Spring 2000

Hydrostratigraphy, groundwater flow, and nitrate transport within the Abbotsford Sumas aquifer, Whatcom County, Washington

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HYDROSTRATIGRAPHY, GROUNDWATER FLOW, AND NITRATE TRANSPORT WITHIN THE ABBOTSFORD SUMAS AQUIFER WHATCOM COUNTY, WASHINGTON

BY

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Accepted in Partial Completion

of the Requirements for the Degree

Master of Science

[redacted]

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MASTER'S THESIS

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MASTER'S THESIS

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A Thesis
Presented to
the Faculty of
Western Washington University

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ABSTRACT

From April 1997 to January 1999, a water quality study in a four square mile area in northern Whatcom County was conducted by the Geology Department and the Institute for Watershed Studies at Western Washington University. As part of this study, this thesis focused on characterizing the hydrostratigraphy, groundwater flow directions and flow velocities and developing a groundwater model using MODFLOW and Boss GMS version 2.0 (GMS) to simulate groundwater flow and nitrate transport within this area.

Monthly groundwater levels and water quality data were collected and analyzed from 21 domestic wells and one piezometer in the field and at Western Washington University's Institute for Watershed Studies State Certified Laboratory. This thesis used data collected from April 1997 to August 1998 which was divided into six seasons.

To characterize the hydrostratigraphy, five geologic cross sections were constructed from well logs in the study area using Autocad. Six geologic units were identified, which were grouped into two hydrostratigraphic units defined as the Sumas Aquifer and the Sumas Aquitard. The Sumas Aquifer in this area is an unconfined aquifer ranging in thickness from 180 feet in the northeast portion of the study area to 80 feet in the southeast portion of the study area. The Sumas Aquifer is a heterogeneous mixture of gravel and sand with some scattered silt and clay lenses and displays good hydraulic continuity. The average hydraulic conductivity for the Sumas Aquifer was determined to be 929 feet/day. The Sumas Aquitard is primarily a clay layer underlying the Sumas Aquifer interpreted as Bellingham glaciomarine drift. The Sumas Aquitard also consists of scattered lenses of clay and or silt interpreted as ice contact and lacustrine deposits.

Water table contour maps were created using the computer program Surfer version 6.0 (Surfer) for each of the six seasons using seasonally averaged water level data. A separate water table contour map was generated using the results of a groundwater model simulation. Groundwater flow directions determined from both sets of water table contours showed an overall northwest to southeast trend with the exception of the northwest portion of the study area which showed a south to southwest trend shifting to a southeast trend in the southeast portion of the study area. Groundwater flow

velocity determined from seasonal water table contour maps using Surfer was approximately 20.0 feet/day in the northwest to southeast direction. The approximate travel time from the international border to the southern end of the study area in the direction of groundwater flow determined using field data was 1.8 years. Groundwater flow velocity using the model simulation was approximately 25 feet/day. The approximate travel time from the international border to the southern end of the study area in the direction of groundwater flow using GMS was approximately 1.5 years. Groundwater levels varied from season to season with the largest average difference of 4.4 feet (throughout the study area) occurring between Spring 1997 and Fall 1997. The greatest variation in water level in any one well due to seasonal recharge was 7.8 feet between Spring 1997 and Fall 1998 at well 3. Well 1 was the only well having a correlation between rising water levels and elevated nitrates.

Two dimensional nitrate contours were created for each of the six seasons using seasonally averaged monthly nitrate data. Two dimensional nitrate contours indicate that the highest concentrations were down-gradient from large dairies and fertilized crops within the study area. Water quality data and two-dimensional nitrate contours indicate that most of the contamination in the central portion of the study area is localized and likely coming from sources up-gradient of wells 9, 14, and 18. However, elevated nitrates in wells 5, 6, and 7 in the northeast portion of the study area are attributed to sources across the international border in Canada.

A groundwater model was developed for the study area using MODFLOW and GMS. Three nitrate transport simulations were created using GMS and a transport model (MT3D). A 50 mg/L spike of nitrate was entered into the model domain at selected points for one day. The nitrate spikes created contaminant plumes which were contoured at the end of one year for scenarios one and three, and at the end of six months for scenario two. Comparing nitrate transport simulations with nitrate concentrations obtained in the field revealed correlations of elevated nitrates from known up-gradient loading sources. Nitrate transport simulations indicate that large nitrate concentrations in the north and south central portions of the study area are likely caused by local source loading rather than source loading in Canada (specifically wells 14, and 18). However, transport simulations also suggest that the relatively stable elevated nitrate concentrations in the northwest (specifically wells 1 and 2) and northeast (specifically wells 5 and 6) portions of the study area are likely caused from sources across the international border in Canada.

ACKNOWLEDGMENTS

I dedicate this thesis to God. I thank God for watching over me and saving enough of my brain cells to not only pass all of my graduate courses, but giving me the strength and courage to finish this thesis. I thank my wife Sharon for standing by my side through this long and tortuous process. I thank both my parents, and my wife's parents (who I call my own) for their continual love and support through this whole experience. I thank my family, who for the most part have no clue what I am doing but love me anyway. I would especially like to thank my younger sister Deanna, who has taught me more about myself, life, and strength, than any person I know.

I would like to thank Scott Babcock for providing me the opportunity to work on this project, and his unwavering confidence in my abilities. I would especially like to thank Bob Mitchell who acted not only as my thesis advisor, but also became a mentor, friend, and critic who helped me to better myself in many ways which will last a lifetime. I would like to thank George Mustoe for always being himself, and his friendship. Thanks to Vicki Critchlow and Chris Sutton for their support throughout my years at Western and making it all happen behind the scenes. I would like to thank my field partner Leora Nanus. I hope that we remain friends for life. Thanks to the many undergraduate and graduate students I have not mentioned.

I would like to thank everyone at BEK Engineering including John Einerson, Tom Bennett, Ron Kensok, and Ken Koenig. I would especially like to thank Mike Stoner at the Port of Bellingham who was the best supervisor I have ever worked for and gave me some really good advice: "Do what you love to do and you will always be able to get a job". Finally, I would like to thank Dan McShane for his steadfast belief in my ability, continual encouragement, and friendship. Words cannot describe the true character and integrity of Dan McShane.

Thanks to my friends and mentors at the Island County Health Department. Special thanks to the best practicing hydrogeologist I know, Doug Kelly, and to Keith Higman who is truly an exceptional human being. Although this chapter of my life has ended, it will never be forgotten. Thanks to all.

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1.0 INTRODUCTION

1.1 ABBOTSFORD-SUMAS AQUIFER

The Abbotsford Sumas Aquifer is predominately an unconfined aquifer located in southwestern British Columbia, Canada, and extends across the international boundary into northwestern Washington State. The aquifer lies within the Fraser and Nooksack Lowlands (Figure 1) and is comprised mainly of glacial sands and gravel deposited during the Pleistocene Epoch. The aquifer serves as a water supply for nearly 10,000 people in the U.S. and about 100,000 people in Canada (Abbotsford Sumas Aquifer 1996 Status Report). Due to extensive agricultural activity in Canada and Whatcom County, a continuing deterioration of water quality has occurred within the Abbotsford Sumas Aquifer over the past 40 years (Abbotsford Sumas Aquifer 1996 Status Report). Nitrate is the most documented and long term contaminant in the Abbotsford Sumas Aquifer with concentrations consistently above both the Canadian Drinking Water Guidelines (CDWG) (Liebscher et al. 1992; Gartner Lee 1993) and the United States Environmental Protection Agency (EPA) drinking water standards (Garland and Erickson, 1994; Cox and Kahle, 1999), both of which are 10 milligrams per liter (mg/L) nitrate as nitrogen ($NO^{-}_{3}N$).

Nitrogen in the form of nitrate (NO^{-}_{3}) is a negatively charged ion that is found in both commercial fertilizers and animal manures. In the United States, it is estimated that the farm animal population voids about 20 times as much manure solids as does the human population (Gillies, oral communication 2000). Land application of the manures beyond those agronomically required by crops can result in excess nitrogen loss in the form of nitrates to surface and groundwater. Nitrates, because of their negative charge, are not readily adsorbed by soils and are easily leached into the water table where they may reach domestic wells and surface waters such as streams, lakes, and estuaries. Nitrates are considered one of the most problematic and widespread of all groundwater contaminants (Canter, 1997).

Nitrate in drinking water can cause harmful effects on human health. Concentrations of 10 (mg/L) or higher are believed to cause methemoglobinemia or “blue baby syndrome” which occurs primarily in infants, and have also been cited as a risk factor in developing gastric and intestinal cancer (State of Washington Department of Health, 1992). Moreover, elevated levels of nitrate in groundwater serve as an indication of poor water quality in general, and can be associated with other harmful agrochemicals (e.g. pesticides) (Liebscher et al., 1992).

Nitrate levels in groundwater vary considerably within the Abbotsford-Sumas Aquifer (Liebscher et al., 1992; Gartner Lee, 1993; Garland, 1994; Garland, unpublished; Szeto,1994; Wassenaar, 1994; Cox and Kahle, 1999). Several recent groundwater studies have documented levels of nitrates that exceed the EPA limit for nitrate (Gartner-Lee Ltd., 1993; Garland and Erickson, 1994; Cox and Kahle, 1999). The Washington State Department of Ecology (Ecology) has identified groundwater nitrate contamination as high as 50 mg/L nitrate near Halverstick and Pangborn Roads in north Whatcom County (Garland, 1997) (Figure 2). It is recognized that dairy and berry farms in northern Whatcom County are contributing to nitrate contamination of groundwater. However, sources for high nitrate levels are not necessarily just from local agricultural practices. For example, sixty percent of British Columbia's poultry industry is located on or near the Abbotsford-Sumas Aquifer (Ryan, 1994). Groundwater flow directions near the international border have been shown to be to the south and southeast (Creahan, 1988; Kahle, 1990, Liebscher et al. 1992; Cox and Kahle, 1999). Some have suggested that heavy poultry farming and agricultural practices in Canada may be responsible for at least some of the elevated nitrate levels observed in groundwater in the United States.

1.2 WHATCOM COUNTY AGRICULTURAL SETTING

Higher than normal nitrate concentrations in the groundwater of northern Whatcom County have generally been associated with the agricultural setting and is the driving force for this thesis. Whatcom County, Washington, is the second leading dairy producing county in Washington State and ranks eighth in dairy production for the entire United States (Thompson, oral communication 2000). Northern Whatcom County is also prime agricultural land ranking fifth in world raspberry production as well as producing large crops of potatoes, corn, strawberries and blueberries (Seeger, oral communication 1999). Large areas of northern Whatcom County have relatively permeable soils and a high water table. Because of this, unconfined portions of the aquifer in this region are particularly susceptible to nitrate contamination from surface activities. The primary surface activities of concern include the spreading of animal manure wastes and nitrogen based fertilizers, and the use of pesticides related to agricultural activities.

1.3 PREVIOUS GEOLOGICAL RESEARCH

A number of geologic investigations and mapping efforts by Easterbrook (1963, 1966, 1971, 1973, 1974, 1975, and 1976), Armstrong (1981), and Armstrong and Brown (1953, 1954), describe the glacial chronology and surficial geology, but tend to have very general interpretations of hydrostratigraphy both in the United States and Canada. In 1986, Halstead investigated groundwater supply for the Fraser Lowland, British Columbia, Canada, which included a detailed representation of the hydrostratigraphy only on the Canadian side of the border (Halstead, 1986). On the U.S. side, Creahan and Kelsey (1988) produced a report on the hydrogeology and groundwater flow in two areas near Lynden, Washington, and Kahle (1990) conducted MS thesis research on the hydrostratigraphy and groundwater flow in the Sumas, Washington area. Interpretations of the hydrostratigraphy by Creahan and Kelsey (1988) was cursory and did not include the area of interest. Kahles study (1990) included the area of interest, but interpretations of the hydrostratigraphy were determined to be incorrect based on available well log data. The most recent study in this area was conducted by the United States Geological Survey (USGS) and covered approximately 225 square miles in northern Whatcom County and a portion of British Columbia, Canada (Cox and Kahle, 1999). The USGS study (Cox and Kahle, 1999) provided good overview on the regional hydrostratigraphy, but still lacks the detail needed for this study and was only made available after this study was near completion.

Although the above studies outlined a general depiction of the geology and hydrostratigraphy of the study area and surrounding region, a more detailed understanding is required for this thesis for a variety of reasons. Little is known about the hydrogeologic properties of the aquifer specific to this area, including unit depths and thickness. Estimates of permeability and porosity of the aquifer materials are scarce and tend to be regional in nature. The hydraulic continuity of various geologic deposits within this portion of the aquifer are not well documented. Previous interpretations of the hydrostratigraphy in this area was determined to be incorrect based on available well log data. Most importantly, a more detailed picture of the hydrostratigraphy is needed to develop an accurate groundwater model of the study area to aid in the understanding of nitrate distribution and transport.

1.4 PROJECT PURPOSE

It remains unclear as to why elevated levels of nitrate exist in localized areas within the Abbotsford-Sumas Aquifer. To help quantify nitrate distributions, a two-year nitrate study funded by Ecology was conducted by the Geology Department and the Institute for Watershed Studies at Western Washington University from April 1997 to January, 1999. The overall purpose of this study was to monitor a small portion of the aquifer near the international border (Figure 2) to determine the extent and variability of nitrate contamination in this area and help determine possible sources. As part of this study, this thesis will focus on characterizing the hydrostratigraphy and its relationship to groundwater flow directions and flow velocities. The research will also apply a groundwater model and a contaminant transport model to simulate groundwater flow and nitrate transport in the study area.

1.5 PROJECT OBJECTIVES

1. Characterize the hydrostratigraphy. Five geologic cross sections within the study area will be constructed using Autocad version 14.0 (Autocad). Information on the hydrostratigraphy will be gathered primarily through reviewing drillers well logs and conducting site visits to active and abandoned gravel pits within and outside of the project area. Aquifer properties will be determined from samples collected in the field for laboratory analyses.

2. Construct water table contour maps. Water table contour maps will be constructed using Surfer version 6.0 (Surfer) for each of the six seasons water levels were measured in the field. Each season will consist of three months of averaged water level data. Water table contours will provide a tool by which estimates of groundwater flow directions and general groundwater flow velocities can be determined. Water table contours will also be used to interpret seasonal water table fluctuations within the aquifer and aid in groundwater model calibration.

3. Develop a groundwater flow model. MODFLOW and Boss GMS version 2.1 (GMS) will be used to develop a groundwater model to simulate groundwater flow within the study area.

The groundwater flow model will be coupled with a contaminant transport model to predict nitrate transport.

4. Construct two-dimensional nitrate concentration contour maps. Surfer will be used to construct two-dimensional nitrate concentration contour maps. Nitrate contour maps will help identify spatial and temporal trends of nitrates within the study area.

5. Simulate nitrate transport within the study area. A numerical transport model (MT3D) will be used to simulate two-dimensional advection and dispersion of nitrate concentrations within the study area. Three scenarios will be used to reflect nitrate loading sources in the field and predictions from nitrate loading across the international border in Canada. Estimations will be made concerning residence times for nitrates within this portion of the aquifer.

2.0 BACKGROUND

2.1 STUDY AREA DELINEATION

The Abbotsford-Sumas Aquifer covers approximately 100 square miles and is located in southwestern British Columbia extending across the international boundary into northwestern Washington State. The study area encompasses approximately four square miles of the Abbotsford-Sumas Aquifer in the northernmost part of Whatcom County, WA, beginning at the international boundary (Figure 2). The area is located west of Sumas and northeast of Lynden on the proximal portion of the Sumas outwash plain, also known as the Lynden Terrace, and includes the following Townships Sections and Ranges:

T41N, Sec. 36, R3E and T41N, Sec. 31, R4E.

T40N, Sec. 1 and 12, R3E and T40N, Sec. 6 and 7, R4E.

The study area was chosen because Ecology had previously identified elevated nitrate levels in the area and studies involving stratigraphy, groundwater, and contamination had already been conducted in and around the region (e.g., Kahle,1990; Liebscher 1992; Garland and Erickson, 1994; Garland, 1997; Cox & Kahle, 1999).

2.2 REGIONAL GEOLOGIC SETTING

The Abbotsford-Sumas Aquifer lies within the Fraser and Nooksack Lowlands which is part of a major structural trough that has subsided repeatedly since late Cretaceous time

(Halstead, 1986). The tectonic activities responsible for this subsidence also produced the Coast and Cascade Mountain Ranges, which have undergone continuous weathering and erosion supplying enormous quantities of sediment to the Fraser and Nooksack Lowlands. These sediments were deposited along with plant and organic matter in fluvial, glacial and marine environments. Post-depositional lithification and consolidation of these sediments produced sandstones, siltstones, mudstones, shales, conglomerates, and hydrocarbon deposits including coal. Post-depositional deformation of these sedimentary rock units produced an irregular bedrock surface (Cox and Kahle, 1999). The Lowland was repeatedly invaded by glaciers during the Pleistocene Epoch, which further shaped the topography prior to depositing thick variable sequences of both glacial and nonglacial sediments which comprise some of the most productive aquifers in this region.

2.3 LOCAL GEOLOGIC SETTING

Test drilling and geophysical surveys indicate that bedrock is beneath 1,000 to 2,000 feet of Pleistocene deposits throughout much of the Fraser-Nooksack Lowlands (Cox and Kahle, 1999). However, one well log located less than 3 miles north of the international border encountered bedrock at approximately 400 feet below land surface (Halstead, 1986). Repeated advances and retreats of continental glaciers during the Pleistocene Epoch deposited variable sequences of glacial, glaciofluvial, and glaciomarine sediments (Figure 3). Little is known about the oldest and deepest deposits in the study area because they are relatively inaccessible. Much more has been published about the more recent deposits of the last major glaciation known as the Fraser Glaciation.

2.3.1 The Fraser Glaciation

The Fraser Glaciation began approximately 20,000 years ago and had a 10,000-year duration (Easterbrook, 1963, 1966). Four phases (or stades) have been defined, each representing a different time period during the advance and retreat of glacial ice. The first stade, known as the Evans Creek Stade, was the advance of alpine glaciers in the North Cascades and did not affect the study area so will not be discussed.

Vashon Stade

The Vashon Stade (20,000 to 13,000 years ago) began with the advance of glacial ice southward across the international border and into the Puget Sound Lowland. Meltwater streams from the advancing glacial ice deposited outwash sand and gravel south of the glacier terminus. Outwash deposits were soon covered with glacial till (Vashon till) as the ice thickened and moved farther southward. Vashon till is usually a compact, poorly sorted mixture of clay, silt, sand, pebbles, cobbles, and boulders which has a texture somewhat resembling concrete (Easterbrook, 1975). The ice responsible for depositing the Vashon till is believed to have been more than a mile thick in the vicinity of Bellingham, WA (Easterbrook, 1975).

Everson Interstade

The Everson Interstade began approximately 13,500 years ago when the massive ice sheet retreated and thinned in response to global climate changes. Relative sea level at that time was several hundred feet higher than at present due to the depressed land surface caused by the overlying weight of glacial ice and the large influx of water from melting glaciers. The continental ice was lifted up by rising sea water levels and floated as the ice continued to thin and retreat. As the ice melted, an unsorted mixture of clay, silt, sand, and gravel fell to the sea floor burying clams and various other mollusks creating a deposit resembling glacial till with shells known as glaciomarine drift (GMD). Not all GMD deposits contain shells.

In the Nooksack Lowland and westward to Bellingham, the Everson Interstade is believed to be represented by two GMD units separated by fluvial sand and peat. Elsewhere, a single GMD unit (Bellingham GMD) represents the Everson Interstade. According to Easterbrook (1975), the oldest unit of the Everson Interstade (Kulshan GMD) consists of an unsorted, blue-gray mixture of silt, clay, sand, and pebbles. The younger Deming Sand unit overlies the Kulshan GMD and generally consists of stratified, brown, well sorted, medium to coarse sand deposited on flood plains and beaches when sea level dropped relative to land surface. The youngest unit (Bellingham GMD) overlies the Deming Sand and consists of blue-gray, unsorted, pebbly, sandy silt and pebbly clay.

Sumas Stade

The Sumas Stade (10,000 to 11,000 years ago) represents the most recent phase of Pleistocene glaciation in the area. During that time the main glacial terminus was just north of the present-day international border with a lobe extending south into Whatcom County Washington, near Sumas (Figure 4). Three Sumas Stade units were identified by Easterbrook (1975) including till and ice contact deposits, outwash sand and gravel, and silt and clay sediments. Glacial meltwaters deposited large quantities of sand and gravel forming an outwash plain sloping southward from the border to the modern Nooksack floodplain near Lynden, Washington. The rich sand and gravel deposits of the Sumas outwash makes up the unconfined aquifer within the study area which is the primary source of irrigation and drinking water. The Sumas outwash is also an important natural resource that has been and continues to be mined for sand and gravel.

2.4 Hydrology (Climate and Precipitation)

The intention of this section is to report precipitation values during the course of this study, not to discuss long term climatic trends. Additional information related specifically to climate can be obtained through the U.S. Department of Commerce National Oceanic and Atmospheric Administration. Briefly, northern Whatcom County is unique in that the climatic controls of latitude, air mass source region, and topography are well blended for the production of large quantities of high quality water (Washington State Division of Water Resources, 1960). The region comprising the Abbotsford-Sumas Aquifer tends to experience warm, relatively dry summers and cool rainy winters.

Precipitation data were obtained from the Clearbrook climatological data station, which was selected because of its proximity to the study area (Figure 5) and its long history of accurate daily observations (Washington State Division of Water Resources, 1960). Seasonal precipitation data for 1997, 1998, and the 30-year precipitation averages are listed in Table 1 and shown in Figure 6. The monthly precipitation values were averaged into four seasonal blocks per year defined as Spring (March, April, and May), Summer (June, July, and August), Fall (September, October, and November), and Winter (December, January, and February). The total precipitation for 1997 was 61.4 inches and the total precipitation for 1998 was 46.15

inches.

2.5 Surface Water Lakes

There are two small surface water lakes in the study area known as Judson Lake and Pangborn Bog (Figure 2). Both Judson Lake and Pangborn Bog occupy deep kettles that have been filled with peat but are surrounded by very permeable outwash sand and gravel (Easterbrook, oral communication 1999). Judson Lake, which lies in the northern portion of the study area and crosses the international boundary into Canada, is a shallow lake (reportedly 2-7 feet in depth) covering about one half square mile. A small lake of unknown depth occupies the center of Pangborn Bog and is only visible from aerial photographs. Much of Pangborn Bog is heavily vegetated making the lake virtually inaccessible. The surface water lake associated with Pangborn Bog once occupied a much larger area and was artificially drained in 1947 (Riggs, 1958).

2.6 Surface Water Streams

Surface water streams in the study are limited to a small perennial stream entering the west side of Judson Lake which originates in Canada, and Pangborn Creek which flows year round out of Pangborn Bog (Figure 2). Two small springs feed Pangborn Bog from the north and west as well as several man made drainage ditches to the north and east. The resulting outflow stream from Pangborn Bog flows south and east and is the only source of surface water drainage in the study area as there is no outflow stream associated with Judson Lake.

2.7 Soils

Because soils vary throughout the study area in type and thickness, their physical properties may affect the quantity and quality of water recharging shallow aquifers (Cox and Kahle, 1999). There are six soil types found within the study site described by the Soil Survey of Whatcom County Area, Washington. Each will be discussed below; the number in parentheses correlates to the soil type seen in the aerial photograph (Figure 7). The Soil Survey of Whatcom County Area (1992) uses the following terms to describe a soils permeability based on inches per hour water moves downward through saturated soil. Slow =

0.06 to 0.2 inch; moderate = 0.6 inch to 2.0 inches; rapid = 6.0 to 20 inches; very rapid = more than 20 inches.

2.7.1 Kickerville silt loam, 0-15 percent slopes (79), (80), (81)

Kickerville silt loam soils are the most productive and widespread soils in the study area. These soils are primarily used for growing raspberries with some areas used as pasture for dairy cows and for spreading manure. The Kickerville silt loam formed in a mixture of loess and volcanic ash over glacial outwash. The substratum of this unit is very gravely to extremely gravely sand (Soil Survey, 1992). Permeability is moderate in the upper portions of this unit and very rapid in the lower portions (Soil Survey, 1992).

2.7.2 Pangborn muck, drained, 0-2 percent slopes (116)

Pangborn muck is the next most abundant soil type located within the study area. This is a very deep, very poorly drained soil formed in depressions on outwash terraces and in abandoned outwash channels (Soil Survey, 1992). It has moderate permeability and has been artificially drained. Open drainage ditches are used to drain the Pangborn muck in which the water table is commonly 1.5 to 2.5 feet below the surface from October through May (Soil Survey, 1992).

2.7.3 Histosols, ponded, 0 to 1 percent slopes (72)

These are deep, poorly drained soils in backswamps, floodplains, and on the edge of bodies of water. Histosols are located within the portion of the study area which makes up Pangborn bog and the areas within and surrounding Judson lake. Histosols are formed of mixed organic material consisting of mosses and shrubs over mineral matter with moderate to slow permeability. The underlying material to a depth of 70 inches is typically a gray silt loam (Soil Survey, 1992).

2.7.4 Clipper silt loam, drained, 0-2 percent slopes (31)

There is one small patch of Clipper silt loam on the eastern edge of the study area. The Clipper silt loam, like the Kickerville silt loam, is a deep, poorly drained soil also found in depressions on outwash terraces and outwash plains (Soil Survey, 1992). The substratum of this unit to a depth of 60 inches is dark grayish brown and grayish brown, mottled very gravely loamy sand to gravely sandy loam. Permeability is moderate in the upper part of the soil and rapid in the substratum.

2.8 Recharge

Recharge to groundwater is essentially the amount of precipitation that infiltrates into the soil after runoff and evapotranspiration. Recharge may also be in the form of irrigation, septic drain fields, manure lagoons, and losing reaches of streams or rivers. Since most of the study area is either open pasture or field crops, it is assumed that recharge is primarily controlled by precipitation and soil permeability. Cox and Kahle (1999) reviewed monthly soil water budgets for the Clearbrook and Abbotsford weather stations and reported that evapotranspiration typically exceeded precipitation between May and September while precipitation exceed evapotranspiration from October to April. The average groundwater recharge estimated for the study area was 26-30 inches per year (Cox and Kahle, 1999).

3.0 METHODOLOGY

Various methods were used to accomplish the five objectives outlined in section 1.5. A thorough review of all available well log data and numerous field investigations were conducted to aid in characterizing the hydrostratigraphy. Standard techniques and procedures were used in sieve analyses and water quality sampling. Several software packages including Autocad, Surfer, MODFLOW, GMS, MT3D, and Microsoft Excel were used to produce the results of this study.

3.1 SITE SELECTION

A representative study area, outlined in section 2.1, was selected to monitor groundwater levels and various chemical parameters in 21 wells on a monthly basis for a period of 24 months. The 21 wells were selected based on several criteria which included geographic location, previous sampling by Ecology, depth and diameter of the well, and whether or not a drillers log was available. During the course of this study, a piezometer and three new wells were added (wells 22, 23, and 26) in addition to the 21 wells already being sampled (Figure 8). This thesis uses 17 months of the collected data.

3.2 DRILLERS WELL LOGS

Drillers well logs for the study area were obtained through the Whatcom County Health Department, Ecology, and previous studies (e.g., Halstead, 1986; Kahle, 1990). Drillers well logs were separated by Township, Range, and Section within the study area. All well logs were examined, however, only selected well logs were used in the development of five geologic cross sections within the study area using Autocad. The selection of well logs for use in the cross sections was based primarily on their proximity to cross section locations and quality of the well logs. Drillers well logs were also used for several sections outside of the study area, including Canada, in the interpretation of the regional hydrostratigraphy.

3.2.1 SIEVE ANALYSES

A sieve analysis was used to determine the distribution of grain sizes within a sample to quantify hydraulic properties of a hydrostratigraphic unit. Sieve analyses were conducted on ten sediment samples collected at various depths and locations within the study area (Figure 9). The sieve analyses followed the American Society of Testing Methodology (ASTM) standards. ASTM standards for particle size boundaries are determined by sieve size and are broken into five major categories: cobbles, gravel, sand, silt, and clay. Sub-categories within the five major categories are also defined by sieve size and include coarse and fine gravel; coarse, medium and fine sand (Appendix A).

Particle size distributions obtained from the sieve analyses were used to estimate the hydraulic conductivity of a sample using empirical equations. Two empirical equations were used in the analyses, the Hazen method (Hazen, 1911) and the Harleman method (Harleman et. al., 1963). They are given as:

Hazen Method: $$K = C(d_{10})^2$$

Where K is hydraulic conductivity (cm/s), d_{10} is the effective grain size (cm), and C is a coefficient based on type of material (fine to coarse sand).

Harleman method: $k_i = (6.54 \times 10^{-4})\, d_{10}^{2}$

Where k_i is the intrinsic permeability (cm^2),and d_{10} is the effective grain size (cm).

Hydraulic conductivity (K) is obtained using the equation:

$$K = k_i\,(\rho g/u)$$

Where K is hydraulic conductivity (cm/s), k_i is the permeability (cm^2), ρ is the density of water at 15°C, g is gravity (cm/s^2), and u is the viscosity of water at 15°C (g/s-cm).

