by examining stiff diagrams. All locations were grouped according to chemistry, resulting in four groups. Surface water, although in its own group, closely resemble groundwater at FT5, FT6, 91-11, and ABB5. Groundwater higher in sulfate and calcium include FT1, FT3, 91-12, and ABB1. Finally, the last group, which is high in sodium and chloride, consists only of FT8.

5.2.3 Piper Plots

Piper plots consist of two triangular diagrams which describe the relative compositions of cations and anions, and a diamond-shaped diagram that combines the compositions of cations and anions (Appelo and Postma, 1994). A program developed by Environment Canada, "Triplot", was employed for the construction of piper plots. An input file, which contained concentrations (meq/l), of calcium, magnesium, sodium, potassium, bicarbonate, carbonate, sulfate, and chloride was created in Excel. The program was then used to plot the piper diagrams for each sampling event.

Figure 5.2.2 contains the piper plot constructed for May 12 1998, along with a legend for sampling locations. Each number will appear in each of the two triangles according to its relative concentrations (percent) of cations and anions. The program then combines this data for each location and places the resulting water type in the diamond. Thus locations which are close to each other in the diamond diagram are considered to have derived from similar sources. It appears as though most of the waters are classified as calcium-magnesium/sodium-potassium type. Water chemistry at FT8 is again very different from all other sites, and is representative of sodium-potassium water. FT5, FT6, and 91-11 were found to be similar to surface water as was the case with stiff diagrams. FT1, FT3, 91-12, and ABB1 were found to be similar, again comparable results to those derived from stiff diagrams. Stiff diagrams are visual tools for grouping water types, while piper plots are typically used to determine common sources of water types (Appelo and Postma, 1994). Thus, both methods were employed during this study in order to accurately group the various water types present over the aquifer.

Identification Number	Location
1	Zero Avenue and FTC
2	Major Culvert
3	Huntingdon Avenue and FTC
4	FT1
5	FT3
6	FT5
7	FT6
8	FT8
9	91-11
10	91-12
11	ABB1
12	ABB5

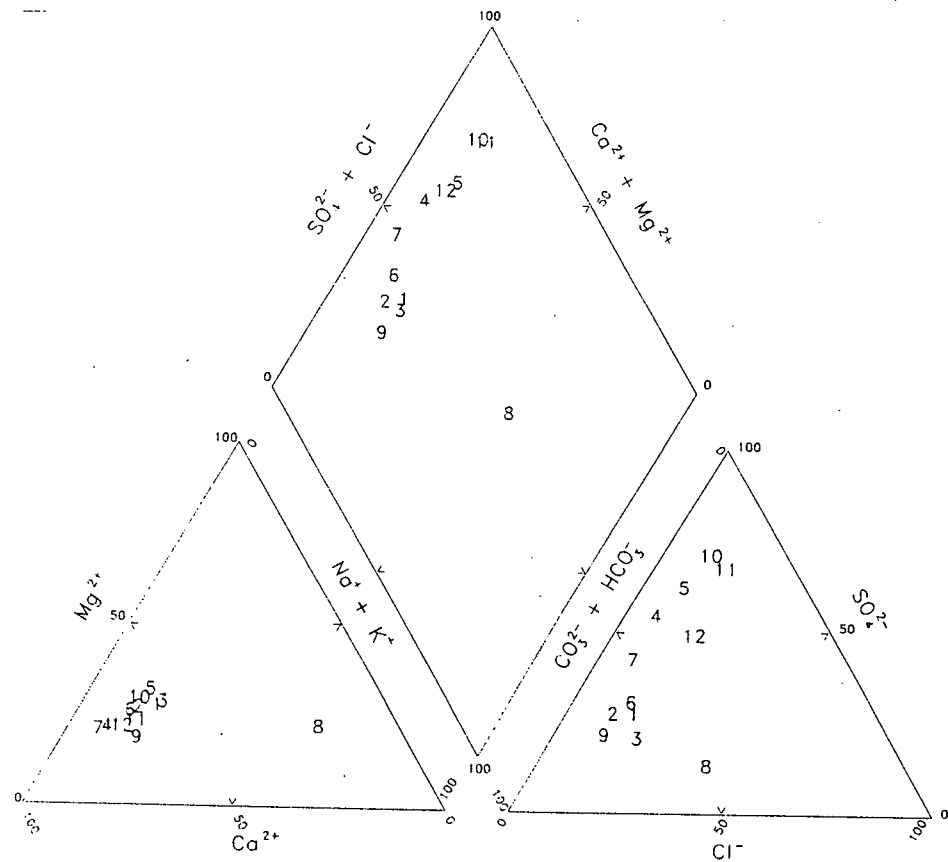


Figure 5.2.2: Piper Plot for May 12, 1998

5.2.4 Minor Constituents

Further chemical analyses included monitoring chloride and sulfate concentrations, temperature, pH and dissolved oxygen levels at various points along Fishtrap Creek. By examining fluctuations along the creek, the influence of groundwater infiltrating, and exfiltrating stream water can be assessed. Table 5.2.2 is an example of data collected during each sampling event and contains data obtained for May 12, 1998. Similar tables for various sampling days have been included in Appendix B. The chloride concentration along the stream appears to remain fairly constant, while the sulfate concentration increases consistently along the stream. Conversely, bicarbonate concentrations decrease from upstream to downstream. The content of total organic carbon is fairly consistent, but appears to be higher upstream.

Dissolved oxygen typically was higher at the downstream location, as was temperature. pH also tended to increase along the stream, although no specific pattern was developed. Infiltrating groundwater is generally warmer than stream water during the winter months, and may account for warmer temperatures downstream. The increase in pH may also be due to infiltrating groundwater. Groundwater from wells in close proximity to the stream contain higher concentrations of sulfate than the stream, and similar concentrations of chloride. It appears as though infiltrating groundwater influences the surface water chemistry from the upstream to downstream locations.

Table 5.2.2: Surface Water Quality in Fishtrap Creek for May 12, 1998

Station	DO (mg/L)	Temp °C	pH	Flow (m ³ /s)	NO ₃ (mg N/l)	Cl (mg/l)	SO ₄ (mg/l)	HCO ₃ (mg/l)	TOC (mg/l)
<i>Huntingdon Ave</i>	7.7	12.5	7.16	0.65	1.77	8.4	11.0	80.3	7.4
<i>FT5 Bridge</i>	7.3	12.3	7.22	0.63		8.5	14.3	75.7	7.1
<i>Culvert</i>	9.0	10.6	6.98	0.03	6.81	7.4	24.5	46.8	6.4
<i>FT3 Bridge</i>	8.6	12.5	7.26	0.66		8.3	16.2	72.2	7.5
<i>Zero Ave</i>	9.7	12.9	7.31	0.70	2.47	8.5	19.2	75.7	6.6

5.2.5 Dilution

Minor constituents can also be used to determine the amount of dilution occurring between two wells. By examining the dilution of conservative tracers occurring between two points, the amount of nitrate loss due to dilution can be estimated. This exercise is useful for determining quantities of nitrate lost due to processes other than dilution, such as denitrification.

The ratio of concentrations of chloride, sulfate, and calcium at several wells were determined and compared to that of nitrate, in order to estimate the potential for denitrification. Table 5.2.3 is a summary of the ratio of concentrations for each ion between ABB1 and FT5. In general, calcium is diluted by roughly 50 percent, while chloride is diluted between 30-70 percent. On several occasions the proportion of nitrate dilution is much greater than other ratios including September 17, 1997; December 15, 1997; March 15 and 23 1998; April 6 and 28, 1998; and finally May 12, 1998. During these times, nitrate is being reduced by means other than dilution. In general, sulfate was reduced far more significantly than chloride between the two sites.

Table 5.2.3: Concentration Ratios between ABB1 and FT5

Date	nitrate	Chloride	sulfate	Calcium
17-Sep-97	0.45	0.55	0.35	0.51
30-Sep-97	0.49	0.98	0.37	0.54
14-Oct-97	0.45	0.57	0.36	0.45
28-Oct-97	0.46	0.80	0.35	0.49
11-Nov-97	0.44	0.77	0.37	0.46
25-Nov-97	0.34	0.68	0.36	0.39
8-Dec-97	0.42	0.67	0.35	0.40
15-Dec-97	0.36	0.49	0.43	0.41
20-Jan-98	0.43	0.39	0.35	0.44
26-Jan-98	0.49	0.34	0.34	0.47
9-Feb-98	0.59	0.43	0.25	0.45
24-Feb-98	0.29	0.62	0.22	0.45
15-Mar-98	0.31	0.60	0.40	0.55
23-Mar-98	0.27	0.54	0.39	0.51
6-Apr-98	0.36	0.62	0.40	0.62
28-Apr-98	0.41	0.66	0.37	0.53
12-May-98	0.48	0.63	0.30	0.61
25-May-98	0.87	0.58	0.30	0.64
9-Jun-98	1.68	0.70	0.28	0.71
AVERAGE	0.50	0.61	0.35	0.51

Similarly, dilution between ABB1 and FT3 are summarized in Table 5.2.4. Nitrate

concentrations at FT3 are less than 1mg N/l, and thus the ratio of nitrate at FT3 to ABB1 is typically extremely small. Several sampling events suggest that nitrate reduction far exceeds the amount of dilution occurring. Sampling dates during November 1997 through to February 1998 indicate roughly a 50 percent dilution of chloride and calcium, while nitrate is virtually completely removed.

Table 5.2.4: Concentration Ratios between ABB1 and FT3

Date	nitrate	Chloride	sulfate	calcium
11-Nov-97	0.07	0.68	1.22	0.55
25-Nov-97	0.03	0.60	1.35	0.53
8-Dec-97	0.03	0.69	1.23	0.54
15-Dec-97	0.00	0.56	1.61	0.56
20-Jan-98	0.00	0.51	1.44	0.56
26-Jan-98	0.00	0.51	1.44	0.56
9-Feb-98	0.00	0.59	1.15	0.43
24-Feb-98	0.00	0.70	0.92	0.45
15-Mar-98	0.00	0.70	1.56	0.48
23-Mar-98	0.00	0.67	1.64	0.55
6-Apr-98	0.00	0.76	1.41	0.59
28-Apr-98	0.01	0.80	1.35	0.57
12-May-98	0.01	0.86	1.25	0.64
25-May-98	0.00	0.88	1.03	0.63
9-Jun-98	0.00	1.01	1.01	0.66
AVERAGE	0.01	0.70	1.31	0.55

Finally, dilutions between ABB5 and FT1 were examined. In this case, concentrations of chloride, sulfate, and calcium were all typically higher at FT1 than at ABB5. Groundwater sampled at FT1 is more representative of deeper groundwater, and for this reason proper comparisons cannot be made. Unpublished data from the USGS for a 4 meter piezometer at the same location as FT1 may be more useful. In examining this data, it was found that concentrations of sulfate, chloride, and calcium were higher than at ABB5, while nitrate concentrations were significantly reduced. Thus evidence of nitrate removal between ABB5 and FT1 also exists.

5.2.6 Surface and Ground Water Interactions

Charge balances performed on the inorganic chemistry data indicated that electro neutrality was typically between 0.5-12 percent. Discrepancies may be due to approximated

bicarbonate data, absence of iron data, and accumulative analytical error.

Stiff diagrams and piper plots were used to investigate the various water types present within the study area. These methods were useful in determining relationships between various groundwater sources and in predicting influences from one location on another. It is obvious from these diagrams that an intimate relationship between the surface and ground waters exists. It is also obvious that little vertical mixing is occurring since the chemistry of water at different depths varies significantly.

Overall, groundwater quality over the entire aquifer has been studied intensively and results continue to demonstrate the influence of land use practices. Dasika (1996) summarized the general influence of manure stockpiling on water quality at the water table and compared results to those obtained for an Abbotsford study well. In general, calcium and magnesium concentrations were higher at the water table than would have been expected. Chloride, sulfate, sodium, and potassium probably originated from the land applied poultry manure (Dasika, 1996). Dasika (1996) also studied the change in concentration of various ions with depth. Concentrations of nitrate, sulfate, and chloride were each found to be lower at the surface, increase with depth to about 8 m and then decrease with depth. Chloride concentrations tended to be the most variable. pH tended to be higher at the surface, decrease slightly with depth until approximately 8 m and then increase with depth. Inorganic chemistry present in the Abbotsford aquifer was summarized by Liebscher (1992), and was comparable to that found at the study site.

Calcium concentrations varied between 15-45 mg/l over the aquifer and similarly over the study area. Calcium concentrations tended to decrease with depth, and were higher in areas closer to the creek. Sulfate concentrations seemed diluted at FT5 and ABB5 since they were much lower than concentrations at similarly shallow wells over the area. Sulfate concentrations followed the typical trend of decreasing with depth after approximately 8 m, with the exception of the location 91-12. Chloride concentrations were fairly consistent over the study area with the exception of location FT8, which was the deepest well and contained the

highest concentration of chloride. Nitrate is widespread over the aquifer, and exceeded the MAC at three locations within the study area. However, nitrate concentrations at several shallow groundwater locations were not detectable, indicating that nitrate reduction had occurred. Chemistry of the surface water is a reflection of infiltrating groundwater and dilution.

Analysis of minor constituents in the surface water indicated that the water chemistry of Fishtrap Creek is influenced by the infiltrating groundwater. Dissolved oxygen, temperature, and pH increased from upstream to downstream sampling locations. Background groundwater temperature and pH tended to be higher than that of the surface water during the winter months and thus may be responsible for the increases.

Studying the ratio of conservative tracers present at two points and comparing these to the ratio for nitrate allows for an estimation of the amount of nitrate reduction due to dilution that is occurring. Between ABB1 and FT5, dilution results indicated that on several occasions, nitrate reduction exceeds the amount occurring due to dilution. The same results were found when examining dilutions between ABB1 and FT3. However, dilutions between ABB5 and FT1 did not yield the same results since concentrations of sulfate, chloride, and calcium increased over the 1 km distance. The lack of influence on FT1 by ABB5 may be due to the larger distance between the two wells, and also due to varying water chemistry at different depths.

5.3 Mass Balances

In order to assess the chemical and biological reactions taking place over the site, flow and mass balances were performed. The completion of a flow balance on the stream provides an understanding of flow gains and losses. By incorporating this data with water elevations of both stream and ground water, sections of the creek where flow is added or lost can be identified. Mass balances for nitrogen, chloride, sulfate, calcium and magnesium provide further insight as to dilution percentages and the possibility of denitrification.

5.3.1 Flow Balance on Creek

A flow balance is useful in determining flow contributions along the creek. It is also essential in studying the relationship between the creek and the groundwater. Flows were continuously monitored for Fishtrap Creek at both Huntingdon Avenue and Zero Avenue. As well, flow entering the creek directly through a culvert that is fed from an agricultural ditch, which drains an area to the northeast of the site, was monitored. A ditch, which collects runoff along Ross Road and drains into the creek at Zero Avenue, was monitored during several sampling events and was estimated as approximately half the flow of the major culvert. A detailed cross section of the creek was taken at Huntingdon Avenue since the hydrologic station at that location is no longer used. A data-logger which records the height of the creek has been established at Zero Avenue, and flows at this location were obtained from Environment Canada. Intermediate flows at two locations along the creek were obtained by measuring water depths and velocities.

Flow from the culvert enters the creek between the two intermediate locations. Thus flows taken at Huntingdon and the culvert should contribute to the flow at the second intermediate station, FT3 bridge. Flow at this location in addition to flow added from the ditch along Zero Avenue should theoretically contribute to the total flow at Zero Avenue. Table 5.3.1 contains the complete flow balance performed on the section of Fishtrap Creek contained within the study area. All flows discussed in this paper are in units of cubic meters per second.

Theoretical flows at FT3 Bridge, and Zero Avenue were calculated by adding contributing flows at that point. Discrepancies between theoretical flows and actual flows at FT3 bridge and Zero Avenue may be a result of runoff, infiltrating groundwater, and precipitation. Approximately 0.3-2% of the flow was gained between FT5 and FT3, while 2-20% was gained between FT3 and Zero Avenue. The loss of flow between Huntingdon Avenue and FT5 bridge is probably due to the loss of streamwater into the groundwater, and will be further discussed during the investigation of water levels in Section 5.3.2. Approximately 1-6% of the flow at Huntingdon was lost before reaching the FT5 bridge.

Table 6.3.1: Flow Balance for Fishtrap Creek (m³/s)

Date	Huntingdon Ch	FTC at FT6 Qb6	Culvert Qt	FTC at FT3 Qb3	Theo at FT3	Ditch Qd	Precipitation Qp	Zero Qz	Zero Qt+Qc+Qd+Qp	Calc-Meas Gain/Loss	Flow gain b/m hundFT6	Flow gain b/m FT6/FT3	Flow gain b/m FT3/Zero	Flow gain b/m FT6/Zero	Percent Gain of Total Flow
25-Aug-97	0.175	0.155	0.020			0.010	0.003	0.218	0.207	0.011				0.031	14.1
17-Sep-97	1.714	1.694	0.080			0.040	0.002	3.560	1.836	1.725				1.745	49.0
30-Sep-97	0.675	0.655	0.028			0.014	0.001	0.700	0.718	-0.018				0.002	0.3
14-Oct-97	0.840	0.820	0.076			0.038	0.001	0.934	0.954	-0.020				0.000	0.0
27-Oct-97	0.725	0.705	0.035			0.017	0.000	0.844	0.777	0.067				0.087	10.3
11-Nov-97	0.460	0.440	0.049			0.025	0.000	0.614	0.534	0.080				0.100	16.3
25-Nov-97	1.351	1.331	0.127			0.064	0.001	1.810	1.543	0.267				0.287	15.8
8-Dec-97	0.600	0.560	0.085			0.043	0.001	0.750	0.729	0.021				0.041	5.5
15-Dec-97	0.535	0.515	0.074	1.520	1.518	0.037	0.001	0.660	0.647	0.013	-0.022	0.002	0.349	0.033	5.0
20-Jan-98	1.365	1.363	0.155	1.660	1.655	0.221	0.000	2.090	1.761	0.329	-0.020	0.005	0.362	0.351	16.8
26-Jan-98	1.531	1.511	0.144	1.758	1.752	0.218	0.000	2.240	1.893	0.347	-0.010	0.008	0.073	0.367	16.4
9-Feb-98	0.646	0.636	0.116	0.758	0.752	0.058	0.001	0.889	0.820	0.069	-0.010	0.006	0.073	0.079	8.8
24-Feb-98	0.653	0.627	0.082	0.725	0.709	0.041	0.000	0.846	0.776	0.070	-0.026	0.016	0.080	0.096	11.3
15-Mar-98	0.772	0.730	0.065	0.799	0.795	0.033	0.000	0.848	0.870	-0.022	-0.042	0.004	0.017	0.020	2.4
23-Mar-98	1.215	1.140	0.116	1.280	1.256	0.058	0.000	1.600	1.389	0.211	-0.075	0.024	0.262	0.286	17.9
6-Apr-98	0.626	0.600	0.105	0.711	0.705	0.052	0.000	0.799	0.782	0.017	-0.026	0.006	0.036	0.042	5.3
28-Apr-98	0.568	0.539	0.033	0.578	0.572	0.017	0.000	0.609	0.617	-0.008	-0.029	0.006	0.015	0.021	3.4
12-May-98	0.646	0.630	0.025	0.659	0.655	0.013	0.000	0.702	0.685	0.017	-0.016	0.004	0.030	0.034	4.8
25-May-98	0.650	0.645	0.026	0.678	0.671	0.013	0.002	0.702	0.691	0.011	-0.005	0.007	0.011	0.016	2.3
9-Jun-98	0.570	0.553	0.020	0.578	0.573	0.010	0.000	0.609	0.600	0.009	-0.017	0.005	0.021	0.026	4.3
								average	average	0.077			average	0.101	8.5

A complete flow balance should include factors such as precipitation, evaporation, evapotranspiration, irrigation, and overland flow. Precipitation data was obtained from Deol (1998) and the Vancouver Sun. The data was included in the balance and was not found to impact the balance due to its relative insignificance. Some irrigation data was obtained through personal communication with the farmers and was ignored since the amount of irrigation throughout the time period of the study was limited. The amount of evaporation occurring was estimated using two empirical equations, knowing both water and air temperatures. A summary of these calculations has been included in Table B2 in Appendix B. Evaporation rates were estimated as approximately $3.5 \times 10^{-4} \text{ m}^3/\text{s}$ and were found to be insignificant relative to creek flows. Upon considering these variables, the flow balance was not significantly affected. This is probably due to the fact that the study area is fairly small. Since the accuracy of these estimated values is somewhat uncertain, the flow balance considered only flows measured at four locations along with precipitation data.

Overall an average gain of $0.077 \text{ m}^3/\text{s}$ occurred over the section of the creek, the majority of the gain occurring between FT3 bridge and Zero Avenue. Flows obtained for September 17, which were much larger than typical flows obtained for the creek, were considered suspect and were not included in the calculations of averages. During lower flow conditions, groundwater springs were visible along the stream bank and bottom near the bridge at FT3. As seen in Figure 5.3.1, theoretical flows were consistently lower than actual flows. Percentage gains to the creek were calculated for each sampling event and represent the percentage of flow added from infiltrating groundwater. Percent gains ranged from 0 to 18 percent, excluding that achieved on September 17th.

Based on an average aquifer thickness near the border of 20 m, a length of 1600 m, and an approximate hydraulic conductivity of 10^{-4} m/sec , the flow through the aquifer at this location was estimated as $3.2 \text{ m}^3/\text{s}$. The average flow in Fishtrap Creek is approximately $0.825 \text{ m}^3/\text{s}$, which is 26 percent of the total flow in the aquifer. The portion of Fishtrap Creek generated from the infiltrated groundwater is about 3 percent of the flow from the aquifer. Thus, the potential for

Fishtrap Creek to play a role in nitrate removal exists. Since the contribution of infiltrating groundwater to the creek is considered significant, the potential for water quality in the creek to be influenced by surrounding groundwater and vice versa, is high. Flow measurements were taken accurately to $0.005 \text{ m}^3/\text{s}$, and thus results of this research should be reliable.

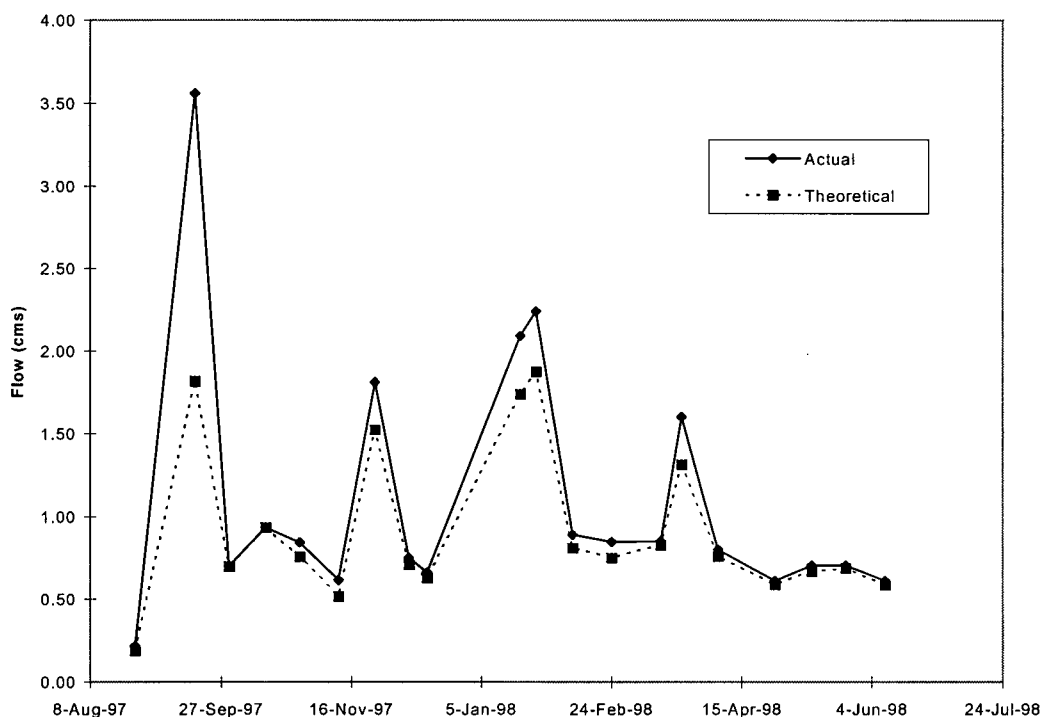


Figure 5.3.1: Comparison of Theoretical and Actual Discharges in Fishtrap Creek

5.3.2 Water Table Fluctuations

The regional groundwater flow direction is in the southwestern direction, while local groundwater directions vary due to the presence of the creek, and surrounding topography. As well, the water table is close to the surface in some areas, which may increase the influence of surrounding topography. The water table is approximately two meters higher in the eastern and northern portion of the site. The analysis of flowlines is useful in developing a more complete understanding of groundwater flow and the interaction between surface and ground water.

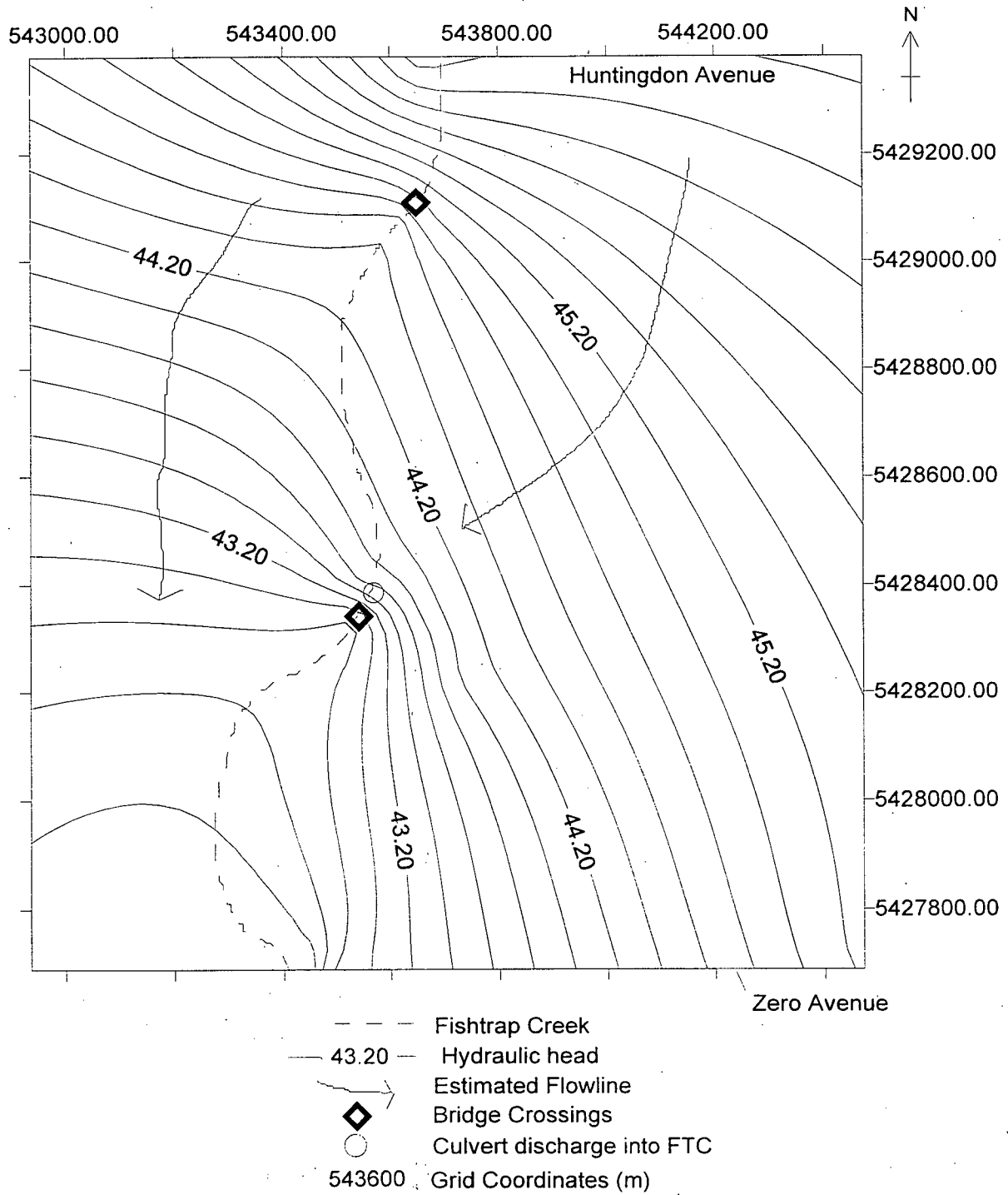


Figure 5.3.2: Hydraulic Head and Flowlines

Figure 5.3.2 contains hydraulic head lines obtained from depth measurement over the site, as well as estimated sub-surface flowlines. The location of intermediate flow stations, as well as the location of the culvert have been included on the map.