The Hazen method is applicable to sands where the effective grain size is between approximately 0.1 and 3.0 mm (Fetter, 1994). Only two of the nine samples collected meet the effective grain size criteria for the Hazen method. The hydraulic conductivity for these two samples were calculated using both the Hazen method and Harleman method. Because of the large effective grain size for the remaining seven samples, only the Harleman method was used to determine the hydraulic conductivity.

Ten samples were collected from four different locations within the study area (Figure 9) and sieved to determine the relative particle size distribution of each sample. Seven gravel and sand samples, two sand samples, and one sandy silty clay with gravel sample, were collected. Table 2 lists the hydraulic conductivity calculated for each sample. The effective grain size for the sandy silty clay with gravel could not be accurately obtained using sieve analysis because d_{10} (effective grain size) falls below the number 200 sieve. A hydrometer analysis would be required to obtain the effective grain size for this sample. This was not done because the silt and clay content was high enough that the unit was considered an aquitard for the purposes of this study.

3.3 WATER QUALITY SAMPLING PROCEDURES

Chemical parameters measured in the field included water temperature, pH, conductivity, and dissolved oxygen. Water samples were collected consistently from the same location, which was the closest tap to the well. Water was allowed to run through a flow through cell for a minimum of 10 minutes or until the conductivity stabilized. Conductivity, dissolved oxygen, and temperature were measured using a YSI model 85 multimeter. Water pH was measured after the conductivity had stabilized using an Orion 9707 pH meter with automatic temperature compensation. Samples were collected in 500ml Nalgene bottles that were rinsed three times at each site prior to sample collection. Samples were stored in an iced cooler and transported the same day to Western Washington University. Chloride, ammonia, nitrite, nitrate + nitrite, and total nitrogen were measured at Western Washington University's Institute for Watershed Studies State certified laboratory. All values of nitrate used in this report from this point forward are reported as nitrate + nitrite levels measured in mg/L which are equivalent to parts per million (PPM).

3.4 WATER TABLE CONTOUR MAPS

Maps of the water table for an unconfined aquifer are two-dimensional representations of three-dimensional surfaces (Fetter, 1994). Data used for the construction of water table maps should be from wells screened only in the same aquifer; the aquifer of interest. Accurate elevations of well casings and or water level measuring points are critical in the development of accurate water table contour maps. A majority (17) of the 21 wells were surveyed including the peizometer to the nearest 0.01 feet using laser survey equipment from a United States Geological Survey bench mark located at the intersection of Halverstick and Holmquist roads (Table 3). Of the 21 wells selected for this study, only 17 wells were accessible to obtain water levels. Only 16 wells were used in constructing water table contour maps because consistent water levels in well 11 could not be obtained (Figure 8). Of these 16 wells, only 8 had drillers logs; the other 8 had owner-reported or estimated depths.

Water levels in wells reflect the heads in the aquifer of interest. Therefore, wells that have large variations in depths below the water table may not accurately reflect the actual water table elevations. If there are large variations in the screened portions of wells below the water table, inaccurate water table contours may result. The average depth below the water table of the 16 wells within the study area from which water levels were obtained is approximately 28 feet. The largest variation in depth between two wells in the study area is between well 3 (67 feet below the water table) and well 14 (4 feet below the water table).

Land surface at well number 3 is approximately 165 feet above sea level and 157 feet above sea level at well number 14 (Table 3). It is assumed that all of the wells used in the collection of water level data are completed in the same aquifer and have a relatively small difference in completed well depths below the water table on average. It is further assumed that variations in elevation head due to depth of the well screens are not *significantly* impacting the water table contour maps.

Monthly water level readings were collected from 17 of 21 wells and one peizometer. Only 16 of the 17 wells were used in constructing seasonal water table contour maps. A depth-to-water meter and standard measurement techniques were used to determine water levels. Because of the large number of sample sites and sample collection procedures, water level readings were taken over two days. When possible, alternating wells were measured on both days to ensure water levels did not change significantly over a 24 hour period. Water level data are listed in Table 4 and Appendix B.

Water table levels varied slightly from month to month, however, larger variations were recorded between seasons. For this reason, water level measurements were divided into four seasons per year, each with three months of averaged water level data as follows: Spring (April, May, and June), Summer (July, August, and September), Fall (October, November, and December), and Winter (January, February, and March). Sampling began in April of 1997 so the spring season data set of 1997 consists only of April and May. Water table contours were generated with a geostatistical gridding method known as kriging using Surfer.

A water table transect was placed from the northwest corner of the study area to the southeast corner of the study area (Figure 10). The location of this transect was chosen because it closely approximates the overall groundwater flow direction as interpreted from the water table contour maps. A water table cross section displaying the four average seasonal water tables having the greatest variation over six seasons was created along this transect (Figure 11).

3.5 HYDRAULIC GRADIENTS

Water table contours were used to obtain hydraulic gradients within the study area. The hydraulic gradient (*dh/dl*) is a dimensionless value derived by taking the incremental change in water level head (*dh*) divided by the distance over which the change in head occurs (*dl*). Hydraulic gradients were calculated along the same transect described in section 3.3 from the northwest corner of the study area to the southeast corner of the study area (Figure 10). Three sets of hydraulic gradients were calculated because of the change in slope of the water table across the transect. The three segments along the transect included the north half of the study area, the south half of the study area, and the overall transect. The 130-foot water table contour was chosen as the mid point of the transect because it consistently remained the contour at which the primary change in slope of the water table occurred (Figure 10). Hydraulic gradients were also calculated along this transect and in the east and west portions of the study area using water table contours generated by the groundwater model as a basis for computation.

3.6 GROUNDWATER FLOW VELOCITIES

The following equation is used to calculate average linear groundwater flow velocity:

$$V = K_G\,(dh/dl)/n_e$$

Where V = average linear velocity, K_G = geometric mean of hydraulic conductivity, dh/dl = hydraulic gradient, and n_e = effective porosity.

Hydraulic conductivity values frequently vary by more than two orders of magnitude within the same hydrostratigraphic unit (Fetter, 1994). For this reason, a more representative value of the average hydraulic conductivity of a hydrostratigraphic unit is the geometric mean. The geometric mean for hydraulic conductivity (K_G) is determined by taking the natural log of each value, finding the mean of the natural logs, and then obtaining the exponential (e^x) of that value to arrive at the geometric mean (Fetter, 1994). Six representative gravel and sand samples were averaged to produce a geometric mean (K_G) (Table 5) using hydraulic conductivity values derived from section 3.2 (Table 2).

The effective porosity (n_e) is the porosity available for fluid flow in a porous media. It is assumed that the effective porosity is the same as the porosity under saturated conditions, therefore, standard porosity values reported in various texts can be used as the effective porosity. Porosity for well-sorted sand or gravel sediments range from 25-50% (Fetter, 1994). An estimated porosity of 35% (0.35) was used to calculate the linear groundwater flow velocities within the study area.

3.7 GROUNDWATER MODEL

A groundwater model is a tool designed to represent a simplified version of a real hydrogeologic system. Groundwater models can be used for a variety of reasons. Generally, groundwater models are used to understand why a flow system behaves in a certain manner and to predict how a flow system may behave in the future (Fetter, 1994). One of the most widely used and versatile groundwater flow models is MODFLOW, which was developed by the USGS (McDonald and Harbaugh, 1988). MODFLOW is a quasi-three dimensional, cell-centered, finite difference, saturated flow model used by most practicing hydrogeologists today. GMS is a computer program that has a graphical pre- and post-processor interface with the groundwater model MODFLOW. GMS was used for this project.

The purpose of constructing a groundwater model for this study area was to: 1) estimate groundwater flow directions and travel times in the study area using a water table contour map generated by a numerical model which included sources and sinks, 2) utilize groundwater model results to conduct contaminant transport simulations in an attempt to better understand nitrate residence times within this portion of the aquifer, and 3) develop a groundwater model that may be used for future studies within this area.

3.7.1 CONCEPTUAL MODEL

The conceptual model is intended to describe a simplified representation of the hydrogeologic system to be modeled. As the conceptual model is being developed, a number of assumptions and simplifications must be made in order to obtain a workable model. It is assumed that the geologic and hydrologic data gathered within the study area allowed for the elimination of enough detail to make the model workable while retaining enough detail to make the model accurate and useful. Numerous field investigations provided a solid understanding of the conceptual model within the study area (Figure 12). The conceptual model used for this study assumed steady-state conditions, two-dimensional flow, homogeneous aquifer properties, and a no-flow confining layer at sea level. The no-flow boundary was set at sea level and is supported by geologic cross sections created as part of this study and other studies within this area (Cox and Kahle, 1999).

The model design must conform to the conceptual model including the model boundary, grid, and model parameters. All models have limitations and varying degrees of accuracy depending upon the model design. For the design of this model, a portion of a scaled location map produced by the USGS (Cox and Kahle, 1999) was used as a background image from which the model boundaries were chosen (Figure 13). Model boundaries were chosen far enough away from the actual study area so that variations in hydrogeologic parameters outside of the study area would not adversely impact model results within the study area.

The western boundary of the model follows Fishtrap Creek which begins in British Columbia, Canada, and continues to flow southwest into Whatcom County, Washington (Figure 14). Fishtrap Creek was chosen as a boundary for a number of reasons. Fishtrap Creek represents a specified head boundary so that specified points along the boundary (nodes) could be placed where topographic contour lines intersect the Creek. It was assumed in this model that the Creek represents the level of the groundwater table above sea level. The pre-processor in the GMS program calculates the head values between nodes of known elevation along the specified head boundary. These values were later reviewed and modified when necessary. Moreover, Fishtrap Creek was far enough away from the study area focus so that changing hydrogeologic conditions are less likely to affect the study results. Lastly, west of Fishtrap Creek the Sumas Aquifer pinches out and it was important for modeling purposes that the entire model area be within the Abbotsford-Sumas Aquifer.

The southern boundary of the groundwater model begins at Fishtrap Creek and traverses east across Sumas Outwash deposits for approximately one and one half miles. It then follows the Sumas silt and clay as described on the surfacial geology map of western Whatcom County (Easterbrook, 1976) (Figure 14). The boundary limits were chosen primarily because the Hampton Clay represents a relatively impermeable hydrostratigraphic unit which is believed to alter groundwater flow in this area. For modeling purposes, the western portion of the southern boundary was modeled as Sumas Outwash deposits while the eastern portion was modeled as a no-flow boundary (Figure 14).

The eastern boundary of the groundwater model begins in the southern portion of the model area where the Hampton Clay stops according to the geologic map of western

Whatcom County (Figure 3) (Easterbrook, 1976). The eastern boundary then follows Johnson Creek towards the northeast until it enters the Sumas River at which point the boundary continues to the northeast corner of the groundwater model (Figure 14). As with the western model boundary, Johnson Creek and the Sumas River represent a specified head boundary so head nodes could be placed where topographic contour lines intersect the Creek and River. The Creek and River are assumed to represent the level of the groundwater table above sea level. Water table elevations between nodes of known elevations were calculated by GMS along the specified head boundary. These values were later reviewed and modified if necessary.

The northern groundwater model boundary follows the scaled location map mentioned previously (Figure 14) (Cox and Kahle, 1999). The northern boundary does not represent the termination or beginning of the Sumas Abbotsford Aquifer and for this reason was input as a general head boundary. However, there were two specified head points input along a small portion of the northern model boundary where approximate water level elevations had been obtained from prior studies in Canada (Liebscher et. al., 1992; Halstead, 1986).

3.7.2 GROUNDWATER FLOW EQUATION

The governing equation for groundwater flow for an isotropic, homogeneous aquifer under steady state conditions in two dimensions is given as:

$$\frac{\delta^2 h}{\delta x^2} + \frac{\delta^2 h}{\delta y^2} = 0$$

Where h = total hydraulic head and x and y = spatial dimensions. This equation is known as Laplace's Equation in two dimensions. Laplace's equation is a second-order partial differential equation which combines Darcy's law with the continuity equation (Wang and Anderson, 1982). The solution of Laplace's equation requires boundary conditions (discussed in section 3.6.4) in order to constrain the problem and produce a unique solution (Wang and Anderson, 1982). The MODFLOW model generates a simplified form of Laplace's equation by converting the partial differential equation into a set of algebraic equations at each grid point in the model domain using a finite difference technique. Head values are obtained at each point in the problem domain from solutions to the algebraic equations based on the specified boundary conditions established for that problem. A more detailed discussion on Laplace's equation and groundwater modeling can be found in Wang and Anderson (1982).

3.7.3 MODEL PARAMETERS

Groundwater model parameters are required to simulate the flow, these include: hydraulic conductivity, aquifer porosity, recharge, conductance values for lakes and streams, and initial head values. Two groundwater flow simulations were created using two different values of hydraulic conductivity: 929 feet per day, and 270 feet per day representing high and medium values, respectively. Conductivity values were obtained by sieve analyses (section 3.2.1) and the median USGS value obtained by Cox and Kahle (1999). The aquifer porosity used for model simulations was 0.35. Recharge values were obtained from the most recent USGS study within the area (Cox and Kahle, 1999). Groundwater recharge values used in the model were based on the approximate average of the Clearbrook Weather Station, Whatcom County, and the Abbostford Weather Station, Abbotsford Airport, British Columbia. The recharge values used do not represent precipitation, but rather actual groundwater recharge (section 2.8). The value obtained was approximately 30 inches per year and input into the model as 0.007 feet per day.

Conductance in GMS represents conductivity per unit length of a drain or sink cell. Pangborn Creek, Judson Lake, and Laxton Lake all required conductance values. It was assumed that fine grained materials have accumulated at lake bottoms and creek beds, therefore, the conductance values used in the model for lakes and creeks were less than the average hydraulic conductivity calculated for the study area of 929 feet per day. Conductance values were based on field observations and reviewing core samples obtained from previous studies (Riggs, 1958, and Easterbrook, oral communication 2000). A conductance of 400 feet per day was estimated for Judson Lake, while 600 feet per day was estimated for Laxton Lake and Pangborn Creek. Initial head values are used only as a starting point for the model simulation and technically have no effect on steady state models other than to speed up simulation times. Initial head values were input as 210 feet above sea level which approximated the highest head levels found to exist within the model area according to the most recent USGS study (Cox and Kahle, 1999).

3.7.4 MODEL GRID AND CALIBRATION

After the model boundaries and parameters were established, a finite difference grid was developed using GMS. Grid cell dimensions were initially determined by the overall model area, average distance between wells, and hydrostratigraphic information. The model was calibrated by running the model and then comparing the model solution with observed water table elevations. The initial grid cell size was reduced from 1,000 feet to 500 feet in x and y dimensions. Using these dimensions, the model closely approximated water table elevations calculated through recorded field observations and other studies. Reducing the grid cell sizes to 250 feet in the X and Y dimensions did not improve the model solution. For this reason, the grid cell sizes of 500 feet in X and Y dimensions were used. The z grid dimension was one layer 300 feet thick representing the Sumas Outwash resting on the relatively impermeable clays believed to be Bellingham GMD.

Model verification is typically the next step in developing a groundwater model. In order to verify a model, information such as water levels through time and the location and pumping rates of wells are needed. Since this information was not available, the calibrated model could not be verified.

3.8 NITRATE CONCENTRATION CONTOUR MAPS

Two-dimensional nitrate contours were mapped using Surfer and the kriging method for each of the six seasons sampled. The six seasons were Spring (March, April, and May), Summer (June, July, and August), Fall (September, October, and November), and Winter (December, January, and February). Data used for this thesis began in April of 1997 and ended in August of 1998 so the spring 1997 two-dimensional nitrate contour map does not include the month of March. All 21 wells regularly sampled were used in generating the two-dimensional nitrate contour maps (Table 6).

3.9 NITRATE TRANSPORT

The calibrated groundwater flow model was coupled with a transport model known as MT3D (Zheng in 1990) to simulate nitrate transport in the study area. MT3D is a model that can be used with MODFLOW and simulates advection, dispersion and, chemical reactions of dissolved constituents in groundwater systems. GMS supports MT3D as a pre- and post-processor (Boss GMS, 1996). Nitrate transport simulations for this study used only the advection and dispersion packages within MT3D.

Advection is the process by which solutes are transported by the motion of flowing groundwater (Fetter, 1994). Contaminants that are advecting are traveling at the same rate as the average linear velocity of the groundwater. Given the heterogeneity of geologic materials, advective transport in different geologic media usually result in solute fronts spreading at different rates through each medium (Fetter, 1993). However, in this case, advection was fairly simple to simulate because a single layer of the same geologic material (Sumas Outwash deposits) was used for the model. Although there are known lenses of less permeable materials within the study area, hydraulic continuity within the aquifer was assumed to be very high.

As a contaminated fluid flows through a porous medium, it will mix with noncontaminated water. The result will be a dilution of the contaminant by a process known as dispersion, often referred to as mechanical dispersion (Fetter, 1994). The mixing that occurs along the streamline of fluid flow is called longitudinal dispersion. Dispersion that occurs normal to the pathway of fluid flow is lateral dispersion (Fetter, 1994). Groundwater is moving at rates that are both greater and less than the average linear velocity, this causes dispersion of a contaminant. Within MT3D, there is one longitudinal dispersion value and two ratios for horizontal and vertical dispersion that need to be entered to simulate contaminant transport. The longitudinal dispersion value entered for the transport simulation was 25 feet and the ratios of horizontal and vertical dispersion entered was 0.1. Given these values, the horizontal and vertical dispersion values were 2.5 feet. The values for longitudinal dispersion were chosen based on the hydrogeologic parameters of the aquifer and similar examples provided within the GMS users manual.

Four solution schemes are offered within the MT3D advection package. The solution scheme chosen for this model utilizes a particle tracking approach for the advective transport simulation. The scheme chosen was a hybrid of two other schemes within MT3D and was believed to be the most appropriate for this study area based on examples provided within the GMS users manual.

MT3D was used to model three different nitrate transport scenarios. Nitrate contours were plotted at the end of the designated travel times established for each scenario. In scenario one, a 50 mg/L nitrate spike is placed in selected cells within the model domain for a duration of one day. The selected cells represent a known source (confirmed through field observations) within the study area. The spike in scenario one was monitored for a period of one year and nitrate concentrations were contoured at the end of one year.

In scenario two, an additional 50 mg/L nitrate spike is placed in a second set of selected cells within the model domain for a duration of one day while keeping the first nitrate spike previously established in scenario one. The second set of selected cells in scenario two represents another known source (confirmed through field observations) within the study area. The spikes in scenario two will be monitored for a period of six months rather than one year because one of the nitrate plumes will travel outside of the study area after one year and will not be able to be contoured. Nitrate concentrations in scenario two will be contoured at the end of six months.

In scenario three, a 50 mg/L nitrate line spike is placed just north of the international border in Canada for a duration of one day. Scenario three is thought to represent possible nitrate source loading across the international border in Canada. The spike in scenario three was monitored for a period of one year and nitrate concentrations were contoured at the end of one year. These scenarios may be used in future studies to help understand and predict the lag time between nitrate source loading and nitrate concentrations observed in down gradient wells.

4.0 RESULTS AND DISCUSSION

4.1 GEOLOGIC UNITS

Drillers well logs completed for domestic and irrigation wells, and various types of natural resource explorations (e.g., gravel, coal, and gas) are the only source of information about the subsurface geology other than road cuts or gravel pits. Drillers well logs are highly variable and serve only as general indicators of the types of geologic mediums encountered. Six geologic units were identified by correlating information from more than 50 individual well logs within the study area and visiting three gravel pits within or adjacent to the study area (Figure 15) (Appendix C). Each geologic unit will be discussed below (Figures 16-20).

4.1.1 Sumas Outwash Gravel and Sand

The primary geologic medium encountered within the study area is Sumas Outwash deposits consisting of fine to coarse gravel with varying amounts of sand, pebbles, cobbles, and in some areas boulders (Figures 16-21). Six samples of the Sumas Outwash were collected and sieved to determine the relative percentages of cobbles, gravel, sand, and silts and or clays (Figure 9). Of the six samples collected, the average cobble content was 5.4%, the average gravel content was 67.8%, the average sand content was 26.1%, and the average silt and or clay content was 0.72% (Appendix D).

4.1.2 Sumas Outwash Sand

Numerous sand lenses were observed in drillers well logs in the area and were visible within the gravel pit just south of Pangborn Road (Figure 22). Most sand lenses recorded in drillers logs within the study area are on the order of five to twenty feet thick (figures 16-20). One larger sand lens, approximately forty feet thick, was observed in a well log in the southwest portion of the study area (Figure 17). The thin discontinuous beds of sand are indicative of a glacio-fluvial environment. Two samples from the sand lens within the gravel pit south of Pangborn Road were collected and sieved to determine the relative percentages of coarse, medium, and fine sand, and silts and or clays. There was no coarse sand found in either sample collected. The average medium sand content was 5.2%, the average fine sand content was 86.4%, and the average silt or clay content was 8.4% (Appendix D).

There is a sand unit believed to be the Deming Sand observed in one well log below the Bellingham GMD. This unit is one hundred feet thick and begins at approximately 30 feet below sea level. This unit is not part of the Sumas Outwash deposits but does appear in the geologic cross section E-E' (Figure 20).

4.1.3 Ice Contact Deposits

Lenses of sand, gravel, and clay, or clay, silt and sand are also reported in the drillers well logs near the eastern margin of the study area. These deposits are interpreted as ice contact deposits and coincide with the general location of the Sumas ice margin as interpreted by Easterbrook (personal communication, 1999) (Figure 3). Most ice contact deposits within the study area range from only a few feet to ten or fifteen feet in thickness (Figures 19 and 20). However, two thick lenses (averaging 65 feet in thickness) were identified near the eastern boundary of the study area (Figure 20).

4.1.4 Peat Deposits

Peat is found in and around Pangborn Lake and Judson Lake. Core samples of peat in and around Pangborn Lake were taken by Riggs, 1958, and Easterbrook (personal communication). A core sample was also taken from Judson Lake by Easterbrook (personal communication). The peat in the Pangborn Lake area ranges from a few feet thick on the fringes of the kettle, occupying an area much larger than the current Lake, to over 30 feet thick closer to the center of the Lake (Figures 16 and 23). The peat around Judson Lake is not as laterally far reaching as Pangborn Lake. A core towards the western edge of Judson Lake taken by Easterbrook found the peat to be approximately 10 feet thick (Easterbrook, personal communication).

4.1.5 Lacustrine Deposits

Lake sediments consisting of blue-gray clay, silt and sand are found beneath peat in both Pangborn Lake and Judson Lake (Riggs, 1958; Easterbrook, personal communication). The depth of lake sediments depend upon the sedimentation rates, which are a function of the amount of time the kettles were occupied with quiet water and the amount of fine material available for deposition. To date, the lake sediments beneath the peat of Pangborn and Judson lakes have not been fully penetrated and the relative depths remain unknown.

4.1.6 Glaciomarine Deposits

Differentiating Glaciomarine deposits from ice contact deposits within the study area is difficult. Two distinct glaciomarine units have been interpreted within the study area based on drillers well logs and a literature review of glacial chronology. The first, and oldest, of these units is found 340 feet below land surface. The unit has a thickness of 20 feet in the northern most portion of the study area (Figure 17). This unit *may* correlate with the Kulshan Drift of the Everson Interstade, which is encountered in southern areas of the Nooksack Lowland. A second, younger glaciomarine unit was identified in the same well log 213 feet below land surface (21 feet thick). One hundred and six feet of fine sand, described in section 4.1.2, separate the two glaciomarine units in this well log. Possible correlations exist between the younger glaciomarine drift unit found in the northern portion of the study area and clay units encountered in the southern portion of the study area (Figures 18-21). A sample of silty clay, thought to be part of the Hampton Clay unit (believed to be Bellingham GMD), was collected from the base of the gravel pit south of Pangborn Road and sieved to determine the relative amounts of gravel, sand, silt and or clay. The sample contained 9.0% fine gravel (rounded to sub-rounded), 40.3% sand (3.4% coarse, 7.7% medium, and 29.2% fine), and 50.8% silt and or clay (Appendix D).

4.2 SIEVE ANALYSES AND HYDRAULIC CONDUCTIVITY

Through sieve analyses and empirical equations outlined in section *3.1.1*, an average hydraulic conductivity using the geometric mean (K_G) was estimated at 929 feet per day within the study area. The conductivity value of 929 feet per day is relatively high, but assumed to be reasonable for this aquifer based on several different factors. Samples collected within the study area were a fairly good spatial representation of the aquifer within the study area (Figure 9). The median hydraulic conductivity value obtained by the USGS within the same general area was 274 feet per day (Cox and Kahle, 1999). Furthermore, the USGS study concluded that the Sumas Aquifer has a higher hydraulic conductivity than is typical of similar glacial outwash deposits in the Puget Sound region (Cox and Kahle, 1999).

4.3 HYDROSTRATIGRAPHY

Hydrostratigraphic units comprise geologic units grouped together on the basis of similar hydraulic conductivity (Fetter, 1994). Using this definition, several geologic units may be grouped together into a single aquifer or confining unit. The six distinct geologic units that were identified within the study area were grouped into two hydrostratigraphic units. The Sumas Aquifer is the youngest deposit in the study area; however, clay lenses of the Sumas Aquitard are found within the Sumas Aquifer. The Sumas Aquitard is primarily made up of an older underlying clay unit at depth interpreted as Bellingham GMD. The Sumas Aquifer and the Sumas Aquitard are reserved for this study area only.

4.3.1 Sumas Aquifer

The Sumas Aquifer in the study area is an unconfined aquifer comprised of three geologic units that have been grouped together based on similar high hydraulic conductivities. The three units that define the Sumas Aquifer include the Sumas outwash gravel and sand, Sumas outwash sand, and peat deposits. The thickness of the Sumas Aquifer ranges from approximately 180 feet in the northeast portion of the study area, near the international border, to approximately 80 feet in the southeastern portion of the study area (Figure 20). Outside of the study area, the Sumas Aquifer tends to increase in thickness to the north and east. The Sumas Aquifer is the only source of groundwater currently being used for domestic and irrigation purposes within the study area based on available well log data. Although clay layers or lenses exist within the Sumas Aquifer, their discontinuous nature allows for good hydraulic continuity and does not drastically effect the ability of the aquifer to transmit water. It is reasoned that the conductivity is higher in the northern portions of the aquifer and lower in the southern portions of the aquifer because gravel and sands are more prominent in the northern portions of the aquifer which then grades to coarse and fine sands in the southern portions of the aquifer. Moreover, geographic trends in hydraulic conductivity reported by the USGS indicate higher values near the international border and lower values at the southern end of the aquifer (Cox and Kahle, 1999).

4.3.2 Sumas Aquitard

The Sumas aquitard consists of three geologic units in the study area having low hydraulic conductivities. The three units are glaciomarine drift deposits, ice contact clays with sand and gravel and or till, and lacustrine deposits. Glaciomarine units were only fully penetrated in one well log in the northeast portion of the study area. The two glaciomarine units have an average thickness of 20 feet (Figure 20). Similar glaciomarine units are found less than two miles to the north (Halstead, 1986). The Glaciomarine unit which underlies the Sumas Aquifer is interpreted as Bellingham Glaciomarine Drift (Fort Langley Formation in Canada). Although evidence of a continuous clay layer at depth within the study area could not be verified from available well log data, it is believed to be continuous. This sequence of deposition is consistent with regional geologic interpretations by Easterbrook (1966, 1973, 1975, 1976), Armstrong (1981), and Cox and Kahle (1999).

Clay lenses appear throughout the study area in the Sumas Aquifer and range in thickness from 5 to 20 feet. Several drillers logs north of the study area in Canada indicate that outwash deposits of the Sumas Aquifer are inter-layered with at least one clay deposit of glaciomarine origin (Halstead, 1986). Thick clay lenses and or layers in excess of 30 feet are found beneath Pangborn bog (Figure 18), in the southern portion of the study area (Figure 16), and in the eastern portion of the study area (Figure 20).

The Bellingham GMD of the Sumas Aquitard is believed to be stratigraphically continuous with the Hampton Clay to the south of the study area, and the Fort Langley Formation to the north, in Canada (Halstead, 1986). One piece of supporting evidence for this is a regional blanket of Bellingham GMD present south and west of the study area, as mapped by Easterbrook (1976). A regional pebbly silty clay unit approximately 60 feet thick interpreted as glaciomarine drift also exists to the north in Canada (Halstead, 1986). The USGS also concluded this in geologic cross sections reported in the most recent study conducted in this area (Cox and Kahle, 1999).

Although this scenario fits the glacial chronology, which has been well documented by Easterbrook and Armstrong as mentioned in section *1.3*, there was not enough evidence in the drillers logs to conclusively prove the existence of a continuous clay layer at depth in the study area. The lack of evidence in the drillers logs was due to the distance between drillers logs, a lack of deep descriptive drillers logs, and the discontinuous nature of the glacio-fluvial depositional environment. Moreover drillers logs, within and outside of the study area, encountered several clay lenses which could be interpreted as fluvial or glaciomarine in origin and are extremely difficult to correlate. One example of the difficulty in properly interpreting the hydrostratigraphy is a previous study conducted within this area by Kahle, 1990. Kahle correlated the Hampton Clay (improperly referred to as Badger Clay, Easterbrook, personal communication) which crops out just south of the study area boundary (Figure 3) with clay lenses found at very shallow depths (5-15 feet) in the Pangborn bog area to the north. Such correlations were based on encountering clay in two or three drillers logs located in most cases over one mile apart. However, the most recent USGS study, co-authored by Kahle (Cox and Kahle, 1999), does not correlate the Hampton Clay with the near surface clay deposits of the Pangborn bog area.