The following profiles were constructed using measurements of the elevations of the groundwater table, Fishtrap Creek, ground surface and the stream bottom. Figure 5.3.3 and Figure 5.3.4 each depict the difference in elevations using average water table elevations.

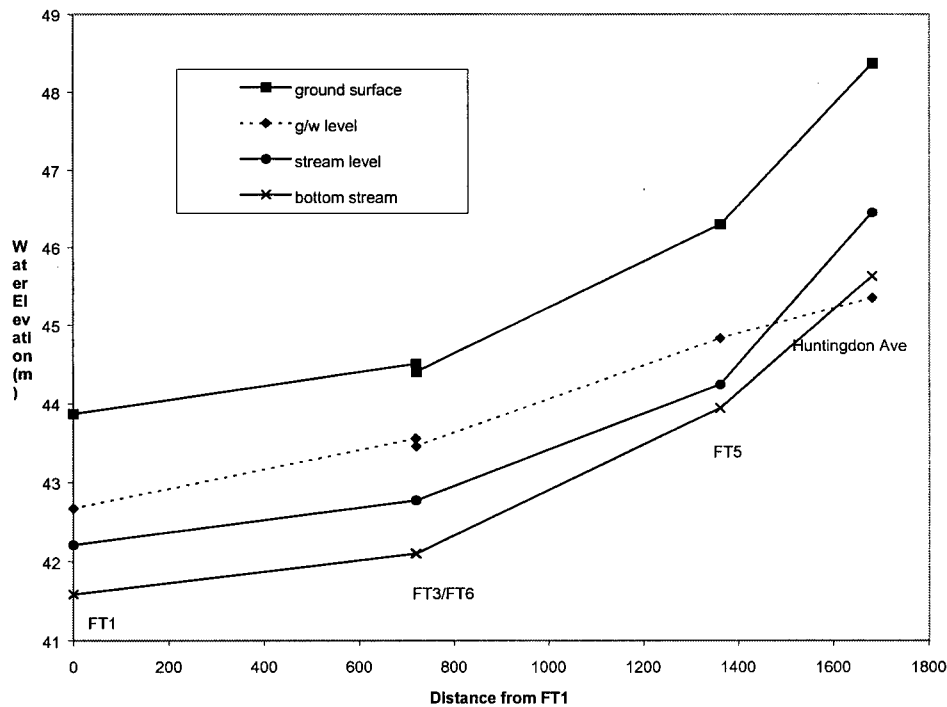


Figure 5.3.3: North-South Water Elevation Profile

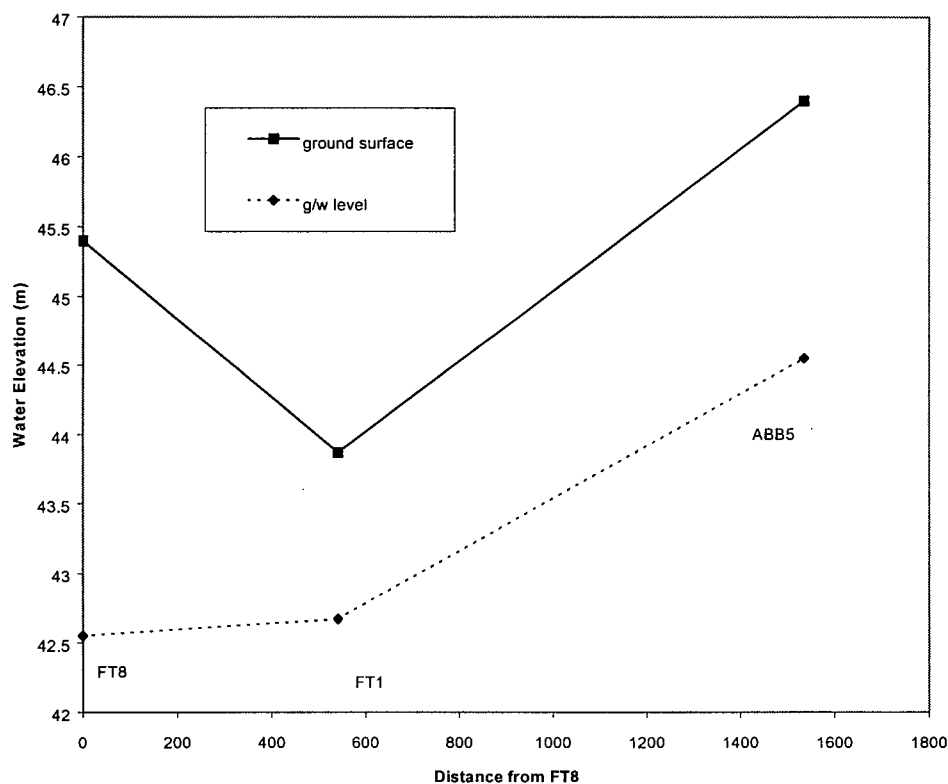


Figure 5.3.4: West-East Water Elevation Profile

Water table fluctuations over the entire aquifer have been reported as high as 3 meters. In the north end of the site, at Huntingdon Avenue, surface elevations of Fishtrap Creek were consistently higher than groundwater elevations. Since no wells exist along Huntingdon Avenue, groundwater elevations were projected from elevations measured at FT5. In general, the groundwater table was located 30-50 cm below the stream bottom. Thus, groundwater would not tend to influence the streamwater, but conversely, the exfiltrating water would influence the groundwater at this location. As can be observed from the profiles, the groundwater table is above the water surface of the creek at FT5. Thus it is probable that groundwater is infiltrating into the stream at this point. From the flow balance, it is known that flow is lost between Huntingdon Avenue and FT5 bridge. This loss is expected to occur near Huntingdon Avenue, since the water table rises closer to the surface water elevation at the FT5 bridge.

The water table remained above the creek's surface between FT3 bridge and FT5 bridge. Flow was consistently gained between these two stations. South of FT3 bridge, the groundwater table remained above the creek's surface, and flow continued to be gained by the creek. A complete record of water levels for both groundwater and Fishtrap Creek at all four locations has been included in Appendix B.

It is important to consider the fluctuation of the groundwater table and the creek's surface along with the flow variations. The relationship between change in water table elevation and amount of flow gained at FT3 bridge is shown in Figure 5.3.5. The elevation difference represents the difference between the elevation of the creek's surface and the groundwater table. In general, as the elevation difference increased (i.e. groundwater elevation even higher above surface water), the amount of flow gained increased as well. Comparing rainfall data to the changes in elevation, the two follow similar patterns for the most part. However, the relative change in elevation does not always reflect the amount of rainfall during that period. This data supports the theory that the increased flow along the creek is partly due to infiltrating groundwater.

It is important to note that the findings of this report differ from the common belief that the aquifer provides baseflow to Fishtrap Creek for six months of the year, and in return the creek provides recharge to the aquifer for the other six months of the year. The results of this study may only be applicable to the section of Fishtrap Creek monitored and the overall recharge/discharge relationship may be different when considering the creek in its entirety.

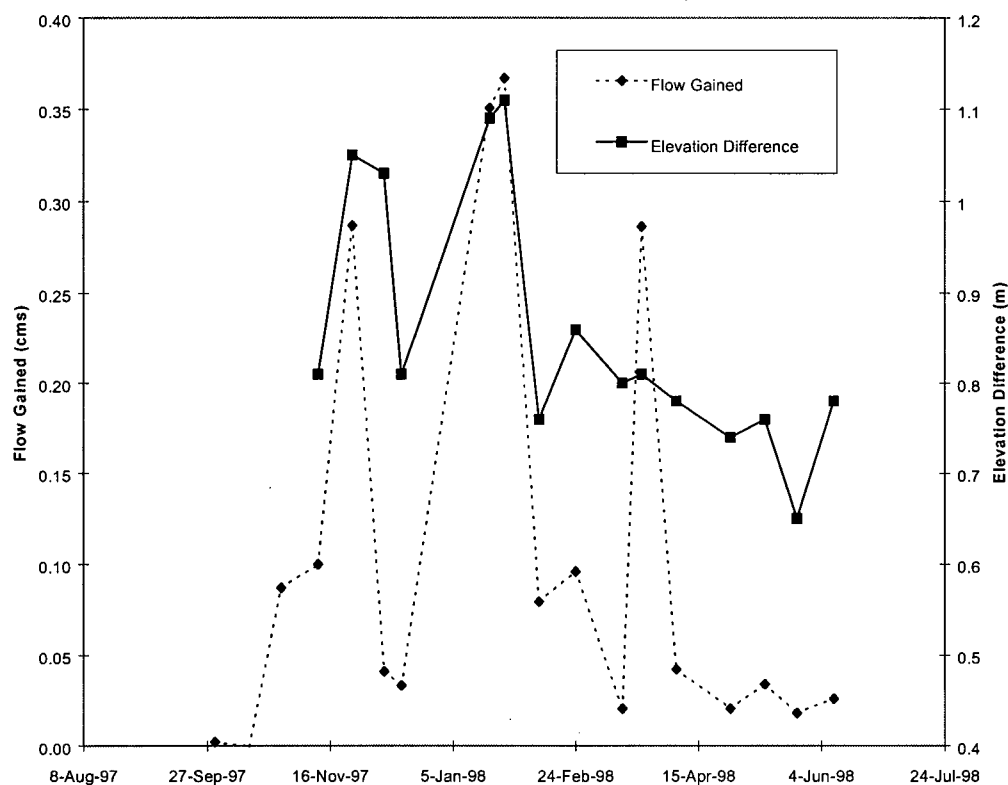


Figure 5.3.5: Flow Gain and Water Elevation Difference at FT3

Topography influences both the regional and local flow systems. The slightly sloping topography present over the area of interest has a direct impact on the local sub-surface flow. Since the groundwater table is fairly close to the ground surface in some areas (1.5 m below), the impact will be stronger. Figure 5.3.6 depicts the relationship between ground topography and direction of flow. Ground elevations were obtained during a survey performed for the purpose of this research. In areas where ground elevations were not known, data was interpolated from an orthophoto taken by the City of Abbotsford (1996). Flowlines were estimated from constant head lines which were superimposed onto the topographical surface. The approximate location of Fishtrap Creek and culvert were also superimposed.

Local groundwater flow is influenced by the presence of Fishtrap Creek since this is a significant area of discharge. Thus, interaction of surface water and groundwater very close to

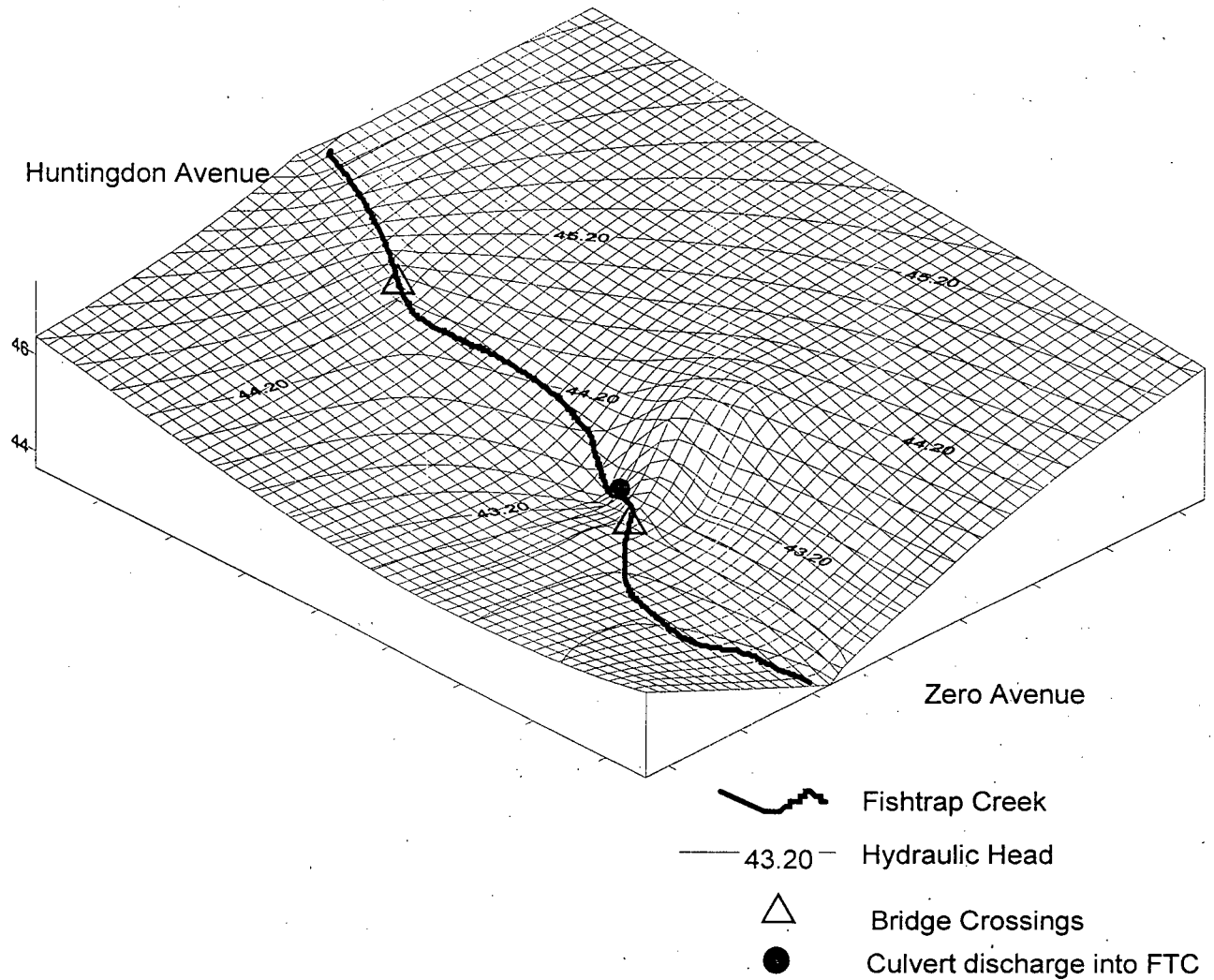


Figure 5.3.6: Site Topography and Hydraulic Head

the stream occurs, especially in areas where groundwater elevations exceed those of the surface water. This is the situation for more than two thirds of the site, thus the influence of groundwater on surface water and vice versa must be considered when studying the water chemistry over the site. Gradients near the creek are large indicating that groundwater enters the creek from both below and near the surface. Flow to the east of Fishtrap Creek tends to travel in a southwesterly direction. To the west of the creek, flow tends to travel in a more southerly direction. This slight change in direction may be a result of topography. As well, predicted flows to the west of the creek may be less accurate due to the lack of data available for this area.

One final component which will influence groundwater flow and cannot be neglected is the presence of a 4 foot culvert. The culvert runs below the raspberry fields between Ross Road and Fishtrap Creek and water is discharged into the creek slightly south of ABB1 and FT3. Surface water was collected at the bridge near FT3, which is slightly south of the culvert. Groundwater near the surface will be influenced by the presence of a culvert, redirecting flow in a more westerly direction, and also creating pooling action. Thus it is probable that surface water, which exfiltrated from the creek north of FT5, will be returned to the creek prior to reaching FT3 due to redirected local flows occurring as a result of the presence of the culvert.

5.3.3 Nitrogen Balance on Creek

In order to carry out a nitrogen balance on the study site, the prevalent forms of nitrogen which are present in the study site needed to be identified. The following nitrogen compounds were determined during the research period; nitrate-N, nitrite-N, ammonia, and organic nitrogen (Table 5.3.2). The predominant form of nitrogen in the surface water was nitrate. Overall, the predominant form of nitrogen in groundwater, if present in a significant concentration, was nitrate.

Upon establishing the dominant form of nitrogen, a mass balance using nitrate-N concentrations over the creek was performed. Nitrate flux was calculated using flow values

(m³/s) and nitrate concentrations (mg N/l). Theoretical nitrate concentrations at Zero Avenue were obtained by adding flux contributions from Huntingdon Avenue, the major culvert, the drainage ditch, and from the infiltrating groundwater. Groundwater nitrate concentrations infiltrating into Fishtrap Creek were calculated from background shallow groundwater concentrations at FT5, ABB1, and ABB5. Infiltrating groundwater flows were obtained from the flow balance already discussed in Section 5.3.1.

Table 5.3.2: Average Concentrations of Nitrogen Species (mg N/l)*

WATER	NITRATE-N	NITRITE-N	AMMONIA	TKN
CREEK				
Huntingdon Ave	2.92	0.03	0.03	0.59
Culvert	5.58	0.02	0.04	0.63
Zero Ave	3.65	0.02	0.03	0.74
GROUNDWATER				
FT1	0.07	0.01	0.02	0.16
FT3	0.25	0.02	0.02	0.35
FT5	9.95	0.01	0.02	0.12
FT6	0.04	0.01	0.01	0.23
FT8	0.09	0.01	0.07	0.33
91-11	0.13	0.01	0.01	0.12
91-12	0.25	0.02	0.03	0.36
ABB1	22.62	0.03	0.01	0.35
ABB5	15.62	0.01	0.02	0.08

*number of samples = 19

Theoretical nitrate concentrations at Zero Avenue were compared with actual measured

concentrations at that station (Figure 5.3.7). Actual nitrate concentrations were lower than expected. During the winter months, it appears as though a greater discrepancy exists between actual and theoretical nitrate concentrations. There are several possible explanations for this discrepancy. One possible explanation could be that the flow gained directly to the creek due to precipitation may have diluted the concentration of nitrates. As well, the estimated background concentrations of nitrate in the infiltrating groundwater may have been too high. This would have led to higher theoretical concentrations. More importantly, the groundwater which infiltrated into the creek may have been near surface groundwater which may have been diluted due to precipitation.

However, bed material below the creek is coarse and it is likely that infiltrating groundwater is entering from below the creek as well. Background nitrate concentrations were fairly consistent at ABB1 and ABB5, and thus should not have been the cause for the discrepancy. The most likely explanation for the difference between theoretical and actual nitrate concentrations in Fishtrap Creek is nitrate reduction or denitrification occurring along the stream bed as groundwater infiltrates into the stream.

An average loss of 1.06 mg N/l (23%) occurred between Huntingdon Avenue and Zero Avenue. The relationship between nitrate loss and fluctuations in flow is presented in Figure 5.3.8. As flow in the creek increased, nitrate-N concentrations decreased and for the most part, these fluctuations in nitrate concentrations and flows appear to be proportional. This evidence would support the explanation for dilution of nitrate concentrations in the stream.

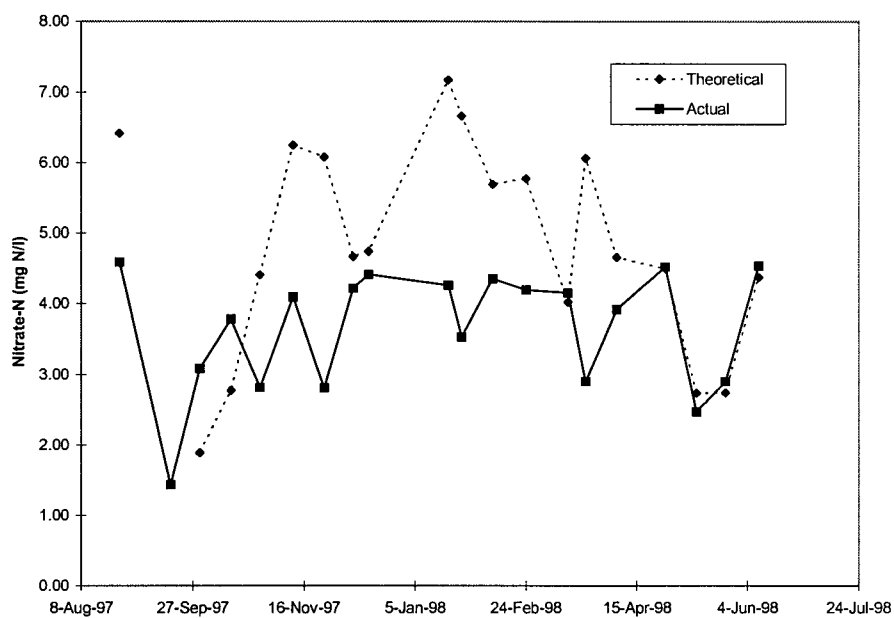
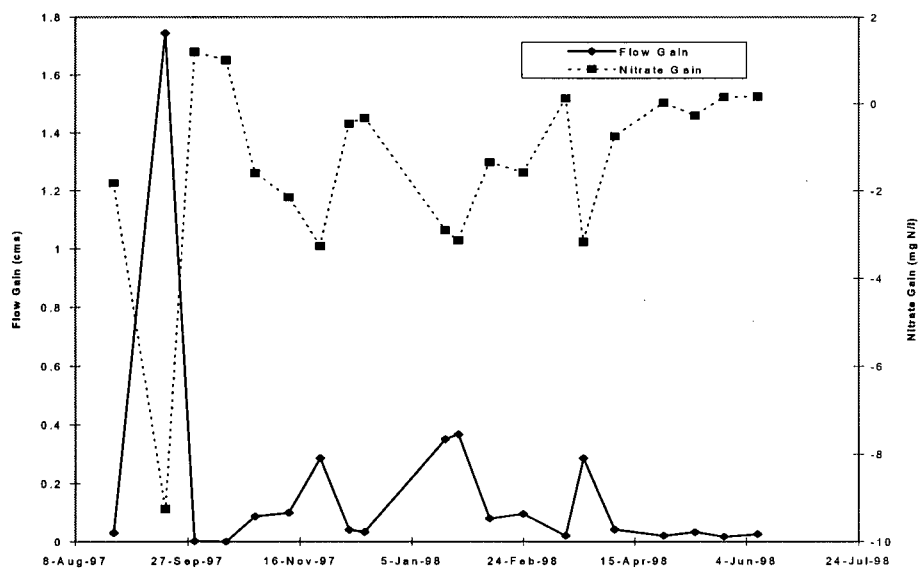


Figure 5.3.7: Comparison of Theoretical and Actual Nitrate Concentration for Fishtrap Creek



5.3.8: Flow Gain and Nitrate Loss Occurring in Fishtrap Creek

Table 5.3.3 is a summary of the mass balance for nitrate-N in Fishtrap Creek and includes a comparison of actual and theoretical concentrations. As well, flows required to balance the nitrate levels expected with those measured directly from the creek were calculated.

Overall, the required flows were negative indicating that a loss in flow would be required to balance nitrate concentrations over the creek. However, flow is known to increase along the creek. This evidence supports the theory that nitrate reduction is definitely occurring along the stream.

A complete mass balance should account for all nitrogen additions and removals over the site. Nitrogen additions include inorganic fertilizer, manure application, and atmospheric nitrogen. Nitrogen removals, which would prevent nitrate from leaching directly into the groundwater, include crop removal, denitrification, and surface runoff. The final component mentioned would carry nitrogen directly into the stream. Stockpiling of manure occurs in the area, and it is estimated that most farmers apply approximately 40 kg/ha/yr (Zebarth et. al, 1994). For the purpose of this study, atmospheric nitrogen was estimated as 30% (11 kg/ha/yr) of the manure N applied which would be lost by volatilization (Zebarth et. al, 1994).

The contribution of nitrogen from inorganic fertilizer was estimated on an annual basis. Wassenaar (1995) reported that 50-70 kg N/ha was applied annually, while personal communication with the farmers indicated that some applied as much as 90 kg N/ha annually. A portion of this fertilizer is diluted at the surface, taken up by crops, denitrified before reaching groundwater, and carried into Fishtrap Creek as surface runoff. Typical estimates of fertilizer penetration vary and in this case, 60 percent was estimated to reach groundwater. Thus approximately 65 kg/ha (including manure and atmospheric contributions) is expected to infiltrate into the groundwater annually. Groundwater recharge for Abbotsford Aquifer was estimated as 37 percent of the annual precipitation, which is 1515 mm. Thus, approximately 600 mm of rainfall carries nitrogen into the groundwater annually. By dividing the mass applied by the annual recharge, an excess of 11 mg/l is entering the groundwater annually. Background concentrations on the west side of Fishtrap Creek within the study area are expected to be similar to those on the east side, and thus the excess nitrogen is not expected to significantly influence the mass balance. Ideally, the presence of wells located on the west side of Fishtrap Creek would have been useful in determining nitrate levels in the groundwater.

Table 5.3.3: Nitrate-N Balance for Fishtrap Creek (mg N/l)

Date	FT5 Flow cms	NO3	Background Flow cms	NO3	Culvert Flow cms	NO3	Ditch Flow cms	NO3	Zero Theoretical	Zero Actual	Gain Actual-Theo	Required Flow cms
25-Aug-97	0.155	3.97	0.03	20.00	0.020	5.14	0.01	5.14	6.42	4.59	-1.83	-0.026
17-Sep-97	1.694	1.32	1.74	20.56	0.080	4.51	0.04	4.51	1.44	1.44		
30-Sep-97	0.655	1.69	0.00	19.53	0.028	4.04	0.01	4.04	1.89	3.08	1.19	0.051
14-Oct-97	0.820	2.48	0.00	20.59	0.076	4.93	0.04	4.93	2.77	3.78	1.01	0.056
27-Oct-97	0.705	2.39	0.09	20.40	0.035	4.95	0.02	4.95	4.41	2.81	-1.60	-0.077
11-Nov-97	0.440	3.44	0.10	19.47	0.049	5.06	0.02	5.06	6.24	4.09	-2.16	-0.086
25-Nov-97	1.331	2.46	0.29	24.12	0.127	4.23	0.06	4.23	6.08	2.81	-3.27	-0.278
8-Dec-97	0.580	3.44	0.04	21.87	0.085	4.73	0.04	4.73	4.67	4.22	-0.45	-0.019
15-Dec-97	0.515	3.39	0.03	22.09	0.074	5.82	0.04	5.82	4.74	4.42	-0.32	-0.012
20-Jan-98	1.363	3.14	0.35	23.95	0.155	6.13	0.22	6.13	7.17	4.26	-2.91	-0.309
26-Jan-98	1.511	2.87	0.37	22.79	0.144	6.14	0.22	6.14	6.66	3.53	-3.14	-0.365
9-Feb-98	0.636	3.52	0.08	22.19	0.116	6.15	0.06	6.15	5.70	4.35	-1.34	-0.067
24-Feb-98	0.627	3.47	0.10	20.00	0.082	6.42	0.04	6.42	5.78	4.19	-1.59	-0.085
15-Mar-98	0.730	3.42	0.02	17.00	0.065	5.81	0.03	5.81	4.02	4.15	0.13	0.008
23-Mar-98	1.140	2.22	0.29	22.00	0.116	5.04	0.06	5.04	6.07	2.90	-3.17	-0.266
6-Apr-98	0.600	3.31	0.04	20.00	0.105	5.66	0.05	5.66	4.66	3.91	-0.74	-0.037
28-Apr-98	0.539	3.81	0.02	17.00	0.033	6.83	0.02	6.83	4.50	4.52	0.03	0.001
12-May-98	0.630	1.77	0.03	16.13	0.025	6.81	0.01	6.81	2.73	2.47	-0.27	-0.014
25-May-98	0.645	2.27	0.02	11.00	0.026	6.60	0.01	6.60	2.74	2.90	0.16	0.014
9-Jun-98	0.553	3.99	0.03	10.00	0.02	6.60	0.01	6.60	4.37	4.54	0.17	0.019
									average		-1.06	-0.08

In general, nitrate concentrations near the surface of an aquifer may be diluted as a result of high rainfall during periods when fertilizer is not applied. In this case, nitrate concentrations at and near the surface would be very low, while slightly lower down, concentrations would be much higher, and then tend to decrease with depth. This surface effect is not expected to effect results of this study since most wells were at least 7 meters below ground surface. However, the mass balance on the creek may be influenced by this factor since groundwater infiltrating into the creek may be near surface groundwater that is lower in nitrate-N concentrations. Bed material below the creek is coarser and it is assumed that infiltrating groundwater is entering from below the creek, and thus the influence of surface dilution is not expected to be a concern.

5.3.4 Minor Constituent Balances

Mass balances for chloride, sulfate, calcium and magnesium were carried out in the same fashion as the nitrate balance. Again, the chemistry found at FT5, ABB1, and ABB5 (shallow wells) was used to compute typical background concentrations for infiltrating groundwater. Tables 5.3.4-5.3.7 summarize mass balances for sulfate, chloride, calcium and magnesium. Sulfate concentrations increased over the creek significantly, while the increase in chloride concentrations was less dramatic. The background concentration of sulfate in the groundwater was significantly higher than that present in Fishtrap Creek, which may account for the large gain experienced along the reach. The increase in sulfate along the creek may be partly attributed to the addition of fertilizer to the land, although no surface runoff was seen flowing into the creek. Sulfate concentrations are higher near the surface, and then decrease with depth (Dasika, 1996).

The reduction of nitrate and increase of sulfate may also be due to the reduction of nitrate by pyrite oxidation. During this reaction, nitrate is reduced to nitrogen gas, while pyrite is oxidized to sulfur and Fe(II) (Appelo and Postma, 1994). Data from the USGS (unpublished data) for a 4 m deep well at Zero Avenue and Fishtrap Creek, indicates the presence of

Table 5.3.4: Sulfate Balance for Fishtap Creek (mg/l)

Date	FT5 Flow cms	SO4	Background Flow cms	SO4	Culvert Flow cms	SO4	Ditch Flow cms	SO4	Zero Theoretical	Zero Actual	Gain Actual-Theo	Required Flow cms
25-Aug-97	0.155	16.25	0.03	55.00	0.020	26.15	0.01	26.15	23.15	16.35	-6.80	-0.038
17-Sep-97	1.694	15.96	1.74	58.27	0.080	26.15	0.04	26.15	37.05	11.63	-25.42	-1.939
30-Sep-97	0.655	18.59	0.00	59.65	0.028	27.06	0.01	27.06	19.23	27.11	7.89	0.169
14-Oct-97	0.820	20.45	0.00	61.43	0.076	41.36	0.04	41.36	22.99	30.17	7.18	0.214
27-Oct-97	0.705	21.54	0.09	56.49	0.035	40.90	0.02	40.90	26.34	25.74	-0.59	-0.016
11-Nov-97	0.440	24.09	0.10	57.70	0.049	35.20	0.02	35.20	30.90	31.23	0.33	0.008
25-Nov-97	1.331	23.27	0.29	51.11	0.127	37.54	0.06	37.54	29.19	23.93	-5.25	-0.350
8-Dec-97	0.580	24.66	0.04	54.89	0.085	33.26	0.04	33.26	27.78	30.76	2.97	0.092
15-Dec-97	0.515	23.74	0.03	49.24	0.074	32.92	0.04	32.92	26.57	30.44	3.87	0.136
20-Jan-98	1.363	13.98	0.35	54.45	0.155	34.26	0.22	34.26	24.42	24.43	0.00	0.000
26-Jan-98	1.511	13.87	0.37	53.96	0.144	34.26	0.22	34.26	23.73	22.57	-1.17	-0.083
9-Feb-98	0.636	12.48	0.08	55.81	0.116	28.50	0.06	28.50	19.47	21.88	2.40	0.063
24-Feb-98	0.627	14.71	0.10	60.93	0.082	27.65	0.04	27.65	21.84	21.65	-0.19	-0.004
15-Mar-98	0.730	11.93	0.02	43.75	0.065	24.21	0.03	24.21	14.11	18.97	4.86	0.166
23-Mar-98	1.140	6.33	0.29	39.89	0.116	25.51	0.06	25.51	14.42	13.82	-0.60	-0.037
6-Apr-98	0.600	13.98	0.04	48.78	0.105	24.97	0.05	24.97	17.98	23.11	5.13	0.160
28-Apr-98	0.539	18.44	0.02	50.20	0.033	24.95	0.02	24.95	20.03	26.55	6.52	0.168
12-May-98	0.630	10.97	0.03	51.96	0.025	24.46	0.01	24.46	13.68	19.17	5.48	0.117
25-May-98	0.645	18.90	0.02	67.00	0.026	22.25	0.01	22.25	20.32	25.00	4.68	0.078
9-Jun-98	0.553	26.20	0.03	67.10	0.02	22.25	0.01	22.25	27.75	34.80	7.05	0.133
										average	2.51	0.05

Table 5.3.5: Chloride Balance for Fishtrap Creek (mg/l)

Date	Huntingdon Flow cms	Cl- Flow cms	Background Flow cms	Cl- Flow cms	Culvert Flow cms	Cl- Flow cms	Ditch Flow cms	Cl- Flow cms	Zero Theoretical	Zero Actual	Gain Actual-Theo	Required Flow cms
25-Aug-97	0.155	6.57	0.03	12.00	0.020	5.26	0.01	5.26	7.16	6.78	-0.38	-0.016
17-Sep-97	1.694	6.28	1.74	11.21	0.080	5.26	0.04	5.26	8.66	6.15	-2.51	-1.766
30-Sep-97	0.655	6.74	0.00	12.00	0.028	4.64	0.01	4.64	6.63	7.97	1.34	0.233
14-Oct-97	0.820	7.21	0.00	11.00	0.076	5.66	0.04	5.66	7.02	7.99	0.97	0.300
27-Oct-97	0.705	7.34	0.09	11.00	0.035	6.63	0.02	6.63	7.67	7.62	-0.06	-0.014
11-Nov-97	0.440	8.55	0.10	11.00	0.049	6.12	0.02	6.12	8.66	8.68	0.02	0.006
25-Nov-97	1.331	4.76	0.29	12.00	0.127	4.78	0.06	4.78	5.91	4.90	-1.01	-0.258
8-Dec-97	0.580	8.52	0.04	12.00	0.085	4.78	0.04	4.78	8.07	8.35	0.27	0.056
15-Dec-97	0.515	12.10	0.03	12.15	0.074	5.90	0.04	5.90	11.07	10.62	-0.44	-0.191
20-Jan-98	1.363	16.15	0.35	12.45	0.155	5.78	0.22	5.78	13.66	14.03	0.37	-0.488
26-Jan-98	1.511	8.00	0.37	11.78	0.144	5.78	0.22	5.78	8.26	8.30	0.04	0.023
9-Feb-98	0.636	8.47	0.08	11.53	0.116	5.97	0.06	5.97	8.25	8.45	0.20	0.058
24-Feb-98	0.627	8.63	0.10	12.37	0.082	6.79	0.04	6.79	8.79	8.36	-0.43	-0.090
15-Mar-98	0.730	7.62	0.02	11.31	0.065	5.59	0.03	5.59	7.48	7.64	0.16	0.037
23-Mar-98	1.140	5.26	0.29	10.88	0.116	4.79	0.06	4.79	6.22	5.21	-1.01	-0.285
6-Apr-98	0.600	8.72	0.04	12.00	0.105	6.60	0.05	6.60	8.48	8.97	0.49	0.130
28-Apr-98	0.539	9.92	0.02	11.00	0.033	7.42	0.02	7.42	9.75	10.10	0.34	0.233
12-May-98	0.630	8.39	0.03	11.00	0.025	7.43	0.01	7.43	8.46	8.54	0.07	0.021
25-May-98	0.645	6.90	0.02	10.80	0.026	6.86	0.01	6.86	7.00	7.60	0.60	0.132
9-Jun-98	0.553	9.10	0.03	9.50	0.02	6.86	0.01	6.86	9.01	8.90	-0.11	-0.108
									average		0.03	-0.03

Table 5.3.6: Calcium Balance for Fishtrap Creek (mg/l)

Date	FT5 Flow cms	Ca 2+ Flow cms	Background Flow cms	Ca 2+ Flow cms	Culvert Flow cms	Ca 2+ Flow cms	Ditch Flow cms	Ca 2+ Flow cms	Zero Theoretical	Actual	Gain Actual-Theo	Required Flow cms
25-Aug-97	0.155	20.40	0.03	30.00	0.020	24.40	0.01	24.40	22.33	27.90	5.57	0.572
17-Sep-97	1.694	19.80	1.74	37.17	0.080	25.30	0.04	25.30	28.50	25.00	-3.50	-1.024
30-Sep-97	0.655	20.80	0.00	38.63	0.028	22.10	0.01	22.10	20.93	24.10	3.17	0.152
14-Oct-97	0.820	19.50	0.00	36.43	0.076	27.80	0.04	27.80	20.51	23.30	2.79	0.198
27-Oct-97	0.705	19.50	0.09	36.73	0.035	28.10	0.02	28.10	21.81	23.50	1.69	0.108
11-Nov-97	0.440	20.90	0.10	41.00	0.049	27.50	0.02	27.50	24.97	28.90	3.93	0.200
25-Nov-97	1.331	20.50	0.29	37.97	0.127	21.50	0.06	21.50	23.37	23.50	0.13	0.016
8-Dec-97	0.580	29.50	0.04	35.00	0.085	23.50	0.04	23.50	28.78	25.00	-3.78	-0.283
15-Dec-97	0.515	20.60	0.03	29.00	0.074	25.60	0.04	25.60	21.86	28.30	6.44	6.058
20-Jan-98	1.363	18.40	0.35	43.70	0.155	32.40	0.22	32.40	25.17	21.90	-3.27	-0.313
26-Jan-98	1.511	18.30	0.37	44.27	0.144	29.30	0.22	29.30	24.33	22.60	-1.73	-0.179
9-Feb-98	0.636	16.50	0.08	34.13	0.116	22.30	0.06	22.30	19.21	18.40	-0.81	-0.046
24-Feb-98	0.627	16.20	0.10	33.23	0.082	21.20	0.04	21.20	18.86	17.50	-1.36	-0.073
15-Mar-98	0.730	15.50	0.02	34.37	0.065	18.20	0.03	18.20	16.27	15.90	-0.37	-0.017
23-Mar-98	1.140	16.10	0.29	38.87	0.116	19.20	0.06	19.20	20.51	16.50	-4.01	-0.287
6-Apr-98	0.600	19.20	0.04	34.00	0.105	20.20	0.05	20.20	20.18	21.00	0.82	0.050
28-Apr-98	0.539	18.20	0.02	32.37	0.033	20.00	0.02	20.00	18.82	18.70	-0.12	-0.005
12-May-98	0.630	17.20	0.03	30.00	0.025	21.60	0.01	21.60	18.06	17.70	-0.36	-0.020
25-May-98	0.645	15.10	0.02	28.00	0.026	20.20	0.01	20.20	15.71	18.70	2.99	0.225
9-Jun-98	0.553	22.00	0.03	31.00	0.02	20.20	0.01	20.20	22.30	23.10	0.80	0.062
										average	0.45	0.33

Table 5.3.7: Magnesium Balance for Fishtrap Creek (mg/l)

Date	FT5 Flow cms	Mg 2+ Flow cms	Background Flow cms	Ca 2+ Flow cms	Culvert Flow cms	Mg 2+ Flow cms	Ditch Flow cms	Mg 2+ Flow cms	Zero Theoretical	Zero Actual	Gain Actual-Theo	Required Flow cms
25-Aug-97	0.155	5.30	0.03	7.00	0.020	2.90	0.01	2.90	5.21	5.10	-0.11	-0.01
17-Sep-97	1.694	4.90	1.74	7.80	0.080	2.90	0.04	2.90	6.25	4.50	-1.75	-1.89
30-Sep-97	0.655	3.50	0.00	7.60	0.028	4.10	0.01	4.10	3.55	4.10	0.55	0.11
14-Oct-97	0.820	3.80	0.00	7.00	0.076	3.60	0.04	3.60	3.77	4.60	0.83	0.32
27-Oct-97	0.705	3.60	0.09	7.30	0.035	3.60	0.02	3.60	3.98	3.50	-0.48	-0.11
11-Nov-97	0.440	4.70	0.10	7.20	0.049	3.60	0.02	3.60	4.97	5.20	0.23	0.07
25-Nov-97	1.331	3.40	0.29	8.20	0.127	3.30	0.06	3.30	4.15	2.80	-1.35	-0.45
8-Dec-97	0.580	4.50	0.04	7.20	0.085	3.30	0.04	3.30	4.44	4.80	0.36	0.11
15-Dec-97	0.515	4.80	0.03	8.70	0.074	3.90	0.04	3.90	4.85	5.20	0.35	0.07
20-Jan-98	1.363	3.30	0.35	7.90	0.155	3.70	0.22	3.70	4.14	6.80	2.66	5.05
26-Jan-98	1.511	3.10	0.37	7.90	0.144	3.70	0.22	3.70	3.98	3.40	-0.58	-0.29
9-Feb-98	0.636	3.20	0.08	6.80	0.116	2.80	0.06	2.80	3.44	3.60	0.16	0.04
24-Feb-98	0.627	3.60	0.10	7.30	0.082	3.20	0.04	3.20	3.96	4.00	0.04	0.01
15-Mar-98	0.730	3.70	0.02	8.60	0.065	3.30	0.03	3.30	3.77	4.00	0.23	0.04
23-Mar-98	1.140	2.80	0.29	8.00	0.116	2.80	0.06	2.80	3.73	3.00	-0.73	-0.23
6-Apr-98	0.600	4.70	0.04	6.90	0.105	2.10	0.05	2.10	4.31	5.20	0.89	0.42
28-Apr-98	0.539	4.60	0.02	6.80	0.033	3.80	0.02	3.80	4.61	5.40	0.79	0.34
12-May-98	0.630	4.90	0.03	6.00	0.025	5.20	0.01	5.20	4.97	4.70	-0.27	-0.15
25-May-98	0.645	4.10	0.02	7.20	0.026	5.80	0.01	5.80	4.27	4.40	0.13	0.03
9-Jun-98	0.553	5.00	0.03	6.00	0.02	5.80	0.01	5.80	5.08	5.20	0.12	0.09
						average					0.20	0.32

elevated iron levels in the groundwater. Groundwater extracted at this location contains relatively higher colour than at other locations, possibly indicating the greater presence of iron. Nitrate reduction coupled with pyrite oxidation (Equations 2.1 and 2.2) is also characterized by a reduction in pH, while carbonaceous denitrification (Equations 2.4 and 2.5) is characterized by a rise in pH. During this research, the pH was found to fluctuate between upstream and downstream locations. No specific pattern can be derived and thus, it is difficult to conclusively distinguish denitrification from nitrate reduction by pyrite oxidation. In any case, this evidence demonstrates that nitrate reduction is occurring along Fishtrap Creek.

Calcium gains and losses were extreme, and the average change is not representative. Background calcium concentrations infiltrating the creek ranged from 28 mg/l to 45 mg/l. Calcium concentrations appear to be influenced by seasonal variation, decreased concentrations occurring in lower flow periods. Variations of magnesium concentrations were less extreme, with an average gain of 0.20 mg/l over the reach of Fishtrap Creek. Background concentrations in the groundwater were slightly higher than the concentrations present in the creek, but in both cases were fairly low.

As discussed in Chapter 2, chloride to nitrate ratios were used to study dilution in previous studies on the Abbotsford aquifer. Dasika (1996) concluded that some denitrification was occurring using nitrate to chloride ratios. Table 5.3.8: is a summary of the mass balances, containing the gains and losses experienced along the segment of Fishtrap Creek studied. By comparing the gain/loss of a conservative tracer to that of nitrate, the amount of nitrate loss due to dilution can be assessed. Chloride gains/losses appear to be more consistent than those of sulfate, and are comparable to those of nitrate. On several occasions, nitrate and chloride gains/losses are very similar, while other sampling dates show a gain in chloride and a loss in nitrate. Dates with significant differences include October 27, 1997; November 11-25, 1997; January and February sampling dates; and April 6, 1998. During these periods, processes other than dilution probably contributed to nitrate reduction over the reach.

Table 5.3.8: Summary of Mass Balances

Date	Gain/Loss (mg/l) in Creek			Calcium	Magnesium
	NO3	Sulfate	Chloride		
25-Aug-97	-1.83	-6.80	-0.38	5.57	-0.11
17-Sep-97		-25.42	-2.51	-3.50	-1.75
30-Sep-97	1.19	7.89	1.34	3.17	0.55
14-Oct-97	1.01	7.18	0.97	2.79	0.83
27-Oct-97	-1.60	-0.59	-0.06	1.69	-0.48
11-Nov-97	-2.16	0.33	0.02	3.93	0.23
25-Nov-97	-3.27	-5.25	-1.01	0.13	-1.35
8-Dec-97	-0.45	2.97	0.27	-3.78	0.36
15-Dec-97	-0.32	3.87	-0.44	6.44	0.35
20-Jan-98	-2.91	0.00	0.37	-3.27	2.66
26-Jan-98	-3.14	-1.17	0.04	-1.73	-0.58
9-Feb-98	-1.34	2.40	0.20	-0.81	0.16
24-Feb-98	-1.59	-0.19	-0.43	-1.36	0.04
15-Mar-98	0.13	4.86	0.16	-0.37	0.23
23-Mar-98	-3.17	-0.60	-1.01	-4.01	-0.73
6-Apr-98	-0.74	5.13	0.49	0.82	0.89
28-Apr-98	0.03	6.52	0.34	-0.12	0.79
12-May-98	-0.27	5.48	0.07	-0.36	-0.27
25-May-98	0.16	4.68	0.60	2.99	0.13
9-Jun-98	0.17	7.05	-0.11	0.80	0.12
Average	-1.06	2.51	0.03	0.45	0.20

Table 5.3.9 is a summary of calculations for required flows that would result in a net balance over the stream. Again comparing nitrate and chloride, flows are generally similar for various sampling events. Significant difference exist for several dates, including September 30, 1997; October 14, 1997; January 26, 1998; and April 6-28, 1998. These results also suggest that other processes besides dilution are contributing to nitrate reduction. In general, a negative flow is required to balance nitrate concentrations, suggesting that a loss of flow would have to occur in order to result in a net balance over the segment. However, from the flow balance it is known that flow was gained over the reach, and thus nitrate reduction must be occurring by means other than dilution.

Table 5.3.9: Summary of Required Flow Calculations

Date	Flow required (cms)			Calcium	Magnesium
	Nitrate	Sulfate	Chloride		
25-Aug-97	-0.03	-0.04	-0.02	0.57	-0.01
17-Sep-97		-1.94	-1.77	-1.02	-1.89
30-Sep-97	0.05	0.17	0.23	0.15	0.11
14-Oct-97	0.06	0.21	0.30	0.20	0.32
27-Oct-97	-0.08	-0.02	-0.01	0.11	-0.11
11-Nov-97	-0.09	0.01	0.01	0.20	0.07
25-Nov-97	-0.28	-0.35	-0.26	0.02	-0.45
8-Dec-97	-0.02	0.09	0.06	-0.28	0.11
15-Dec-97	-0.01	0.14	-0.19	6.06	0.07
20-Jan-98	-0.31	0.00	-0.49	-0.31	5.05
26-Jan-98	-0.36	-0.08	0.02	-0.18	-0.29
9-Feb-98	-0.07	0.06	0.06	-0.05	0.04
24-Feb-98	-0.08	0.00	-0.09	-0.07	0.01
15-Mar-98	0.01	0.17	0.04	-0.02	0.04
23-Mar-98	-0.27	-0.04	-0.28	-0.29	-0.23
6-Apr-98	-0.04	0.16	0.13	0.05	0.42
28-Apr-98	0.00	0.17	0.23	-0.01	0.34
12-May-98	-0.01	0.12	0.02	-0.02	-0.15
25-May-98	0.01	0.10	0.01	0.23	0.03
9-Jun-98	0.02	0.06	0.02	0.06	0.09
Average	-0.08	0.05	-0.03	0.33	0.32

5.3.5 Hydraulic Conductivity

The horizontal hydraulic conductivity was studied using Darcy's Law which describes the specific discharge as $v = -kdh/dx$. The velocity (m/s) is a function of permeability (k), and the one dimensional hydraulic gradient (dh/dx). The Darcy velocity is defined as specific discharge per unit area A of the aquifer (Appelo and Postma, 1994). The permeability of the aquifer was tested by performing falling head tests at several well locations within the study area. In all cases, an accurate value could not be obtained due to the high permeability of the aquifer. Typical permeability values for sand and gravel range from 10^{-2} to 10^{-4} . From the results of the falling head tests, the permeability is estimated to be greater than 10^{-4} m/s.

Pore water velocities between various wells and the creek were calculated by dividing the specific discharge by the porosity. The porosity of sand and gravel aquifers varies between

0.15 and 0.35 and was taken as 0.30. The distance between the wells was calculated from known co-ordinates, and the difference in head was calculated from field measurements of the water table. The pore water velocities between FT3 and the creek; FT1 and the creek; FT6 and the creek; ABB5 and FT1; and finally ABB1 and FT3 were calculated as 2.22 m/day, 4.80 m/day, 4.80 m/day, 0.09 m/day, and 0.24 m/day respectively. All calculations have been included in Appendix B. Typical values for hydraulic conductivity within the Abbotsford Aquifer are 0.05-0.41 m/day. Pore water velocities are much higher closer to the creek as a result of higher gradients. An understanding of the velocity is important when examining changes in groundwater chemistry between different locations. In most cases when comparing the chemistry of the well, bi-monthly data is sufficient due to the relatively high groundwater flows. However, water chemistry at FT1 may not be influenced by changes in groundwater chemistry at ABB5 for years. However, previous data indicates that the chemistry in this well is fairly consistent.

The vertical hydraulic conductivity was examined by observing water levels in nested piezometers. Several wells contained piezometers for two or three depths, including FT1, FT3, FT5, FT6, and FT8. FT1 contained two functioning piezometers including the one sampled at a depth of 12 meters, and one at 2.5 meters. The depth to the water was consistently greater (approximately 30 cm) in the shallower well, indicating upward vertical movement. Overall, depths within piezometers at the same location were very similar.

5.3.6 Occurrence of Denitrification

A gain in flow typically occurred over the studied segment of Fishtrap Creek mostly due to infiltrating groundwater. Groundwater seeps were seen over the course of study indicating mixing of groundwater and stream water occurs. The elevation of groundwater was generally higher than that of the stream water for over two thirds of the study area. As a result of this occurrence and due to the proximity of the water table to the ground surface, groundwater flow is probably influenced by the discharge area and by topography. Thus, local flows will vary from

the regional groundwater flow, which is to the southwest. Hydraulic conductivity testing revealed pore water velocities ranging from 0.09-4.8 m/day. For the purpose of this study, comparing chemistry data from various locations on a bi-monthly basis was felt to be sufficient.

Nitrogen balances along the stream demonstrate that theoretical nitrate levels at Zero Avenue should be higher than actual concentrations. This difference appears to mostly due to the reduction of nitrate which is occurring along the stream. In terms of mass flux, the average nitrogen flux in Fishtrap Creek as it crosses the international boundary was 3.69×10^{-3} kg N/s. Mass balances of conservative tracers are useful in estimating dilution potential of nitrate along the stream. Results of the chloride balances appeared to be fairly stable and were used for comparisons. During several sampling dates, chloride loss was less than that of nitrate indicating that processes other than dilution may have led to the decreasing nitrate concentration along the stream. As well, computed flows which would be required to result in zero gain/loss were compared. On several occasions flows required to balance nitrate and chloride were similar, while on other sampling days, a loss of flow would be required for nitrate and a gain for chloride. This evidence also supports the occurrence of nitrate reduction occurring along Fishtrap Creek.

5.4 Overview and Summary

The objective of this research was to determine whether or not denitrification is occurring and to better understand the relationship between the stream and the groundwater. The results obtained over the course of this research were presented in the previous three sections. In order to fully assess processes which are occurring within and over the site, all three sections must be considered simultaneously.

The potential for denitrification exists since the four main components which are required conditions were found to be present at the site. Jar test confirmed that nitrate reduction was possible, and although some reduction may have occurred due to nitrate assimilation and reduction to ammonia, dissolved oxygen levels in the water were indicative of denitrification

potential. Dissolved oxygen levels were low in areas where nitrate concentrations were low, and high where nitrate levels were high. These findings suggest that areas over the site where denitrification is occurring exist where both nitrate and dissolved oxygen levels are low. The potential for aerobic denitrification has been studied in the field of wastewater treatment with some success. However, the author holds no knowledge of similar studies performed in the form of an aquifer study. A carbon source was confirmed from TOC tests and was also assumed to exist due to the unique geological setting. Shake tests indicated that the carbon source is available for denitrification since it was found to dissolve into solution. The most likely region for denitrification to be occurring is in the area along the creek, not only because of the unique geology, but also as a result of carbon being available in bed material. The final condition for denitrification is the presence of nitrate. Monitoring by Environment Canada has shown an increasing trend in nitrate concentrations over the aquifer. However, only three wells over the study site exceeded the MAC, indicating that nitrate reduction has occurred in this area. Nitrate concentrations in Fishtrap Creek were higher than typical surface water nitrate concentrations.