4.4 WATER TABLE CONTOURS

Groundwater flow directions interpreted from water levels measured in the field were generally south in the west half of the study area and south to southeast in the east half of the study area. There is a stronger southeast groundwater flow direction in the southeast portion of the study area (Figures 24-29). Over the 6 seasons of data collection (17 months), water table levels were highest in the spring of 1997 with the exception of the southeast portion of the study area during the winter of 1998. Water table levels were lowest in the summer of 1998 with the exception of the northern most portion of the study area during the fall of 1997. The largest average variation occurred between the spring of 1997 (high) and the fall of 1997 (low): approximately 5 feet was calculated in the northern half of the study area and approximately 3.5 feet in the southern half of the study area (Table 4). Similar variations were observed between spring 1997, and summer 1998 (Table 4). During 1998, the largest difference in water table levels was approximately 0 to 1 foot in the northern portion of the study area increasing to 3.5 feet in the center, then increasing to 4.5 feet in the southern portion between winter and summer (Figure 11). Comparing water table contour maps with topography, the water table is predicted to be a maximum of 60 to 65 feet below land surface in the northeast portion of the study area to anywhere from 0 to 30 feet below land surface in the southern portion of the study area.

The greatest variation in any one well sampled was 7.8 feet between Spring 1997 and Fall 1997 at well 3 (Table 4 and Appendix B). The large variation of water levels in well 3 is believed to be in part due to recording water levels while the pump was still on, or taking water levels before full recovery was achieved within the well. Well 3 presented this problem throughout the duration of the study sometimes shifting the water table contours north as can be seen in Figures 24 through 29.

Water table cross sections for all seasons show that the largest fluctuations were in the central portion of the study area with smaller differences in water table levels in the far north and south portions of the study area. There are a number of factors that may help explain this phenomenon. Contouring a limited number of water level data points over a large area created data gaps and water table contours are best estimates fitted to this data. Dummy water level points were inserted around Judson Lake (along the international border) to ensure that water table contours matched lake levels and the dummy points did not change from season to season with the water table. Changes in topography, especially in the central and southern portions of the study area, most likely impact water levels (Figure 2). Heavy irrigating during the summer and fall months, especially in the north and central portion of the study area, likely affect water levels in this area as well.

4.5 HYDRAULIC GRADIENTS

The overall hydraulic gradient for the study area was calculated from the first water level contour to the last water level contour along the transect (Figure 10 and Table 7). The hydraulic gradient of the north half of the study area was calculated from the first water level contour to the intersection of the 130 foot water level contour with the transect (Figure 10 and Table 7). The hydraulic gradient of the south half of the study area was calculated from the intersection of the 130 foot water level contour with the transect to the last water level contour (Figure 10 and Table 7). Water level contours varied from season to season so the distance over which the hydraulic gradient was calculated also changed (Table 7). The average hydraulic gradient over six seasons (17 months) was 0.0075 along the entire water table cross section (northwest to southeast), 0.0036 for the north half of the cross section, and 0.0115 for the south half of the cross section.

4.6 GROUNDWATER MODEL

After adjusting various MODFLOW input parameters (discussed in section 3.6), a successful simulation was created using an iterative solver package based on the strongly implicit procedure for a steady-state system. The strongly implicit procedure solves a system of simultaneous linear equations by iteration (McDonald and Harbaugh, 1988). The head change criterion for convergence of the model was set to 0.01 feet. The groundwater model output file contains a head value for each cell within the model domain (Appendix E). From this output file, a water table contour map was created within GMS. Two Figures were generated using this function, one for the entire model domain (Figure 30) and one for the study area only (Figure 31).

Calibration of a groundwater model is important to ensure that it produces reasonable and accurate representations of groundwater flow. The model produced for this study was calibrated, but was not verified due to a lack of available data as described in section 3.6. Nevertheless, predictions made from groundwater models that have not undergone model verification are useful, but are not as accurate as those made with a verified model (Fetter, 1994). The groundwater model produced for this area was based on a simplified conceptual picture (i.e. a single layer two-dimensional model with the assumptions made as outlined in section 3.6). After careful calibration, the accuracy of this groundwater model is presumed to be good. The head change criteria for convergence of the groundwater model simulation was 0.01 feet. This criterion is considered acceptable given that actual head values throughout both the model area and the study area are not known beyond this range of accuracy and more often than not, less than this range of accuracy.

Head contours generated from the groundwater model closely approximate observed field data and previous studies conducted in and around the study area as outlined in section 1.3. Naturally occurring springs are found in the southeast portion of the study area around 100 feet above sea level on the USGS topographic map (Figure 2). The springs are believed to be caused by the intersection of the water table with land surface due to a pinching out of the Sumas Aquifer near the Hampton Clay (Bellingham GMD). The groundwater model head contours predict with good accuracy the intersection of the water table with land surface at this same location (Figure 31). Water table contours generated in Surfer intersect the spring locations at approximately 80 feet above sea level. The fact that the groundwater model head contours predict the spring locations is another indication that the model produces a better representation of the actual water table than that contoured from field data.

There are two key items that would significantly impact the groundwater model and associated water table contours within the study area: the interaction of Judson Lake and Laxton Lake with the water table, and the depth, hydrostratigraphic extent, and permeability of the Hampton Clay (believed to be Bellingham GMD) at the south end of the study area. The interaction of Judson Lake and Laxton Lake with groundwater in this area remains uncertain. Judson Lake and Laxton Lake are both presumed to be the surface of the groundwater table (Cox and Kahle, 1999). Laxton Lake is surrounded by very obvious coarse gravel and sand, which indicates that it communicates directly with the aquifer. However, these same features are not seen around Judson Lake indicating that Judson Lake may be perched, thus not accurately representing the groundwater table. If this is true, corrections to water table contours would need to be made and could alter groundwater flow directions in the region around Judson Lake and to a lesser degree affect groundwater flow velocities.

Understanding the depth, hydrostratigraphic extent, and permeability of the Hampton Clay is essential for predicting groundwater flow in the southern portions of the study area. It was assumed, for this study, that the Hampton Clay generally follows the surficial geology as mapped by Easterbrook, 1976 (Figure 3). The Hampton Clay creates a no-flow boundary which forced groundwater to the west and east of the outcrop as shown in Figure 31. Although the depth of the Hampton Clay is not known for certain, several drillers logs south of the study area indicate that the unit is continuous and over 100 feet thick in places. Sieve analysis on a sample believed to be part of the Hampton Clay indicate that it is relatively impermeable (Appendix D). More detailed information about the hydrostratigraphic extent and or continuity of the Hampton Clay and its permeability will increase the accuracy of the groundwater model and may affect the directions and velocity of groundwater flow in this area.

Hydraulic gradients calculated from the water table contour maps were compared to gradients calculated from the groundwater model water table contours. Heads generated by the model simulate steady-state groundwater flow in the aquifer over a one year period. Therefore, the model does not account for seasonal fluctuations of the water table or fluctuations in precipitation, both of which were observed in the field over the course of this study. Moreover, the model does not account for groundwater withdrawals. Nevertheless, the head contours produced by the groundwater model closely approximate flow directions, gradients, average groundwater levels observed in the field, and those reported by previous studies within the area (e.g. Liebscher, 1992; Cox and Kahle, 1999).

Given that groundwater flow directions are perpendicular to water table contours, three hydraulic gradients were calculated in the study area because of changing contour direction: one for the east and west (Figure 32), and one from the northwest to the southeast along the same transect described in section 3.4 (Figure 10). The gradients were approximately 0.010 for the east portion of the study area, 0.003 in west portion of the study area, and 0.008 from the northwest to the southeast in the general direction of groundwater flow (Table 8). Using the gradient calculated from the groundwater model along the water table cross section (Figure 10), the estimated travel time is approximately 557 days or 1.5 years. Calculated flow velocities in the east portion were approximately 0.8 years and approximately 3.0 years in the west portion of the study area.

The gradient for the far east portion of the study area which most closely approximated the groundwater flow direction was 0.010 using model head contours (Figure 32). The 0.010 gradient was higher than the 0.0075 value calculated along the transect using Surfer contoured field data (figure 10) because it was calculated further east and the model water table contours are closer together. The gradient calculated using the groundwater model for the west portion of the study area was 0.003 (Figure 32). The gradient calculated from the model in the west is much lower than that calculated from the model in the east, but closely matches the north half gradient of 0.004 calculated from water table contour maps using Surfer (Table 7). The gradient calculated along the transect from northwest to southeast was 0.0077 using groundwater model head contours compared to 0.0075 using the water table contour maps from field data. The difference in gradients along the transect from the northwest to the southeast is considered to be negligible.

4.7 CALCULATED FLOW VELOCITIES

Groundwater flow velocities were calculated to approximate groundwater travel times from the international border to the south end of the study area. Groundwater flow velocities calculated from water table contours and the groundwater model are used to obtain nitrate travel times within the study area. The geometric mean for hydraulic conductivity of the gravel and sand samples within the study area was determine to be K_G = 929 ft/day (Table 5). Using the equation listed in section 3.5, the following average linear groundwater flow velocities were calculated along the transect (Figure 10) within the study area:

Northwest to Southeast = 20.0 ft/day

North Half = 9.4 ft/day

South Half = 30.6 ft/day

Average linear groundwater flow velocity represents the average rate at which the water moves between two points. This average was used to estimate approximate travel time rates of groundwater within the study area from the northwest to the southeast. Assuming flow begins at the international boundary and travels a total distance of 12,990 feet to the southeastern end of the study area at an average rate of 20.0 feet/day, the approximate travel time is 650 days or 1.8 years. Using the distance over the north half of the study area (international border to the 130 foot water table contour = 7,442 feet) and the linear groundwater flow velocity calculated at 9.4 feet/day, the approximate travel time is 792 days or 2.2 years. Using the distance over the south half of the study area (130 foot water table contour to 65 foot water table contour = 5,548 feet) and the linear groundwater flow velocity calculated at 30.6 feet/day, the approximate travel time is 181 days or 0.5 years. These results are summarized below:

Northwest to Southeast = 650 days or 1.8 years

North Half = 792 days or 2.2 years

South Half = 181 days or 0.5 years

4.7.1 Flow Directions And Velocities From Water Table Contour Maps

Water table contours generated in Surfer reveal that groundwater flow directions are almost due south in the north half and west portions of the study area (Figures 24-29). Groundwater flow directions are to the southeast in the far east and southeast portion of the study area. Due to the lack of data points in the southwest portion of the study area, groundwater flow using contoured field data has more of a southern component rather than a southeastern component predicted by groundwater model contours. For this reason, it is assumed that the actual groundwater flow direction is more closely approximated by the groundwater model contours than the contoured field data, especially in the southwest portion of the study area.

Groundwater flow velocity in the southern half of the study area is a little over four times that in the north half of the study area using water table contours. One explanation for this large variation is the impact of topography on the slope of the water table. The northern portion of the study area loses approximately 30 feet in elevation over 7,442 feet in distance while the southern portion of the study area loses approximately 65 feet in elevation over 5,548 feet in distance. This large variation between the north half and the south half of the study area is not as pronounced in the groundwater model simulation.

4.7.2 Flow Directions And Velocities From The Groundwater Model

Groundwater flow directions predicted by MODFLOW show a more defined southeasterly trend than flow directions predicted by head contours generated from the field data using Surfer. This is attributed to the southwestern half of the model area being defined as a no-flow boundary (Hampton Clay) which forces groundwater to flow to the southwest and southeast (Figure 31). Although the depth and continuity of the Hampton Clay in the southeastern half of the model area is not known for certain, evidence from drillers logs, surficial geology, and freshwater springs, suggest that the flow pattern generated by the groundwater model is a close approximation of actual groundwater flow within the study area. There may also be a vertical groundwater flow component due to the location of the impermeable Hampton Clay in southwest portion of the study area. Unlike the contoured field data, which rely on points scattered throughout the study area, the model simulation uses computed head values in each cell within the model domain to create water table contours. For this reason, model contours appear to be more evenly distributed than the contoured field data and may not reflect any localized groundwater flow directions due to topography.

The largest difference between the groundwater model contours and the contoured field data occurs in the southwest and far east half of the study area. In the northeast portion of the study area, the model water table contours are approximately 5 to 7 feet lower than those predicted by contoured field data. In the east central portion of the study area, the model water table contours are approximately 10 to 12 feet lower than contoured field data. In the south east portion of the study area, the model water table contours are approximately 5 to 10 feet lower than contoured field data. Water table differences between contoured field data and the groundwater model are attributed primarily to the lack of data points in the field, and topographic variability within the study area. The lack of data points along the far east portion of the study area caused water table contours to be truncated and thus does not reflect the true water table surface in this area (Figure 24-29). In the southwest portion of the study area the lack of data points creates water table contours that do not reflect the no-flow boundary to the south. For this reason, there appears to be a strong southerly flow which is not predicted by the groundwater model. The effect of fewer data points is fairly evident by a break in slope of water table contours using Surfer seen along Trapline Road in the south central portion of the study area (Figure 33).

Groundwater flow velocities predicted by the model simulation differ from velocities predicted from field data contour maps because there is not a large variation from north to south within the study area. There is, however, a large variation in groundwater flow velocities from west to east within the study area (Figure 31). In the east portion of the study area, the model predicts a maximum velocity of approximately 25 feet per day compared to 20 feet per day from water table contours generated from field data in the direction of groundwater flow. In the west portion of the study area, the model predicts a velocity of approximately 8 feet per day compared to 11 feet per day from water table contours generated from field data in the direction of groundwater flow. Groundwater flow velocity variations within the study area are attributed primarily to the sharp contrast in topography from east to west (Figure 2), and regional groundwater flow directions established by the model (Figure 30).

4.8 NITRATE CONCENTRATION CONTOUR MAPS

One set of nitrate contour maps were created for each of the six seasons using Surfer (Figures 34-39). Two-dimensional nitrate contour maps do not accurately reflect actual nitrate plumes and/or nitrate concentrations, as samples were obtained from wells screened at varying depths within the aquifer. However, nitrate contour maps still provide a valuable tool from which generalizations can be made about spatial and temporal trends within the study area. The data set used for two-dimensional nitrate contours can be found in Table 8. Wells 1, 2, 5, 6, 9, 10, 13, 14, 17, and 18 had consistent nitrate levels at or above the maximum contaminant level of 10 mg/L nitrate. Wells 5, 6, and 7 showed a gradual increase in nitrate concentration over the course of the study. Two wells in the study area with the highest concentrations of nitrates (wells 14 and 18) showed some interesting trends. Well 14 showed a gradual decrease in nitrates over the entire course of the study while well 18 showed a rising trend from Spring of 1997 to the Fall of 1997 and then a sharp decrease for the duration of the study. Comparing nitrate levels with water levels did not reveal any distinct correlations with the exception of well 1. Well 1 did show some correlation with water table levels and nitrate concentrations from April, 1997 to March, 1998. Generally when water levels increased in well 1, nitrate levels increased and vice versa.

There are three factors which will influence the occurrence of nitrates within the Sumas Aquifer. These include 1) the geographic location of the nitrate source, 2) recharge and groundwater levels, and 3) the concentration, duration, and form of nitrate being applied. Two-dimensional nitrate contours indicate the highest concentration in wells down-gradient of large dairies in the central portion of the study area and down-gradient of large fertilized crop fields identified in field investigations. Two-dimensional nitrate contour data suggests that most of the contamination is localized with some impacts from Canada. The majority of wells sampled were relatively shallow and did not provide access to water at deeper levels within the aquifer. Nitrate levels in wells 5, 6, and 7 (deep wells) seem to indicate some impact from Canada, given their depths and proximity to the border.

A trend in decreasing nitrate levels was observed down-gradient from known point sources (Figures 34-39). This trend is most likely a result of high nitrate loading to the water table from agricultural sources, which is then mixed and diluted as groundwater travels down-gradient. Well 1 was the only well to show some correlation with water levels and nitrate concentrations from April, 1997 to March, 1998. This correlation is attributed to the very shallow groundwater levels (0-5 feet below land surface) and the intense farming directly adjacent to the well. Wells 5, 6, and 7 showed a gradual increase in nitrate concentration but not in relation to rising water table levels. The rising nitrate trend may be from loading sources across the international border in Canada.

Three of the most highly contaminated wells in the study area (wells 9, 14, and 18) did not show any clear correlation between water levels and nitrate concentrations. It remains unclear as to why wells 9 and 14 showed a gradual decrease in nitrates over the duration of the study. Well 14 is a very shallow well (20 feet deep) located down-gradient of known point sources including a dairy pasture, feed lot, and manure lagoon. Well 9 is 71 feet deep and screened approximately 40 to 45 feet below the water table. Well 9 is also located down-gradient of a known point source. A possible explanation for lower nitrate levels observed in wells 9 and 14 may be the increased attention given to dairy farms in Whatcom County by Ecology and EPA shortly after this study began. Ecology and EPA enforced more stringent handling practices of manure wastes at dairy farms and threatened significant enforcement penalties for violators, which may partly explain the decreasing nitrate levels observed in wells 9 and 14 during this study. Well 18 showed a rising trend from Spring of 1997 to the Fall of 1997 and then a sharp decrease for the duration of the study. The apparent convergence of nitrate contours around well 18 is believed to be caused by the lack of data points west of well 18 and the high concentration of nitrates within the well. Well number 18 is down-gradient from very large raspberry fields. It may be that the increasing trend in nitrates from Spring 1997 to Fall 1997 was due to lower water levels in the well from increased use for irrigation during the dry months, however, this same trend was not seen from the Spring of 1998 to the Summer of 1998.

4.9 NITRATE TRANSPORT SIMULATIONS

MT3D was used to model three different nitrate transport scenarios (Appendix E). A 50 mg/L nitrate spike was introduced at selected cell locations in the model domain for a duration of one day as discussed in section 3.9 (Figures 40-42). Results of the nitrate transport simulations are given in Table 9. Nitrate contours for all three scenarios were plotted after one year of travel time with the exception of scenario two. In scenario two, the nitrate plume traveled outside of the study area after one year at the highest hydraulic conductivity value, so nitrate contours were plotted at six months. Nitrate contours within the study area for each transport scenario are shown in Figures 43-48. Because Judson Lake crosses the international border, two sets of nitrate line sources had to be used in scenario three (Figure 42). As a result, two distinct nitrate plumes were produced on the west and east side of Judson Lake (Table 9). To ensure that nitrate transport results reflected the estimates of the groundwater flow model, the distance the contaminant plumes traveled were measured from the center of mass against groundwater flow velocities calculated by the groundwater model. These values were found to be accurate and reasonable and are reported in Table 9.

Two values of hydraulic conductivity were used for each scenario because a range of hydraulic conductivity values have been reported for the Abbotsford-Sumas Aquifer. Using two different hydraulic conductivity values (high and medium), a better representation of possible contaminant transport times within the aquifer was achieved. The medium conductivity value used for transport modeling was obtained from the USGS study conducted within the same general area (Cox and Kahle, 1999). The median value reported in the USGS study was 274 feet per day for the entire USGS study area. The high conductivity value used in transport modeling was the value obtained from this study of 929 feet per day (section 4.2).

The groundwater model was developed in part to enable approximations to be made about residence times for nitrates within the study area and to simulate trends observed in the field data. In scenario one, a hydraulic conductivity of 270 feet per day produced slightly higher travel times and reduced plume concentrations at the end of 1 year. These results are expected given the increase in groundwater flow velocity associated with higher hydraulic conductivity values. Transport simulations using a hydraulic conductivity of 929 feet per day not only generated faster travel times, but also elongated the nitrate plume in the direction of groundwater flow (Figure 44).

In scenario two, the second nitrate spike was located in an area of slightly higher groundwater flow velocity as predicted by the groundwater model. Because of this, both transport simulations produced faster travel times and larger reductions in nitrate plume concentrations. Nitrate levels in the southeast portion of the study area were relatively low throughout the duration of this study. Using high hydraulic conductivity values in the transport simulations (like that estimated within the study area of 929 feet per day) seem to support the fact that high concentrations of nitrate entering groundwater in the northern portions of the study area is rapidly diluted by the time it reaches the southeast portion of the study area (Figure 46).

In scenario three, a hydraulic conductivity of 270 feet per day reduced the nitrate plume concentration by one half after one year (Figure 47). A hydraulic conductivity of 929 feet per day produced nitrate contours that seem to indicate contamination from Canada as a likely source. After three to six months in the transport simulation, the east half of the study area indicated nitrate levels that closely resembled those collected in the field for wells 5, 6, and 7. After one year, nitrate concentrations in the west half of the study area around wells 1 and 2 were beginning to approach nitrate concentrations observed in those wells during the course of this study (Figure 48). If the transport simulation were allowed to run another three months, nitrate levels around wells 1 and 2 would be about the same as those observed during the course of this study. It can also be seen that wells 3 and 4 seem to be somewhat protected from the nitrate plume possibly due to the interaction of Judson Lake with groundwater flow (Figure 48). Groundwater model head contours in the northwest half of the study area show a strong southwest flow component, especially where the nitrate spikes were initiated for scenario three (Figure 42). Because of the strong southwest flow directions, it is not surprising that wells 3 and 4 are somewhat protected from nitrate loading across the international border in Canada. This may explain why nitrate levels in wells 3 and 4 were continually low throughout this study. However, there have been elevated nitrate spikes in the past observed in well number 4 (Garland, personal communication 1998). Furthermore, well 3 is screened between 87 and 92 feet below land surface and the average water table level is approximately 15 feet below land surface in this area. Therefore, well 3 may be drawing water deeper within the aquifer that is less contaminated.

5.0 CONCLUSIONS

This thesis focused on characterizing the hydrostratigraphy and its relationship to groundwater flow directions and flow velocities. Information collected as part of this study was used to develop a groundwater flow model to predict groundwater flow and simulate nitrate transport in the study area. Five project objectives were defined in section 1.4 and have been accomplished by this study.

5.1 HYDROSTRATIGRAPHY

Six geologic units were identified within the study area and grouped into two hydrostratigraphic units defined as the Sumas Aquifer and the Sumas Aquitard. The Sumas Aquifer is unconfined in the study area and ranges in thickness from 180 feet in the northeast portion of the study area to approximately 80 feet in the southeast portion of the study area. The Sumas Aquifer is primarily a heterogeneous mixture of gravel and sand with some sand lenses and scattered silt and or clay lenses, but is believed to have good hydraulic continuity throughout the study area with the possible exception of ice contact deposits in the southeast portion of the study area. The average hydraulic conductivity of the Sumas Aquifer was determined through sieve analyses to be 929 feet/day. This estimate was determined to be a close representation of the actual hydraulic conductivity of the aquifer given the high content of gravel and sand in the study area. The Sumas Aquitard is made up of three relatively impermeable units that are found in scattered lenses throughout the study area. However, the primary unit of the Sumas Aquitard is a clay layer interpreted as Bellingham GMD which is believed to exist at approximately sea level in the study area. This study concludes that the Hampton Clay, which crops out at the south end of the study area as mapped by Easterbrook in 1976 (Figure 3), is the same unit as the Bellingham GMD that occupies large areas northwest, south, and southwest of the study area. This theory is in agreement with the most recent mapping done by the USGS (Cox and Kahle, 1999) and has also been verified by Don Easterbrook (Easterbrook, personal communication 1999). Understanding the relationship between the Hampton Clay and Bellingham GMD is very important in obtaining accurate groundwater flow directions in the southern portion of the study area. The Hampton Clay defines a no-flow boundary which forces groundwater to flow east and west and may also create a vertical groundwater flow component in this area.

5.2 SEASONAL WATER TABLE FLUCTUATIONS

Water table levels fluctuated from season to season and showed the largest variations between the spring and fall, and the spring and summer seasons. The largest overall average variation in water table levels was approximately 5 feet in the north half of the study area and 3.5 feet in the southern half of the study area. The water table is predicted to be a maximum of 60 to 65 feet below land surface in the northeast portion of the study area and anywhere from 0 to 30 feet below land surface in the southern portion of the study area. It is believed that the seasonal water tables contoured from field data using Surfer are not as accurate as the water table contour predicted by the groundwater model. There were no clear trends with rising water levels and rising nitrate concentrations with the exception of well 1, which did show a possible correlation between rising water table levels and rising nitrate concentrations.

5.3 HYDRAULIC GRADIENTS

Hydraulic gradients were calculated utilizing both the water table contour maps generated in Surfer from water levels collected in the field, and the water table contour map generated from the groundwater model results using GMS. Hydraulic gradients are highest in the east portion of the study area and lowest in the west portion of the study area. Comparisons of hydraulic gradients between the contoured field data and the groundwater model data revealed little difference overall. The largest differences between the two occurred in the eastern portion of the study area and the north and southern halves of the study area. Water tables developed from the field data showed a large difference in gradients between the north half and the south half the study area. This difference was not observed in the gradients calculated using the groundwater model. Hydraulic gradients were used to calculate linear groundwater flow velocities in the study area.

5.4 GROUNDWATER FLOW DIRECTIONS AND VELOCITIES

Field data contoured in Surfer showed groundwater flow directions to be almost due south in the north half and west portions of the study area. Contours in the far east and southeast portions of the study area show that the groundwater flow direction is more to the southeast. It is assumed that the actual groundwater flow directions, especially in the southwest portion of the study area, more closely approximate those predicted by the groundwater model. Groundwater flow directions predicted by the model show a more defined southeasterly trend than flow directions predicted by head contours generated from the field data. The difference between the two is attributed to the southwestern half of the model area being established as a no-flow boundary, which forced groundwater to flow to the southwest and southeast. This predicted flow regime corresponds best with the hydrostratigraphy in this area. Three major groundwater flow directions within the study area were observed from contouring the results of the groundwater simulation. In the east half of the study area, the groundwater flow direction is clearly from the northwest to the southeast. In the northwest quarter of the study area, the groundwater flow direction is to the southwest. In the southwest quarter of the study area, the flow direction shifts to the southeast and eventually almost due east because of the no-flow boundary in this location.

Groundwater flow velocity in the southern half of the study area is a little over four times that in the north half of the study area, as indicated by field data. This large variation between the north half and the south half of the study area is not as pronounced in the groundwater model simulation. As stated previously, it is believed that the groundwater model more closely approximates the actual groundwater flow within the study area. Groundwater flow velocities in the east half of the study area range from approximately 20 feet/day using water level data collected in the field to 25 feet per/day using the groundwater model simulation. Groundwater flow velocities in the central and west half of the study area range from approximately 10 feet/day using water level data collected in the field, to 7.5-15 feet/day using the groundwater model simulation. Groundwater flow velocities predicted by the model simulation show a large variation from west to east within the study area. In the east portion of the study area, the model predicts a maximum velocity of approximately 25 feet per day compared to 20 feet per day from water table contours generated from field data in the direction of groundwater flow. In the west portion of the study area, the model predicts a velocity of approximately 8 feet per day compared to 11 feet per day from water table contours generated from field data in the direction of groundwater flow. Groundwater flow velocity variations from east to west within the study area are attributed primarily to topography and regional groundwater flow directions established by the model.

5.5 TWO-DIMENSIONAL NITRATE CONTOURS

Two-dimensional nitrate contours indicate that the highest concentrations occur in wells down-gradient of large dairies in the central portion of the study area and down-gradient of large fertilized crop fields identified in field investigations. This suggests that most of the groundwater contamination is occurring from localized sources within Whatcom County, Washington. However, there is also evidence that suggests groundwater contamination at deeper levels in the northeast portion of the study area, is related to sources across the international border in Canada. This may also be true for the northwest portion of the study area at shallower levels. It is logical to assume that rapid dilution of nitrate would occur given the vast quantity and velocity of groundwater within the Sumas Aquifer. This theory was tested using a transport model with various nitrate spikes monitored over a period of one year.

5.6 NITRATE TRANSPORT

*A*pproximate residence times for nitrate plumes within the study area were determined using the groundwater model developed with MODFLOW, GMS, and a transport model (MT3D). Three transport scenarios were examined with MT3D. Each scenario used two different values of hydraulic conductivity to gain a better distribution of possible contaminant transport times. Transport simulations re-affirm the fact that accurate groundwater flow velocities are critical in determining nitrate residence times. At higher hydraulic conductivity values, and thus higher groundwater flow velocities, nitrate spikes initiated in the study area traveled outside of the study area between 1.5 and two years and were significantly reduced in concentration. By comparison, nitrate travel times from the international border to the southern end of the study area predicted by calculated groundwater flow velocities was approximately 1.8 years. Nitrate transport simulations also suggest that contamination from sources across the international border in Canada is likely in the northeast and northwest portions of the study area.

6.0 RECOMMENDATIONS FOR FUTURE WORK

Recommendations for future work within the Abbotsford-Sumas study area include:

1) Perform pump tests to determine aquifer properties to help verify the groundwater model and future models.

2) Study the interactions of groundwater and surface water between Judson Lake, Laxton Lake and the Sumas Aquifer. This could be accomplished by getting core samples of the underlying lacustrine sediments to establish their depth and obtain vertical leakance factors. The leakance factors could then be used in a groundwater model which may more accurately predict groundwater flow directions and velocities around these areas.

3) Examine the interactions of Pangborn Bog, nitrate concentrations, and groundwater flow. This could be accomplished by inserting nested monitoring wells or piezometers along the northern fringe of the bog across the study area and sampling monthly for water levels and nitrate concentrations. This could be done very cheaply with the cooperation of two or three land owners (two of whom have already allowed such access for this study) and basic materials such as four inch PVC pipe, a hacksaw, screen material, and a post hole digger. The water levels in this area are very near the surface and peat is relatively easy to dig through.