Nitrate levels at Zero Avenue are lower than expected from the nitrogen mass balance. This area is a groundwater discharge area, and the probability that surface and ground waters are mixing is strong due to relative differences in flow velocities. Concentrations of sulfate increase between Huntingdon Avenue and Zero Avenue, as does surface water temperature. Surface water pH varies and no specific pattern was determined. Thus, distinguishing between nitrate reduction due to pyrite oxidation and denitrification is very difficult. Bicarbonate concentrations will increase as a result of denitrification which utilizes organic carbon as its electron donor. An increase in bicarbonate concentrations was observed between FT3 bridge and Zero Avenue. As well, bicarbonate concentrations at FT1 and FT6 are elevated indicating denitrification may have occurred as surface water exfiltrates near FT6 and at FT1. The presence of nitrite in low concentrations supports reasoning that denitrification is occurring since nitrate is reduced first to nitrite and then further to nitrogen gas during denitrification (Appelo and

Postma, 1994).

Stiff diagrams and piper plots were employed to categorize and group waters from various locations. Results in both cases were similar. Relating results from chemical analyses with water level results provides insight as to flow direction and mixing over the site. Chemistry of groundwater at several sites resembled that of surface water including FT5, 91-11, and ABB5. FT5 is located in the north end of the site, approximately 3 meters away from the stream bank. Water level measurements indicated that groundwater elevations are similar to surface water elevations, suggesting mixing of the two waters is likely. Flow is lost between Huntingdon Avenue and this point, and it is expected that due to topography and the influence of regional groundwater flow, the surface water returns to the creek south of FT5. This explanation would account for the influence of surface water at FT5.

Farther south in the study area, it was expected that local flows on the west side of Fishtrap Creek would mirror those on the eastern side. However, the chemistry of water at FT3 and FT6 were fairly different. Groundwater levels are higher than surface water elevations, indicating this is a discharge area. Exfiltrated surface water from the northern portion of the site is expected to be returned to the creek as flows near the surface would be drawn into the creek. Surface water tended to influence groundwater at FT6, although bicarbonate concentrations are elevated. FT6 is closer to the stream than FT3 which may explain the increased influence seen at FT6. As well, the culvert located just south of FT3 may be influencing groundwater flows, causing pooling and forcing near surface groundwater flows to be redirected further to the west.

91-11 and 91-12 are located only 3 meters apart near the green house property, however, the chemistry of water at these two locations is significantly different. Concentrations of sulfate, chloride, calcium and magnesium are much greater at 91-12 which is the shallower of the two. As well, temperatures at 91-12 are significantly higher, which may be a result of recycled flow from the green house being returned to the ground. These results combined with other results found from examining stiff diagrams indicate that various types of waters exist at different depths over the aquifer. Water level measurements at various nested piezometers

indicated that little vertical conductivity exists over the site, which supports results which indicate chemistry differs between vertical depths.

Dilution is partially responsible for decreasing nitrate concentrations over the site. Examining dilution of conservative tracers between two wells and comparing this with decreases of nitrate concentrations may indicate the potential occurrence of denitrification. On several occasions, the amount of chloride dilution occurring between ABB1 and FT5 compared to that of nitrate indicated that another means of nitrate reduction exists. Similar results were found when comparing dilutions between ABB1 and FT3. Groundwater chemistry at ABB5 and FT1 were examined in a similar fashion, but no comparisons were possible since concentrations of sulfate, chloride, and calcium increased significantly while nitrate decreased at FT1. Temperature and pH appeared to be influenced by surface water at FT1, as did concentrations of bicarbonate. However, concentrations of sulfate and calcium were higher at FT1 than in the surface water. At this location, water level measurements in two piezometers indicate that upward movement of groundwater drawn into the creek is typically occurring.

Mass Balances were compared for nitrate and chloride since gains/losses over the stream were reasonably similar. On several occasions, chloride loss was significantly less than that of nitrate, indicating other methods of nitrate reduction besides dilution must be occurring. Comparing flows which would be required to balance nitrate and chloride also suggested the same final result.

Although Fishtrap Creek serves as a nitrogen source, it carries approximately 3.72 mg N/l or 3.69×10^{-3} kg N/s across the international border. Nitrogen reduction along the creek is estimated as approximately 1.02 mg N/l or 14 % of the incoming flux of nitrogen in the creek. The groundwater flow is generally to the south, and in order to assess the amount of nitrogen being carried across the border through subsurface water, wells along the border should be considered. Nitrate concentrations in wells along the creek are generally low, especially in the south portion of the study area. Thus groundwater in close proximity to the stream is not expected to be carrying significant quantities of nitrogen across the border. However, the nitrate

concentration in shallow groundwater at ABB5, which is at the international boundary, consistently exceeded the MAC limit over the course of the study. The mass flux of nitrogen being transported by groundwater in this area is expected to be approximately 2.0×10^{-8} kg N/m²/s (2.0×10^{-3} kg N/m²/day) based on estimates of pore water velocity and an average nitrate concentration of 17 mg N/l. Based on a background nitrate concentration of 25 mg N/l in the groundwater, it is estimated that a reduction of approximately 9 mg N/l or 36 % of the background nitrate concentration is occurring across the site.

In considering these results collectively, evidence supports the theory that nitrate reduction is occurring within the area of study. Conditions which are conducive to denitrification exist in the area. The geological setting in this area, which is quite unique, appears to provide an environment which supports nitrate reduction. Dilution ratios between sites indicates that other nitrate reducing processes must be occurring. Studies on the minor constituents present over the site demonstrated that nitrate concentrations were decreasing at a greater rate compared to chloride during some sampling periods, suggesting nitrate removal from upstream to downstream locations. Groundwater influences were seen occurring along the stream reach, as were surface water influences to groundwater at shallow depths. It is obvious from both water level measurements and water chemistry data that an intimate relationship exists between the groundwater and Fishtrap Creek.

The implications of this research, including mitigation and basin management, will be discussed in the following chapter.

5.5 QA/QC Results

Due to the frequency of sampling, duplicate sampling was not always performed. On the occasion that duplicate sampling was carried out for chemical analyses, results were within 5 percent. Field blanks were used to account for entrainment of atmospheric nitrogen and for the most part contained nitrogen levels below detection. Laboratory blanks were included in the analysis to account for interferences from preservation and acidification. In most cases, the lab

blank contained concentrations at or below the detection level.

Spiked samples were included during several analyses and were found to be within 5 percent of the known concentration. Spike recovery was analysed and results were considered reliable only when the recovery was 100 ± 20 percent.

6.0 IMPLICATIONS OF RESEARCH

As is the case with all research, it is necessary to discuss the implications of the findings. This chapter discusses the usefulness of the study and outlines mitigation and basin management techniques.

6.1 Implications

The results of this study find conclusively that nitrate reduction is occurring in the study area. Findings from water level monitoring and analysis of chemistry suggest that Fishtrap Creek is an important nitrogen sink. The groundwater chemistry present over the site influences that of the surface water, and this influence is related to the amount of flow gained between upstream and downstream locations. A nitrate loss of approximately 14 percent occurs between Huntingdon Ave and Zero Ave, resulting in a nitrogen flux of approximately 3.69×10^{-3} kg/s crossing the international border. The precision of most analytical chemistry methods were high, however, the reliability of this study depends more on the precision of the flow measurements. This study is the first to examine the flow of Fishtrap Creek, and consider its importance in nitrate reduction over the aquifer. Thus, no comparison to other flow measurements are possible. Flow measurements are felt to be fairly reliable and are accurate within +/- 5%.

These results are unique to the study area, and may not be applicable to areas south of the border. It may be the case that the creek remains as a significant nitrogen source below the border as well. However, further research is required. The following section outlines mitigation methods, and discusses basin management.

6.2 Mitigation and Basin Management

Several agricultural management studies have been carried out by Agriculture and Agri-Food Canada, in conjunction with work done at the Agassiz Research Station. Most of these studies are aimed towards educating the public, providing guidelines for fertilizer and manure

application for various crops. Overall, these studies suggest that nitrate contamination in the Abbotsford Aquifer is partially attributable to excess nitrate leaching resulting from poor agricultural practices. It takes only 1 kg of actual nitrogen to bring 100,000 L of water up to the drinking water standard on 10 mg N/l (Zebarth et al., 1994). At present, only a general fertilizer recommendation of 55 kg N/ha for raspberries exists. However, soil tests, which estimate fertilizer requirements based on soil and crop type, may be useful for improved practices. Information on these types of tests is available from Agriculture and Agri-Food Canada.

Raspberry N uptake occurs throughout the growing season, with total uptake reaching a maximum in August (Zebarth et al., 1994). Total N uptake by the crop is often no more than 120 kg N/ha, due to low plant density (Zebarth et al., 1994). The use of cover crops, such as rye and oats, can be effective in reducing nitrate leaching over the fall and winter. Studies have shown that the amount of N taken up by the cover crop was significant, averaging about 80 kg N/ha (Zebarth et al., 1994). Cover crops should be planted as early as possible in order to maximize nitrogen uptake.

Other mitigation practices include altering the practices currently employed for manure spreading. Application of manure should be during the spring and summer, similar to fertilizers. This avoids excess nitrate remaining immediately before the winter precipitation begins. Stockpiling of manure should be minimized since leaching potential is high especially during months of greater precipitation.

Continuing studies which investigate optimal application rates of fertilizers coupled with education of the community farmers will improve agricultural practices.

7.0 Conclusion and Recommendations

7.1 Conclusion

In this study, ground and surface water within a square mile area of the Abbotsford Aquifer was monitored. Water chemistry, water table fluctuations, and surface water flows were each continuously observed on a bi-monthly bases over a period of 11 months. Results were grouped together according to three categories: Conditions for Denitrification; Water Chemistry; and Mass Balances. These results were studied concurrently in order to determine seasonal and temporal trends. The objective of this study was to determine if in-situ denitrification is naturally occurring, and also to develop a better understanding of the relationship that exists between the groundwater and Fishtrap Creek.

Conditions which support denitrification are present in the study area:

1. Nitrate reduction occurred in a reducing environment during jar tests, suggesting the presence of denitrifying bacteria.
2. Dissolved oxygen levels ranged between less than 1 mg/l to 10 mg/l.
3. A carbon source was confirmed from TOC tests and also assumed from the surrounding geology.
4. The presence of nitrate has been confirmed during this research.

Water Chemistry reveals several different water types are present throughout the aquifer. A flow balance was carried out and results indicated that flow is typically lost between Huntingdon Avenue and the bridge at FT5, and gained along the creek south of FT5. The results of this study contrast the common belief that groundwater flow supplies baseflow to the creek for six months of the year and then for the remaining six months, Fishtrap Creek provides recharge to the aquifer. Water level data accompanied by the flow balance results suggest that, with the exception of the segment between Huntingdon and the bridge at FT5, groundwater infiltrates into the creek throughout the whole year. These results may be exclusive to the

segment of Fishtrap Creek studied during the analysis, and the overall discharge/recharge relationship may differ for the entire stream. Mass balances of nitrate, chloride, sulfate, calcium and magnesium were useful for comparing changes in concentration over the stream reach, as well as, flows required to balance various ions. The compilation of this data is useful in studying mixing, dilution, and the potential for denitrification:

1. Water chemistry at Zero Avenue is representative of a mixture of water at Huntingdon Avenue and the major culvert. Gains in sulfate, temperature, and pH from upstream to downstream locations indicate that infiltrating groundwater is influencing the surface water chemistry.
2. Groundwater at FT5, and FT6, which are both located very close to Fishtrap Creek, appears to be influenced by surface water.
3. Comparison of dilution ratios between several wells reveals that nitrate is reduced in greater proportions than chloride during several sampling periods, indicating other means of nitrate reduction are occurring.
4. Comparisons of gain/loss concentrations of chloride with nitrate reveal that a much greater loss of nitrate occurs along Fishtrap Creek, indicating further nitrate reduction, besides dilution, is occurring.

The amount of nitrogen reduction occurring along Fishtrap Creek, as well as in the subsurface have been approximated using the flow and nitrogen balance along with hydraulic conductivity estimates. As well, the amount of nitrate being carried across the international border by Fishtrap Creek and in the groundwater have been estimated using the flow and mass balances along with a background groundwater nitrate concentration estimate of 25 mg N/l. These results include:

1. A reduction of 14% or 1.02 mg N/l is occurring in Fishtrap Creek between upstream and downstream location.
2. A reduction of 36% or 9 mg N/l is occurring in the groundwater across the segment of

the aquifer that was considered in this study.

3. A mass flux of approximately 3.69×10^{-3} kg/s (3.72 mg N/l) is carried across the international border by Fishtrap Creek.
4. A mass flux of approximately 2.0×10^{-8} kg N/m²/s is carried across the international border in the groundwater in the far eastern portion of the study area. The groundwater in close proximity to Fishtrap Creek contains very low concentrations of nitrate-N.

Groundwater flow over the site has been found to be influenced by several factors including:

1. Geology of the surrounding area, which is sand and gravel, is very permeable and allows for relatively high pore water velocities.
2. The presence of Fishtrap Creek and the surrounding topography in the northwest portion of the site probably forces groundwater flow to travel in a more southerly direction than the regional groundwater flow.
3. The water table is fairly close to the ground surface in several areas, in which case, topography plays a larger role influencing on flow.
4. The presence of the culvert just south of FT3 probably influences near surface groundwater to flow in a more westerly direction on the east side of the creek.

It is obvious from results of this study that Fishtrap Creek serves as a nitrogen sink and plays a major role in nitrate reduction over the site. However, these conditions may be unique to this area, and may not be representative of what is occurring across the border.

The first step in reducing nitrate contamination of groundwater is to aim to reduce the application of nitrogenous fertilizer and manure. Other mitigation techniques include the use of winter cover crops and restricting fall spreading. Continued studies which investigate optimizing

the use of fertilizer for crop production are necessary for increased protection of this groundwater resources.

7.2 Recommendations

Some ideas for future research are proposed:

1. Monitoring the concentration of FeS in the area would aid in distinguishing between nitrate reduction due to pyrite oxidation and denitrification. Aside from this method, the use of stable isotopes accompanied by measurements of nitrogen gas production may better quantify denitrification rates.
2. Similar studies south of the border would help complete an overall look at the entire aquifer.
3. Further monitoring of water chemistry and flows over a 12 month period would clearly provide further understanding of seasonal variation.
4. Background groundwater concentrations were estimated from wells in the area which were in the middle or southern part of the study boundaries. It would be beneficial to construct wells in the northern boundary along Huntingdon Avenue. Chemistry at this location is fairly unknown and may be useful in developing groundwater flow patterns.
5. The installation of wells on the western side of Fishtrap Creek would be useful in further understanding the relationship between Fishtrap Creek and the groundwater. As well, chemistry at this location would be useful in developing groundwater flow patterns.
6. Groundwater chemistry at shallower depths near FT1, FT8, FT3, and FT6 may reveal further trends related to changes in chemistry along the groundwater flow path.

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APPENDIX A: RAW DATA

Location:		Zero and Fish Trap Creek																		
Surface/GW:		Surface																		
Date	Nitrogen Balance (mg N/L)			Metals (mg/L)		Tracers (mg/L)			temp (°C)	DO (ppm)	pH	Flow (cms)								
	NO3	NO2	NH3	Ca	Mg	Na	K	SO4					Cl	HCO3						
25-Aug-97	4.59	0.05	0.008	27.9	5.1	7.7	1.7	16.4	6.8	75.0	12.6	9.3	6.81	0.22						
17-Sep-97	1.44	0.02	0.107	25.0	4.5	5.5	1.4	11.6	6.1	75.0	12.8	6.3	6.74	3.56						
30-Sep-97	3.08	0.02	0.034	24.1	4.1	6.0	1.5	27.1	8.0	65.0	12.9	6.9	6.82	0.70						
14-Oct-97	3.78	0.02	0.047	23.3	4.6	6.3	1.5	30.2	8.0	65.0	11.1	8.5	6.84	0.93						
27-Oct-97	2.81	0.02	0.007	23.5	3.5	5.1	1.5	25.7	7.6	65.0	10.4	7.8	6.59	0.84						
11-Nov-97	4.09	0.03	0.078	28.9	5.2	6.4	1.5	31.2	8.7	65.0	8.3	8.3	7.20	0.61						
25-Nov-97	2.81	0.04	0.078	23.5	2.8	3.5	1.4	23.9	4.9	65.0	6.5	9.2	6.62	1.81						
8-Dec-97	4.22	0.03	0.050	25.0	4.8	6.7	1.7	30.8	8.3	65.0	6.8	9.1	7.17	0.75						
15-Dec-97	4.42	0.03	0.011	28.3	5.2	7.6	1.5	30.4	10.6	65.0	7.1	9.1	7.25	0.66						
20-Jan-98	4.26	0.02	0.054	21.9	6.8	8.0	1.5	24.4	14.0	65.0	6.0	8.6	7.27	2.09						
26-Jan-98	3.53	0.03	0.019	22.6	3.4	5.6	1.4	22.6	8.3	54.0	7.9	9.0	6.72	2.24						
9-Feb-98	4.35	0.02	0.025	18.4	3.6	6.0	1.4	21.9	8.5	50.0	9.1	9.0	7.09	0.89						
24-Feb-98	4.19	0.02	0.000	17.51	4.0	6.2	1.4	21.7	8.4	48.0	7.8	9.0	6.79	0.85						
15-Mar-98	4.15	0.02	0.038	15.9	4.0	5.7	1.5	19.0	7.6	48.0	10.2	7.0	7.17	0.85						
23-Mar-98	2.90	0.03	0.000	16.5	3.0	4.3	1.2	13.8	5.2	47.0	9.2	11.0	6.89	1.60						
6-Apr-98	3.91	0.01	0.022	21.0	5.2	6.7	2.4	23.1	9.0	54.0	11.3	12.2	7.19	0.80						
28-Apr-98	4.52	0.01	0.000	18.7	5.4	6.9	1.6	26.6	10.1	54.0	13.9	12.2	7.37	0.61						
12-May-98	2.47	0.01	0.000	17.7	4.7	5.6	1.1	19.2	8.5	58.0	12.9	9.7	7.31	0.70						
25-May-98	2.90	0.02	0.000	18.7	4.4	5.0	1.1	25.0	7.6	54.4	9.2	8.5	7.30	0.70						
9-Jun-98	4.54	0.01	0.000	23.1	5.2	11.84	2.02	34.8	8.9	68.6	10.2	9.1	7.33	0.61						

Table A2: Data for Culvert Location

Location:	Major Agricultural Ditch																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																				
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Table A3: Data for Fishtrap Creek at Huntingdon Avenue

Location:		Huntingdon and Fish Trap Creek															
Surface/GW:	Surface																
		Nitrogen Balance				Metals				Tracers							
Date		NO3	NO2	NH3		Ca	Mg	Na	K	SO4	Cl	HCO3	temp	DO	pH	Flow	
	mg/L												(oC)	(ppm)			
25-Aug-97	3.97	0.04	0.012	0.012	20.4	5.3	7.7	1.6	1.6	16.3	6.6	61	12.5	9.4	6.22	0.17	
17-Sep-97	1.32	0.03	0.072	0.072	19.8	4.9	6.5	1.5	1.5	16.0	6.3	61	13.5	5.9	7.42	1.71	
30-Sep-97	1.69	0.02	0.056	0.056	20.8	3.5	5.1	1.4	1.4	18.6	6.7	61	13.4	7.6	5.34	0.68	
14-Oct-97	2.48	0.02	0.038	0.038	19.5	3.8	5.9	1.5	1.5	20.4	7.2	61	11.1	8.4	7.23	0.84	
27-Oct-97	2.39	0.02	0.007	0.007	19.5	3.6	5.3	1.3	1.3	21.5	7.3	61	10.2	8.5	6.39	0.72	
11-Nov-97	3.44	0.02	0.097	0.097	20.9	4.7	6.5	1.2	1.2	24.1	8.6	61	7.3	7.8	7.17	0.46	
25-Nov-97	2.46	0.04	0.091	0.091	20.5	3.4	3.4	1.4	1.4	23.3	4.8	61	6.3	10.2	6.37	1.35	
8-Dec-97	3.44	0.04	0.018	0.018	29.5	4.5	7.2	1.7	1.7	24.7	8.5	61	6.5	10.2	6.77	0.60	
15-Dec-97	3.39	0.04	0.015	0.015	20.6	4.8	8.5	1.5	1.5	23.7	12.1	61	6.9	10.5	7.04	0.54	
20-Jan-98	3.14	0.05	0.039	0.039	18.4	3.3	8.5	1.3	1.3	14.0	16.2	61	5.1	10.2	7.13	1.39	
26-Jan-98	2.87	0.02	0.055	0.055	18.3	3.1	5.5	1.3	1.3	13.9	8.0	61	7.3	10.0	6.85	1.53	
9-Feb-98	3.52	0.03	0.038	0.038	16.5	3.2	6.1	1.4	1.4	12.5	8.5	53	7.9	9.1	6.82	0.65	
24-Feb-98	3.47	0.02	0.000	0.000	16.2	3.6	6.5	1.6	1.6	14.7	8.6	52	7.6	9.5	6.85	0.65	
15-Mar-98	3.42	0.02	0.012	0.012	15.5	3.7	5.6	1.3	1.3	11.9	7.6	52	9.8	10.0	6.77	0.77	
23-Mar-98	2.22	0.02	0.003	0.003	16.1	2.8	4.1	1.2	1.2	6.3	5.3	61	8.9	12.5	6.94	1.22	
6-Apr-98	3.31	0.02	0.038	0.038	19.2	4.7	6.5	2.2	2.2	14.0	8.7	61	10.6	11.5	6.87	0.63	
28-Apr-98	3.81	0.01	0.000	0.000	18.2	4.6	6.3	1.3	1.3	18.4	9.9	61	13.6	12.2	6.97	0.57	
12-May-98	1.77	0.02	0.009	0.009	17.2	4.9	5.9	1.1	1.1	11.0	8.4	80.3	12.5	7.7	7.16	0.65	
25-May-98	2.27	0.02	0.008	0.008	15.1	4.1	4.8	1.1	1.1	18.9	6.9	61	10.7	8.5	6.31	0.65	
9-Jun-98	3.99	0.01	0.000	0.000	22.0	5.0	11.8	1.8	1.8	26.2	9.1	79.3	10.0	8.5	6.35	0.57	

Table A5: Data for FT3

Location:	FT3		Depth:	26feet	8 m															
Surface/GW:	groundwater																			
	Nitrogen Balance			Metals					Tracers											
Date	NO3	NO2	NH3	Ca	Mg	Na	K	SO4	Cl	HCO3	temp	DO	pH	Depth						
11-Nov-97	1.47	0.03	0.085	27.4	5.0	4.1	0.5	102.9	9.5	45.0	9.1	1.5	6.59	1.64						
25-Nov-97	0.83	0.03	0.020	28.2	8.6	6.5	1.2	99.8	9.2	45.0	9.1	0.8	6.43	1.38						
8-Dec-97	0.75	0.02	0.020	28.2	8.6	6.5	1.2	99.8	9.2	45.0	9.1	0.8	6.43	1.38						
15-Dec-97	0.14	0.02	0.014	31.7	10.2	7.1	1.3	106.2	8.4	55.9	9.3	1.7	7.23	1.61						
20-Jan-98	0.05	0.01	0.007	30.8	9.1	6.7	1.2	117.6	8.8	55.9	9.6	2.0	7.30	1.16						
26-Jan-98	0.05	0.01	0.005	30.8	9.1	6.7	1.2	117.6	8.8	55.9	9.6	2.0	7.30	1.16						
9-Feb-98	0.04	0.03	0.040	20.9	6.2	6.1	1.0	109.6	8.9	55.9	10.1	1.8	6.79	1.45						
24-Feb-98	0.05	0.02	0.000	21.3	6.4	6.5	1.1	102.0	9.2	55.9	10.0	1.8	6.26	1.52	38 feet	54 feet				
15-Mar-98	0.05	0.01	0.008	20.2	8.2	6.6	1.3	97.1	9.3	55.9	10.6	1.6	6.52	1.52		1.56	1.51			
23-Mar-98	0.08	0.02	0.003	24.2	6.8	6.1	1.2	92.5	8.9	55.9	10.5	1.2	6.48	1.41		1.46	1.46			
6-Apr-98	0.06	0.01	0.028	26.1	7.6	6.6	2.3	97.3	11.0	55.9	10.6	1.3	7.11	1.62		1.62	1.62			
28-Apr-98	0.12	0.01	0.000	22.7	7.3	5.9	1.1	99.1	11.0	55.9	11.0	1.3	6.71	1.72		1.72	1.73			
12-May-98	0.09	0.06	0.000	27.5	8.6	6.9	1.4	103.8	11.7	55.9	11.0	0.8	7.23	1.73		1.73	1.73			
25-May-98	0.00	0.03	0.000	26.4	7.4	5.9	1.1	111.6	10.9	60.0	9.0	0.9	7.20	1.75		1.76	1.76			
9-Jun-98	0.00	0.02	0.000	26.4	7.4	5.9	1.1	111.6	10.9	60.0	10.0	0.8	7.20	1.73		1.73	1.73			

Table A9: Data for 91-11

Location:	91-11							20.7 m											
Surface/GW:	Groundwater																		
	Nitrogen Balance					Metals													
Date	NO3	NO2	NH3			Ca	Mg	Na	K		Tracers	SO4	Cl	temp (oC)	DO (ppm)	pH	Depth (m)		
25-Aug-97																			
17-Sep-97	0.07	0.01	0.015			19.5	2.5	4.1	0.7		20.3		6.1	9.9			6.11		
30-Sep-97	0.02	0.01	0.033			19.5	2.5	3.7	0.9		18.2		4.0	12.3	0.6		7.26	3.30	
14-Oct-97	0.22	0.01	0.040			18.9	2.6	3.8	1.0		17.7		3.7	12.2	1.1		7.97	2.68	
28-Oct-97	0.32	0.01	0.004			19.7	2.5	6.7	0.8		21.8		3.6	11.8	1.5		7.66	3.15	
11-Nov-97	0.27	0.01	0.094			19.2	2.6	3.6	0.9		21.5		3.6	12.0	1.7		7.95	3.07	
25-Nov-97	0.05	0.01	0.000			16.5	2.5	3.8	0.9		21.2		3.5	11.7	1.0		7.22	2.92	
8-Dec-97	0.10	0.01	0.000			20.2	2.7	3.9	1.0		21.6		3.2	11.8	1.2		7.33	2.94	
15-Dec-97	0.05	0.01	0.000			20.9	2.8	3.9	0.9		21.2		3.9	11.8	1.5		7.66	3.02	
20-Jan-98	0.10	0.01	0.000			19.3	2.6	3.9	0.9		14.7		4.4	11.6	1.2		7.11	2.46	
26-Jan-98	0.04	0.00	0.000			17.1	2.5	3.9	0.9		14.1		4.9	12.6	1.5		7.33	2.45	
9-Feb-98	0.05	0.01	0.022			13.1	1.9	4.1	0.8		13.7		5.2	11.9	2.0		7.34	2.90	
24-Feb-98	0.04	0.00	0.000			12.9	2.0	4.2	0.9		13.3		4.9	12.1	2.0		7.10	2.99	
15-Mar-98	0.09	0.00	0.000			12.6	2.4	4.6	1.0		10.8		5.1	11.9	1.0		7.37	2.96	
23-Mar-98	0.34	0.01	0.000			14.1	2.1	4.1	0.9		8.9		4.9	11.6	0.7		7.14	2.88	
6-Apr-98	0.11	0.01	0.012			17.1	2.5	5.4	1.9		11.6		8.2	13.0	1.0		7.47	3.10	
28-Apr-98	0.25	0.03	0.000			14.1	2.4	5.8	1.4		12.9		9.5	13.3	0.7		7.28	3.28	
12-May-98	0.11	0.00	0.000			17.2	2.6	4.4	1.2		14.3		6.1	12.2	0.7		7.54	3.38	
25-May-98	0.16	0.02	0.000			14.8	2.3	3.6	0.9		21.3		5.9	10.0	0.8		7.23	3.38	
9-Jun-98	0.06	0.00	0.000			21.0	3.1	7.0	1.1		21.9		6.1	11.0	0.8		7.33	3.42	

Table A10: Data for 91-12

Location:	91-12						Depth:			13.25 m									
Surface/GW:	Groundwater																		
	Nitrogen Balance																		
Date	NO3	NO2	NH3	Metals									Tracers						
				Ca	Mg	Na	K						SO4	Cl	temp (oC)	DO (ppm)	pH	Depth (m)	
25-Aug-97																			
17-Sep-97	0.12	0.04	0.062	42.5	10.4	4.3	0.5						146.9	17.2	9.9			6.11	
30-Sep-97	0.25	0.04	0.053	43.0	10.3	6.9	0.8						163.2	19.3	14.1	0.6		6.14	3.25
14-Oct-97	0.34	0.04	0.058	42.6	10.5	6.8	1.0						168.0	19.9	14.2	1.0		6.74	2.97
28-Oct-97	0.29	0.03	0.050	41.2	10.1	6.7	0.8						157.8	17.5	14.0	0.8		6.88	2.92
11-Nov-97	0.31	0.03	0.097	40.5	9.7	6.5	0.7						146.2	16.7	14.4	1.0		6.89	2.96
25-Nov-97	0.12	0.04	0.105	40.6	9.9	6.9	0.8						162.5	17.7	14.1	0.7		6.85	2.65
8-Dec-97	0.07	0.02	0.012	44.4	10.1	7.2	0.8						150.5	16.3	14.1	0.8		6.85	2.64
15-Dec-97	0.11	0.02	0.067	43.2	10.3	6.8	0.8						142.2	17.1	14.0	0.9		7.11	2.71
20-Jan-98	0.37	0.00	0.029	46.0	10.3	7.0	0.8						164.6	17.7	13.7	3.0		7.14	2.14
26-Jan-98	0.51	0.01	0.000	44.7	10.4	7.2	0.9						166.1	18.0	13.1	2.5		7.08	2.40
9-Feb-98	0.55	0.02	0.026	40.0	9.0	6.5	0.9						158.2	15.5	13.4	2.5		6.80	2.61
24-Feb-98	0.46	0.02	0.000	39.9	9.2	6.8	0.9						148.4	13.7	12.5	2.0		6.69	2.84
15-Mar-98	0.35	0.01	0.023	39.0	11.0	7.0	0.9						139.8	14.3	13.6	1.5		7.17	2.65
23-Mar-98	0.25	0.01	0.012	37.2	10.0	6.3	0.8						127.0	13.7	13.3	1.0		6.76	2.74
6-Apr-98	0.09	0.01	0.021	42.3	10.9	7.6	2.4						134.8	14.7	13.4	1.5		7.30	2.83
28-Apr-98	0.12	0.02	0.000	36.7	10.3	6.7	0.8						134.9	14.2	14.3	2.4		7.00	2.87
12-May-98	0.14	0.01	0.000	36.2	9.5	6.6	1.2						115.4	11.4	13.9	1.4		7.17	3.14
25-May-98	0.12	0.02	0.000	34.8	9.3	6.1	0.8						120.8	10.6	12.0	1.5		7.25	3.10
9-Jun-98	0.14	0.02	0.000	36.6	8.7	10.1	0.6						113.9	9.6	12.5	1.4		7.17	3.34

Location:	ABB 1					7.30 m													
Surface/GW:	Groundwater																		
Date	Nitrogen Balance																		
	NO3	NO2	NH3	Metals															
				Ca	Mg	Na	K	Tracers											
								SO4	Cl	temp	DO	pH	Depth						
										(°C)	(ppm)		(m)						
25-Aug-97																			
17-Sep-97	22.47	0.05	0.005	45.7	8.5	7.1	2.7	87.0	13.1	9.9		6.11							
30-Sep-97	21.05	0.05	0.032	47.0	8.7	7.1	2.7	87.7	13.2	11.1	0.8	6.28	2.67						
14-Oct-97	22.69	0.04	0.013	46.0	8.2	7.1	2.6	92.1	13.0	10.4	1.2	6.17	2.47						
28-Oct-97	22.52	0.03	0.001	46.9	9.1	6.9	2.8	84.3	13.5	10.0	1.1	6.15	2.55						
11-Nov-97	22.12	0.04	0.088	50.1	9.4	7.1	2.7	84.4	13.9	10.5	1.5	6.08	2.46						
25-Nov-97	32.91	0.02	0.000	53.6	9.7	7.6	2.8	73.8	15.3	10.0	1.0	5.68	2.33						
8-Dec-97	26.77	0.02	0.009	52.0	9.8	7.6	2.4	81.4	13.3	10.0	1.5	3.13	2.39						
15-Dec-97	30.24	0.01	0.000	56.5	10.3	8.1	3.0	65.9	15.1	10.0	1.8	6.27	2.77						
20-Jan-98	30.28	0.01	0.009	55.1	10.2	8.0	2.5	81.8	17.2	9.8	2.4	7.08	1.96						
26-Jan-98	30.28	0.01	0.009	55.1	10.2	8.0	2.5	81.8	17.2	10.0	2.2	6.88	2.22						
9-Feb-98	23.38	0.02	0.041	48.3	8.4	7.4	2.3	95.0	15.2	10.0	2.1	6.48	2.34						
24-Feb-98	24.97	0.01	0.020	47.5	8.8	7.9	2.1	110.8	13.2	9.7	2.0	6.52	2.42						
15-Mar-98	23.02	0.01	0.002	41.9	10.2	8.2	2.6	62.2	13.2	10.1	1.8	6.48	2.41						
23-Mar-98	27.92	0.01	0.000	44.3	9.4	7.9	2.7	56.5	13.4	10.0	1.6	6.47	2.31						
6-Apr-98	23.78	0.01	0.055	44.2	9.0	7.3	3.3	68.8	14.6	10.4	2.0	6.76	2.43						
28-Apr-98	19.49	0.03	0.000	40.0	8.5	8.4	2.2	73.4	13.8	10.4	1.5	6.49	2.62						
12-May-98	17.53	0.03	0.000	43.1	8.3	8.5	2.4	82.9	13.6	10.5	1.3	6.69	2.97						
25-May-98	9.85	0.06	0.000	42.1	8.9	10.1	2.2	108.0	12.4	9.0	1.2	6.65	2.72						
9-Jun-98	6.16	0.03	0.000	40.2	7.5	10.7	2.9	111.0	10.8	9.5	1.2	6.49	2.78						

Table A12: Data for ABB5

Location:	ABB5			Depth:			8.8 m												
Surface/GW:	Groundwater																		
	Nitrogen Balance (mg N/L)			Metals (mg/L)			Tracers (mg/L)												
Date	NO3	NO2	NH3	Ca	Mg	Na	K	SO4	Cl	HCO3	temp (oC)	DO (ppm)	pH	Depth (m)					
25-Aug-97																			
17-Sep-97	19.07	0.02	0.005	25.5	5.9	4.5	0.9	26.4	6.2	23.4	9.9		6.11	2.17					
30-Sep-97	16.96	0.03	0.153	22.2	6.1	4.5	0.8	26.5	6.3	23.4	9.6	7.5	6.59	2.63					
14-Oct-97	18.74	0.02	0.065	24.1	4.8	4.0	0.6	26.0	6.5	23.4	9.8	10.6	6.16	2.63					
28-Oct-97	18.13	0.01	0.006	25.2	5.1	4.1	0.6	26.5	6.5	23.4	9.6	10.4	6.40	2.31					
11-Nov-97	16.78	0.02	0.079	32.2	5.7	3.7	1.2	26.0	6.5	23.4	9.9	8.7	6.38	2.13					
25-Nov-97	17.19	0.03	0.002	28.5	4.7	4.5	0.5	26.2	6.9	23.4	9.5	9.8	6.31	2.01					
8-Dec-97	16.47	0.01	0.000	27.8	4.7	4.6	0.6	25.9	6.7	23.4	9.5	8.5	6.35	1.85					
15-Dec-97	14.47	0.01	0.012	22.2	6.8	4.3	0.7	25.2	6.5	23.4	9.3	7.0	6.46	1.69					
20-Jan-98	15.56	0.01	0.006	29.7	4.6	3.9	0.4	24.9	6.5	23.4	9.3	6.8	7.22	1.09					
26-Jan-98	15.81	0.00	0.000	28.5	4.6	4.0	0.5	24.3	6.3	23.4	9.1	6.5	7.04	1.01					
9-Feb-98	15.81	0.00	0.000	28.5	4.6	4.0	0.5	24.3	6.3	23.4	9.1	6.5	7.01	1.11					
24-Feb-98	15.23	0.00	0.000	25.5	3.6	4.4	0.6	22.9	5.8	23.4	9.1	5.5	6.27	1.52					
15-Mar-98	10.94	0.00	0.000	21.3	4.3	3.9	0.5	19.1	5.0	23.4	9.5	6.0	7.11	1.52					
23-Mar-98	14.39	0.00	0.021	27.5	3.8	3.6	0.4	18.7	4.8	23.4	9.3	10.2	6.62	1.48					
6-Apr-98	14.70	0.01	0.013	23.2	4.1	3.8	1.5	22.1	6.4	23.4	9.7	9.0	6.98	1.60					
28-Apr-98	14.60	0.00	0.000	24.5	4.1	3.7	0.4	22.5	6.5	23.4	9.9	9.5	6.84	1.99					
12-May-98	13.88	0.01	0.000	24.9	4.2	4.0	0.5	22.7	6.0	23.4	9.9	10.2	6.92	2.20					
25-May-98	13.96	0.00	0.000	23.1	4.2	3.6	0.5	28.0	5.5	23.9	8.2	10.0	6.65	1.86					
9-Jun-98	14.14	0.00	0.000	25.0	4.9	5.6	0.1	28.2	5.3	36.1	8.5	10.0	6.63	2.47					

Table A13: Charge Balance for Culvert

Charge Balance	Ca	Culvert Mg	Na	K	Cl	SO ₄	HCO ₃	NO ₃ mg/L	Cations	Anions	Balance
25-Aug-97	24.4	2.9	3.4	1.3	5.256	26.153	45	5.141	1.637386	-1.79804	-4.67634
17-Sep-97	25.3	2.9	3.4	1.3	5.256	26.153	45	4.511	1.682297	-1.75304	-2.05924
30-Sep-97	22.1	4.1	2.7	1.1	4.639	27.055	45	4.042	1.585818	-1.72093	-4.0858
14-Oct-97	27.8	3.6	3.7	1.5	5.66	41.356	45	4.931	1.882825	-2.11116	-5.71708
27-Oct-97	28.1	3.6	3.5	1.2	6.631	40.896	45	4.945	1.881423	-2.12997	-6.19607
11-Nov-97	27.5	3.6	3.7	1.2	6.12	35.195	45	5.059	1.860182	-2.00493	-3.74496
25-Nov-97	21.5	3.3	2.9	1.5	4.782	37.536	45	4.232	1.508964	-1.95688	-12.9238
8-Dec-97	23.5	3.3	2.9	1.5	4.782	33.256	45	4.731	1.608765	-1.90336	-8.38798
15-Dec-97	25.6	3.9	3.7	1.1	5.896	32.923	45	5.821	1.787505	-2.00571	-5.75238
20-Jan-98	32.4	3.7	3.3	1.9	5.775	34.264	45	6.13	2.113427	-2.0523	1.467363
26-Jan-98	29.3	3.7	3.3	1.9	5.775	34.264	45	6.142	1.958737	-2.05316	-2.35354
9-Feb-98	22.3	2.8	3.4	1.2	5.968	28.503	35	6.153	1.521808	-1.77543	-7.69203
24-Feb-98	21.2	3.2	4	1.7	6.789	27.65	35	6.424	1.538726	-1.80018	-7.8305
15-Mar-98	18.2	3.3	3.5	1.4	5.585	24.213	35	5.809	1.367834	-1.65068	-9.37043
23-Mar-98	19.2	2.8	3	1.5	4.789	25.514	35	5.039	1.357391	-1.60033	-8.21379
6-Apr-98	20.2	2.1	2.7	1.8	6.596	24.973	34	5.657	1.344302	-1.66778	-10.7395
28-Apr-98	20	3.8	4	1.8	7.419	24.954	36	6.832	1.530786	-1.80732	-8.28416
12-May-98	21.6	5.2	4.2	2	7.431	24.456	46.8	6.814	1.739667	-1.97305	-6.28596
25-May-98	20.2	5.8	4.2	2	6.855	22.251	46.8	6.601	1.719189	-1.89565	-4.88147
9-Jun-98	20.2	5.8	4.2	2	6.855	22.251	46.8	6.601	1.719189	-1.89565	-4.88147
										average	-6.19619

Table A14: Charge Balance for Fishtap Creek at Huntingdon Avenue

Charge Balance		Huntingdon Ave and FTC										
	Ca	Mg	Na	K	Cl	SO4	HCO3	NO3	Cations	Anions	Balance	
25-Aug-97	20.4	5.3	7.7	1.6	6.6	16.3	61	3.97	1.83	-1.81	0.61	
17-Sep-97	19.8	4.9	6.5	1.5	6.3	16.0	61	1.32	1.71	-1.60	3.28	
30-Sep-97	20.8	3.5	5.1	1.4	6.7	18.6	61	1.69	1.58	-1.70	-3.50	
14-Oct-97	19.5	3.8	5.9	1.5	7.2	20.4	61	2.48	1.58	-1.81	-6.66	
27-Oct-97	19.5	3.6	5.3	1.3	7.3	21.5	61	2.39	1.53	-1.83	-8.73	
11-Nov-97	20.9	4.7	6.5	1.2	8.6	24.1	61	3.44	1.74	-1.99	-6.58	
25-Nov-97	20.5	3.4	3.4	1.4	4.8	23.3	61	2.46	1.49	-1.79	-9.39	
8-Dec-97	29.5	4.5	7.2	1.7	8.5	24.7	61	3.44	2.20	-2.00	4.75	
15-Dec-97	20.6	4.8	8.5	1.5	12.1	23.7	61	3.39	1.83	-2.08	-6.32	
20-Jan-98	18.4	3.3	8.5	1.3	16.2	14.0	61	3.14	1.59	-1.97	-10.62	
26-Jan-98	18.3	3.1	5.5	1.3	8.0	13.9	61	2.87	1.44	-1.72	-8.83	
9-Feb-98	16.5	3.2	6.1	1.4	8.5	12.5	53	3.52	1.39	-1.62	-7.68	
24-Feb-98	16.2	3.6	6.5	1.6	8.6	14.7	52	3.47	1.43	-1.65	-7.22	
15-Mar-98	15.5	3.7	5.6	1.3	7.6	11.9	52	3.42	1.35	-1.56	-7.04	
23-Mar-98	16.1	2.8	4.1	1.2	5.3	6.3	61	2.22	1.24	-1.44	-7.31	
6-Apr-98	19.2	4.7	6.5	2.2	8.7	14.0	61	3.31	1.68	-1.77	-2.60	
28-Apr-98	18.2	4.6	6.3	1.3	9.9	18.4	61	3.81	1.59	-1.94	-9.68	
12-May-98	17.2	4.9	5.9	1.1	8.4	11.0	80.3	1.77	1.55	-1.91	-10.46	
25-May-98	15.1	4.1	4.8	1.1	1.1	18.9	61	2.27	1.33	-1.59	-8.89	
9-Jun-98	22.0	5.0	11.8	1.8	1.8	26.2	79.3	3.99	2.07	-2.18	-2.65	
											-5.94	

Table A16: Charge Balance for FT3

FT3 Balance													
	Ca	Mg	Na	K	Cl	SO ₄	HCO ₃	NO ₃	Cations	Anions	Balance		
11-Nov-97	27.4	5.0	4.1	0.5	9.5	102.9	45.0	1.47	1.97	-3.25	-24.56		
25-Nov-97	28.2	8.6	6.5	1.2	9.2	99.8	45.0	0.83	2.43	-3.13	-12.68		
8-Dec-97	28.2	8.6	6.5	1.2	9.2	99.8	45.0	0.75	2.43	-3.13	-12.59		
15-Dec-97	31.7	10.2	7.1	1.3	8.4	106.2	55.9	0.14	2.76	-3.38	-10.00		
20-Jan-98	30.8	9.1	6.7	1.2	8.8	117.6	55.9	0.05	2.61	-3.62	-16.24		
26-Jan-98	30.8	9.1	6.7	1.2	8.8	117.6	55.9	0.05	2.61	-3.62	-16.24		
9-Feb-98	20.9	6.2	6.1	1.0	8.9	109.6	55.9	0.04	1.84	-3.45	-30.39		
24-Feb-98	21.3	6.4	6.5	1.1	9.2	102.0	55.9	0.05	1.90	-3.30	-26.97		
15-Mar-98	20.2	8.2	6.6	1.3	9.3	97.1	55.9	0.05	2.00	-3.20	-23.05		
23-Mar-98	24.2	6.8	6.1	1.2	8.9	92.5	55.9	0.08	2.06	-3.10	-20.09		
6-Apr-98	26.1	7.6	6.6	2.3	11.0	97.3	55.9	0.06	2.27	-3.26	-17.80		
28-Apr-98	22.7	7.3	5.9	1.1	11.0	99.1	55.9	0.12	2.02	-3.30	-24.12		
12-May-98	27.5	8.6	6.9	1.4	11.7	103.8	55.9	0.09	2.42	-3.41	-17.13		
25-May-98	26.4	7.4	5.9	1.1	10.9	111.6	60.0	0.00	2.21	-3.62	-24.11		
9-Jun-98	26.4	7.4	5.9	1.1	10.9	111.6	60.0	0.00	2.21	-3.62	-24.11		
											-20.01		

Table A17: Charge Balance for FT5

	Ca	Mg	Na	K	Cl	SO4	HCO3	NO3	Cations	Anions	Balance
25-Aug-97											
17-Sep-97	23.4	4.5	4.9	1.0	7.2	30.7	47.0	10.07	1.78	-2.33	-13.50
30-Sep-97	25.2	4.0	5.1	2.4	12.9	32.4	48.0	10.29	1.87	-2.56	-15.57
14-Oct-97	20.7	5.5	4.8	0.8	7.5	33.1	48.0	10.17	1.71	-2.41	-16.91
28-Oct-97	23.2	3.8	6.2	2.5	10.8	29.3	48.0	10.28	1.80	-2.44	-14.89
11-Nov-97	23.2	3.2	6.0	2.2	10.7	31.4	48.0	9.76	1.74	-2.44	-16.80
25-Nov-97	20.8	6.5	7.2	2.5	10.4	26.7	48.0	11.13	1.95	-2.43	-10.98
8-Dec-97	20.8	3.6	6.9	2.6	9.0	28.7	48.0	11.18	1.70	-2.44	-17.77
15-Dec-97	22.9	4.5	7.0	2.9	7.4	28.3	48.0	10.79	1.89	-2.36	-10.94
20-Jan-98	24.5	4.5	5.5	2.5	6.8	28.3	48.0	13.01	1.90	-2.50	-13.68
26-Jan-98	25.9	4.4	5.3	2.3	5.9	27.9	48.0	13.00	1.94	-2.46	-11.78
9-Feb-98	21.9	3.7	4.6	2.3	6.6	24.0	48.0	13.69	1.66	-2.45	-19.33
24-Feb-98	21.2	4.7	5.1	0.9	8.2	24.5	48.0	7.31	1.69	-2.05	-9.66
15-Mar-98	22.9	5.6	5.3	0.9	7.9	25.0	48.0	7.11	1.86	-2.04	-4.60
23-Mar-98	22.4	5.4	4.8	1.0	7.2	22.3	66.6	7.51	1.80	-2.30	-12.19
6-Apr-98	27.4	5.9	5.3	1.9	9.0	27.7	66.6	8.53	2.13	-2.53	-8.59
28-Apr-98	21.2	5.3	4.6	0.9	9.2	27.3	66.6	7.97	1.72	-2.49	-18.36
12-May-98	26.1	5.8	4.9	1.0	8.6	25.1	66.6	8.49	2.02	-2.46	-9.93
25-May-98	27.0	4.3	4.3	0.7	7.2	32.5	66.6	8.55	1.91	-2.58	-15.07
9-Jun-98	28.6	6.3	8.3	0.8	7.6	31.1	66.6	10.32	2.33	-2.69	-7.25
											-13.04

[illegible]

Table A19: Charge Balance for FT8

	Ca	Mg	Na	K	Cl	SO ₄	HCO ₃	NO ₃	Cations	Anions	Balance
25-Aug-97											
17-Sep-97	11.3	6.7	42.6	2.8	45.6	25.0	112.9	0.06	3.04	-3.66	-9.30
30-Sep-97	11.5	6.8	42.8	2.5	49.3	24.6	112.9	0.00	3.06	-3.75	-10.20
14-Oct-97	11.1	7.3	42.6	2.9	53.1	25.7	112.9	0.00	3.08	-3.88	-11.51
28-Oct-97	9.5	7.6	41.4	2.4	39.8	26.5	112.9	0.18	2.96	-3.54	-8.86
11-Nov-97	10.2	8.2	41.2	2.5	39.4	26.1	112.9	0.17	3.04	-3.52	-7.31
25-Nov-97	11.9	6.9	41.5	2.4	37.2	25.2	112.9	0.05	3.03	-3.43	-6.19
8-Dec-97	10.1	7.9	42.6	2.8	33.2	25.8	112.9	0.12	3.08	-3.33	-3.98
15-Dec-97	7.9	8.9	39.2	2.5	31.1	24.2	112.9	0.03	2.90	-3.24	-5.56
20-Jan-98	10.2	6.9	36.4	2.6	49.5	21.8	112.9	0.05	2.73	-3.71	-15.23
26-Jan-98	14.3	8.5	42.3	2.7	56.6	24.6	112.9	0.09	3.32	-3.96	-8.82
9-Feb-98	10.1	5.4	37.0	2.2	50.0	21.1	112.9	0.10	2.61	-3.71	-17.30
15-Mar-98	10.1	5.3	36.6	2.3	40.9	16.1	112.9	0.39	2.59	-3.37	-13.03
23-Mar-98	10.7	6.9	42.0	2.3	50.8	18.2	112.9	0.03	2.99	-3.67	-10.19
6-Apr-98	12.6	7.3	42.5	3.6	49.7	19.9	112.9	0.06	3.17	-3.67	-7.35
28-Apr-98	11.1	7.1	40.0	2.2	45.9	19.3	112.9	0.14	2.93	-3.56	-9.59
12-May-98	13.5	7.6	40.6	2.4	51.4	20.2	112.9	0.05	3.13	-3.73	-8.73
25-May-98	15.2	8.0	38.7	2.5	46.4	25.2	112.4	0.01	3.16	-3.68	-7.50
9-Jun-98	15.2	8.0	38.7	2.5	46.4	25.2	112.4	0.01	3.16	-3.68	-9.34

[illegible]

Table A21: Charge Balance for 91-12

	Ca	Mg	Na	K	Cl	SO ₄	HCO ₃	NO ₃	Cations	Anions	Balance
25-Aug-97											
17-Sep-97	42.5	10.4	4.3	0.5	17.2	146.9	47.8	0.12	3.18	-4.34	-15.47
30-Sep-97	43.0	10.3	6.9	0.8	19.3	163.2	47.8	0.25	3.31	-4.75	-17.76
14-Oct-97	42.6	10.5	6.8	1.0	19.9	168.0	47.8	0.34	3.31	-4.87	-19.06
28-Oct-97	41.2	10.1	6.7	0.8	17.5	157.8	47.8	0.29	3.20	-4.59	-17.83
11-Nov-97	40.5	9.7	6.5	0.7	16.7	146.2	47.8	0.31	3.12	-4.32	-16.15
25-Nov-97	40.6	9.9	6.9	0.8	17.7	162.5	47.8	0.12	3.16	-4.68	-19.33
8-Dec-97	44.4	10.1	7.2	0.8	16.3	150.5	47.8	0.07	3.38	-4.38	-12.92
15-Dec-97	43.2	10.3	6.8	0.8	17.1	142.2	47.8	0.11	3.32	-4.24	-12.13
20-Jan-98	46.0	10.3	7.0	0.8	17.7	164.6	47.8	0.37	3.47	-4.74	-15.50
26-Jan-98	44.7	10.4	7.2	0.9	18.0	166.1	47.8	0.51	3.42	-4.79	-16.61
9-Feb-98	40.0	9.0	6.5	0.9	15.5	158.2	47.8	0.55	3.04	-4.56	-19.92
24-Feb-98	39.9	9.2	6.8	0.9	13.7	148.4	47.8	0.46	3.07	-4.30	-16.69
15-Mar-98	39.0	11.0	7.0	0.9	14.3	139.8	47.8	0.35	3.18	-4.12	-12.93
23-Mar-98	37.2	10.0	6.3	0.8	13.7	127.0	47.8	0.25	2.97	-3.83	-12.63
6-Apr-98	42.3	10.9	7.6	2.4	14.7	134.8	47.8	0.09	3.40	-4.01	-8.26
28-Apr-98	36.7	10.3	6.7	0.8	14.2	134.9	47.8	0.12	2.99	-4.00	-14.48
12-May-98	36.2	9.5	6.6	1.2	11.4	115.4	47.8	0.14	2.91	-3.52	-9.53
25-May-98	34.8	9.3	6.1	0.8	10.6	120.8	55.4	0.12	2.79	-3.73	-14.49
9-Jun-98	36.6	8.7	10.1	0.6	9.6	113.9	51.9	0.14	3.00	-3.50	-7.79
											-14.71