4) Pick one field of known size that has had little if any type of fertilizer applied to it for one year in the study area and develop nested monitoring wells directly down gradient. Take monthly water levels and water samples to establish background nitrate and water levels. After six months, physically apply a known nitrate concentration as a spike and then monitor monthly to determine the actual travel times within the aquifer. The nested monitoring wells would help reveal concentration variations with depth.

5) Utilize the existing deep test hole in the northeast portion of the study area to obtain water quality samples to better understand possible impacts from Canada. The existing well has a 6 inch casing that was installed to a depth of 400 feet. The drillers well log indicates that no

screens were installed and two distinct aquifers are present. The first aquifer is interpreted as the Sumas Aquifer which is found from 3 feet to 213 feet below land surface in this well (approximately sea level). There is 21 feet of gray clay separating this aquifer from a 100 foot thick water bearing sand layer (possibly the Deming Sand) at a depth of 234 feet below land surface (approximately zero to 100 feet below sea level). If water is found within this well, it is possible that the water may be representative of the deep aquifer since no screens were installed. If the well was sealed at depth and is dry, it would be simple to perforate the casing at the lower level of the Sumas Aquifer. Water quality sampling of the deepest water within the Sumas Aquifer would provide a wealth of information as to the depth and levels of nitrate contamination. The company that drilled this well (Hayes Drilling) is still in business and has a good working relationship with Western Washington University.

6) Soil sampling at various depths in fields with known nitrate application rates and times along with vadose zone monitoring and or the upper most saturated zone of the aquifer. Soil sampling and vadose zone monitoring would more accurately quantify the concentration of nitrate actually entering the water table.

REFERENCES

Abbotsford/Sumas Aquifer 1996 Status Report. Last modified 20 January, 1999. [online: http://www.env.gov.bc.ca/wat/aquifers/absumas.html].

Armstrong, J.E. and Brown, W. L., 1953. Groundwater Resources of Surrey Municipality, British Columbia: Canada Geol. Survey Water-Supply Paper 322.

Armstrong, J.E. and Brown W.L., 1954. Late Wisconsin Marine Drift and Associated Sediments of the Lower Fraser Valley, British Columbia, Canada: Geol. Soc. America Bull., V.65, p. 349.

Armstrong, J.E., 1981. Post-Vashon Wisconsin Glaciation, Fraser Lowland, British Columbia, Canada: Geol. Survey of Canada Bull., V.322, p.34.

Canter, L.W., 1997. Nitrates in Groundwater, CRC Lewis, Boca Raton, Fla.

Cox, S., and Kahle, S., 1999. Hydrogeology, Ground-Water Quality, and Sources of Nitrate in Lowland Glacial Aquifers of Whatcom County, Washington, and British Columbia, Canada. Water Resources Investigations Report 98-4195.

Creahan, K., and Kelsey, H.M., 1988. Hydrogeology and Groundwater Flow near Lynden, Washington. Final report for Contract C0087216, Washington State Department of Ecology.

Easterbrook, D.J., 1963. Late Pleistocene Glacial Events and Relative Sea-Level Changes in the Northern Puget Lowland, Washington: Geol. Soc. America Bull., V.74, p. 1465-1484.

Easterbrook, D.J., 1966. Glaciomarine Environments and the Fraser Glaciation In Northwest Washington: Guidebook for first annual Pacific Field Conference, International Geological Correlation Program.

Easterbrook, D.J., 1971. Geology and Geomorphology of Western Whatcom County, Washington: Bellingham, Wash., Western Washington University Department of Geology.

Easterbrook, D.J., 1973. Environmental Geology of Western Whatcom County, Washington: Bellingham, Wash., Western Washington University Department of Geology.

Easterbrook, D.J., and Hansen, B.S., 1974. Stratigraphy and Palynology of Late Quaternary Sediments in the Puget Lowland, Washington. Geol. Soc. America Bull., v. 85, p. 587-602.

Easterbrook, D.J., 1975. The Last Glaciation: Guidebook for Field Conference, International Geological Correlation Program.

Easterbrook, D.J., 1976a. Geologic Map of western Whatcom County, Washington: U.S. Geological Survey Map I-854-B, scale 1:62,500.

Easterbrook, D.J., 1976b. Map of engineering characteristics of geologic materials, western Whatcom County, Washington: U.S. Geological Survey Miscellaneous Investigations Map I--854-D, scale 1:62,500.

Fetter, C.W., 1993. Contaminant Hydrogeology. Prentice-Hall, Inc., Upper Saddle River, New Jersey.

Fetter, C.W., 1994. Applied Hydrogeology, Third Edition. Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

Garland, D.P., 1997. Hydrogeologist, Washington State Department of Ecology, Northwest Regional Office, Bellevue, WA, Preliminary Observations of Groundwater Quality in the Abbotsford Sumas Aquifer.

Garland, D.P., and Erickson, Denis, 1994. Groundwater Quality Survey near Edaleen Dairy, Whatcom County, Washington January 1990 to April 1993. Washington State Department of Ecology.

Gartner-Lee, Ltd., 1993. Fraser Valley Groundwater/Drinking Water Study. B.C. Ministry of health, Ministry of Agriculture, Fisheries and Food, Ministry of Environment Lands and Parks, March 1993.

Halstead, E.C., 1986. Groundwater Supply-Fraser Lowland, British Columbia: Environment Canada, National Hydrology Research Paper no. 26.

Harleman, D., Melhorn, P., and Rumer, R., 1963. Dispersion-permeability correlation in porous media. J. Hydraul. Div., Amer. Soc., Civil Engrs., V. 89.

Hazen, A., 1911. Discussion of Dams on Soil Foundations: Trans. Amer. Soc. Civil Engrs., V. 73.

Kahle, S., 1990. Hydrostratigraphy and Groundwater Flow in the Sumas Area, Whatcom County, Washington. M.S. Thesis, Western Washington University, Bellingham, WA.

Liebscher, H., Hii, B., and McNaughton, D., 1992. Nitrates and Pesticides in the Abbotsford Aquifer Southwestern British Columbia.

McDonald, M., and Harbaugh A., 1988. A Modular Three-Dimensional Finite-Difference Ground-Water Flow Model, Chapter A1. Techniques of Water-Resources Investigations of the United States Geological Survey.

Ryan, P.J., 1994. An Evaluation of the State of Nitrate/Nitrogen Contamination of the

Abbotsford-Sumas Aquifer: M.S. Thesis, University of British Columbia, Canada.

Riggs, J.B., 1958. Peat Resources of Washington. Washington State Division of Mines and Geology. Bulletin no. 44.

State of Washington Department of Health, Environmental Health, 1992. Office of Toxic Substances Fact Sheet, Nitrate In Drinking Water.

Szeto, S., et al. 1994. Nonpoint-Source Groundwater Contamination by 1,2,2-Trichloropropane, A Trace Impurity in Soil Fumigant Formulations. J. Environ. Qual. 23:1367-1370.

United States Department of Agriculture, Soil Conservation Service, 1992. Soil Survey of Whatcom County Area, Washington.

Wang, H. F., and Anderson, M. P., 1982. Introduction to Groundwater Modeling. W. H. Freeman and Company, San Francisco, California.

Washington State Division of Water Resources, Department of Conservation 1960. Water Resources of the Nooksack River Basin and certain adjacent streams: Olympia, Wash., Division of Water Resources, Water Supply Bulletin no. 12.

Wassenaar, L.I., 1994. Evaluation of the origin and fate of nitrate in the Abbotsford aquifer using isotopes of ^{15}N and ^{18}O in NO^{-}_{3}: Saskatoon, Saskatchewan, National Hydrology Research Institute, NHRI Contribution no. CS-94009.

Zheng, C., 1990. MT3D: A Modular Three-Dimensional Transport Model for Simulation of Advection, Dispersion, and Chemical Reactions of Contaminants in Groundwater Systems. S.S. Papadopulus and Associates, Inc.

Tables

Table 1. Seasonal and 30-Year Precipitation Data

Season	Average Precipitation (inches)	30-Year Average (inches)	30-Year Season
Spring 1997	10.07	10.55	Spring
Summer 1997	6.84	6.07	Summer
Fall 1997	17.41	13.59	Fall
Winter 1998	14.81	15.57	Winter
Spring 1998	10.62	10.55	Spring
Summer 1998	3.5	6.07	Summer

Data obtained from U.S. Department of Commerce
National Oceanic and Atmospheric Administration

Table 2. Hydraulic Conductivity Values Obtained from Seive Analyses

Harleman Method

sample #	effective grain size	k_i	ρ	u	g	$K=k_i(\rho g/u)$			
	d_{10}(cm)	(cm2)	(g/cm3)	(g/s-cm)	(cm/s2)	K (cm/s)	K (m/day)	K (gal/day/ft2)	**K (ft/day)**
1	0.045	1.324E-06	0.9991	0.011404	980	0.1137052	98	2407	**322.2**
2	0.045	1.324E-06	0.9991	0.011404	980	0.1137052	98	2407	**322.2**
3	0.06	2.354E-06	0.9991	0.011404	980	0.2021425	175	4279	**572.9**
4	0.078	3.979E-06	0.9991	0.011404	980	0.3416208	295	7231	**968.1**
5	0.06	2.354E-06	0.9991	0.011404	980	0.2021425	175	4279	**572.9**
6	0.35	8.012E-05	0.9991	0.011404	980	6.8784602	5943	145603	**19493.0**
7	0.37	8.953E-05	0.9991	0.011404	980	7.6870302	6642	162719	**21784.4**
8	0.007	3.205E-08	0.9991	0.011404	980	0.0027514	2	58	**7.8**
9	0.0097	6.153E-08	0.9991	0.011404	980	0.0052832	5	112	**15.0**

USGS Study max value 58,200 (gal/day/ft2)

USGS max(m/day)	USGS max(ft/day)	USGS median K (ft/day)
2,376	7,800	270

Hazen Method

Sample #	effective grain size	k_i	ρ	u	g	$K=k_i(\rho g/u)$			
	d10(cm)	(cm2)	(g/cm3)	(g/s-cm)	(cm/s2)	K (cm/s)	K (m/day)	K (gal/day/ft2)	**K (ft/day)**
8	0.007	4.90E-08	0.9991	0.011404	980	0.004207	4	89	**292**
9	0.0097	9.41E-08	0.9991	0.011404	980	0.0080792	7	171	**561**

k_i = intrinsic permeability; ρ = density of water at 15 degrees C; u = dynamic viscosity of the fluid
g = acceleration of gravity; K = hydraulic conductivity

Table 3. Well Data

UTM X	UTM Y	well #	Survey point	Measure Point	Well Log	Screened Interval	Well Depth	Well Casing (inches)
546353	5426622	1	149.42	149.34	no		30 feet (R)	36 concrete
546973	5426759	2	164.33	159.08	yes	26-34 feet	34 feet (A)	24 concrete
547363	5427151	3	164.65	167.23	yes	87-92 feet	92 feet (A)	6 metal
547440	5427160	4	*	*	no		20 feet (R)	24 concrete
549039	5427543	5	204.89	198.47	no		90 feet (E)	36 concrete
549236	5427258	6	189.50	183.50	yes	not specified	95 feet (A)	36 concrete
549060	5426977	7	174.59	175.17	yes	no screen	77 feet (A)	6 metal
548008	5426736	8	167.25	168.75	no		75 feet (E)	6 metal
548021	5426644	9	*	*	yes	66-71 feet	71 feet (A)	6 metal
548742	5426759	10	166.65	167.82	yes	42-50 feet	50 feet (A)	6 metal
549062	5426808	11	175.14	176.43	yes	no screen	71 feet (A)	8 metal
548981	5426544	12	177.55	179.80	yes	70-75 feet	75 feet (A)	6 metal
548991	5426119	13	*	*	no		40 feet (R)	36 concrete
548345	5425936	14	157.63	151.21	yes	12-20 feet	20 feet (A)	36 concrete
548135	5425484	15	138.66	142.16	no		30 feet (R)	8 metal
548168	5425398	16	*	*	no		60 feet (R)	8 metal
548441	5425174	17	132.30	133.30	no		37 feet (R)	36 concrete
547523	5425026	18	135.72	142.14	no		43 feet (R)	6 metal
549004	5424723	19	85.51	86.18	no		45 feet (E)	6 metal
548882	5424290	20	79.01	80.51	no		47 feet (R)	6 metal
549215	5426023	21	148.47	150.80	yes	no screen	57 feet (A)	6 metal
546291	5426194	piezometer	132.46	134.79		3-5 feet	5 feet (E)	2 PVC

* = Not able to survey / static water levels not taken

(R) = Reported well depth (A) = Actual well depth (E) = Estimated well depth

UTM X and Y = Universal Transverse Mercator units = meters

Table 4. Average Water Level data used for Seasonal Water Table Contours

Well #	Spr97	Sum97	Fall97	Wtr97	Spr98	Sum98	Difference Spr97-Fall97	Difference Fall97-Spr98	Difference Spr97-Sum98
1	145.8	144.9	143.7	145.3	145.0	142.8	2.1	1.3	3.0
2	144.6	142.3	139.9	142.3	142.2	139.4	4.7	2.3	5.1
3	146.0	142.6	138.2	141.9	142.0	138.5	7.8	3.8	7.5
5	144.9	144.0	140.1	140.6	143.0	142.8	4.7	2.8	2.1
6	142.8	140.2	137.0	137.5	139.2	140.2	5.8	2.2	2.7
7	141.2	138.8	135.8	136.9	138.1	134.5	5.3	2.3	6.7
8	141.9	138.9	136.1	137.6	138.4	135.4	5.8	2.3	6.5
10	141.5	138.9	136.1	137.7	138.3	135.5	5.5	2.2	6.0
12	138.6	135.7	133.9	135.4	135.4	133.0	4.7	1.5	5.6
14	135.8	134.6	133.5	134.6	134.4	133.0	2.3	0.9	2.9
15	121.9	120.4	117.9	122.0	121.1	119.0	3.9	3.2	2.9
17	106.9	105.6	104.4	107.0	106.6	105.0	2.5	2.1	1.9
18	118.1	115.4	115.7	117.8	117.1	114.1	2.4	1.4	4.0
19	75.0	72.8	68.3	73.4	73.9	72.2	6.7	5.6	2.8
20	64.0	63.4	63.4	64.2	64.3	64.5	0.6	0.9	-0.5
21	133.0	130.2	127.5	130.3	130.3	128.7	5.5	2.8	4.3
					Average difference (feet)		4.4	2.3	4.0

Water Levels = feet above sea level
Spr = Spring; Sum = Summer; Wtr = Winter

Table 5. Geometric Mean of Hydraulic Conductivity (K_G)

Sample #	K_G (ft/day)
1	322.2
2	322.2
3	572.9
4	968.1
5	572.9
6	19493
Arithmetic Mean	3708.6
Geometric Mean (G)	929

Table 6. Hydraulic Gradients using the Groundwater Flow Model

Location	dh=Change in Head (feet)	dl=Distance (feet)	dh/dl=Hydraulic Gradient
East Half of Study Area	80	8,361	0.010
West Half of Study Area	25	8,637	0.003
Northwest to Southeast	90	11,693	0.008

Table 7. Hydraulic Gradients -- using seasonal water table contours

Transect Location	Season	*dh*=Change in Head (feet)	*dl*=Distance (feet)	*dh/dl*=Hydraulic Gradient
North to South	Spring 1997	85	11,231	0.0076
North Half	Spring 1997	20	5,683	0.0035
South Half	Spring 1997	65	5,548	0.0117
North to South	Summer 1997	85	11,231	0.0076
North Half	Summer 1997	20	5,683	0.0035
South Half	Summer 1997	65	5,548	0.0117
North to South	Fall 1997	85	11,163	0.0076
North Half	Fall 1997	20	5,480	0.0036
South Half	Fall 1997	65	5,683	0.0114
North to South	Winter 1998	85	11,299	0.0075
North Half	Winter 1998	20	5,750	0.0035
South Half	Winter 1998	65	5,549	0.0117
North to South	Spring 1998	85	11,366	0.0075
North Half	Spring 1998	20	5,683	0.0035
South Half	Spring 1998	65	5,683	0.0114
North to South	Summer 1998	85	11,434	0.0074
North Half	Summer 1998	20	5,548	0.0036
South Half	Summer 1998	65	5886	0.0110
			North to South Average	0.0075
			North Half Average	0.0035
			South Half Average	0.0115

Table 8. Nitrate Data Set used for Two-Dimensional Nitrate Contour Maps

Well #	UTM X	UTM Y	Spr97avg	Sum97avg	Fall97avg	Wtr98avg	Spr98avg	Sum98avg
1	546353	5426622	13.3	11.5	10.5	12.0	13.6	12.4
2	546973	5426759	16.2	14.8	15.5	14.6	14.6	13.4
3	547363	5427151	0.0	0.0	0.0	0.0	0.0	0.0
4	547440	5427160	2.5	0.3	0.1	1.7	4.7	2.0
5	549039	5427543	8.3	8.7	10.2	11.1	12.0	14.2
6	549236	5427258	11.7	12.0	12.2	13.1	13.8	0.0
7	549060	5426977	8.4	7.4	9.4	9.7	9.1	8.7
8	548008	5426736	9.8	2.0	0.6	0.7	0.8	1.2
9	548021	5426644	26.3	16.9	15.9	13.4	11.2	7.5
10	548742	5426759	11.9	11.5	11.1	6.4	8.7	10.0
11	549062	5426808	1.4	2.0	2.2	1.7	1.9	3.8
12	548981	5426544	0.1	0.0	0.0	0.0	0.0	0.0
13	548991	5426119	23.6	18.9	11.7	9.9	11.0	9.9
14	548345	5425936	30.8	30.2	28.4	25.9	20.4	20.5
15	548135	5425484	2.5	2.7	4.0	3.7	3.4	5.9
16	548168	5425398	5.6	7.7	11.6	9.2	7.8	6.7
17	548441	5425174	10.2	11.2	10.9	10.5	10.7	9.6
18	547523	5425026	23.1	29.5	30.8	23.7	16.5	14.0
19	549004	5424723	3.2	3.1	2.2	2.2	2.3	2.1
20	548882	5424290	2.2	2.3	1.9	2.2	2.3	2.4
21	549215	5426023	0.0	0.0	0.0	0.0	0.0	0.0

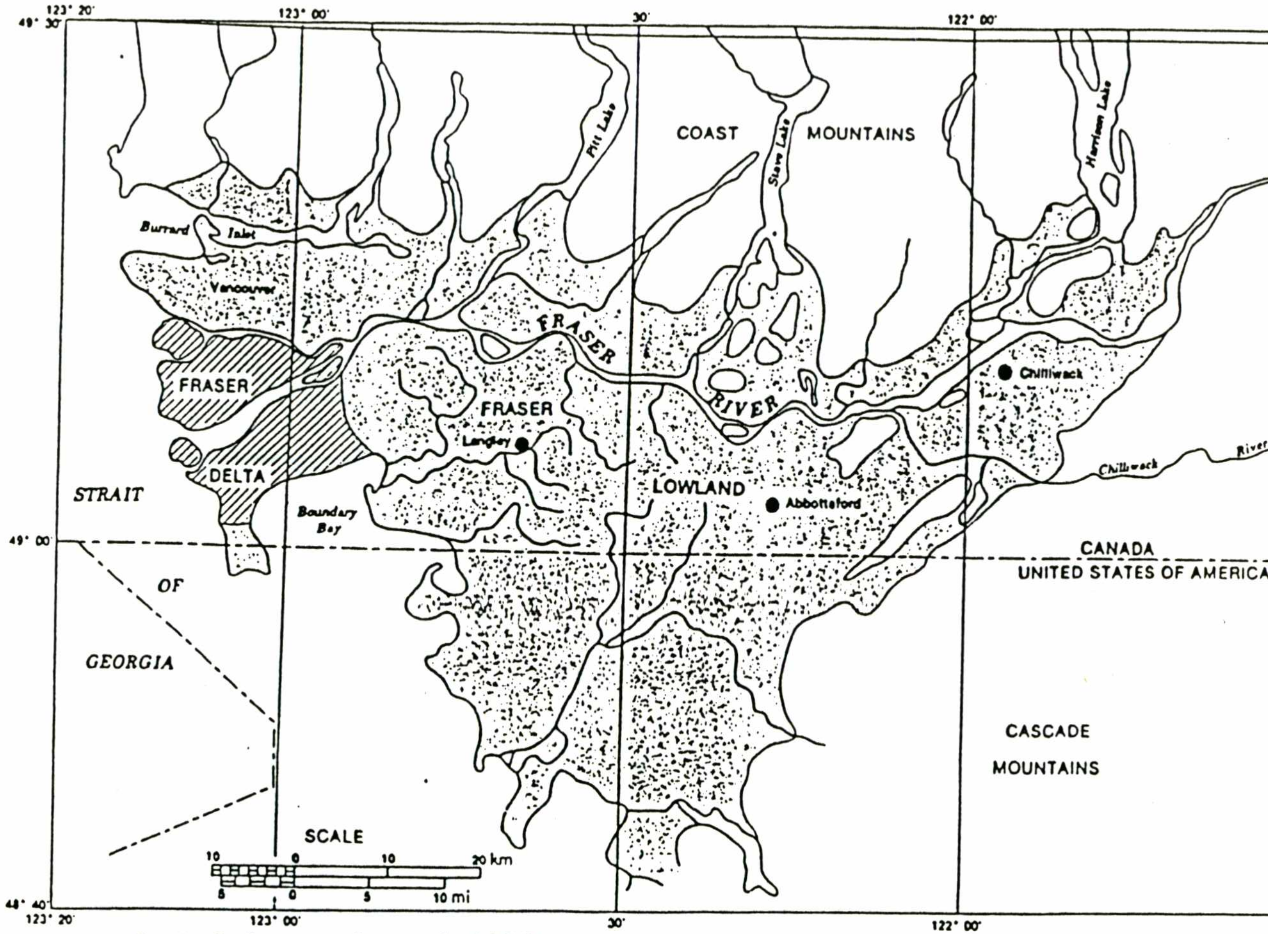
UTM X and Y = Universal Transverse Mercator units = meters

Spr = Spring 3 month nitrate average mg/L; Sum = Summer 3 month nitrate average mg/L; Wtr = Winter 3 month nitrate average mg/L

Table 9. Nitrate Transport Simulation Results

Scenario	Hydraulic Conductivity (K)	Travel Time	Simulated Travel Distance	Calculated Travel Distance	Maximum Nitrate (mg/L)
1	270 feet/day	1 year	1,195 feet	1,126 feet	39
1	929 feet/day	1 year	5,846 feet	5,813 feet	28
2	270 feet/day	6 months	1,595 feet	1,689 feet	39
2	929 feet/day	6 months	3,721 feet	3,391 feet	32
3 West	270 feet/day	1 year	531 Feet	704 feet	20
3 East	270 feet/day	1 year	1063 feet	1,408 feet	20
3 West	929 feet/day	1 year	2,923 feet	2,906 feet	20
3 East	929 feet/day	1 year	7,441 feet	7,266 feet	25

Figures



(Adapted from Halstead, 1986)

Figure 1. Fraser and Nooksack Lowlands

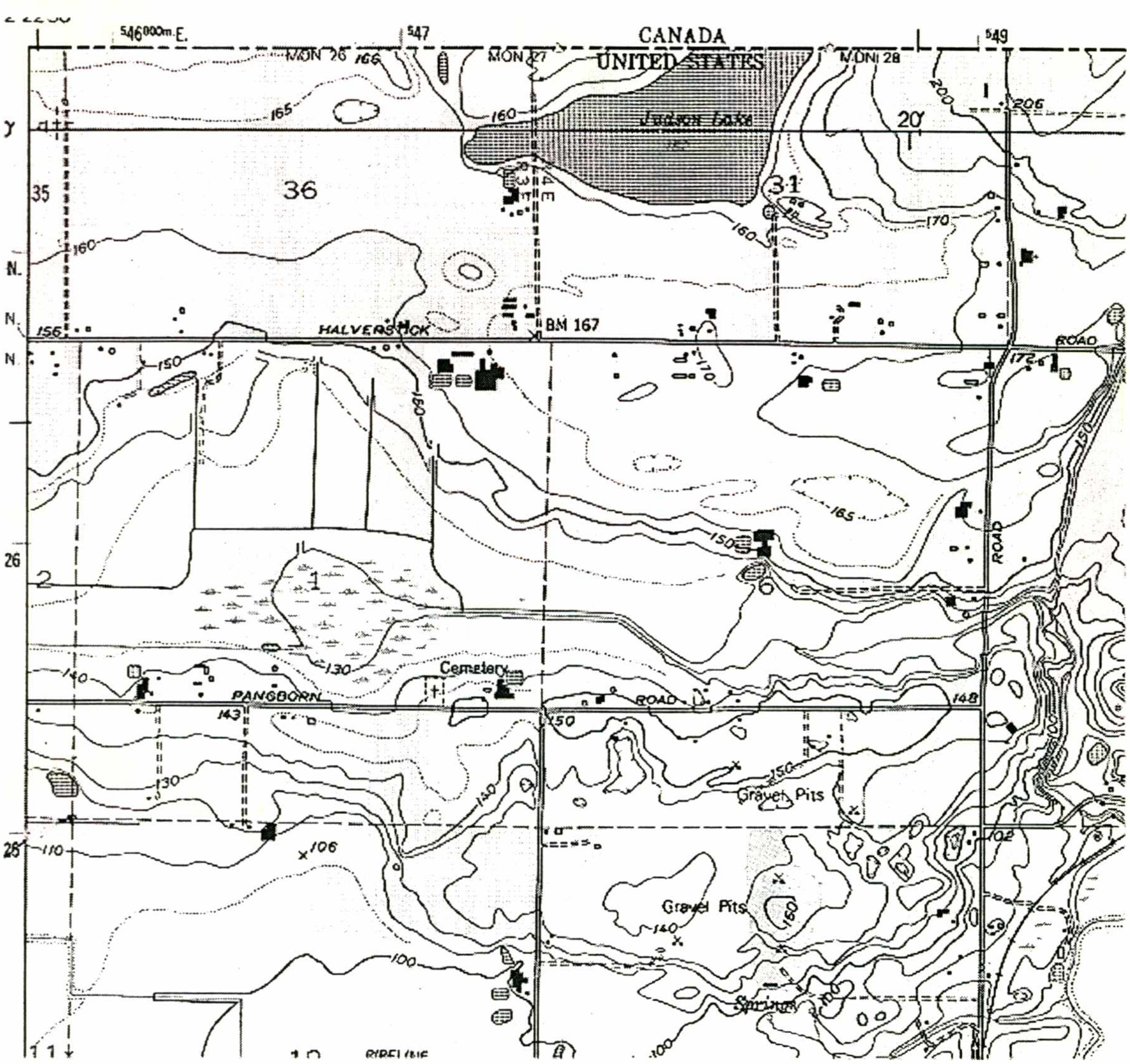


Figure 2. Study Area Map

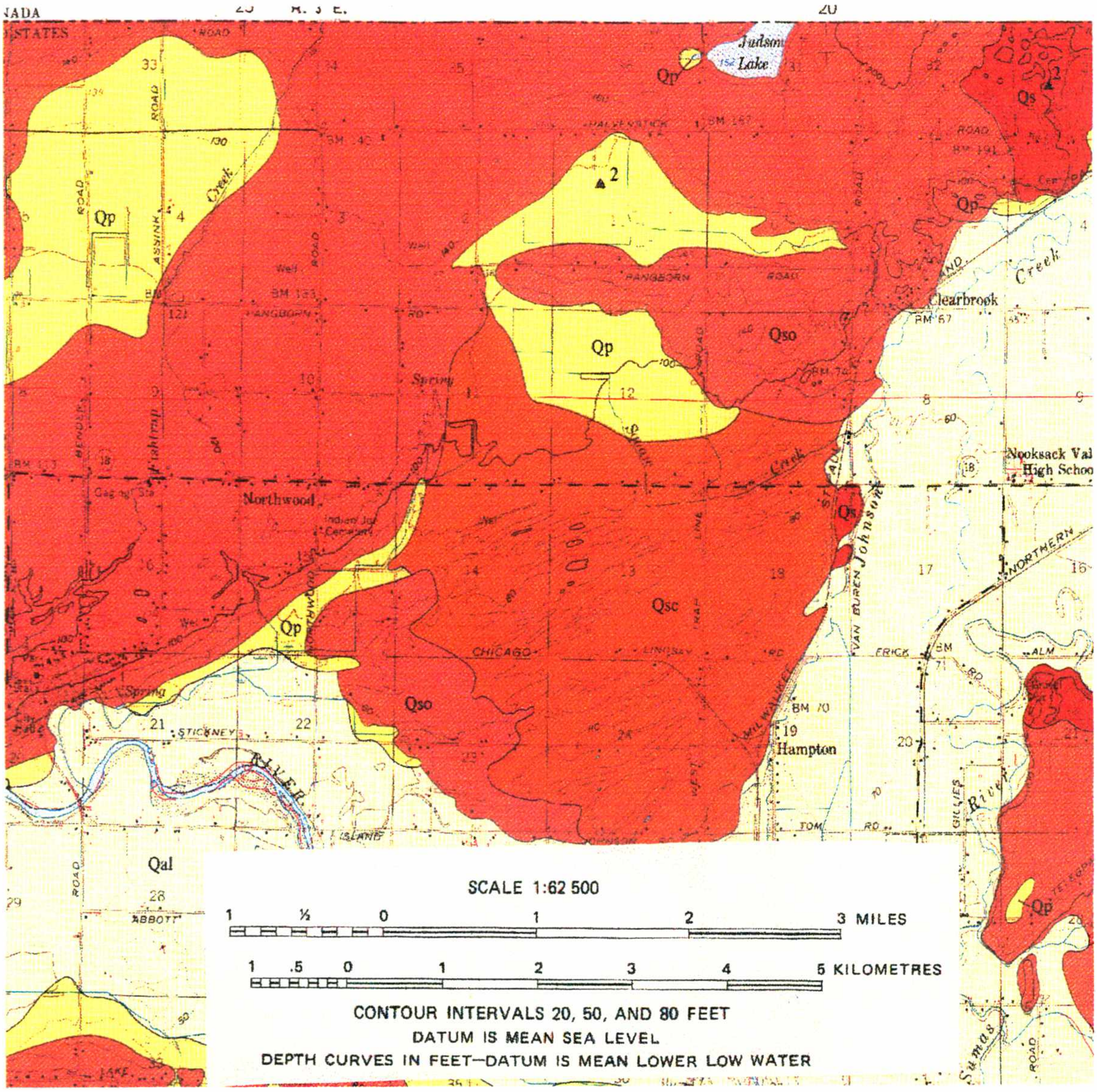


Figure 3. Geologic Map of Western Whatcom County, Washington (Adapted from Easterbrook, 1976)

Qso = Outwash Sand and Gravel
Qp = Peat
Qsc = Silt and Clay
Qal = Alluvial Deposits
Qs = Till and Ice Contact Deposits

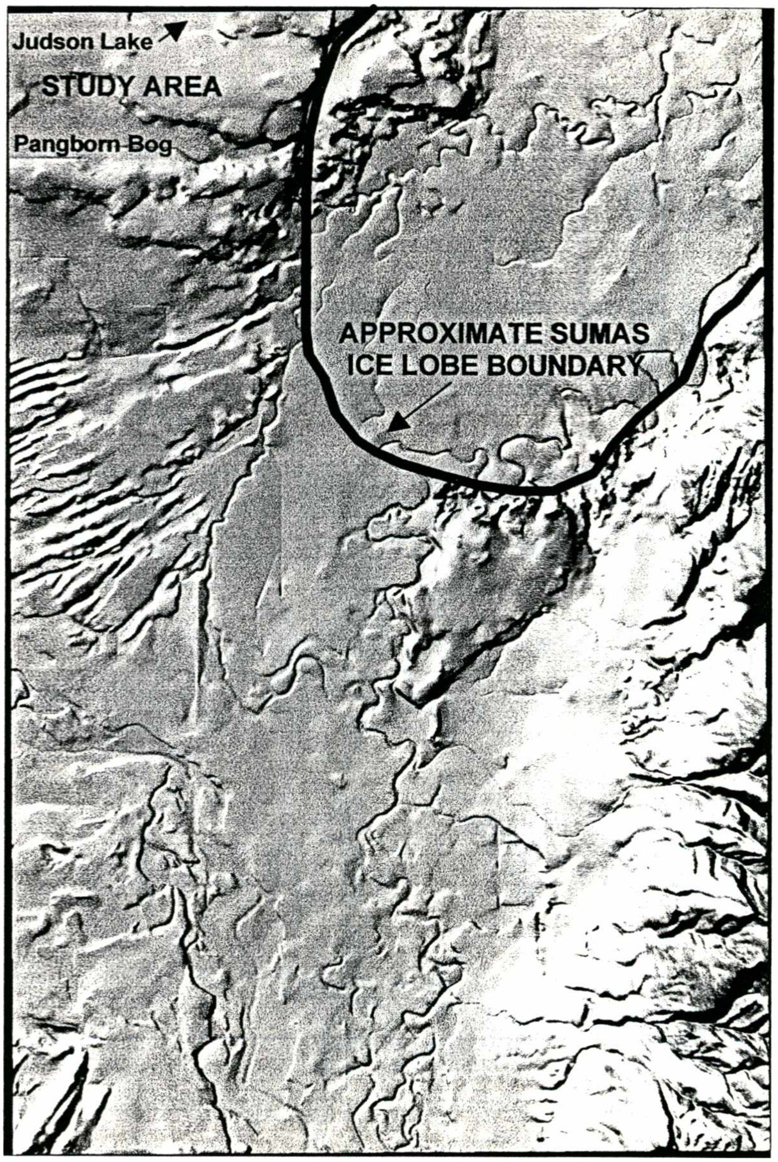
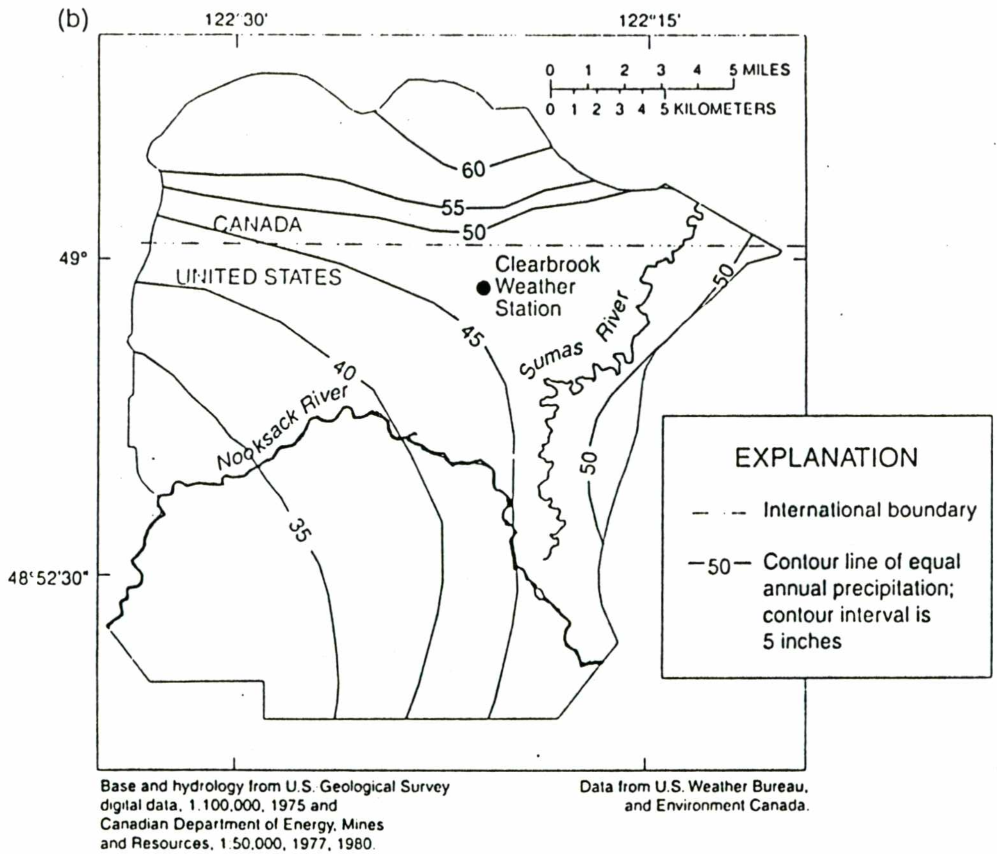


Figure 4. Sumas Ice Lobe Boundary



(Adapted from USGS,1999)

Figure 5. Clearbrook Weather Station

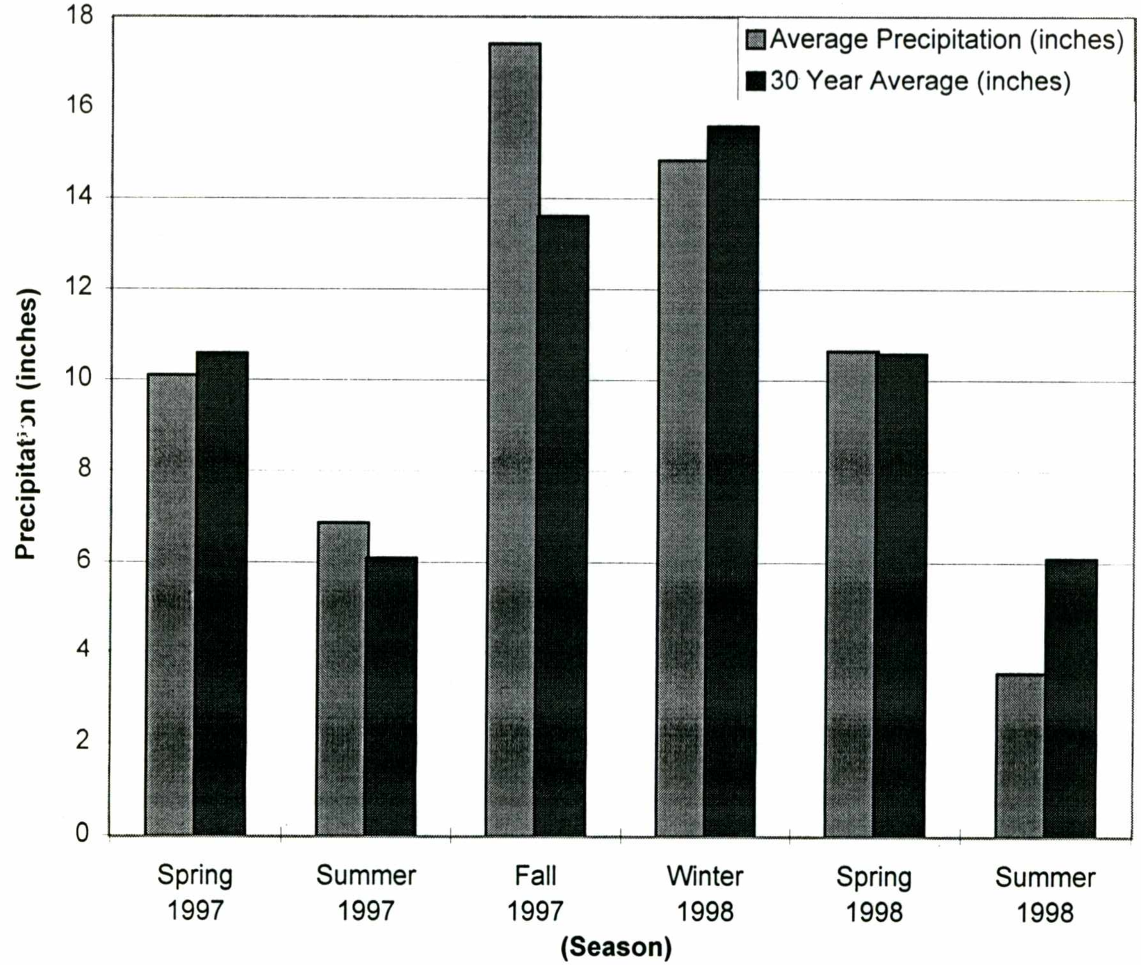


Figure 6. Seasonal and 30-Year Precipitation Graph

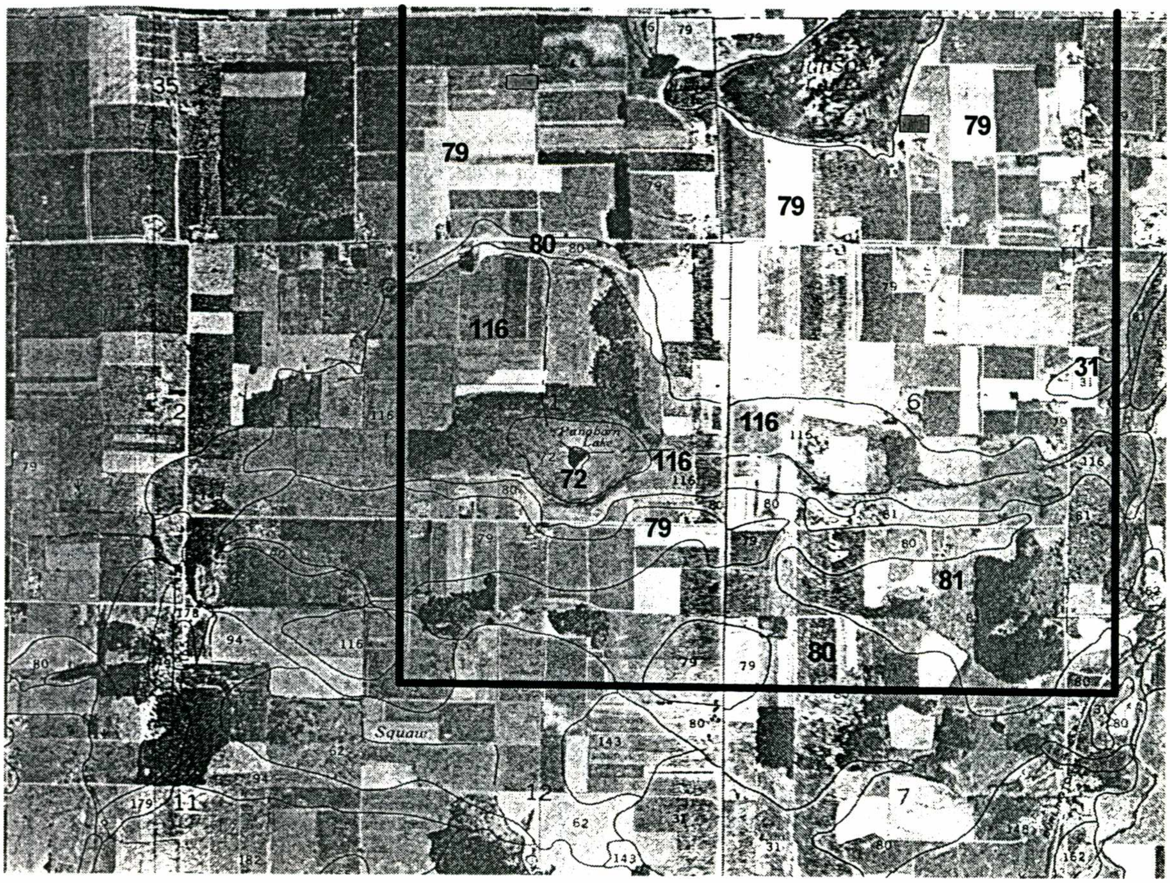


Figure 7. Aerial Photo of Soils within the Study Area
(Adapted from Soil Survey of Whatcom County, Washington, 1985)

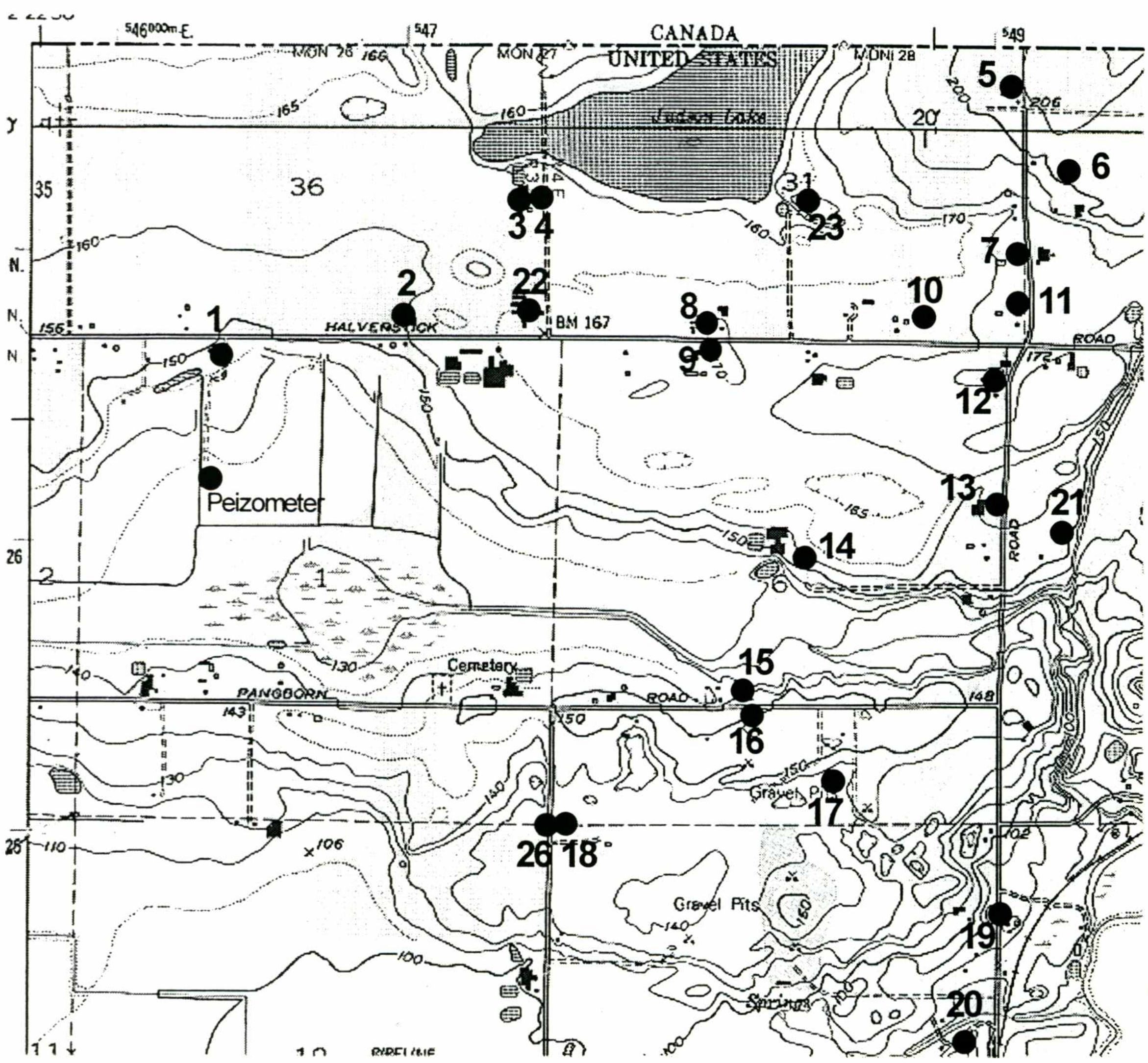


Figure 8. Well Sample Site Location Map

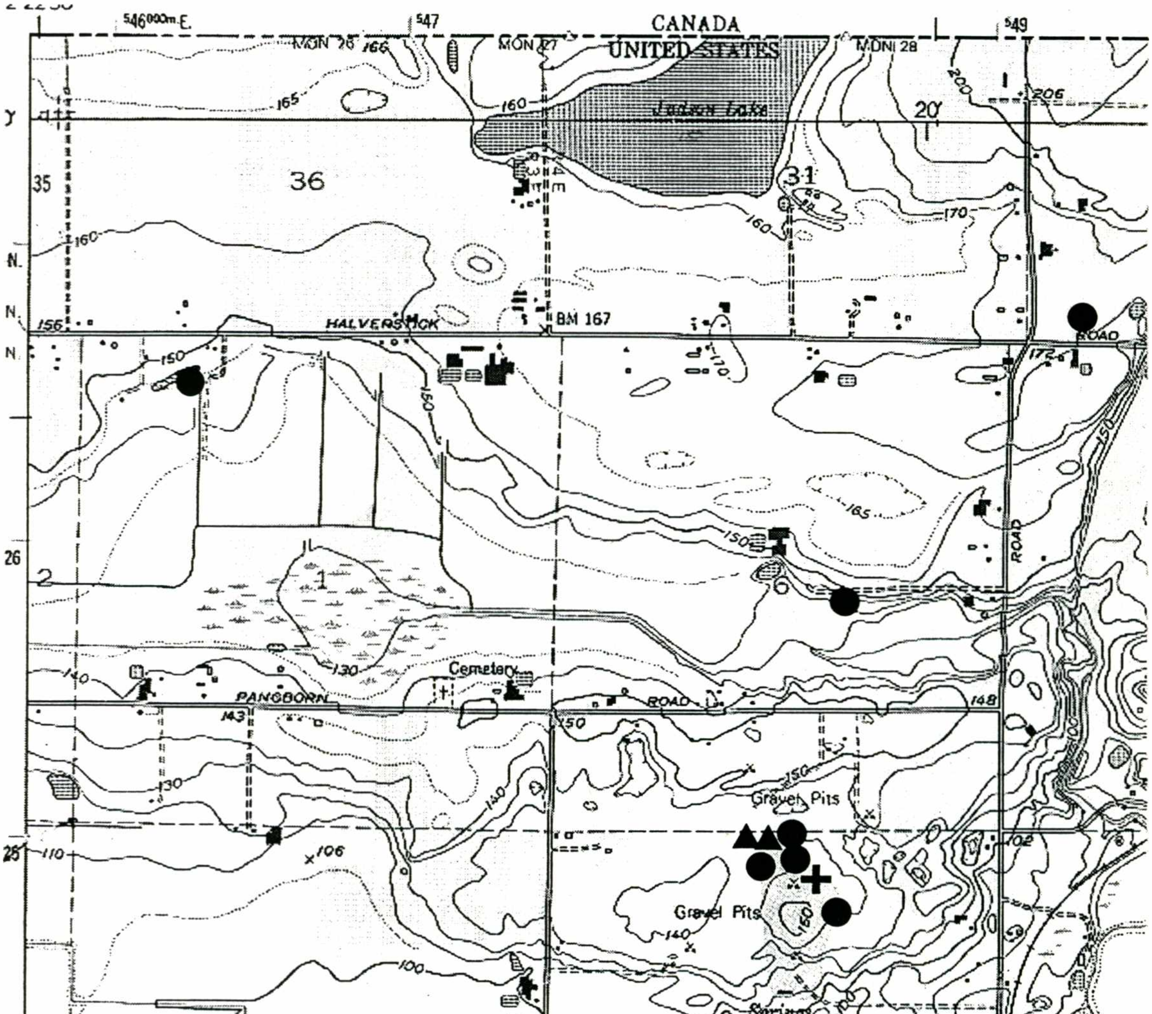


Figure 9. Sieve Sample Locations

● = Gravel & Sand Samples

▲ = Sand Samples

✚ = Clay/Silt Sample

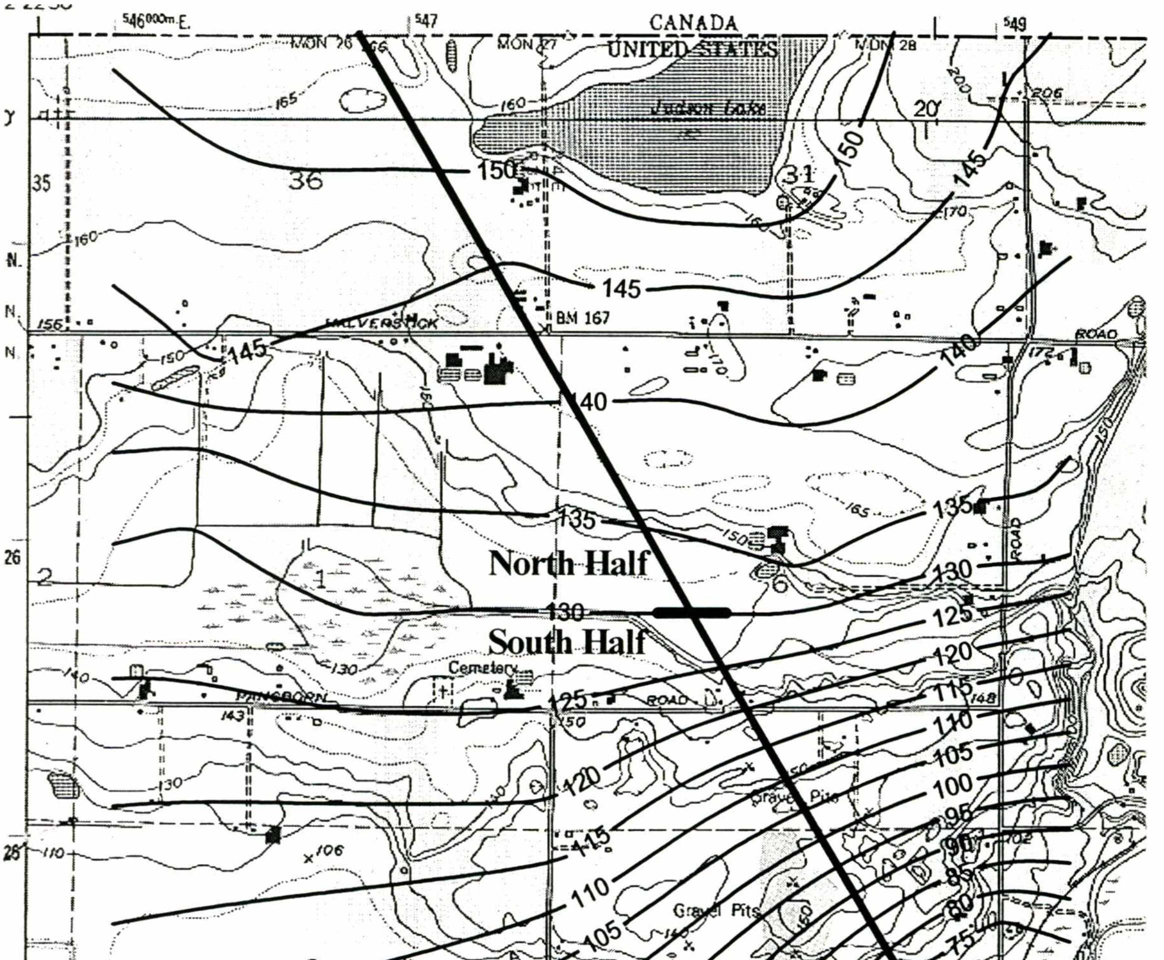


Figure 10. Water Table Cross Section Location

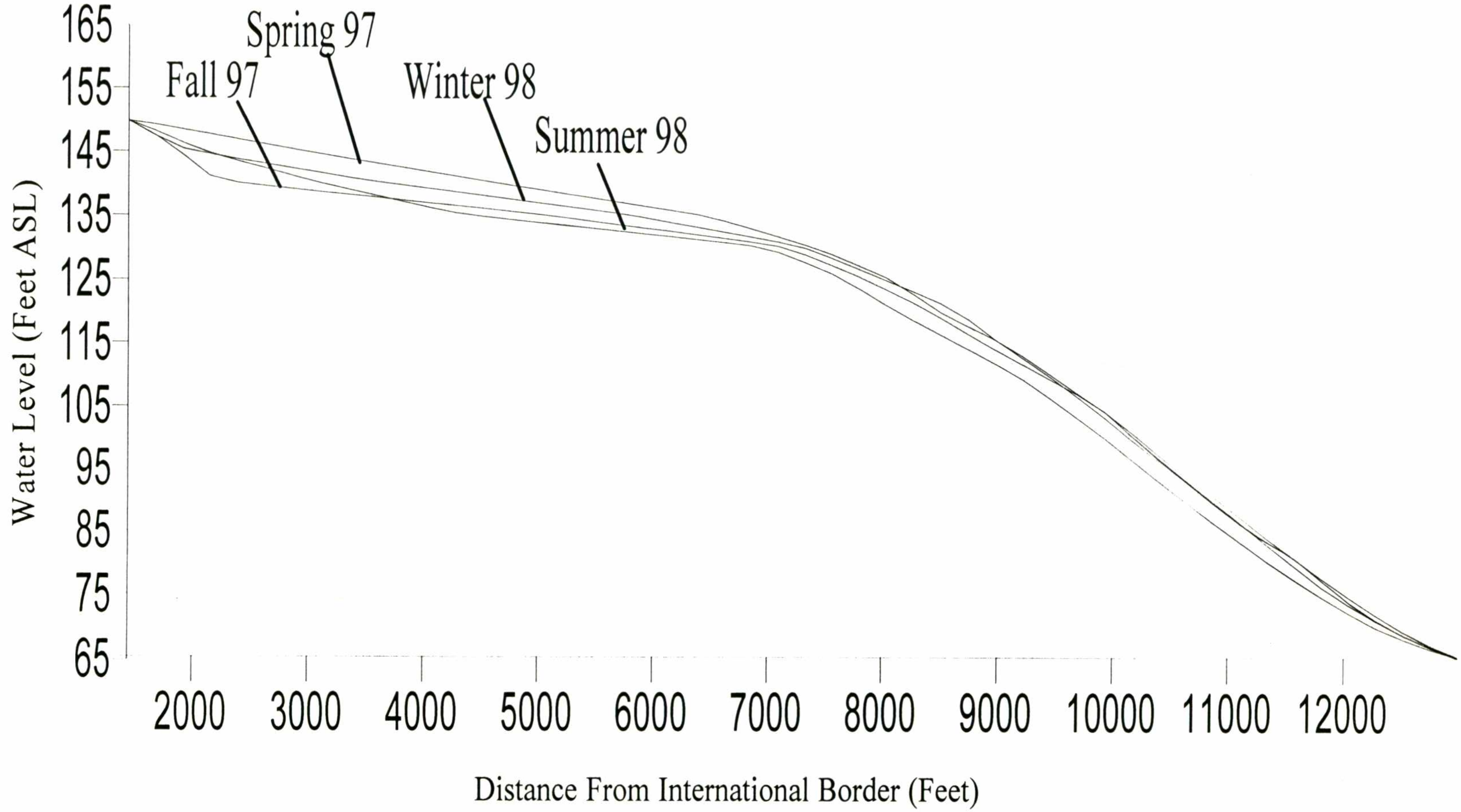


Figure 11. Water Table Cross Section (four seasons with greatest variation)