Table A22: Charge Balance for ABB1

	Ca	Mg	Na	K	Cl	SO ₄	HCO ₃	NO ₃	Cations	Anions	Balance
25-Aug-97											
17-Sep-97	45.7	8.5	7.1	2.7	13.1	87.0	34.1	22.47	3.36	-4.34	-12.81
30-Sep-97	47.0	8.7	7.1	2.7	13.2	87.7	34.1	21.05	3.44	-4.26	-10.67
14-Oct-97	46.0	8.2	7.1	2.6	13.0	92.1	34.1	22.69	3.35	-4.47	-14.35
28-Oct-97	46.9	9.1	6.9	2.8	13.5	84.3	34.1	22.52	3.46	-4.30	-10.86
11-Nov-97	50.1	9.4	7.1	2.7	13.9	84.4	34.1	22.12	3.65	-4.29	-8.03
25-Nov-97	53.6	9.7	7.6	2.8	15.3	73.8	34.1	32.91	3.88	-4.88	-11.46
8-Dec-97	52.0	9.8	7.6	2.4	13.3	81.4	34.1	26.77	3.79	-4.54	-8.97
15-Dec-97	56.5	10.3	8.1	3.0	15.1	65.9	34.1	30.24	4.10	-4.52	-4.89
20-Jan-98	55.1	10.2	8.0	2.5	17.2	81.8	34.1	30.28	4.00	-4.91	-10.23
26-Jan-98	55.1	10.2	8.0	2.5	17.2	81.8	34.1	30.28	4.00	-4.91	-10.23
9-Feb-98	48.3	8.4	7.4	2.3	15.2	95.0	34.1	23.38	3.48	-4.64	-14.23
24-Feb-98	47.5	8.8	7.9	2.1	13.2	110.8	34.1	24.97	3.49	-5.02	-17.99
15-Mar-98	41.9	10.2	8.2	2.6	13.2	62.2	34.1	23.02	3.35	-3.87	-7.17
23-Mar-98	44.3	9.4	7.9	2.7	13.4	56.5	34.1	27.92	3.40	-4.11	-9.47
6-Apr-98	44.2	9.0	7.3	3.3	14.6	68.8	34.1	23.78	3.35	-4.10	-10.12
28-Apr-98	40.0	8.5	8.4	2.2	13.8	73.4	34.1	19.49	3.12	-3.87	-10.78
12-May-98	43.1	8.3	8.5	2.4	13.6	82.9	34.1	17.53	3.26	-3.92	-9.14
25-May-98	42.1	8.9	10.1	2.2	12.4	108.0	44.2	9.85	3.33	-4.03	-9.50
9-Jun-98	40.2	7.5	10.7	2.9	10.8	111.0	43.7	6.16	3.16	-3.77	-8.80
											-10.51

[illegible]

APPENDIX B: CALCULATIONS

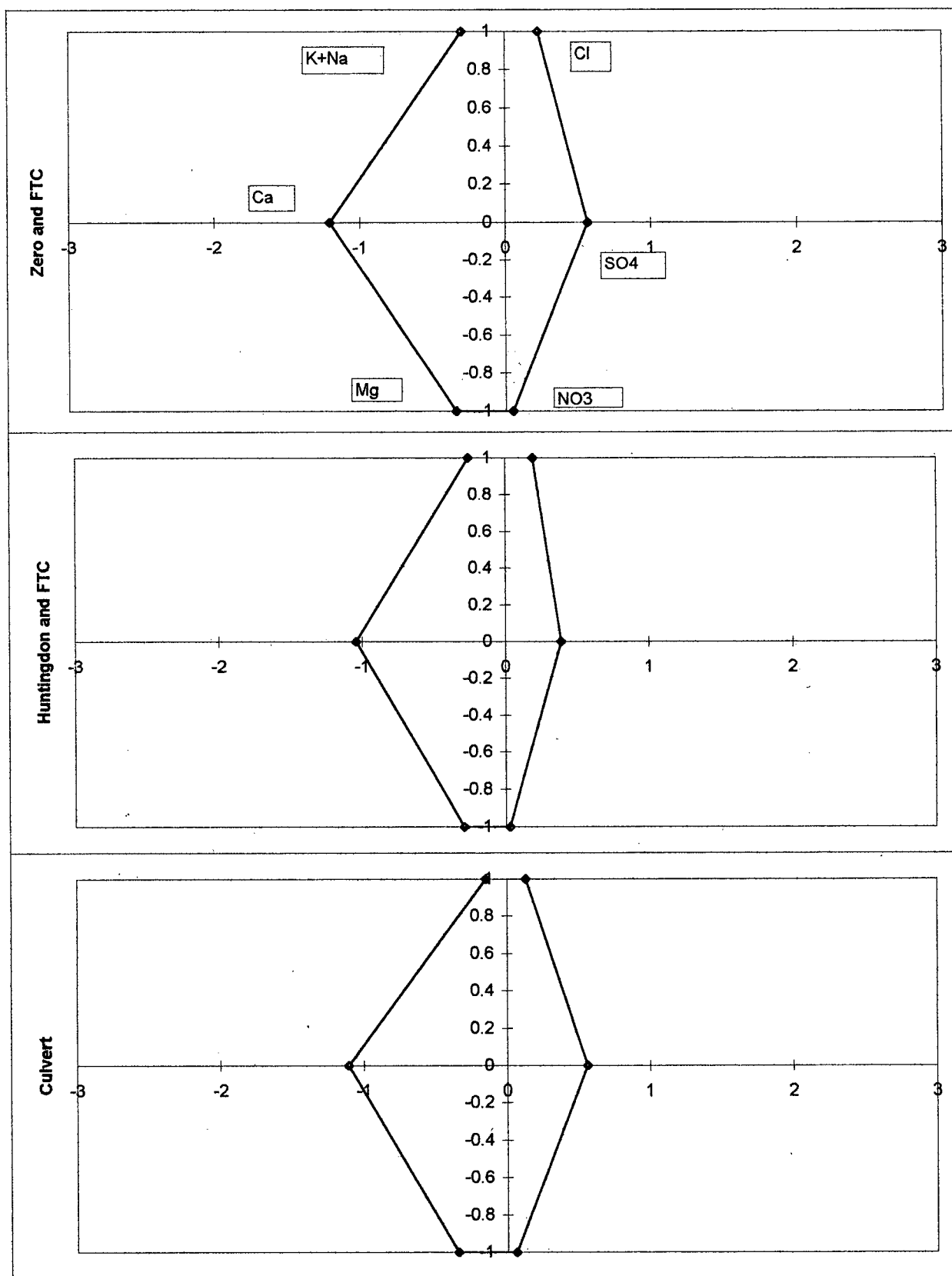


Figure B-1: Stiff Diagrams for September 30, 1997

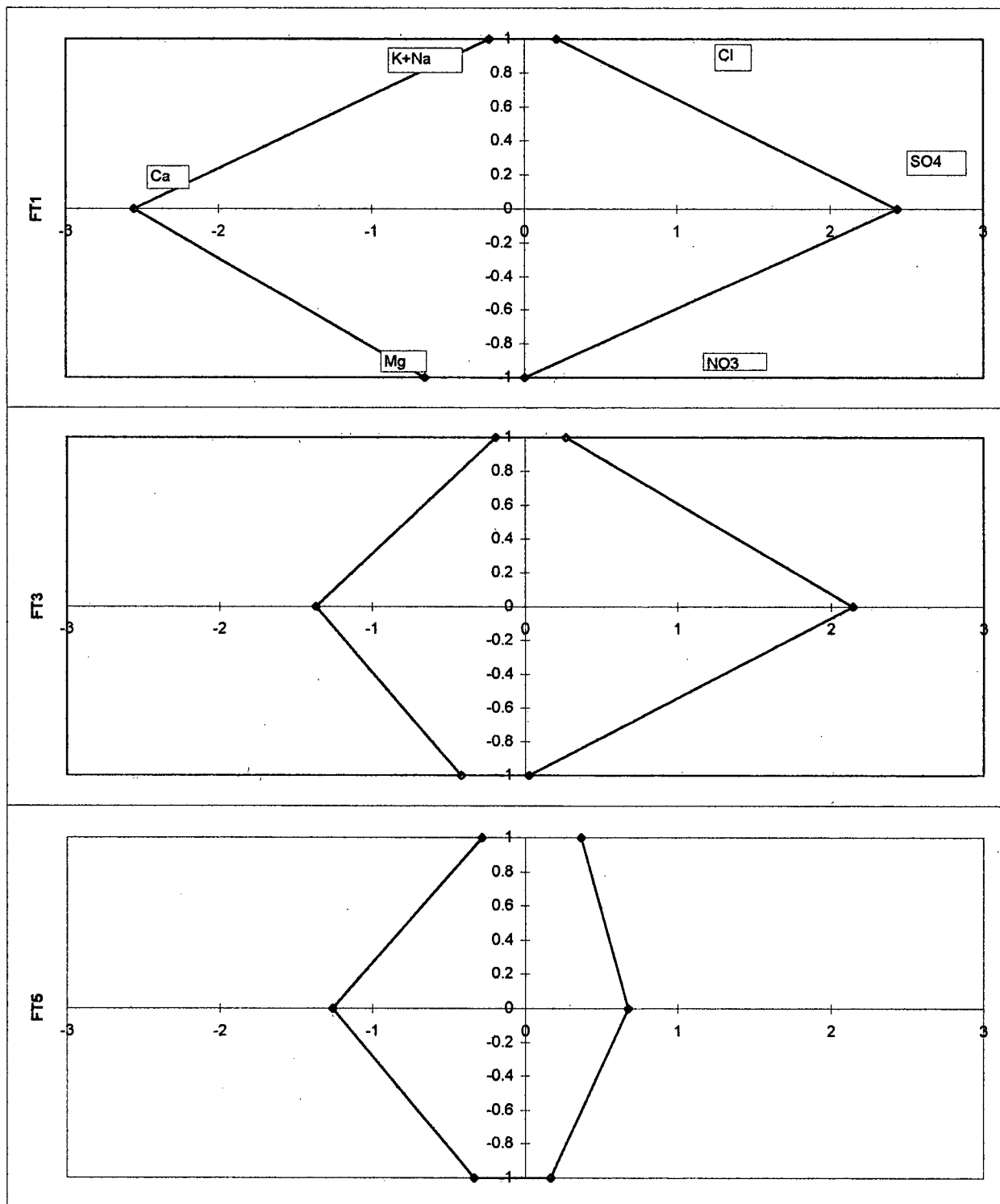


Figure B-1: Stiff Diagrams for September 30, 1997

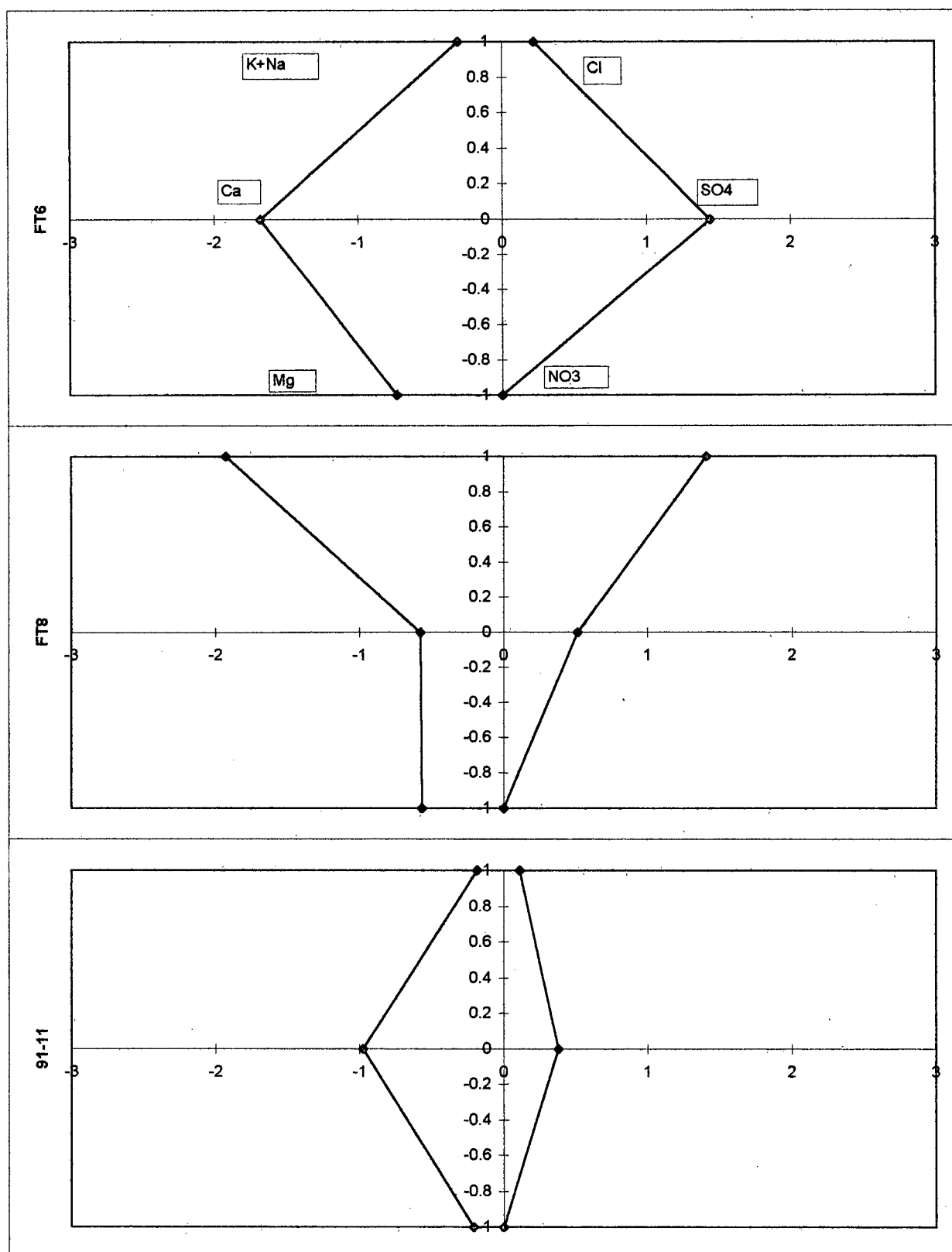


Figure B-1: Stiff Diagrams for September 30, 1997

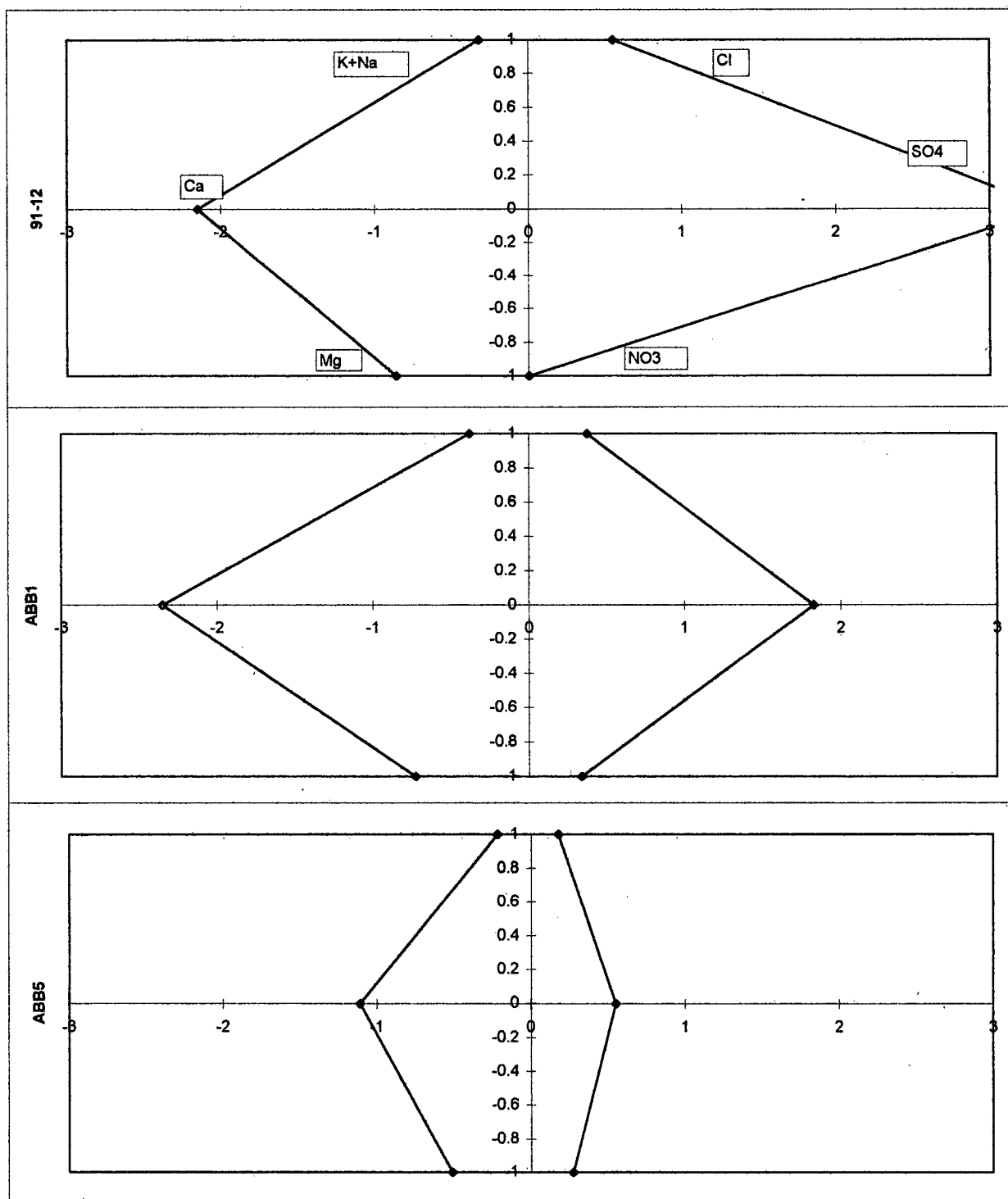


Figure B-1: Stiff Diagrams for September 30, 1997

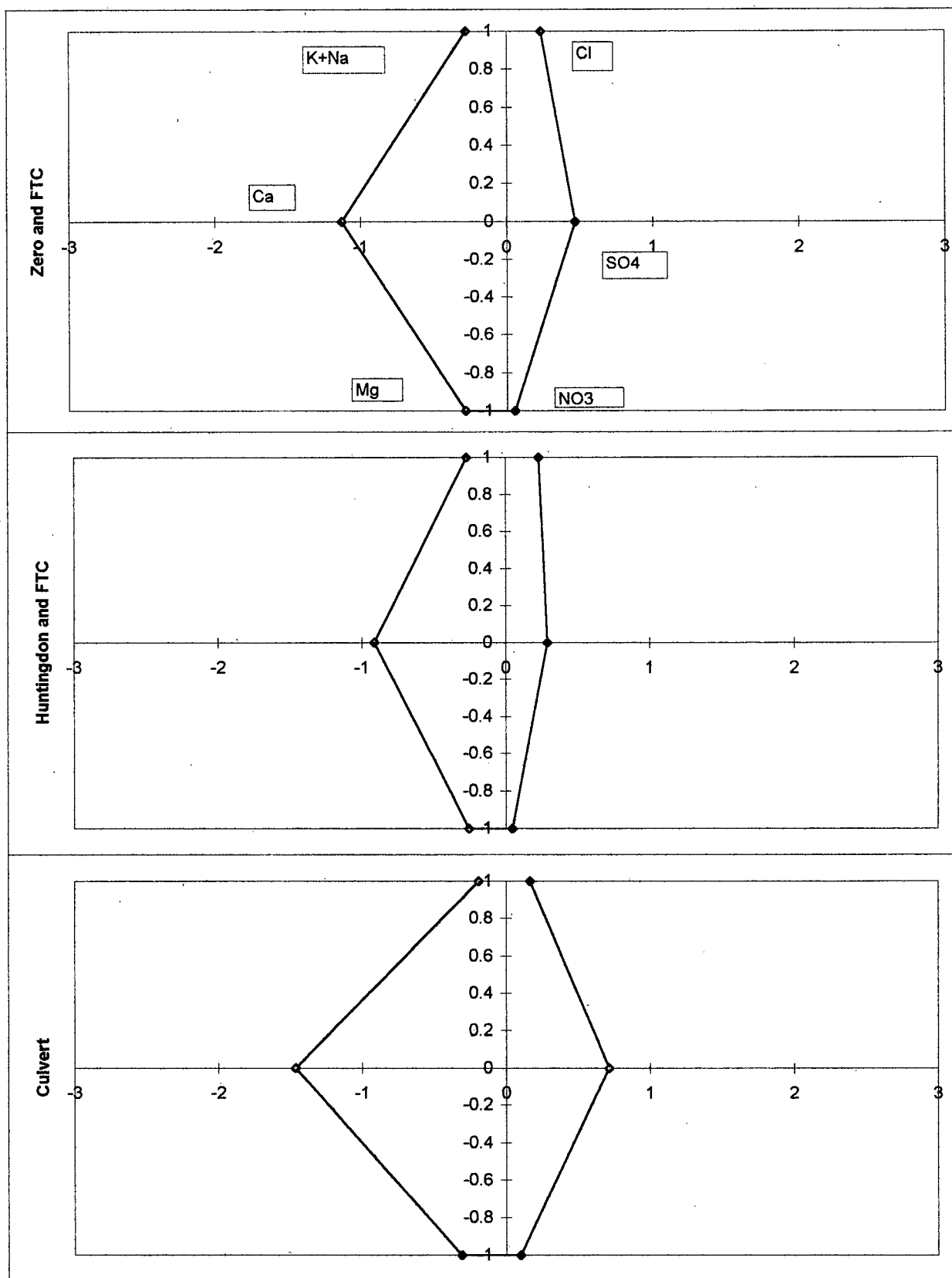


Figure B-1: Stiff Diagrams for January 26, 1998

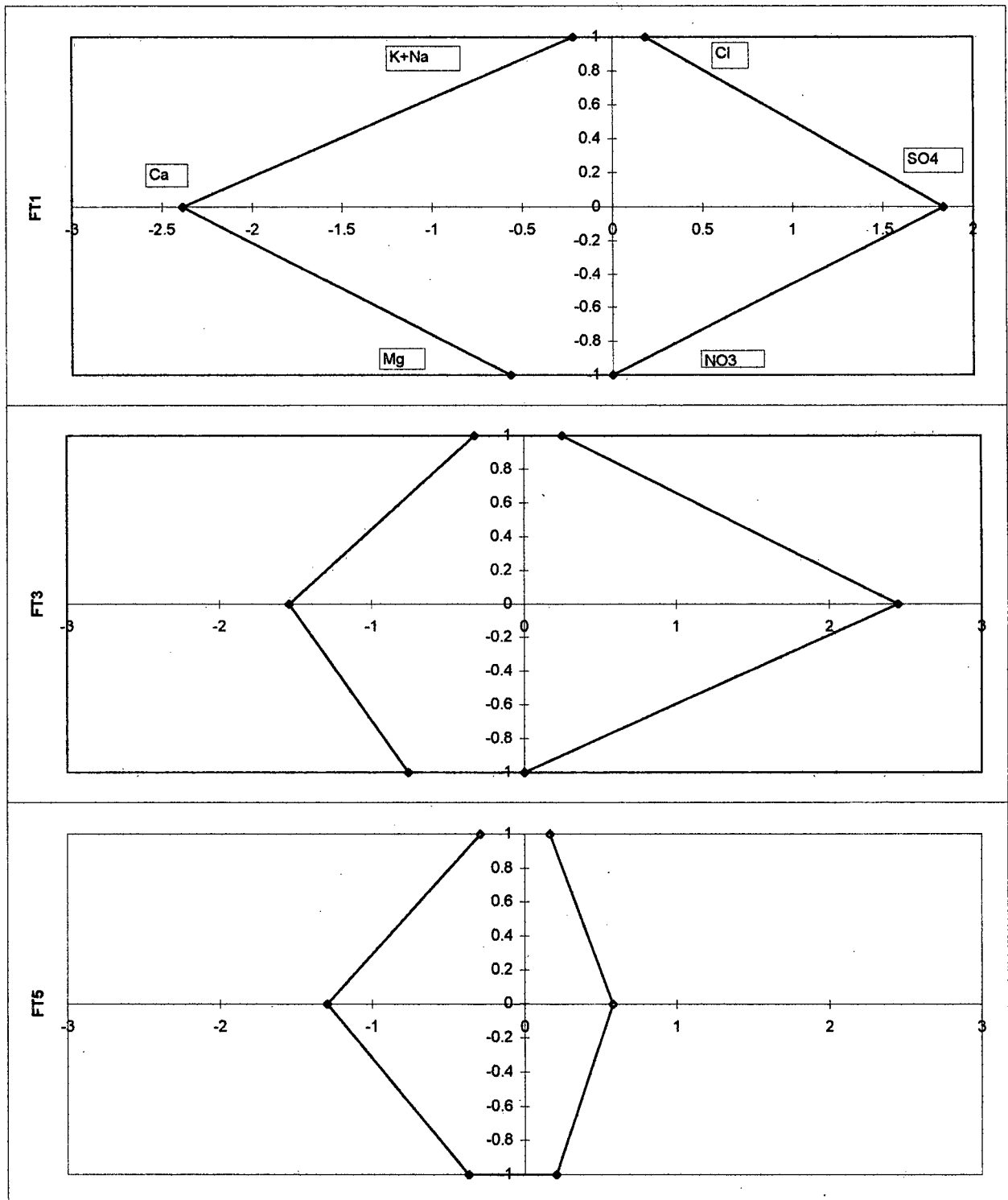


Figure B-1: Stiff Diagrams for January 26, 1998

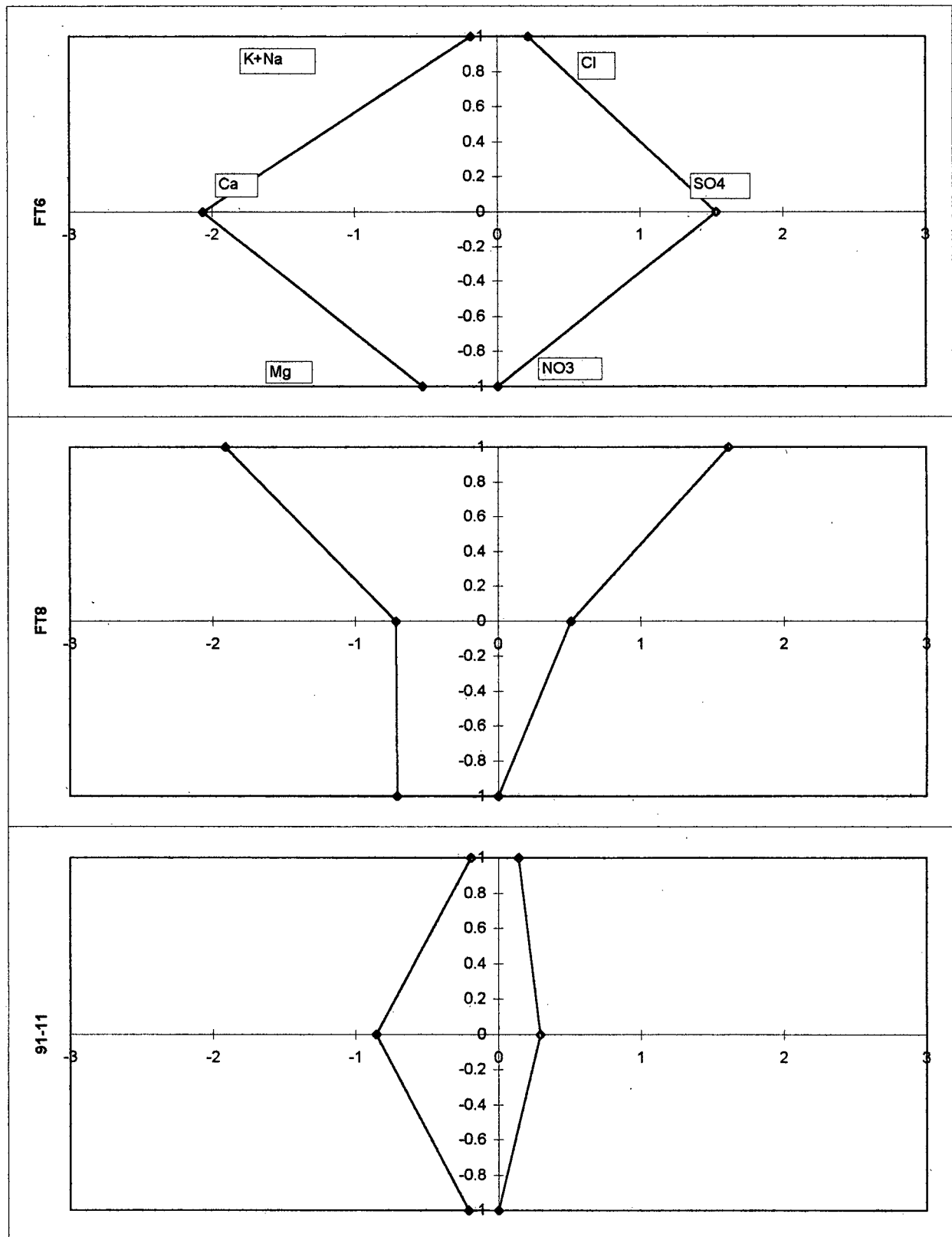


Figure B-1: Stiff Diagrams for January 26, 1998

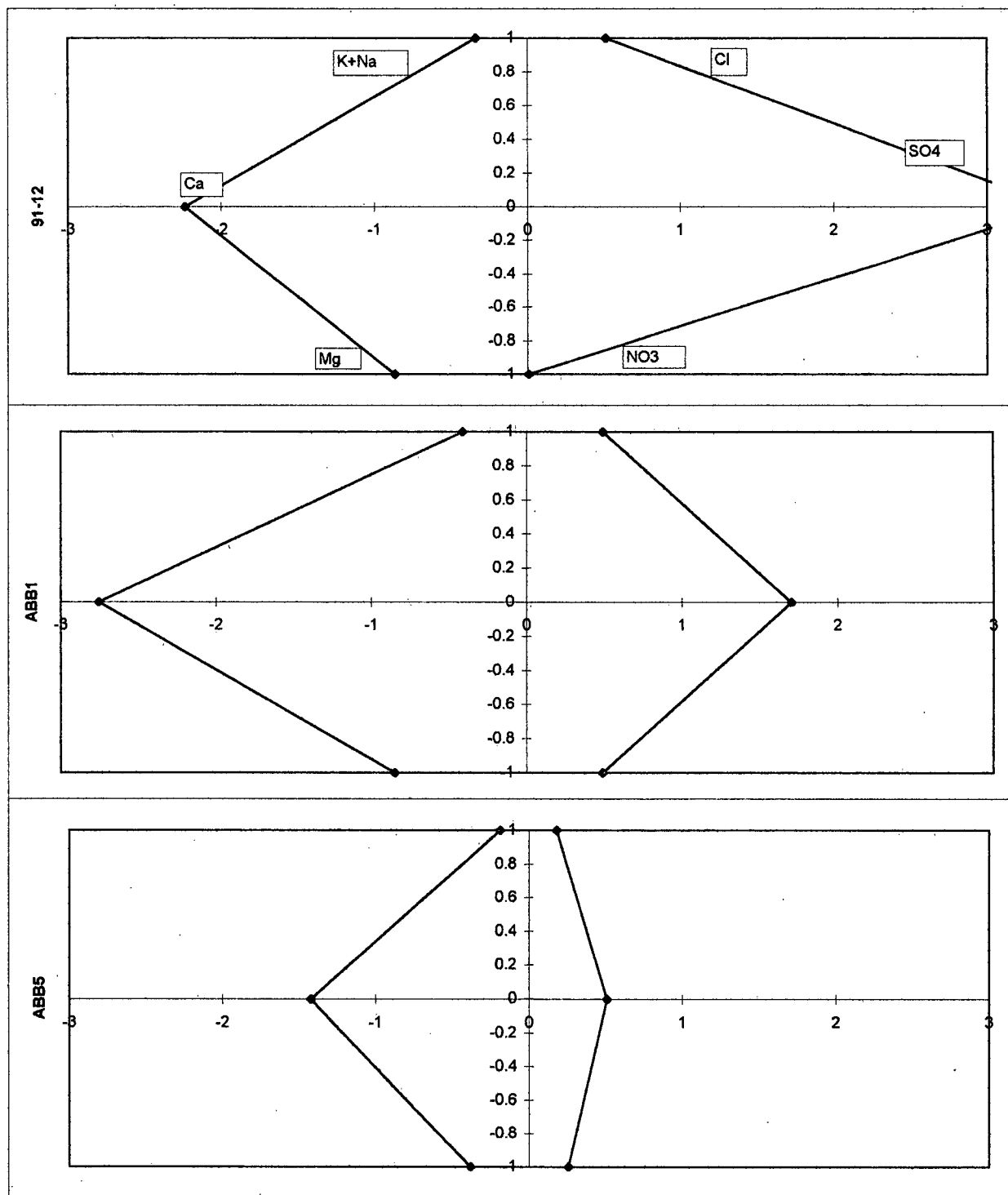


Figure B-1: Stiff Diagrams for January 26, 1998

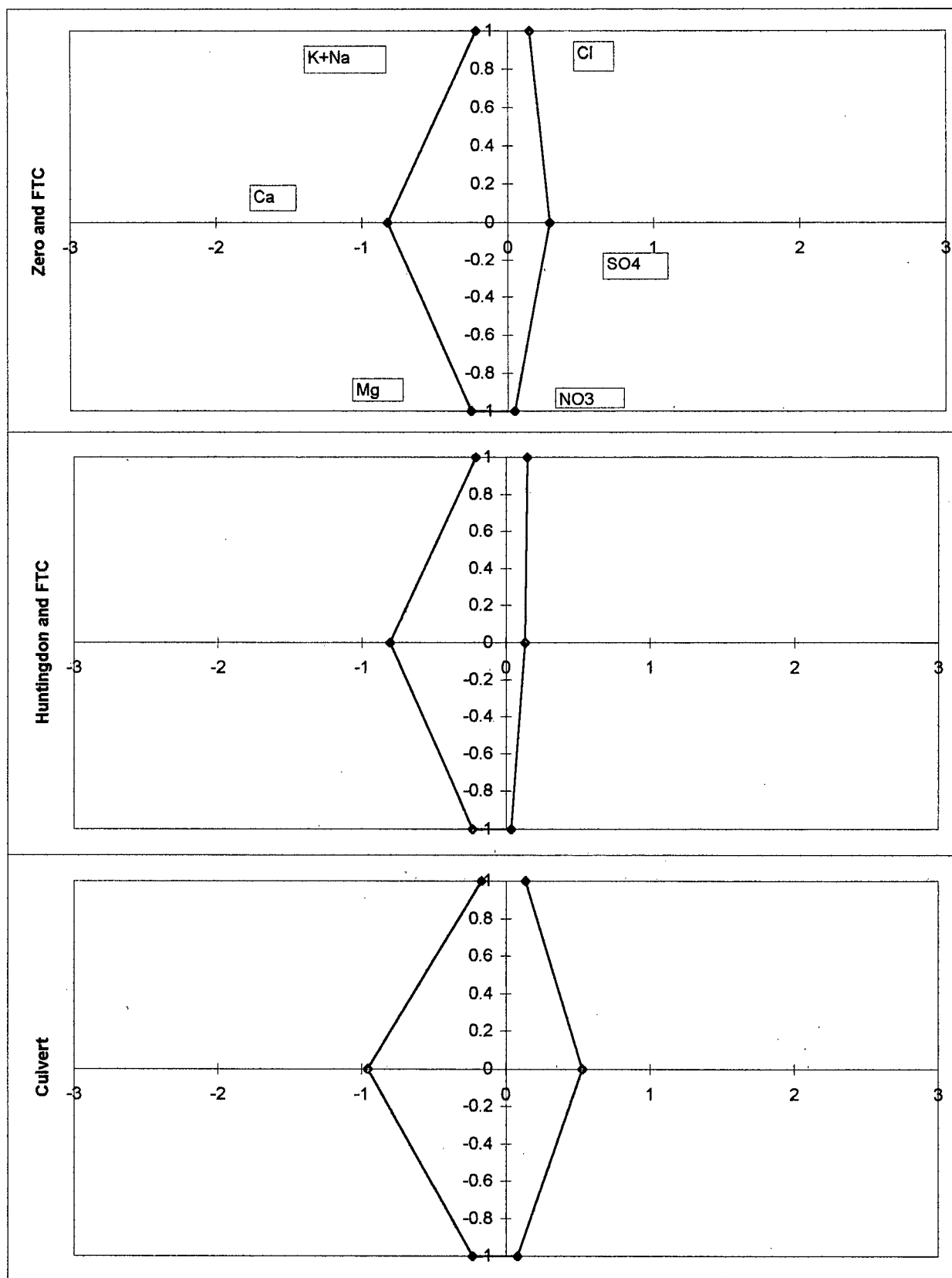


Figure B-1: Stiff Diagrams for March 23, 1998

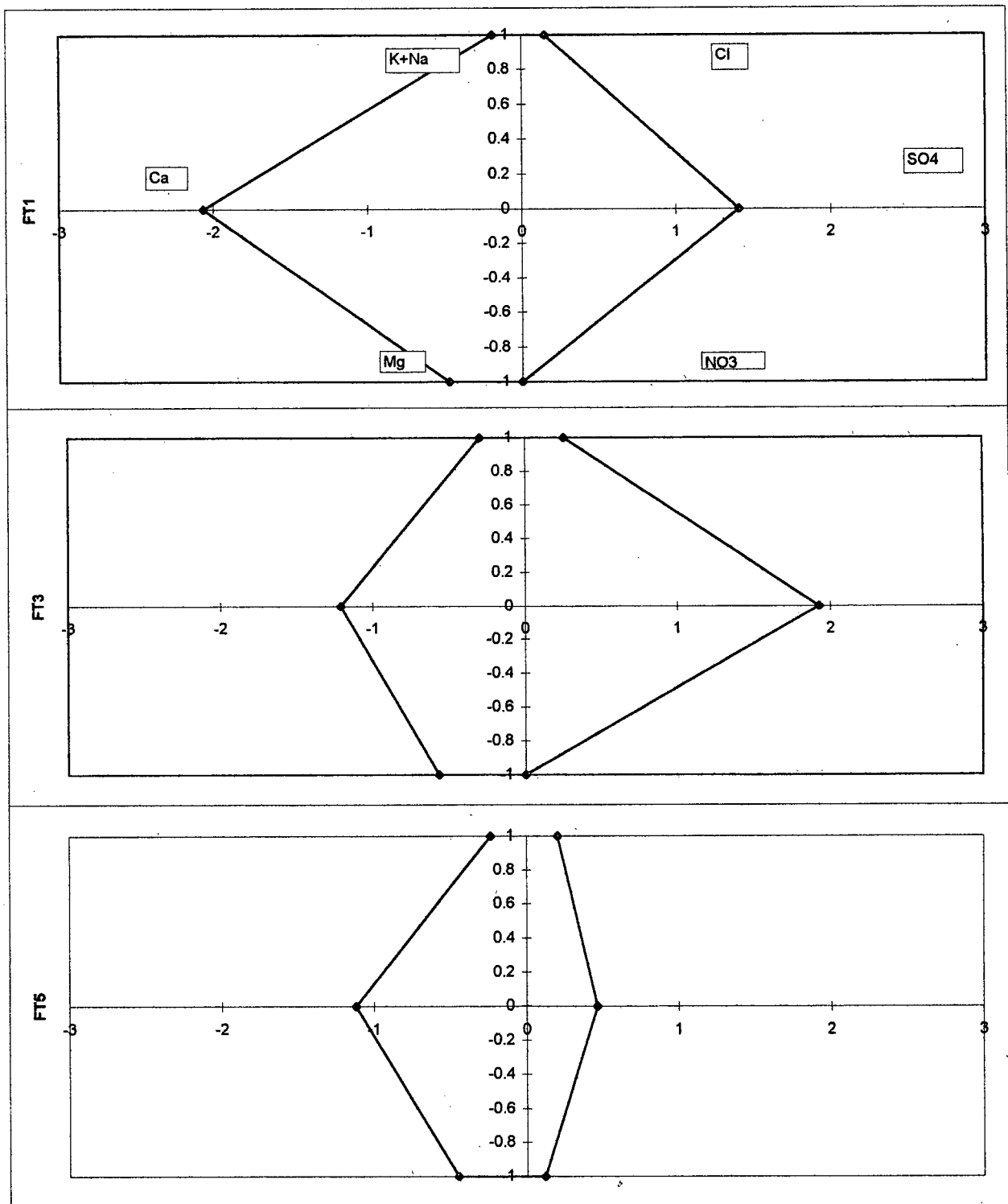


Figure B-1: Stiff Diagrams for March 23, 1998

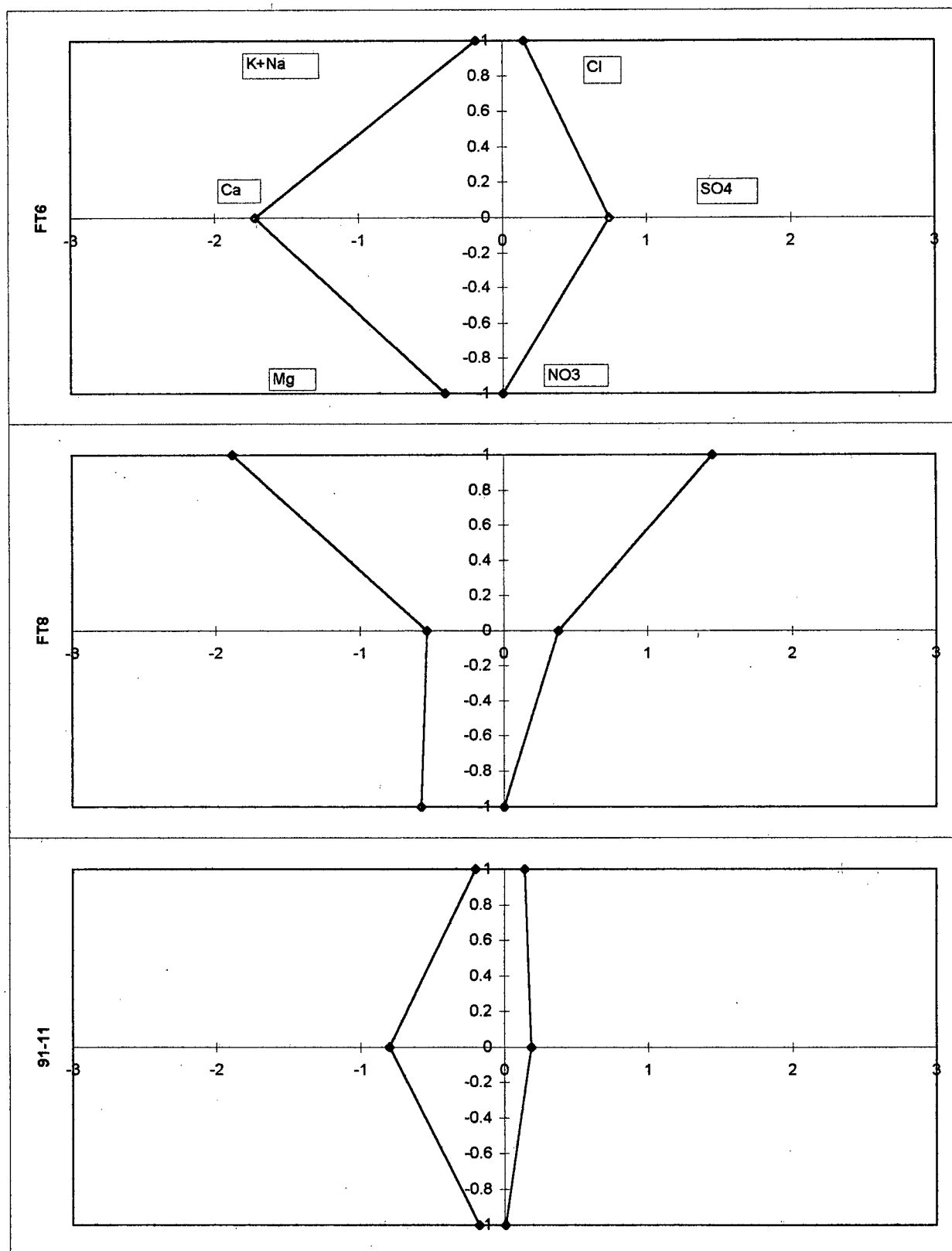


Figure B-1: Stiff Diagrams for March 23, 1998

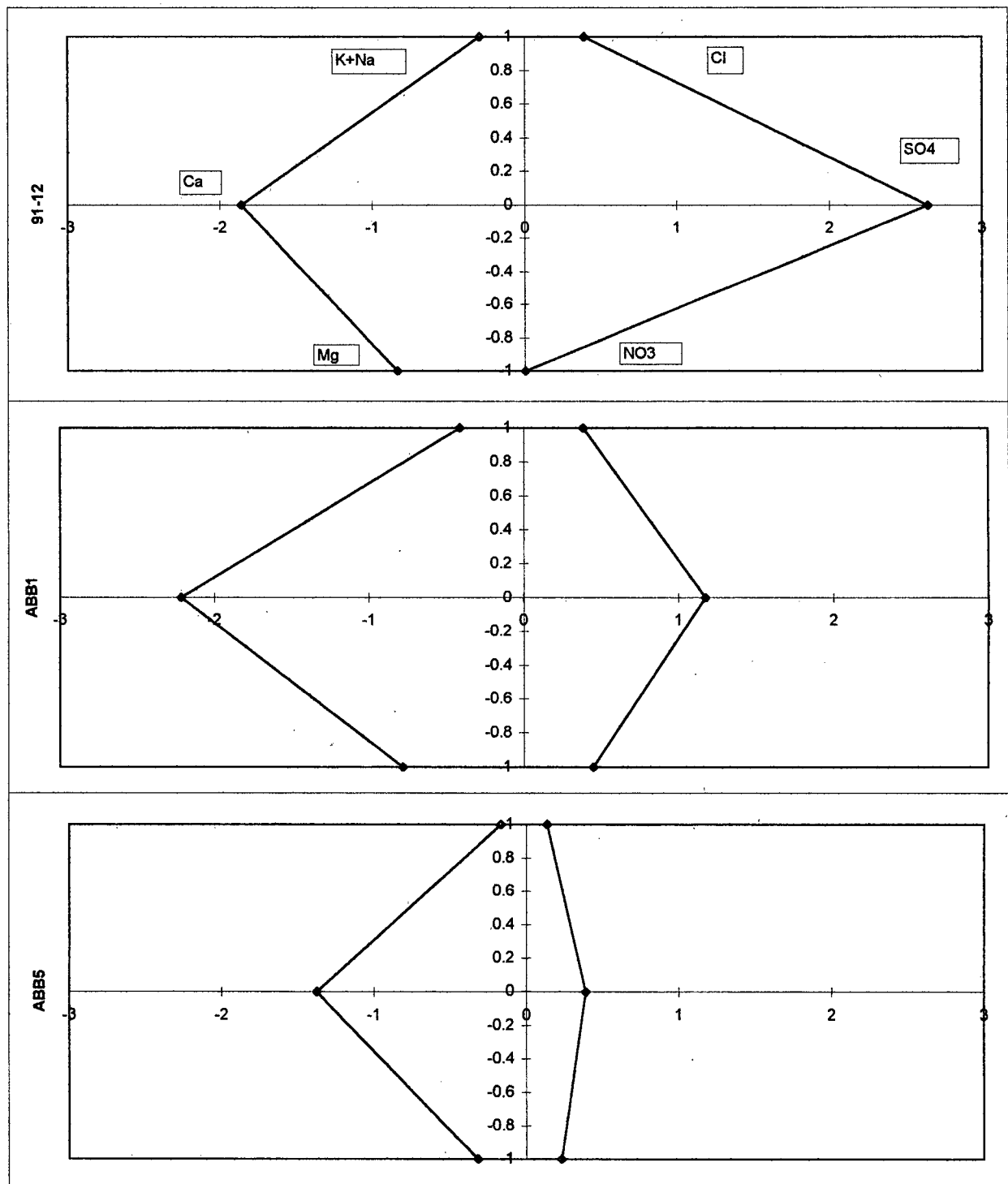


Figure B-1: Stiff Diagrams for March 23, 1998

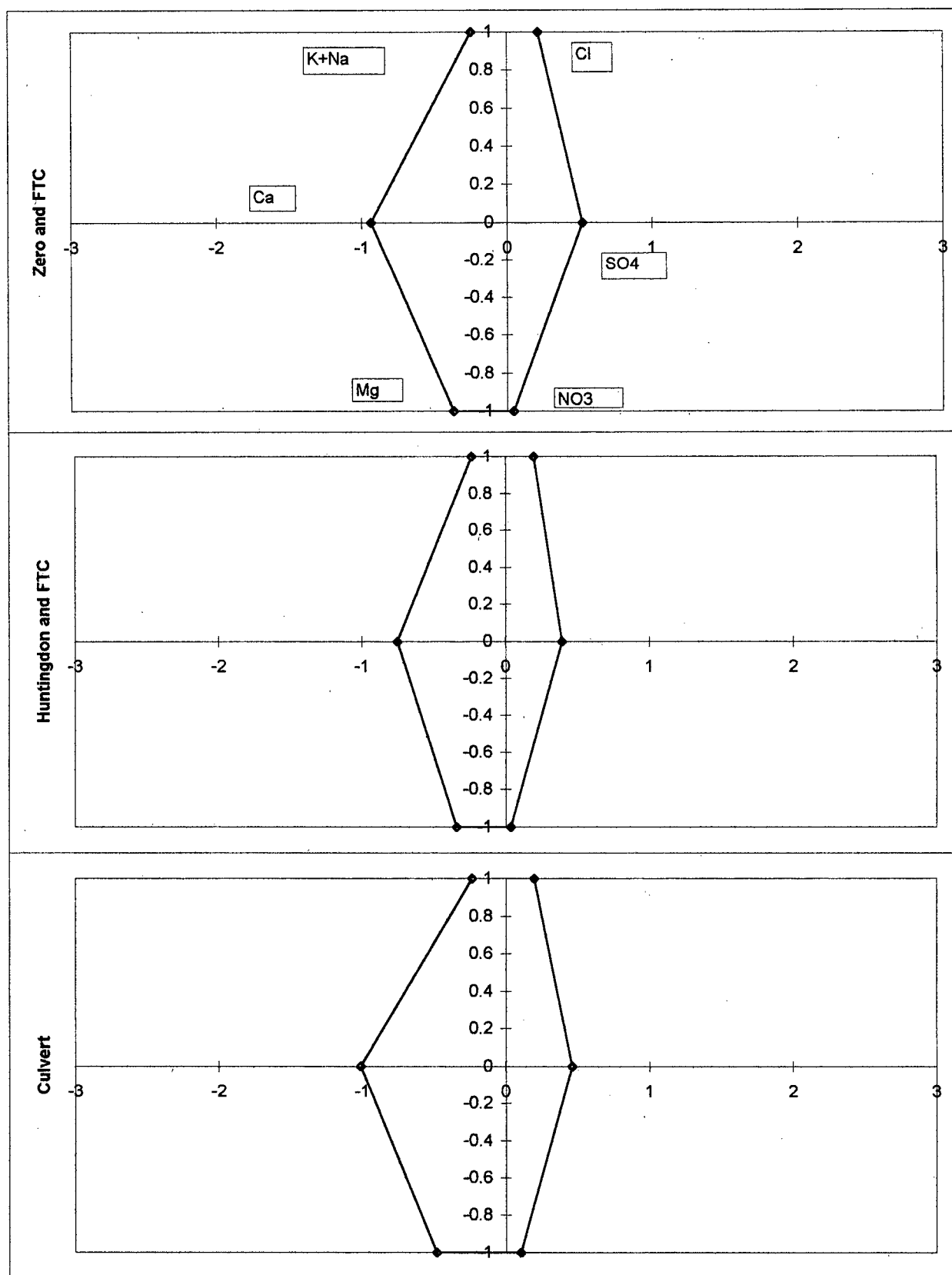


Figure B-1: Stiff Diagrams for May 25, 1998

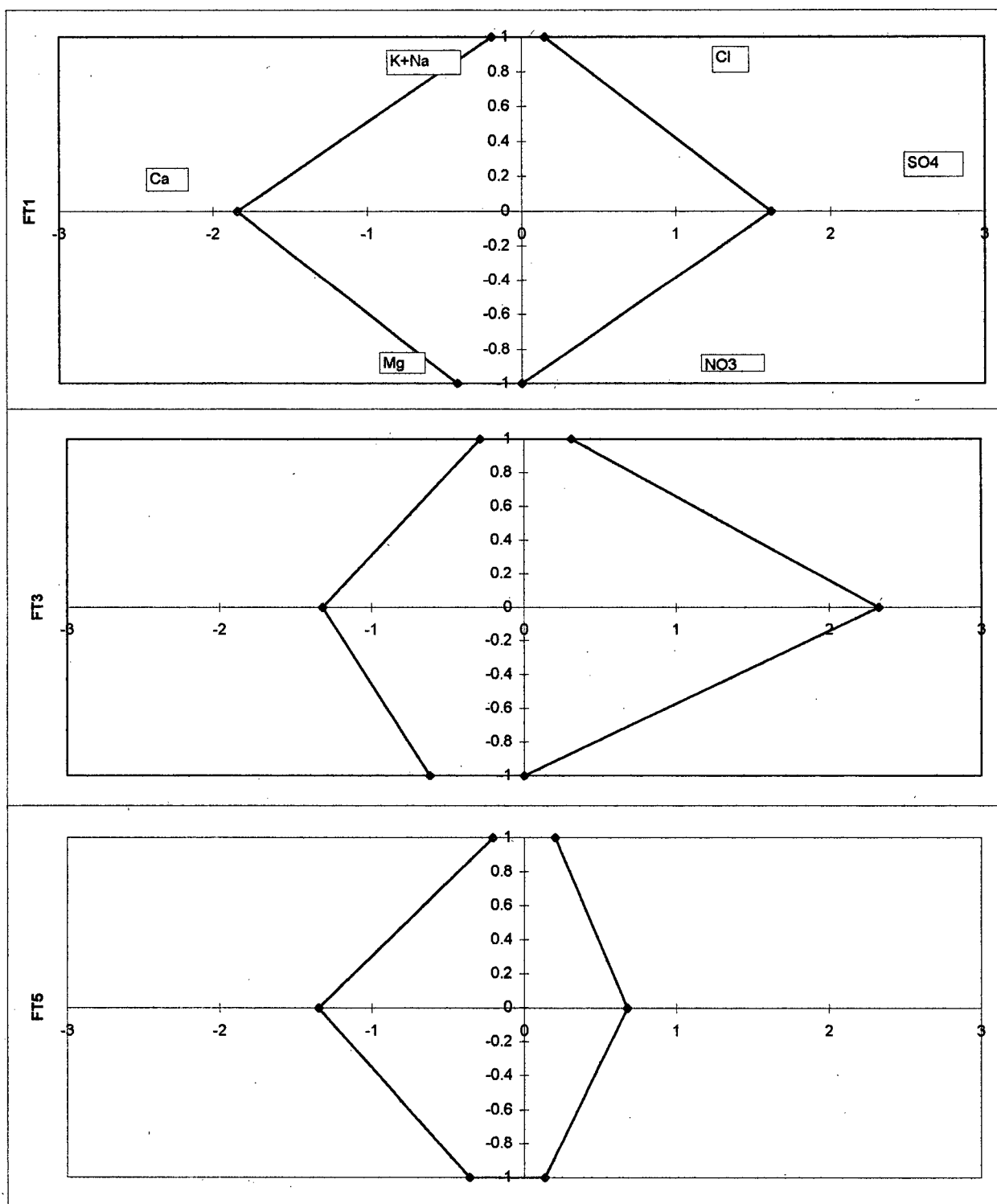


Figure B-1: Stiff Diagrams for May 25, 1998

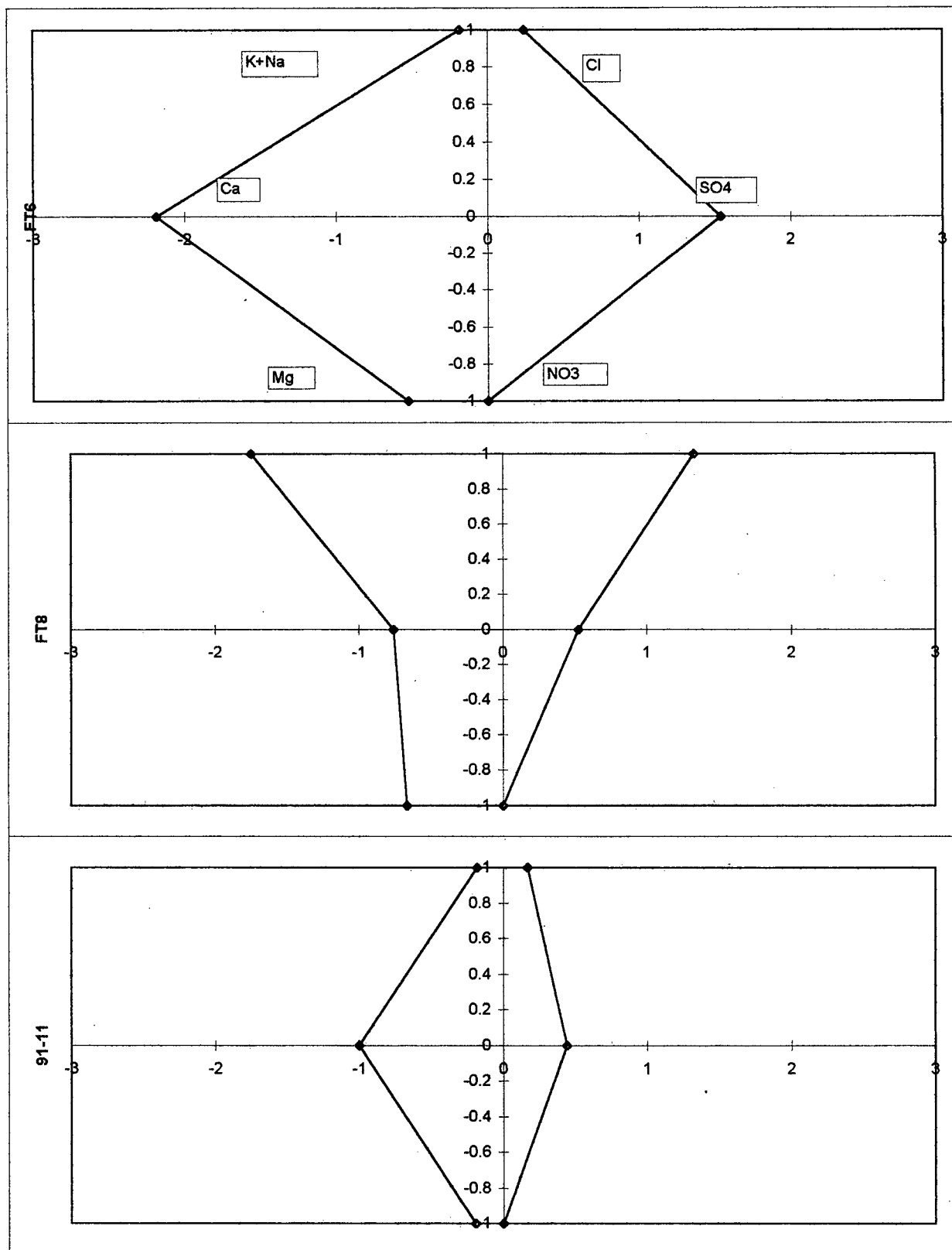


Figure B-1: Stiff Diagrams for May 25, 1998

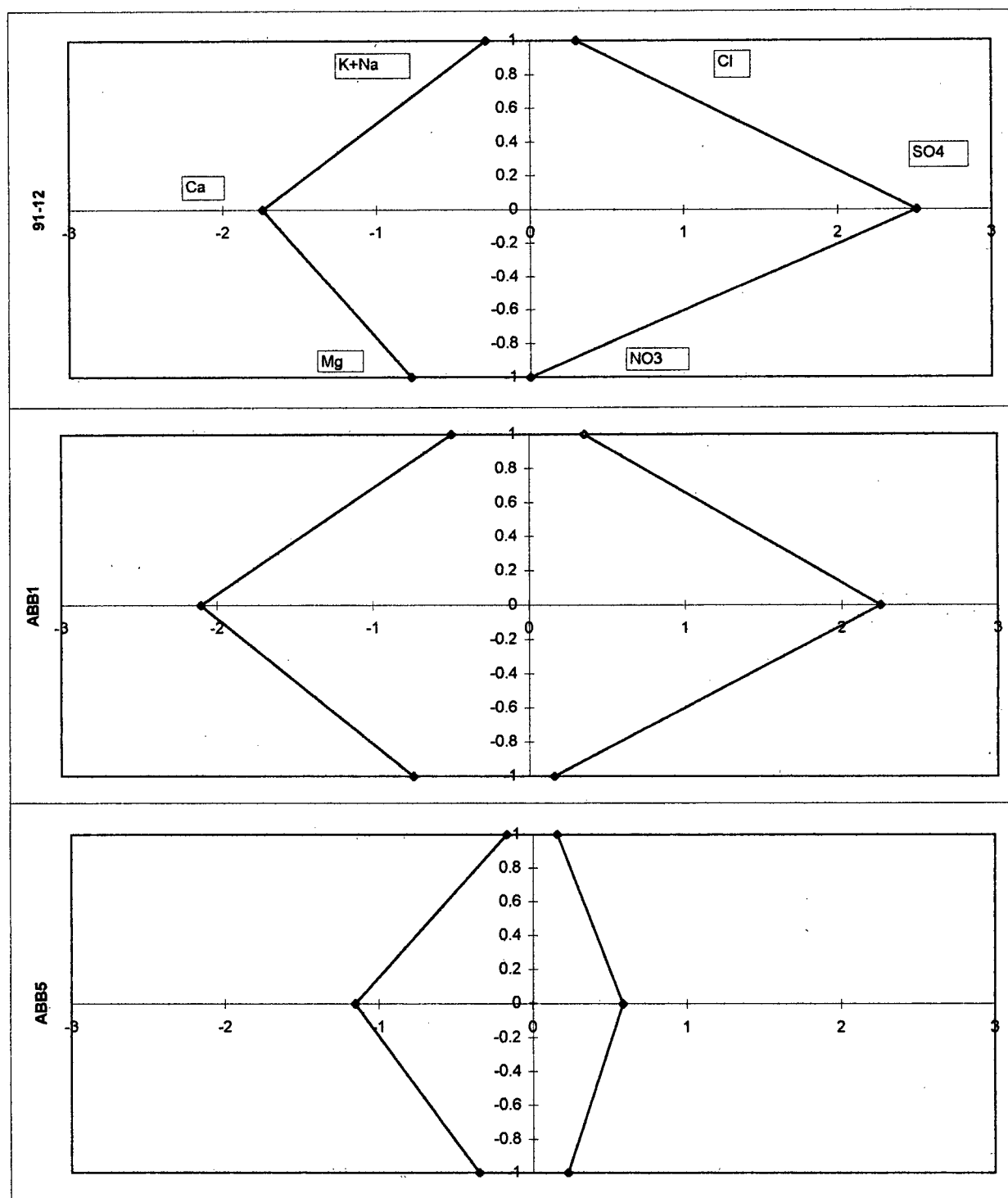


Figure B-1: Stiff Diagrams for May 25, 1998

Table B2: Surface Water Quality

SURFACE WATER ANALYSES									
Date: Feb 17/98									
Station	DO (mg/L)	Temp oC	pH	Flow (cms)	(mg N/L) NO3	(mg/L) Cl	SO4	HCO3	
Huntingdon Ave	9.5	7.6	6.85	0.65	3.47	8.6	14.7	52.0	
FT5 Bridge				0.63					
Culvert	4.5	8.6	6.49	0.08	6.42	6.8	27.7	35.0	
FT3 Bridge				0.73					
Zero Ave	9.0	7.8	6.79	0.85	4.19	8.4	21.7	48.0	

SURFACE WATER ANALYSES									
Date: March 15/98									
Station	DO (mg/L)	Temp oC	pH	Flow (cms)	(mg N/L) NO3	(mg/L) Cl	SO4	HCO3	
Huntingdon Ave	7.0	9.8	6.77	0.77	3.42	7.6	11.9	52.0	
FT5 Bridge				0.73					
Culvert	6.0	10.4	7.12	0.07	5.81	5.6	24.2	36.0	
FT3 Bridge				0.80					
Zero Ave	7.0	10.2	7.17	0.85	4.15	7.6	19.0	48.0	

SURFACE WATER ANALYSES									
Date: March 23/98									
Station	DO (mg/L)	Temp oC	pH	Flow (cms)	(mg N/L) NO3	(mg/L) Cl	SO4	HCO3	
Huntingdon Ave	12.5	8.9	6.94	1.22	2.22	5.3	6.3	61.0	
FT5 Bridge				1.14		5.4	7.5	58.0	
Culvert	10.0	9.3	6.69	0.12	5.04	4.8	25.5	36.0	
FT3 Bridge				1.12		5.3	10.5	53.0	
Zero Ave	11.0	9.2	6.89	1.60	2.90	5.2	13.8	47.0	

SURFACE WATER ANALYSES									
Date: April 1/98									
Station	DO (mg/L)	Temp oC	pH	Flow (cms)					
Huntingdon Ave	12.5	10.0	6.93	0.60					
FT5 Bridge				0.62					
Culvert	11.0	10.0	7.40						
FT3 Bridge									
Zero Ave	13.0	10.2	6.67	0.62					
	11.0	10.0	7.09	0.63					

SURFACE WATER ANALYSES									
Date: April 6/98									
Station	DO (mg/L)	Temp oC	pH	Flow (cms)	(mg N/L) NO3	(mg/L) Cl	SO4	HCO3	
Huntingdon Ave	11.5	10.6	6.87	0.63	3.31	8.7	14.0	61.0	
FT5 Bridge				0.60		8.8	16.0	58.0	
Culvert	13.0	12.1	7.45	0.11	5.66	6.6	24.9	34.0	
FT3 Bridge				0.71		8.9	20.5	55.0	
Zero Ave	12.2	11.3	7.19	0.80	3.91	9.0	23.1	54.0	

Table B2: Surface Water Quality

SURFACE WATER ANALYSES									
Date: April 28/98									
Station	DO (mg/L)	Temp (°C)	pH	Flow (cms)	NO ₃ (mg N/L)	Cl (mg/L)	SO ₄	HCO ₃	
Huntingdon Ave	12.2	13.6	6.97	0.57	3.81	9.9	18.4	61.0	
FT5 Bridge	12.4	13.1	7.09	0.54		9.9	19.4	55.0	
Culvert	11.6	14.2	7.29	0.03	6.83	7.4	25.0	36.0	
FT3 Bridge	12.0	13.5	7.41	0.58		10.0	20.5	55.0	
Zero Ave	12.2	13.9	7.37	0.61	4.52	10.1	26.6	54.0	

SURFACE WATER ANALYSES									
Date: May 12/98									
Station	DO (mg/L)	Temp (°C)	pH	Flow (cms)	NO ₃ (mg N/L)	Cl (mg/L)	SO ₄	HCO ₃	TOC
Huntingdon Ave	7.7	12.5	7.16	0.65	1.77	8.4	11.0	80.3	7.4
FT5 Bridge	7.3	12.3	7.22	0.63		8.5	14.3	75.7	7.1
Culvert	9.0	10.6	6.98	0.03	6.81	7.4	24.5	46.8	6.4
FT3 Bridge	8.6	12.5	7.26	0.66		8.3	16.2	72.2	7.5
Zero Ave	9.7	12.9	7.31	0.70	2.47	8.5	19.2	75.7	6.6

SURFACE WATER ANALYSES									
Date: May 26/98									
Station	DO (mg/L)	Temp (°C)	pH	Flow (cms)	NO ₃ (mg N/L)	Cl (mg/L)	SO ₄	HCO ₃	TOC
Huntingdon Ave	8.5	10.7	6.31	0.65	2.27	6.9	18.9	61.0	6.2
FT5 Bridge	8.2	9.8	6.30	0.65		7.5	18.6	59.5	5.0
Culvert	7.0	9.5	6.85	0.03	6.60	6.9	22.3	46.8	6.0
FT3 Bridge	8.4	9.2	6.30	0.68		7.6	21.6	52.9	4.9
Zero Ave	8.5	9.2	7.30	0.70	2.90	7.6	25.0	54.4	4.5

SURFACE WATER ANALYSES									
Date: June 9/98									
Station	DO (mg/L)	Temp (°C)	pH	Flow (cms)	NO ₃ (mg N/L)	Cl (mg/L)	SO ₄	HCO ₃	TOC
Huntingdon Ave	8.5	10.0	6.36	0.57	3.99	9.1	26.2	79.3	3.0
FT5 Bridge	8.0	10.0	6.38	0.53		9.9	25.8	68.6	2.6
Culvert	8.0	10.2	6.90	0.02	6.60	6.9	22.3	46.8	5.5
FT3 Bridge	8.8	10.2	7.13	0.58		9.5	29.6	75.7	2.3
Zero Ave	9.1	10.2	7.33	0.61	4.54	8.9	34.8	68.6	3.5

Table B3: Evaporation Estimates

Date	water temperature	water temperature	air temperature	air temperature	relative humidity	wind velocity W (mph)	u (km/day)	Vapor Pressure				Meyer ¹ E (cm/day)	Dunne ² E (cm/day)	Meyer ³ E (m ³ /s)
								e _s	e _a	e _a (in. Hg)	e _a (mb)			
25/08/97	12.6	54.7	17.0	62.6	20	10	366	0.44	0.59	0.12	6.11	0.5684264	0.365552	0.0003814
30/09/97	12.9	55.2	15.0	59.0	20	10	366	0.44	0.52	0.10	6.11	0.6140102	0.365552	0.000398
27/10/97	10.2	50.4	10.0	50.0	20	10	366	0.36	0.36	0.07	6.11	0.5262944	0.365552	0.0003411
25/11/97	6.3	43.3	7.0	44.6	20	10	366	0.29	0.30	0.06	6.11	0.4203046	0.365552	0.0002724
15/12/97	6.9	44.4	6.0	42.8	20	10	366	0.31	0.27	0.05	6.11	0.4678173	0.365552	0.0003032
26/1/98	7.3	45.1	8.0	46.4	20	10	366	0.3	0.32	0.06	6.11	0.431269	0.365552	0.0002795
24/2/98	7.6	45.7	7.0	44.6	20	10	366	0.31	0.30	0.06	6.11	0.4566528	0.365552	0.0002961
23/3/98	8.9	48.0	8.0	46.4	20	10	366	0.34	0.32	0.06	6.11	0.5043665	0.365552	0.0003269
28/4/98	13.6	56.5	15.0	59.0	20	10	366	0.47	0.51	0.10	6.11	0.6724873	0.365552	0.0004359
25/5/98	10.7	51.3	14.0	57.2	20	10	366	0.37	0.49	0.10	6.11	0.4970558	0.365552	0.0003222
9/6/98	10.0	50.0	20.0	68.0	20	10	366	0.36	0.70	0.14	6.11	0.4020305	0.365552	0.0002606