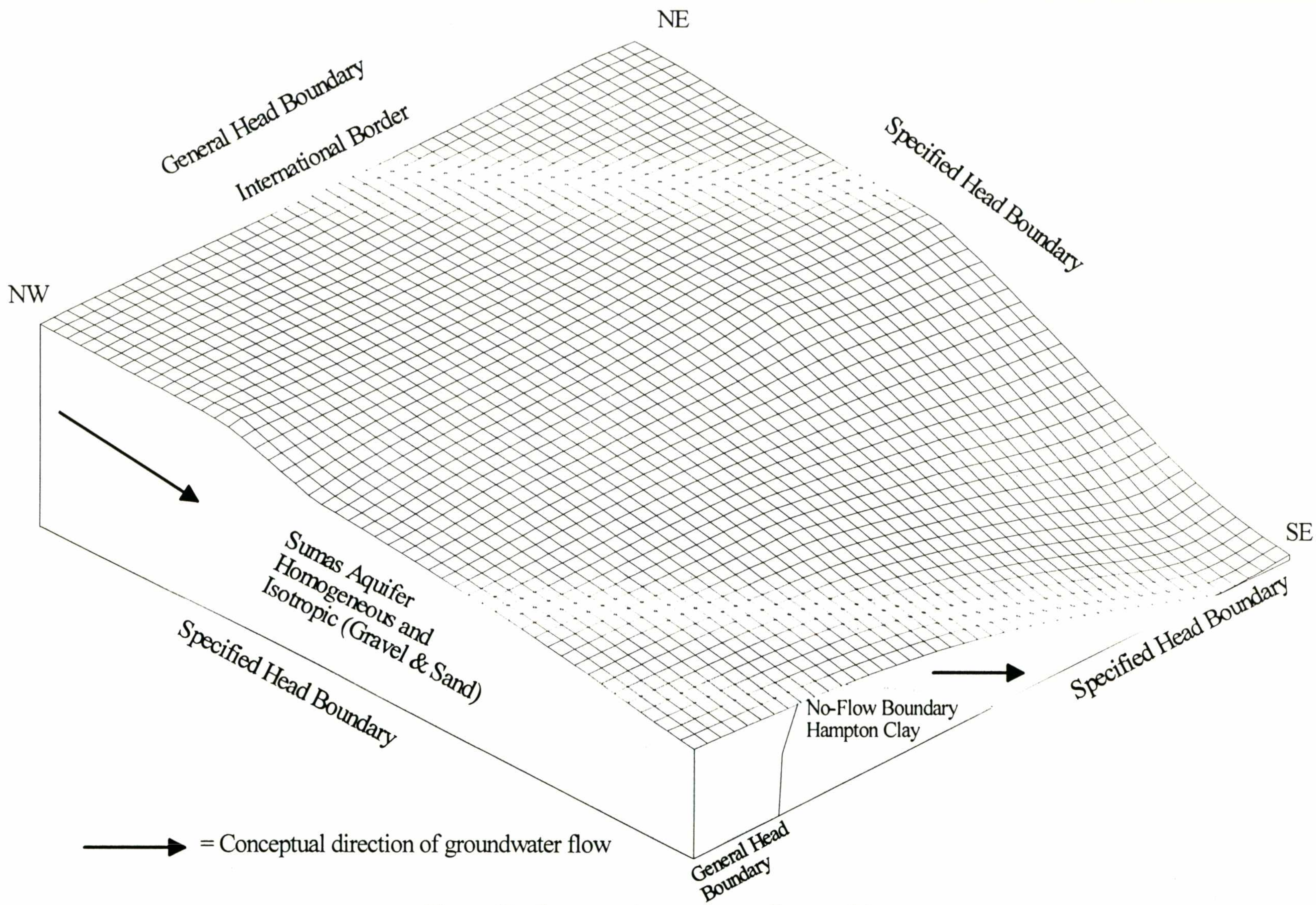


Figure 12. Conceptual groundwater flow model

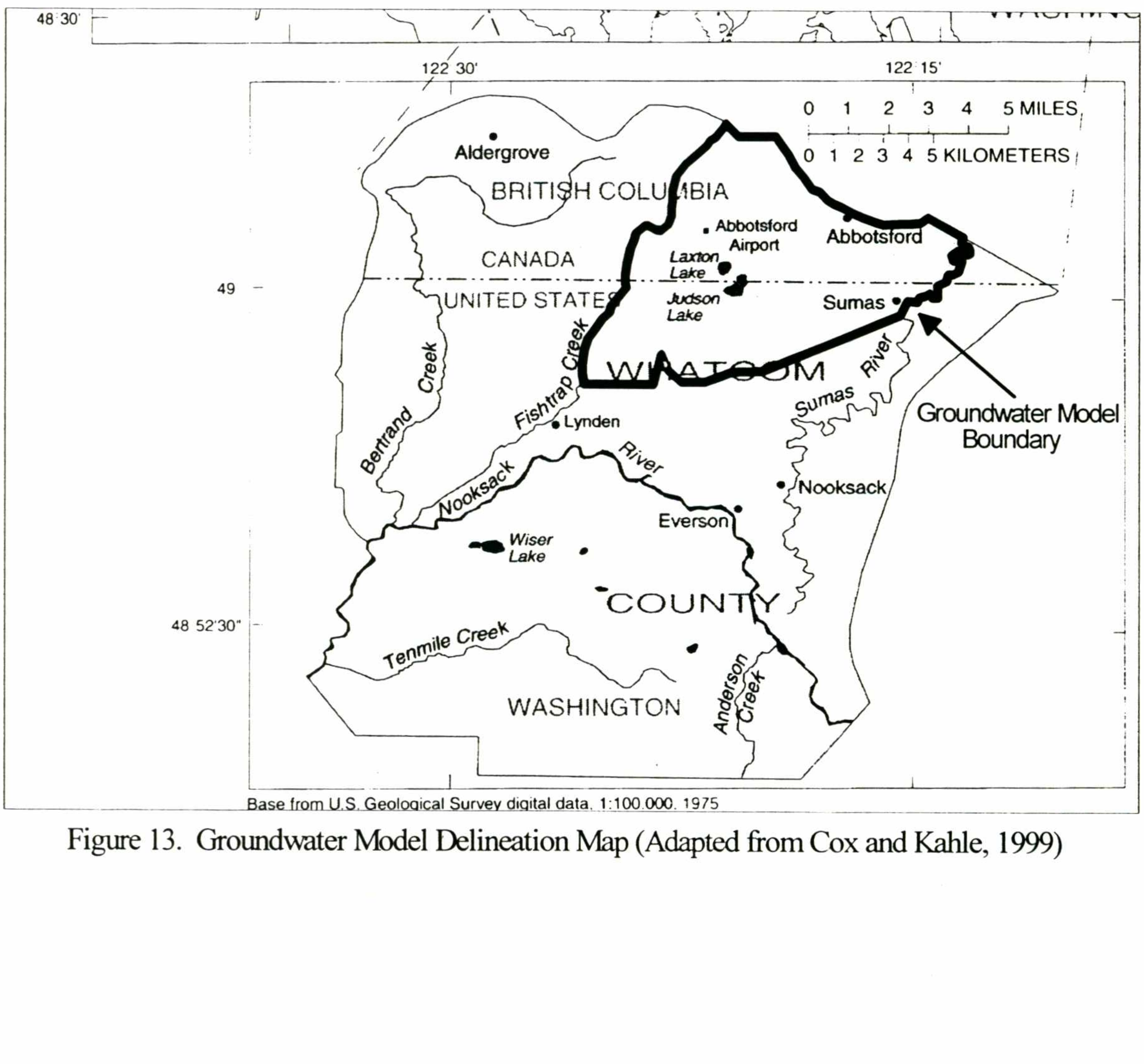


Figure 13. Groundwater Model Delineation Map (Adapted from Cox and Kahle, 1999)

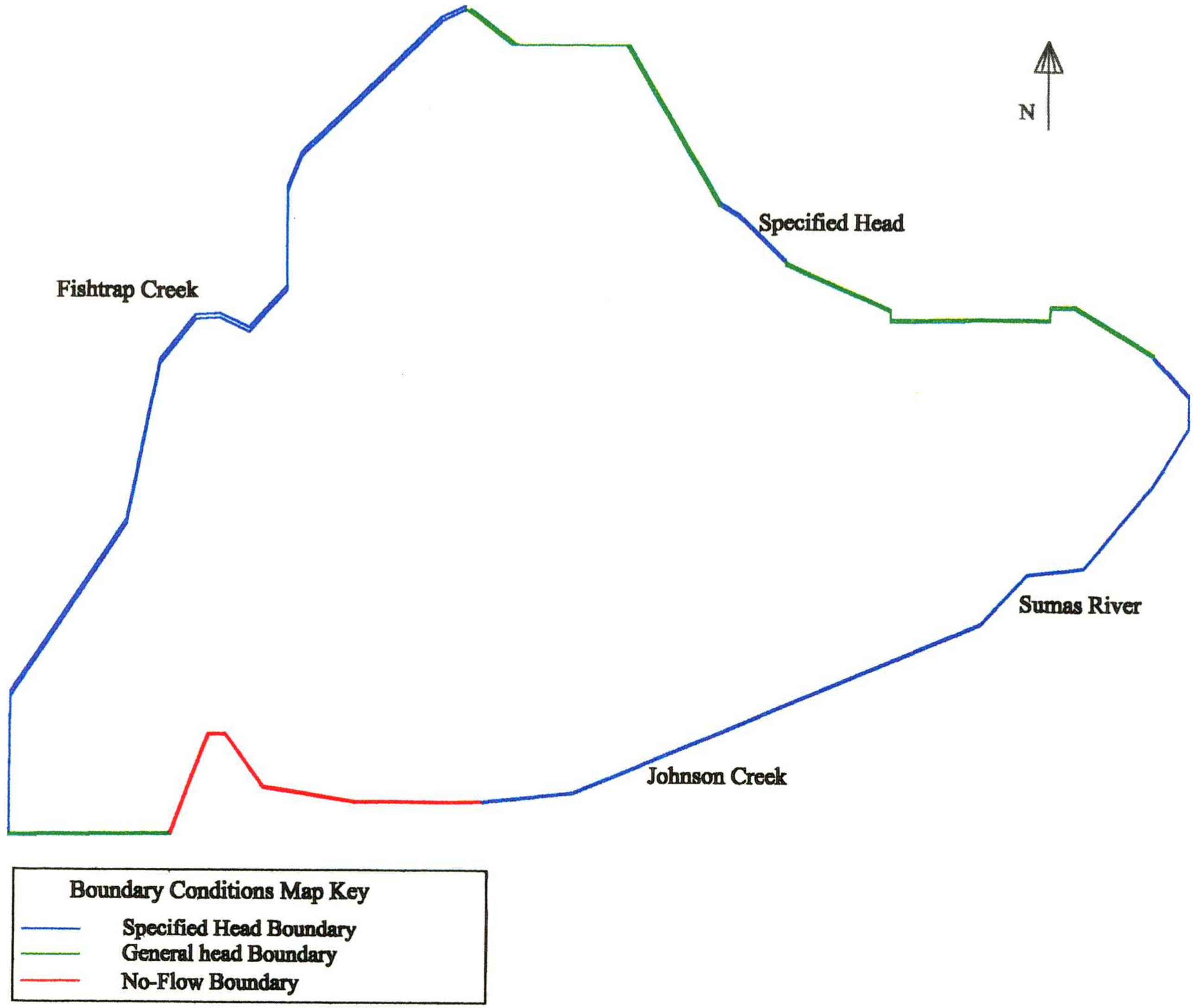


Figure 14. Groundwater Model Boundary Conditions Map

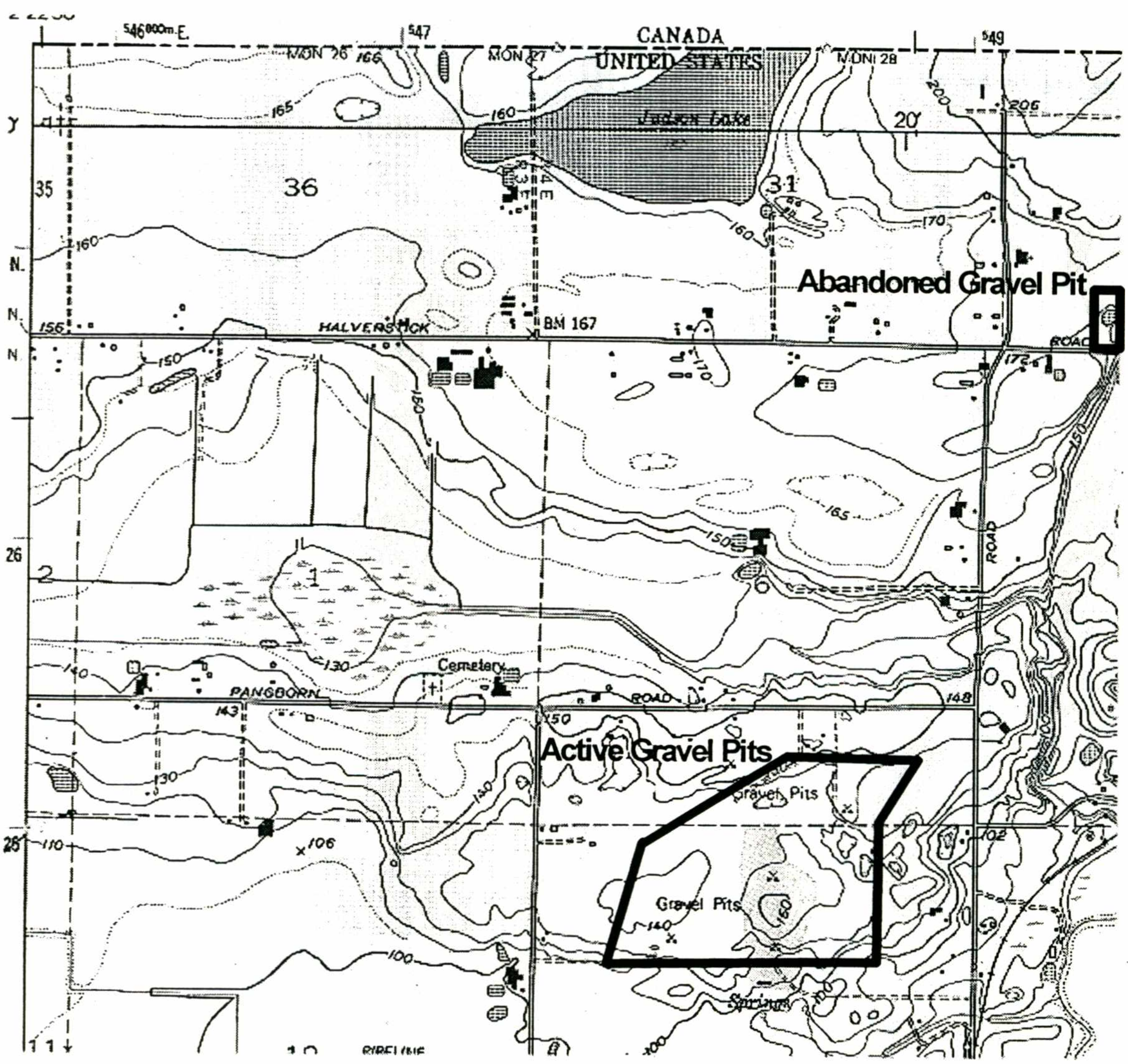


Figure 15. Gravel Pit Locations within the Study Area

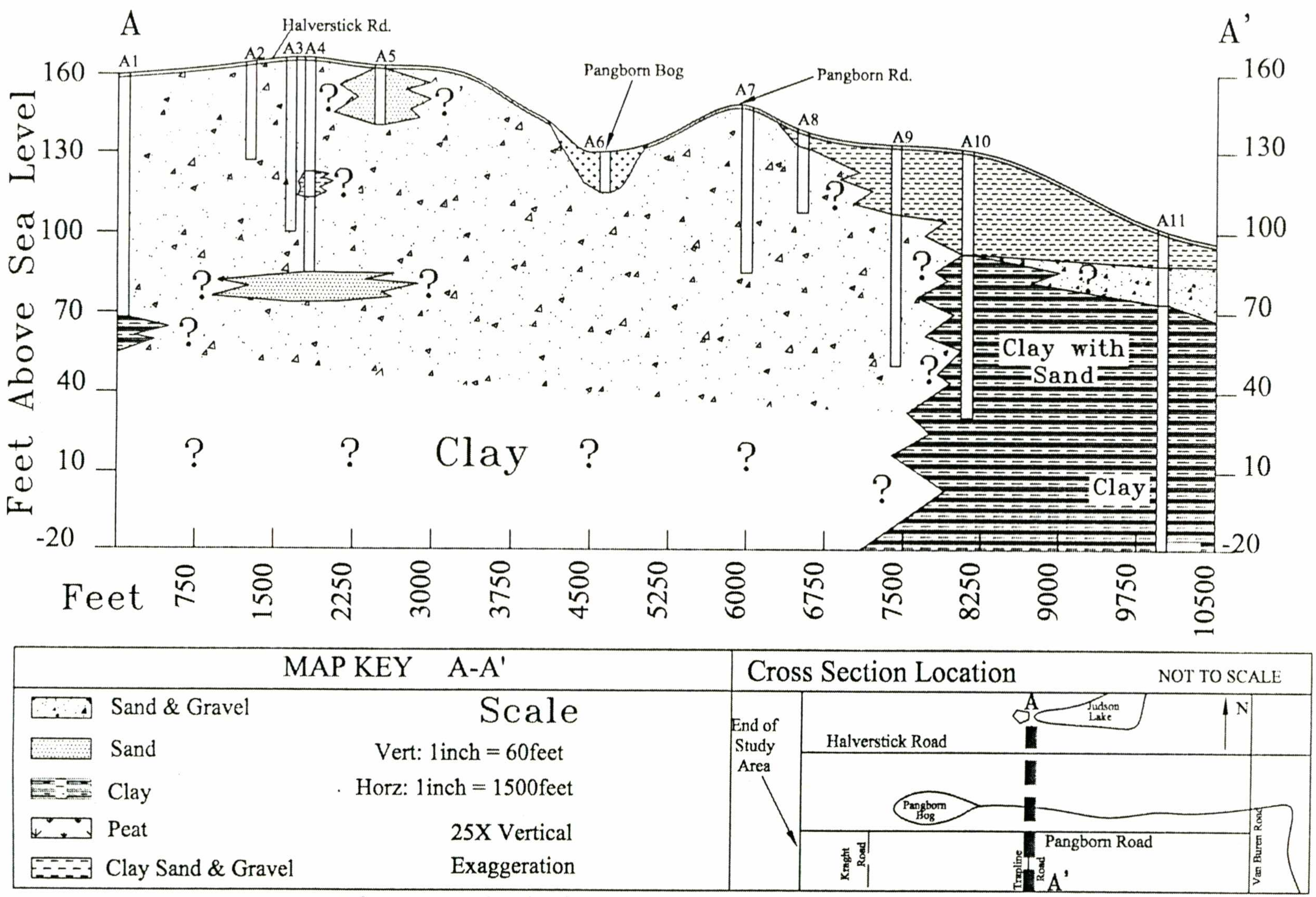


Figure 16. Geologic Cross Section A - A'

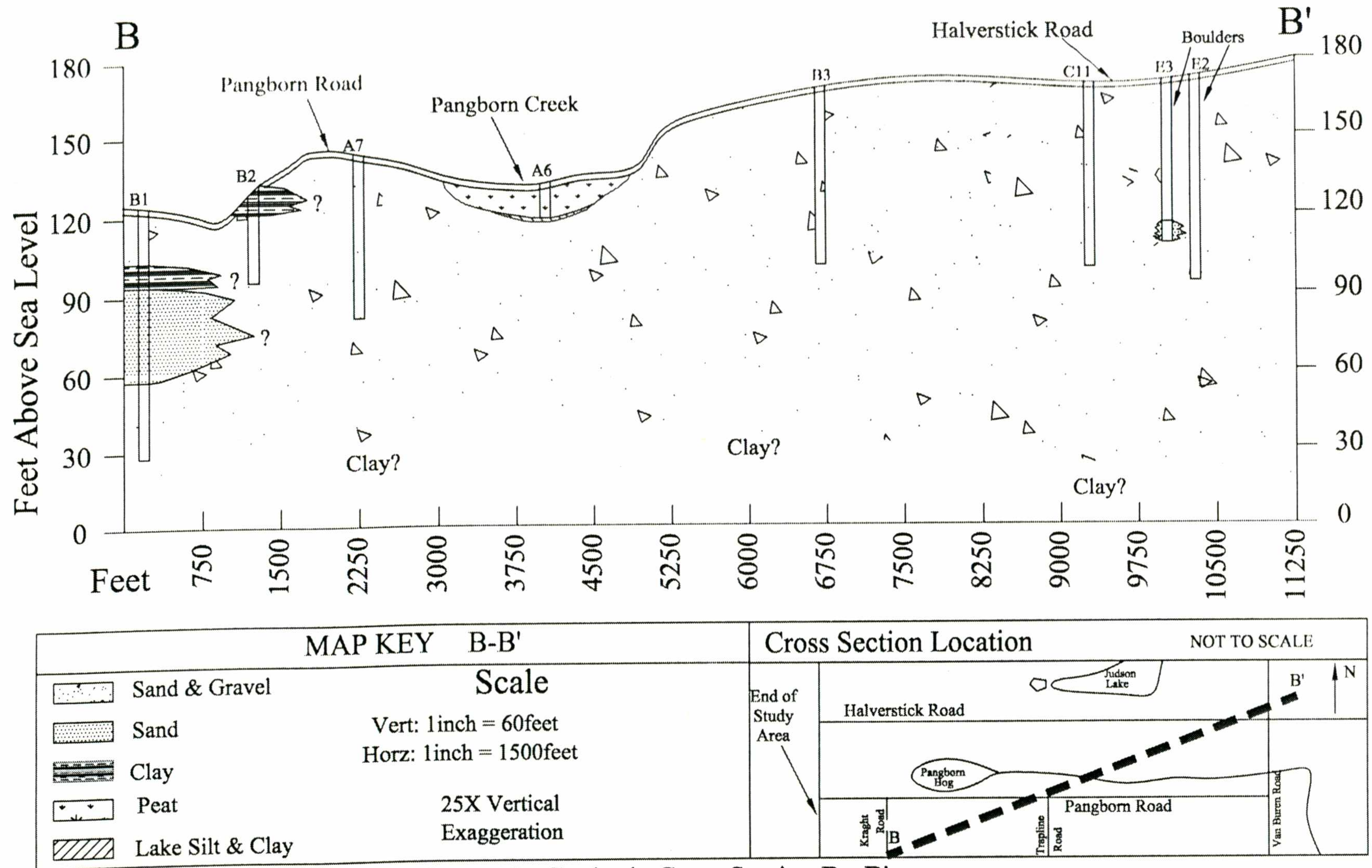


Figure 17. Geologic Cross Section B - B'

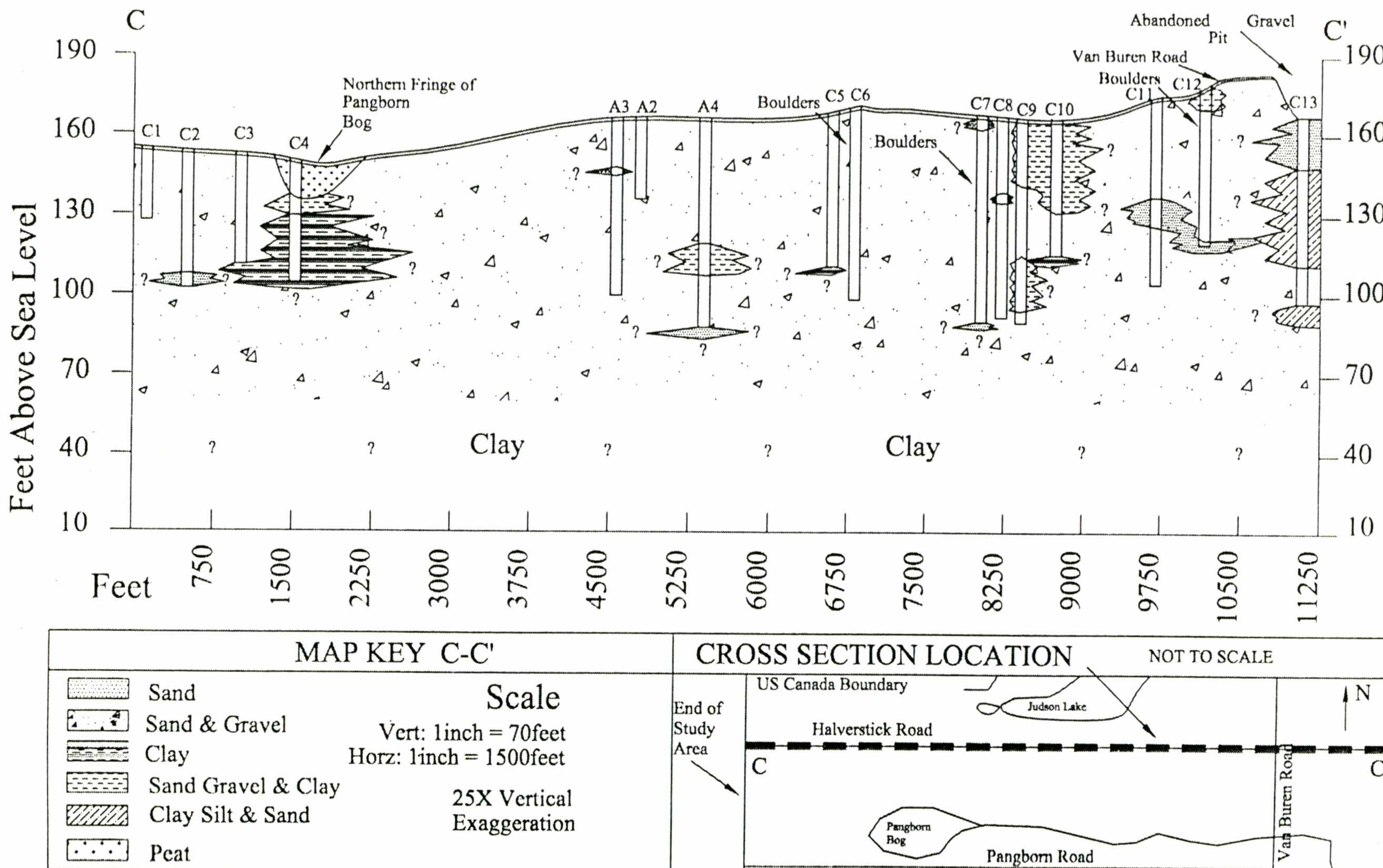


Figure 18. Geologic Cross Secction C - C'

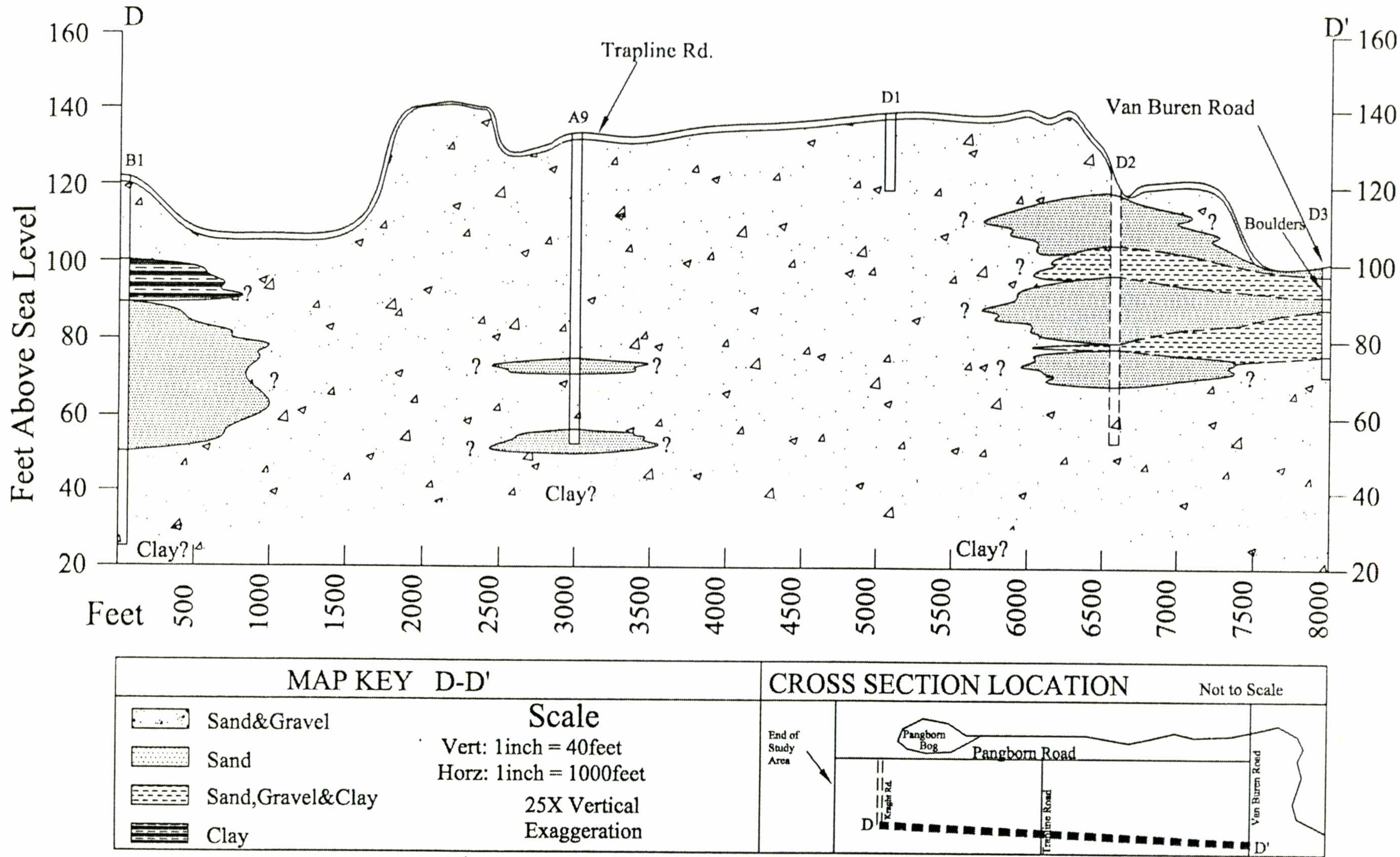


Figure 19. Geologic Cross Section D - D'

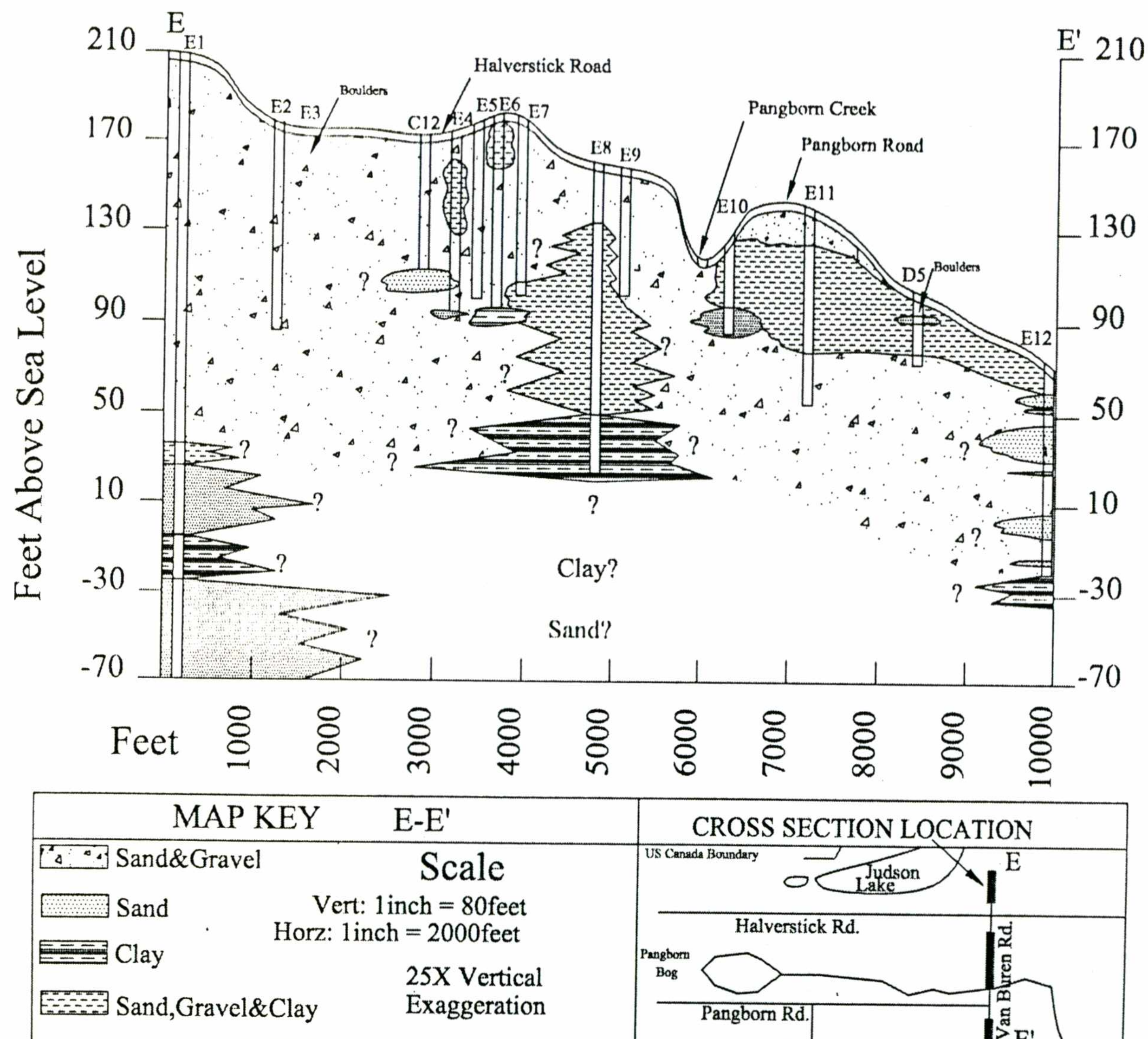


Figure 20. Geologic Cross Section E-E'

Figure 21. Photo of Sumas Outwash from Gravel Pit.
Note arrow pointing to backpack for scale.

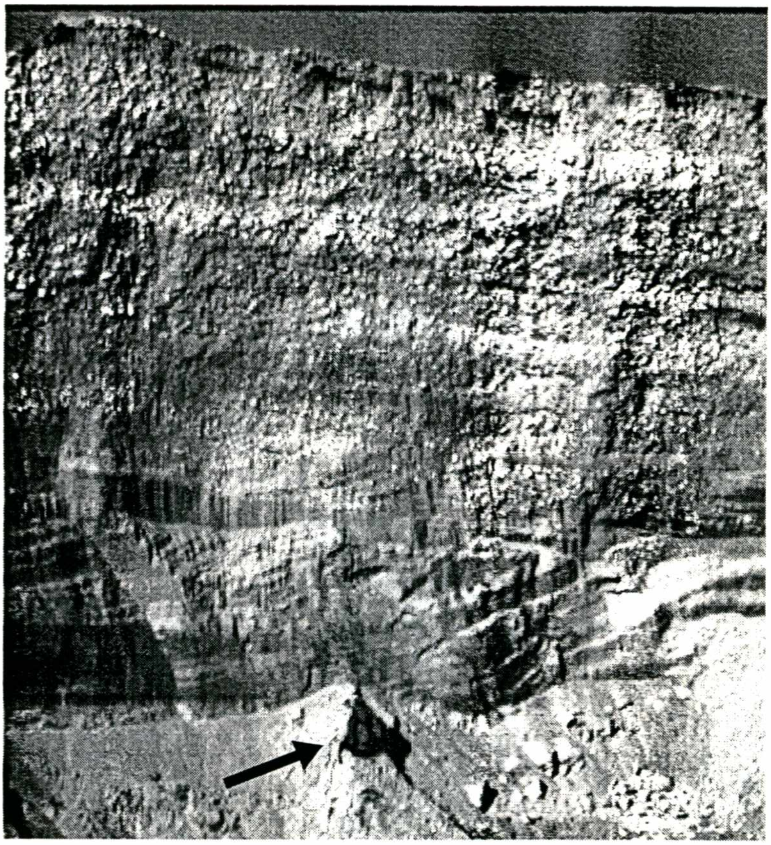
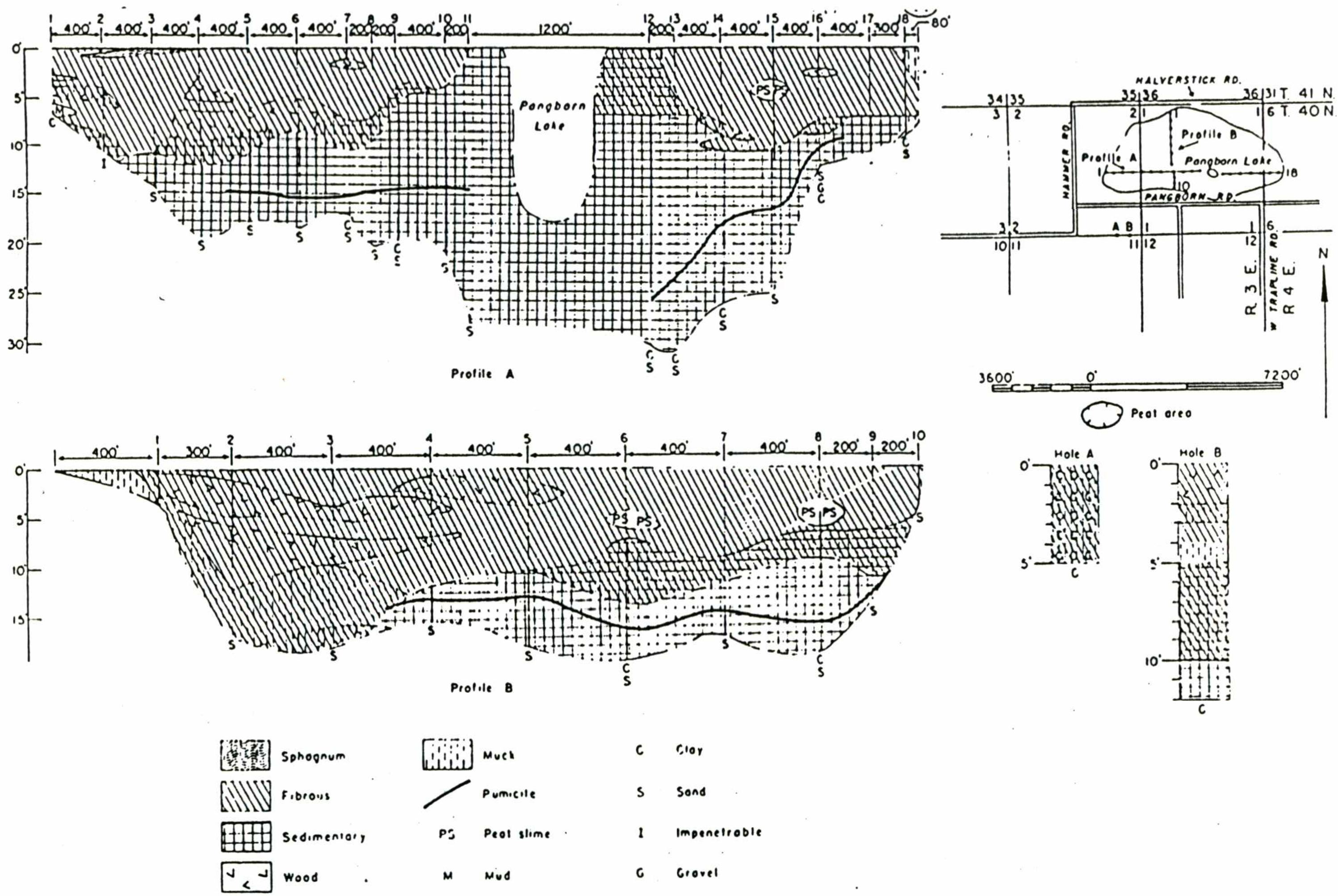


Figure 22. Photo of Sand Lens in Sumas Outwash.
Note arrow pointing to backpack for scale.



(Adapted from Riggs, 1948)

Figure 23. Pangborn Bog Core Samples and Cross Sections

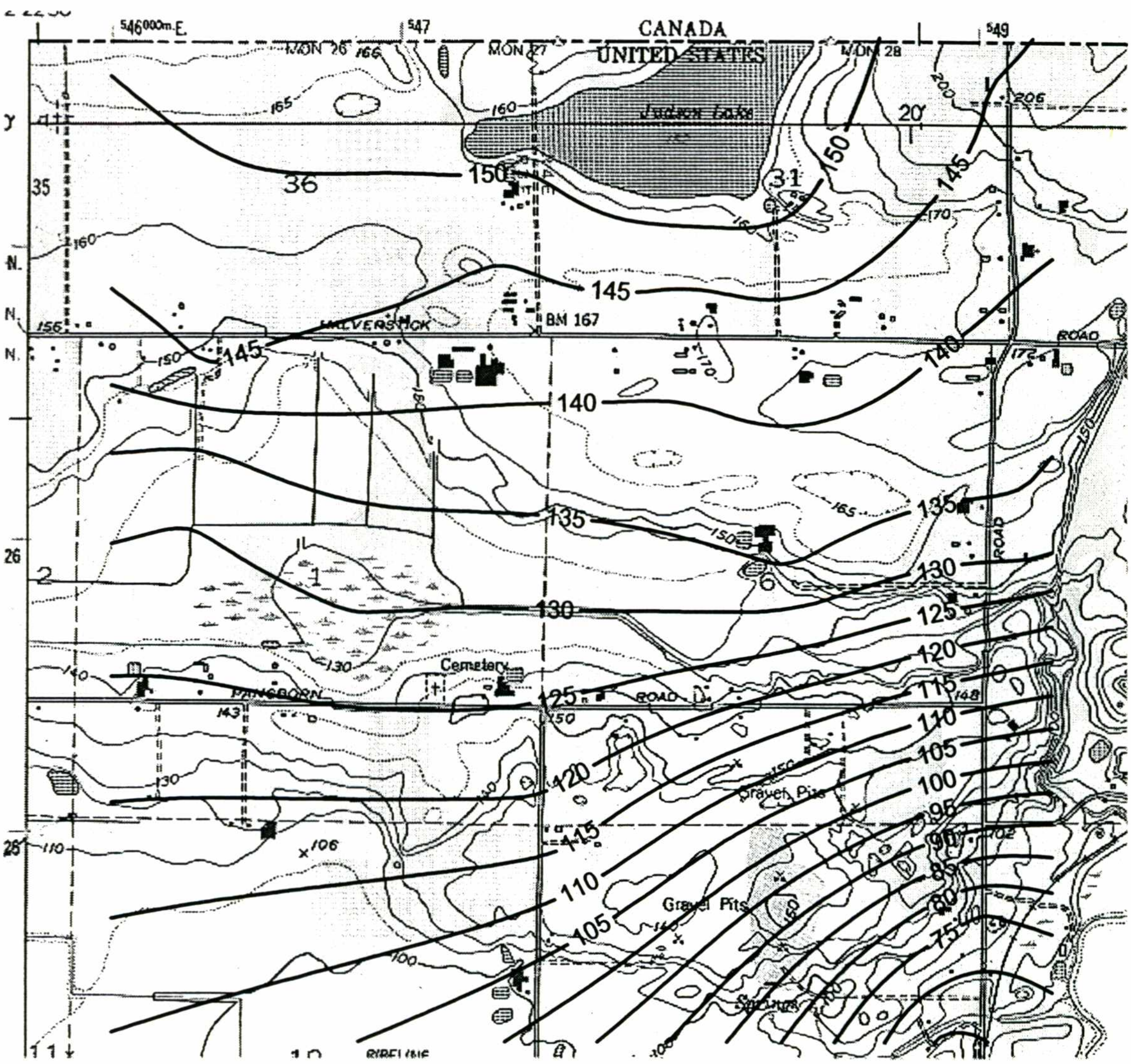


Figure 24. Water Table Contour Map Spring 1997 (feet ASL)

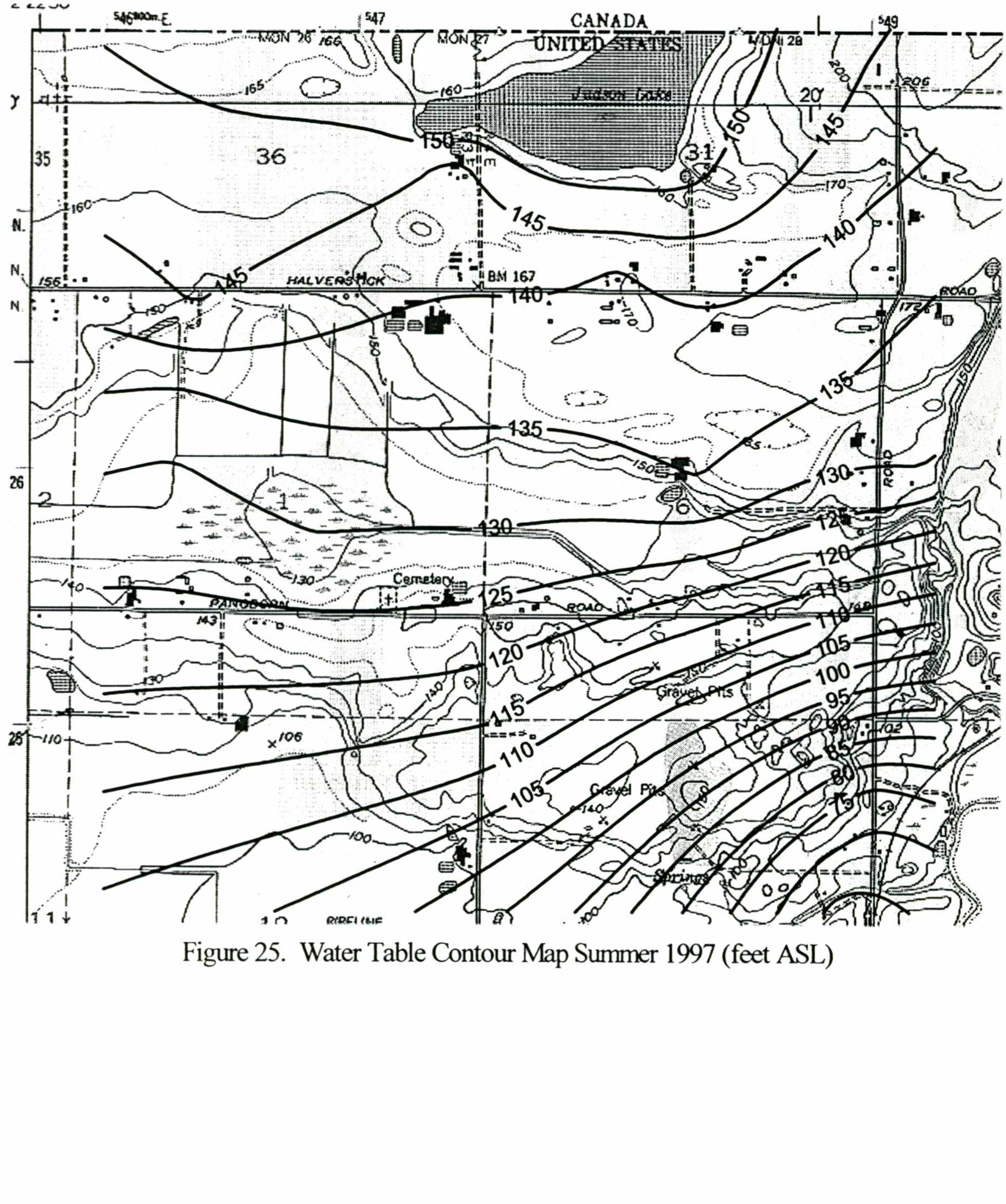


Figure 25. Water Table Contour Map Summer 1997 (feet ASL)

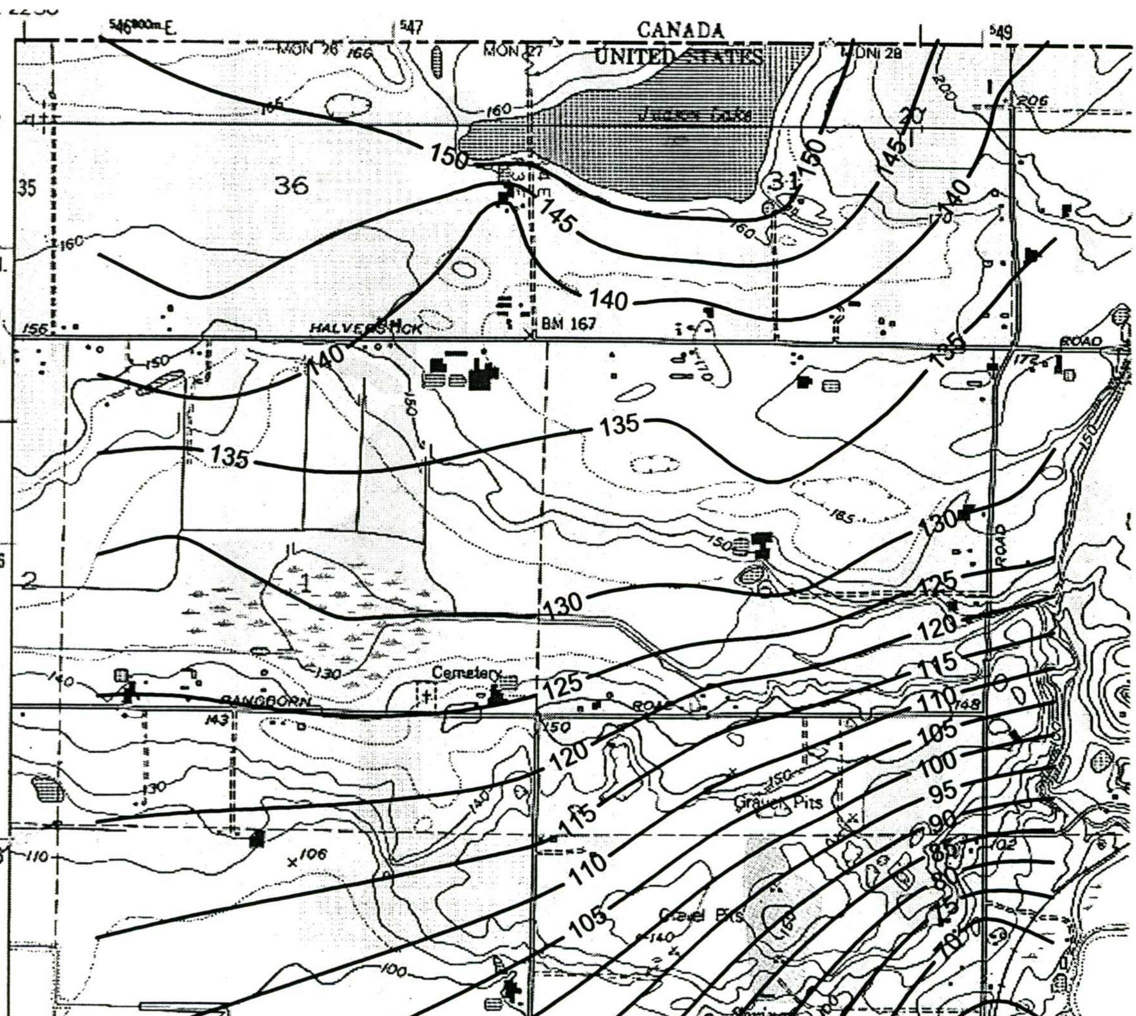


Figure 26. Water Table Contour Map Fall 1997 (feet ASL)

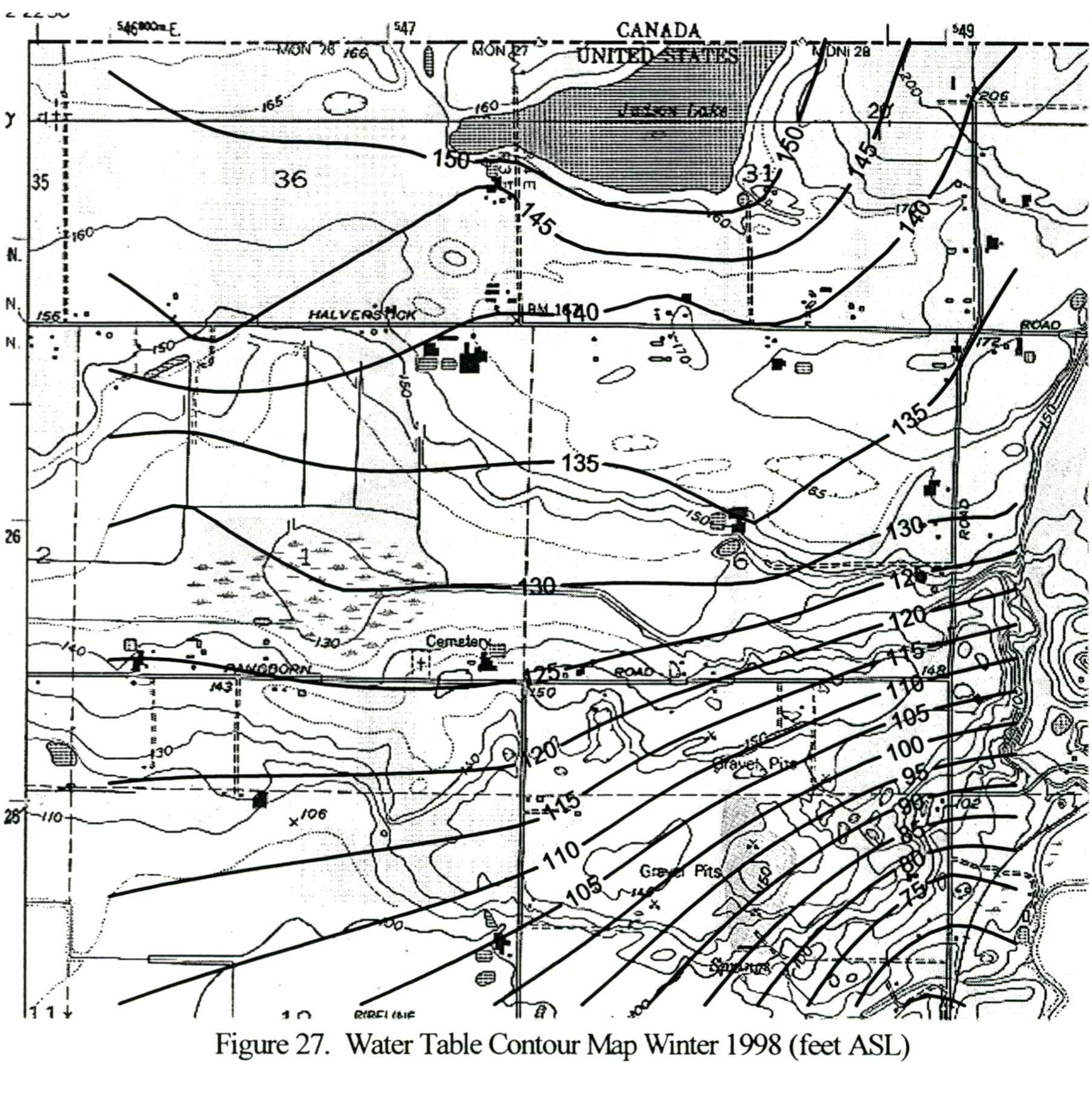


Figure 27. Water Table Contour Map Winter 1998 (feet ASL)

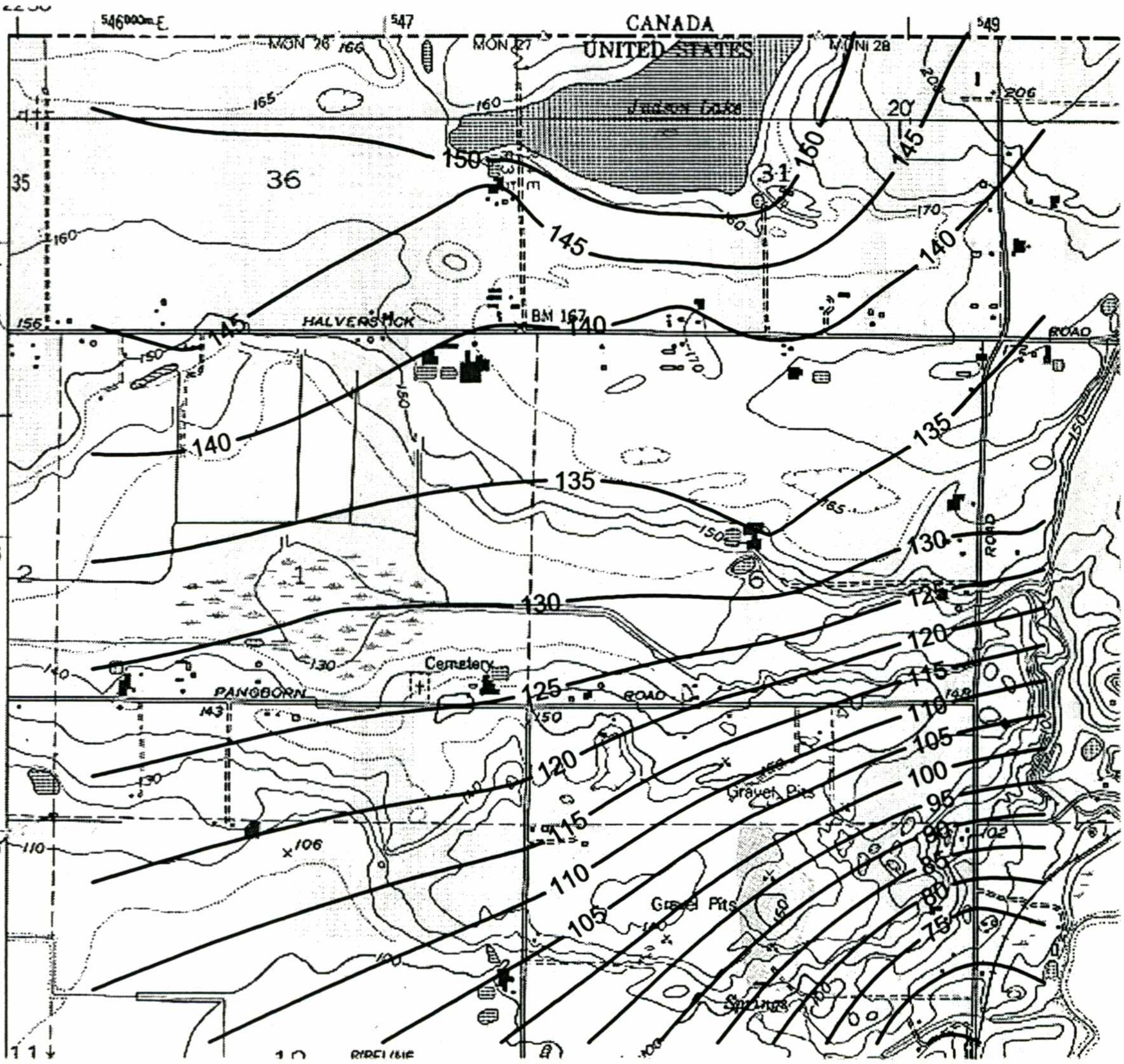


Figure 28. Water Table Contour Map Spring 1998 (feet ASL)