Notes:

1. Empirical Equation by Meyer: $E=C(e_s-e_a)(1+W/10)$ where

C=pan empirical coefficient (0.44 for small rivers)

e_s=saturation vapor pressure at water surface temperature (in. Hg)e_a=vapor pressure of air (in. Hg)

W=wind velocity measured about 25ft above the water surface (mph)

2. Empirical Equation by Dunne: $E=(0.013+0.00016u)[(100Rh)/100]$

where

u=wind velocity at two m above the surface (km/day)

e_a=vapor pressure of air (mb)

Rh=Relative Humidity (percent)

3. Evaporation in m³/sec was calculated using the evaporation (cm/day) from Meyer (conservative) and the area of the creek.

The area of the creek was estimated using a length of 1600 m and an average width of 3.5 m.

Table B4: Water Elevations

Huntingdon Ave and FTC						
Top Bridge = 49.17 m		Stream Bottom = 45.63 m				
Top FT5 = 47.27 m						
Date	Depth to water	Depth below ground	Creek Elevation	g/w level	Stream into gw	Stream -gw
25-Aug-97	2.8		46.37		-	
17-Sep-97	2.1		47.07			
30-Sep-97	2.6	2.9	46.57	45.17 creek>gw	1.4	
14-Oct-97	2.69	2.68	46.48	45.39 creek>gw	1.09	
28-Oct-97	2.73	2.8	46.44	45.27 creek>gw	1.17	
11-Nov-97	2.77	2.75	46.4	45.32 creek>gw	1.08	
25-Nov-97	2.37	2.5	46.8	45.57 creek>gw	1.23	
8-Dec-97	2.71	2.7	46.46	45.37 creek>gw	1.09	
15-Dec-97	2.77	2.78	46.4	45.29 creek>gw	1.11	
20-Jan-98	2.52	2.35	46.65	45.72 creek>gw	0.93	
26-Jan-98	2.45	2.8	46.72	45.27 creek>gw	1.45	
9-Feb-98	2.69	2.62	46.48	45.45 creek>gw	1.03	
24-Feb-98	2.73	2.72	46.44	45.36 creek>gw	1.09	
15-Mar-98	2.7	2.64	46.47	45.43 creek>gw	1.04	
23-Mar-98	2.57	2.52	46.6	45.55 creek>gw	1.05	
1-Apr-98	2.73	2.7	46.44	45.37 creek>gw	1.07	
6-Apr-98	2.72	2.44	46.45	45.63 creek>gw	0.82	
28-Apr-98	2.83	2.87	46.34	45.2 creek>gw	1.14	
12-May-98	2.78	2.85	46.39	45.22 creek>gw	1.17	
25-May-98	2.78	2.89	46.39	45.18 creek>gw	1.21	
9-Jun-98	2.86	2.99	46.31	45.08 creek>gw	1.23	
2-Jul-98	2.86	3.08	46.31	44.99 creek>gw	1.32	

Bridge at FT5						
Top Bridge = 46.28 m		Stream Bottom = 43.94 m				
Top FT5 = 47.27 m						
Date	Depth to water	Depth below ground	Creek Elevation	g/w level	Stream into gw	Creek -gw
11-Nov-97	2	2.75	44.28	44.52 gw>creek	-0.24	
25-Nov-97	1.7	2.5	44.58	44.77 gw>creek	-0.19	
8-Dec-97	2.06	2.7	44.22	44.57 gw>creek	-0.35	
15-Dec-97	2.03	2.78	44.25	44.49 gw>creek	-0.24	
20-Jan-98	1.88	2.35	44.4	44.92 gw>creek	-0.52	
17-Feb-98	1.7	2.67	44.58	44.6 gw>creek	-0.02	
24-Feb-98	1.73	2.72	44.55	44.55 gw>creek	0	
15-Mar-98	2.05	2.64	44.23	44.63 gw>creek	-0.4	
23-Mar-98	1.82	2.52	44.46	44.75 gw>creek	-0.29	
1-Apr-98	2.05	2.7	44.23	44.57 gw>creek	-0.34	
6-Apr-98	2.04	2.44	44.24	44.83 gw>creek	-0.59	
28-Apr-98	2.11	2.87	44.17	44.4 gw>creek	-0.23	
5-May-98	2.13	2.85	44.15	44.42 gw>creek	-0.27	
12-May-98	2.03	2.85	44.25	44.42 gw>creek	-0.17	
25-May-98	2.05	2.89	44.23	44.38 gw>creek	-0.15	
9-Jun-98	2.17	2.99	44.11	44.28 gw>creek	-0.17	
2-Jul-98	2.2	3.08	44.08	44.19 gw>creek	-0.11	

Bridge at FT3									
Top Bridge = 44.71 m		Stream Bottom = 42.10 m							
Top FT3 = 45.17 m		Top FT6 = 45.07 m							
Date	Depth to water	Depth below ground	Creek Elevation	g/w level	g/w level	stream/creek creek-gw3	creek-gw6		
		FT3	FT6	FT3	FT6				
11-Nov-97	1.99			42.72					
25-Nov-97	1.6			43.11					
8-Dec-97	1.95			42.76					
15-Dec-97	1.96			42.75					
20-Jan-98	1.79	1.16	1.23	42.92	44.01	43.84	gwp-creek	-1.09	-0.92
17-Feb-98	1.75	1.45	1.45	42.96	43.72	43.62	gwp-creek	-0.76	-0.66
24-Feb-98	1.92	1.52	1.52	42.79	43.65	43.55	gwp-creek	-0.86	-0.76
15-Mar-98	1.905	1.52	1.52	42.805	43.65	43.55	gwp-creek	-0.845	-0.745
23-Mar-98	1.76	1.41	1.41	42.85	43.76	43.66	gwp-creek	-0.81	-0.71
1-Apr-98	1.93	1.55	1.55	42.78	43.62	43.52	gwp-creek	-0.84	-0.74
6-Apr-98	1.94	1.62	1.62	42.77	43.55	43.45	gwp-creek	-0.78	-0.68
28-Apr-98	2	1.72	1.71	42.71	43.45	43.36	gwp-creek	-0.74	-0.65
5-May-98	2.02	1.72	1.72	42.69	43.45	43.35	gwp-creek	-0.76	-0.66
12-May-98	1.99	1.72	1.72	42.72	43.45	43.35	gwp-creek	-0.73	-0.63
25-May-98	1.94	1.75	1.73	42.77	43.42	43.34	gwp-creek	-0.65	-0.57
9-Jun-98	2.05	1.78	1.78	42.66	43.39	43.29	gwp-creek	-0.73	-0.63
2-Jul-98	2.05	1.88	1.86	42.66	43.29	43.21	gwp-creek	-0.63	-0.55

Zero Avenue						
Top Bridge = 44.44 m		Stream Bottom = 41.59 m				
Top FT1 = 44.79 m						
Date	Depth to water	Depth below ground	Creek Elevation	g/w level	Stream Info gw creek-gw	
30-Sep-97	1.5	2.3	42.26	42.49	gwp-creek	-0.23
14-Oct-97	1.55	2.06	42.31	42.73	gwp-creek	-0.42
28-Oct-97	1.45	2.22	42.21	42.57	gwp-creek	-0.36
11-Nov-97	1.42	2.17	42.18	42.62	gwp-creek	-0.44
25-Nov-97	1.91	1.91	42.67	42.88	gwp-creek	-0.21
8-Dec-97	1.5	2.08	42.26	42.71	gwp-creek	-0.45
15-Dec-97	1.4	2.14	42.16	42.65	gwp-creek	-0.49
20-Jan-98	1.77	1.62	42.53	43.17	gwp-creek	-0.64
26-Jan-98	1.82	1.7	42.58	43.09	gwp-creek	-0.51
9-Feb-98	1.96	1.47	42.72	43.32	gwp-creek	-0.6
24-Feb-98	1.44	1.48	42.22	43.31	gwp-creek	-1.11
15-Mar-98	1.46	1.97	42.22	42.82	gwp-creek	-0.6
23-Mar-98	1.66	1.85	42.42	42.94	gwp-creek	-0.52
1-Apr-98	1.4	2	42.16	42.79	gwp-creek	-0.63
6-Apr-98	1.45	2.12	42.21	42.67	gwp-creek	-0.46
28-Apr-98	1.35	2.24	42.11	42.55	gwp-creek	-0.44
12-May-98	1.44	2.3	42.2	42.49	gwp-creek	-0.29
25-May-98	1.41	2.33	42.17	42.46	gwp-creek	-0.29
9-Jun-98	1.35	2.36	42.11	42.43	gwp-creek	-0.32
2-Jul-98	1.2	2.54	41.96	42.25	gwp-creek	-0.29

Table B5: Hydraulic Conductivity

Pore Water Velocity Calculations

$$\text{velocity} = v/n = (dh/dl) * K/n$$

$$n = .3$$

$$K = 10^{-4} \text{ m/sec}$$

FT3

$$dh = 1$$

$$dl = 13$$

$$dh/dl = 0.076923$$

$$dh/dh/n = 0.25641$$

$$\text{velocity} = 2.215385 \text{ m/day}$$

FT6

$$dh = 1$$

$$dl = 6$$

$$dh/dl = 0.166667$$

$$dh/dh/n = 0.555556$$

$$\text{velocity} = 4.8 \text{ m/day}$$

ABB1

$$dh = 1$$

$$dl = 120$$

$$dh/dl = 0.008333$$

$$dh/dh/n = 0.027778$$

$$\text{velocity} = 0.24 \text{ m/day}$$

FT1

$$dh = 0.5$$

$$dl = 3$$

$$dh/dl = 0.166667$$

$$dh/dh/n = 0.555556$$

$$\text{velocity} = 4.8 \text{ m/day}$$

ABB5

$$dh = 3$$

$$dl = 998$$

$$dh/dl = 0.003006$$

$$dh/dh/n = 0.01002$$

$$\text{velocity} = 0.086573 \text{ m/day}$$