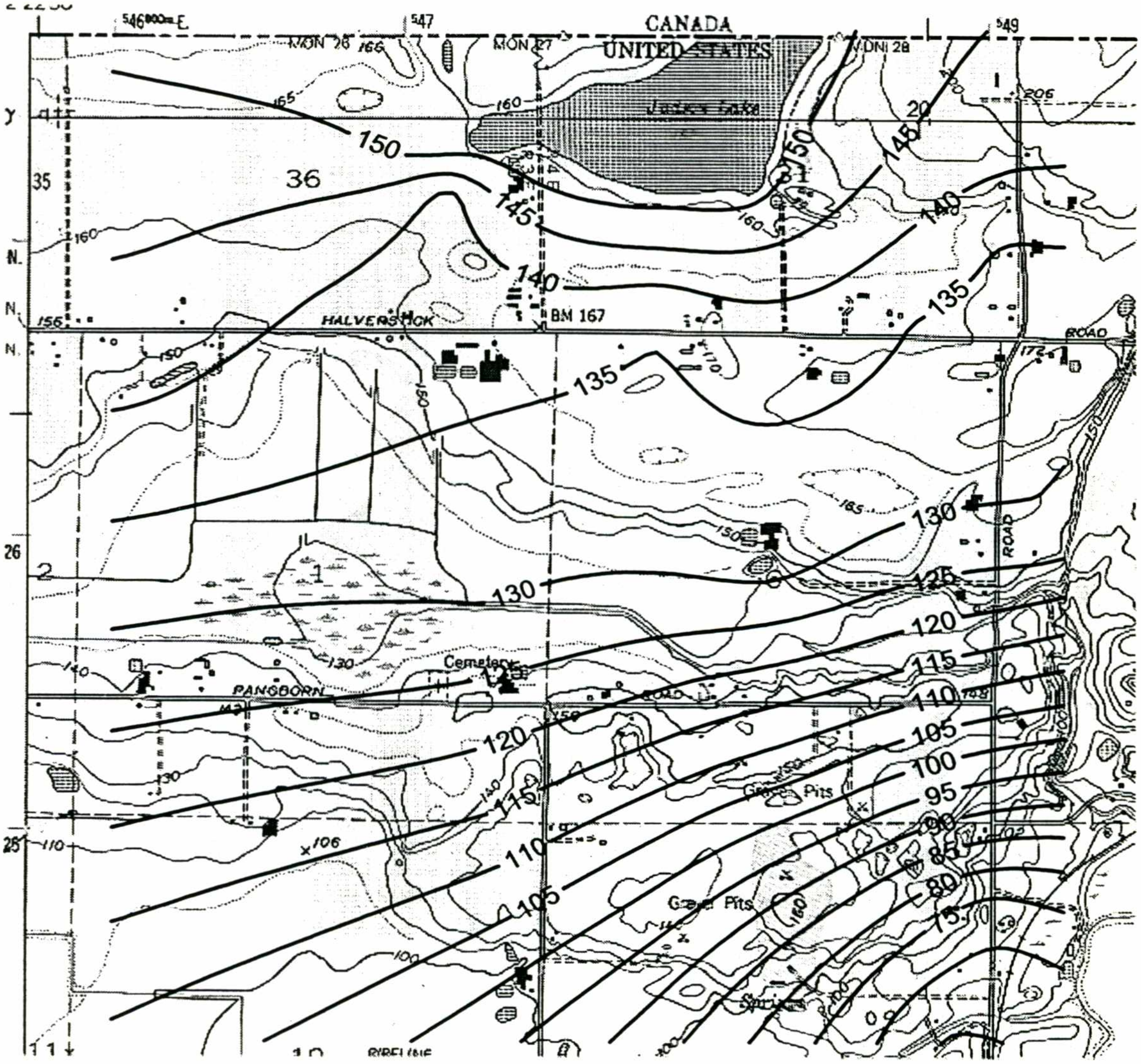


Figure 29. Water Table Contour Map Summer 1998 (feet ASL)

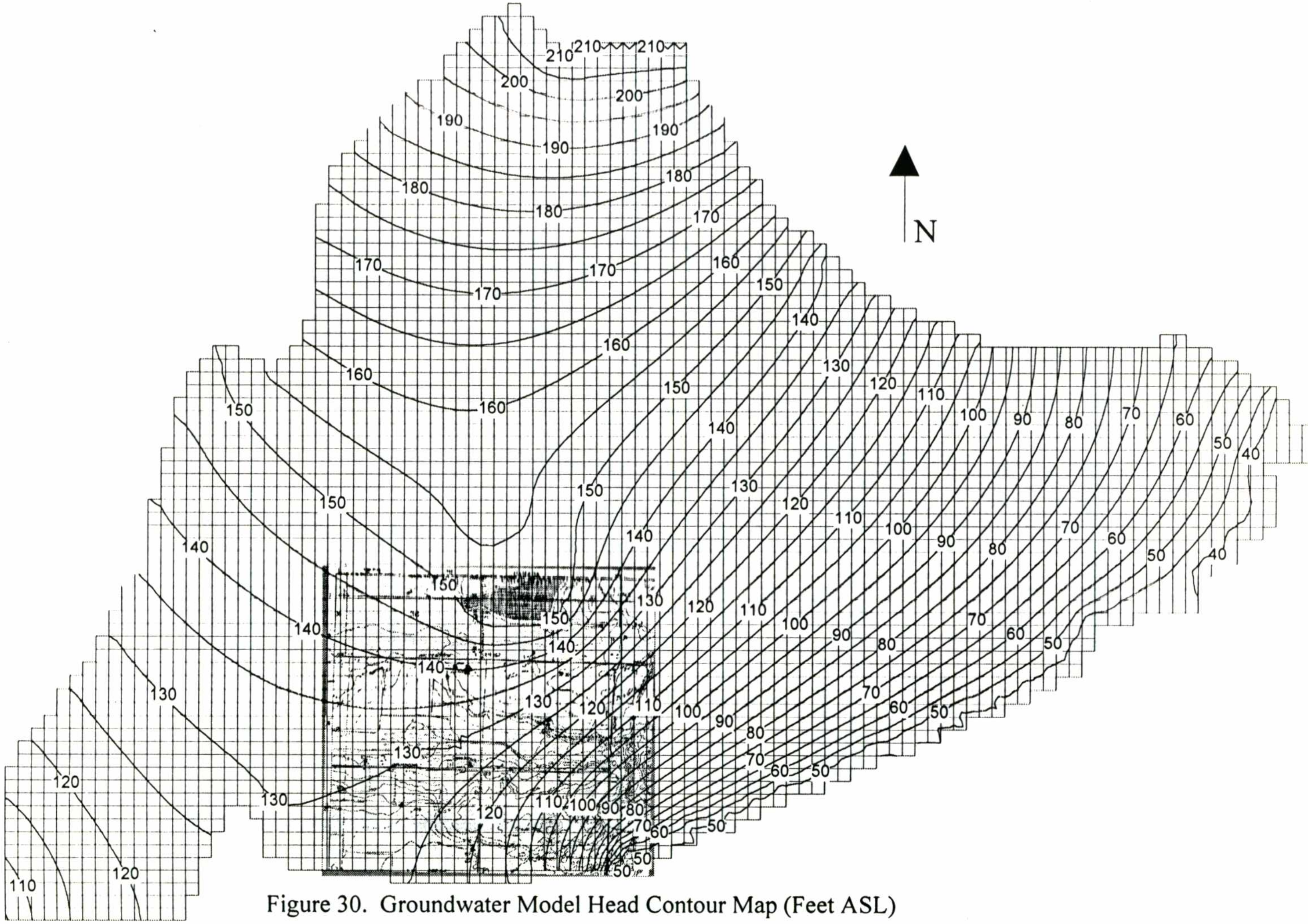


Figure 30. Groundwater Model Head Contour Map (Feet ASL)

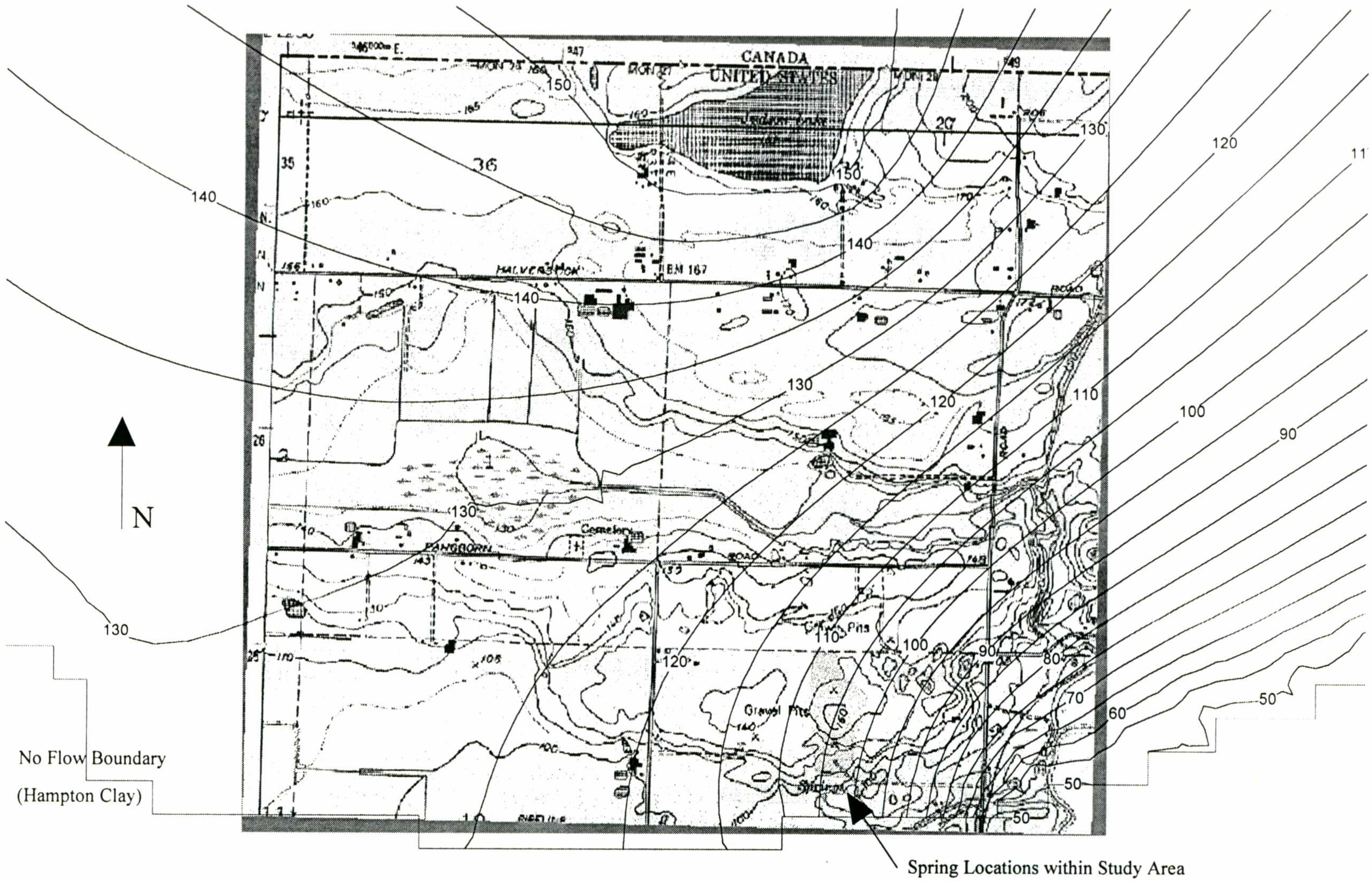


Figure 31. Groundwater Model Head Contour Map of Study Area (feet ASL)

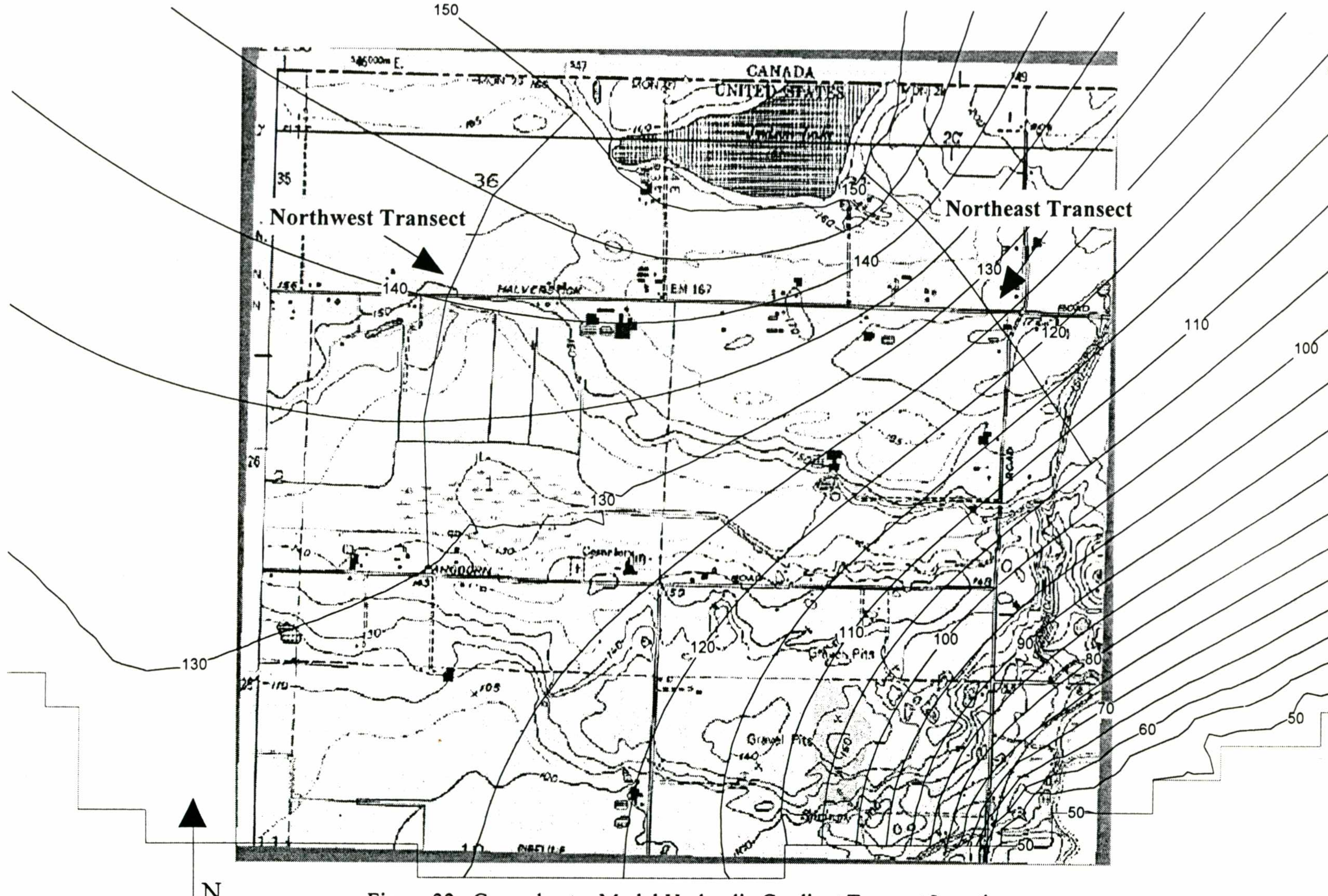


Figure 32. Groundwater Model Hydraulic Gradient Transect Location

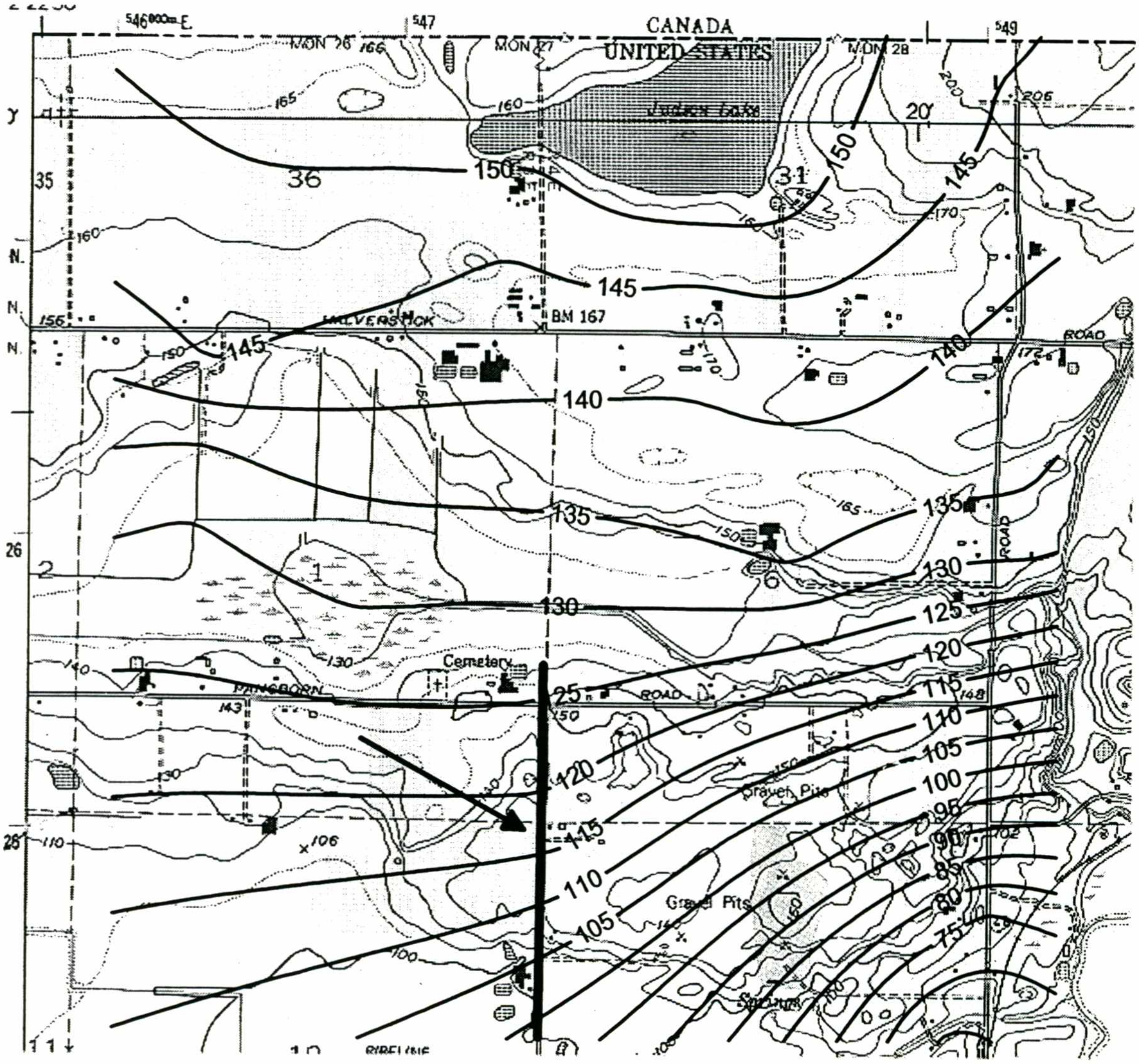


Figure 33. Break in Slope of Seasonal Water Table Contours

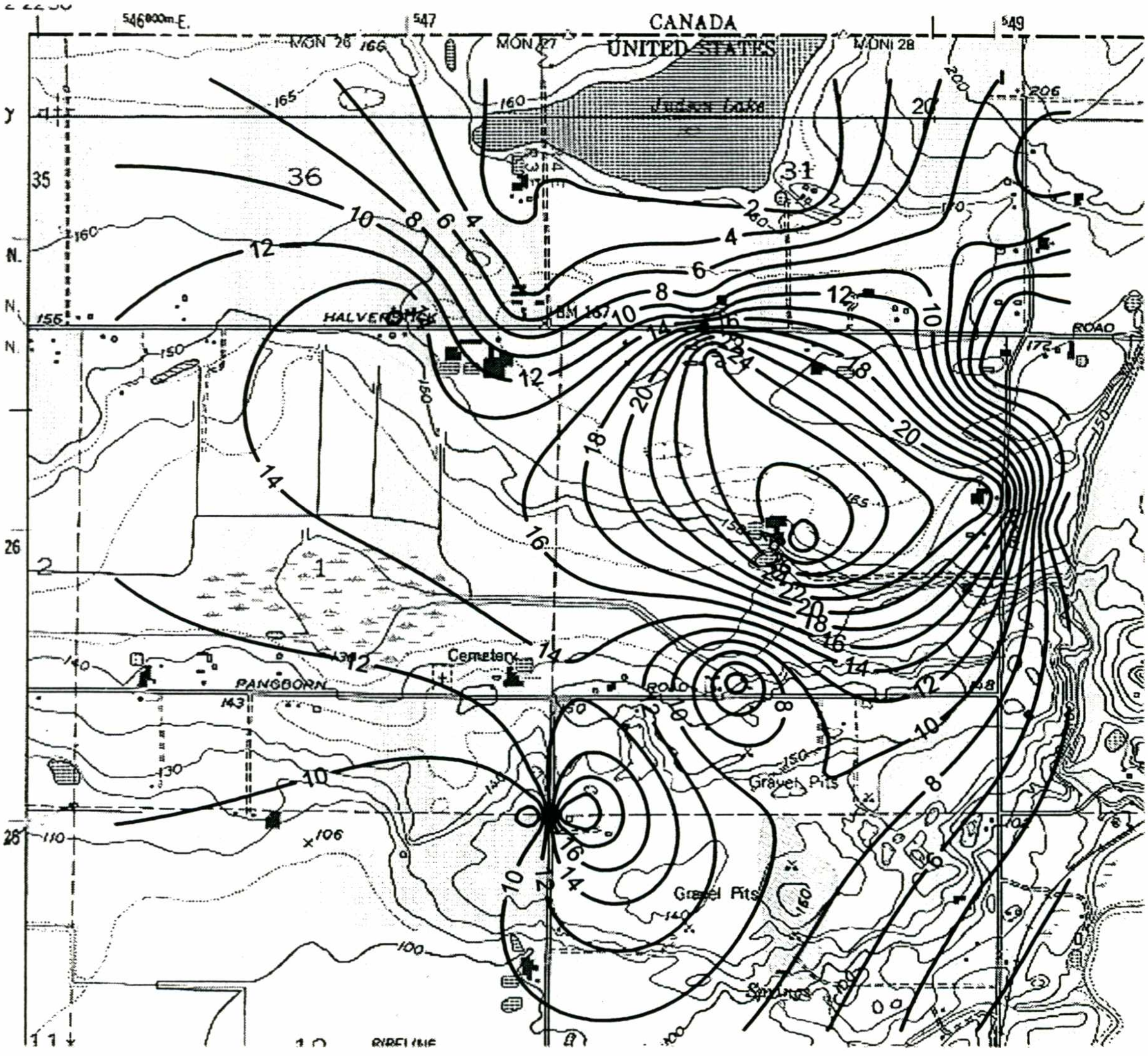


Figure 34. Two-Dimensional Nitrate Contours Spring 1997
Concentrations = mg/L

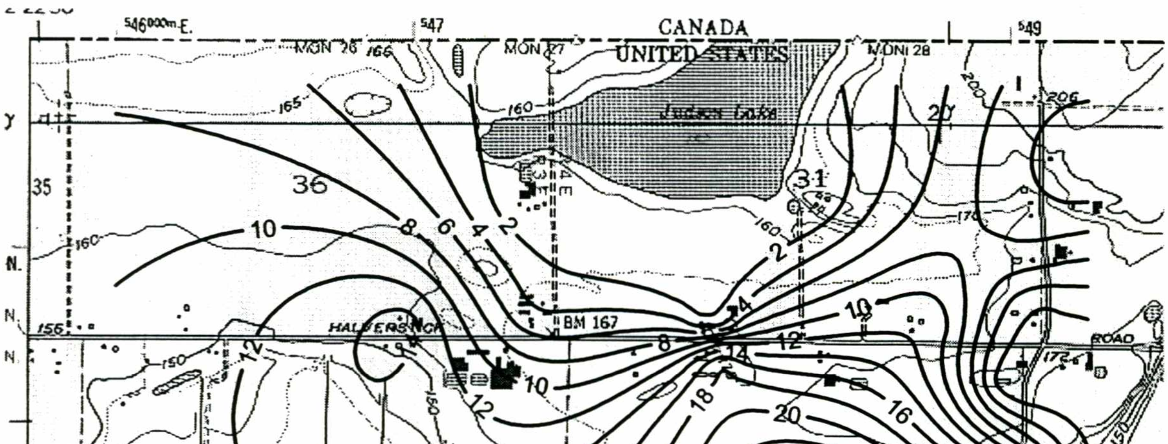


Figure 35. Two-Dimensional Nitrate Contours Summer 1997
Concentrations = mg/L

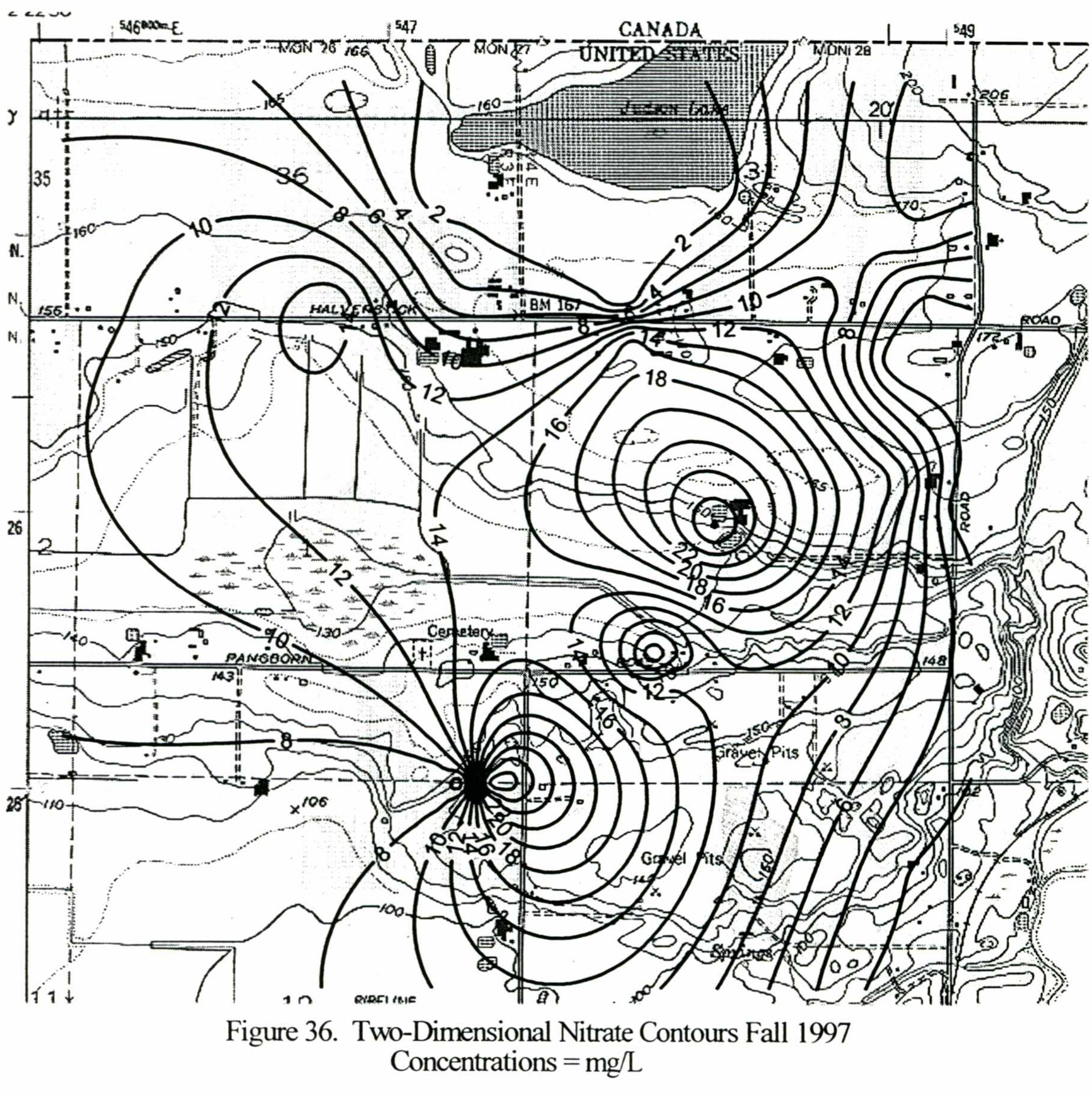


Figure 36. Two-Dimensional Nitrate Contours Fall 1997
Concentrations = mg/L

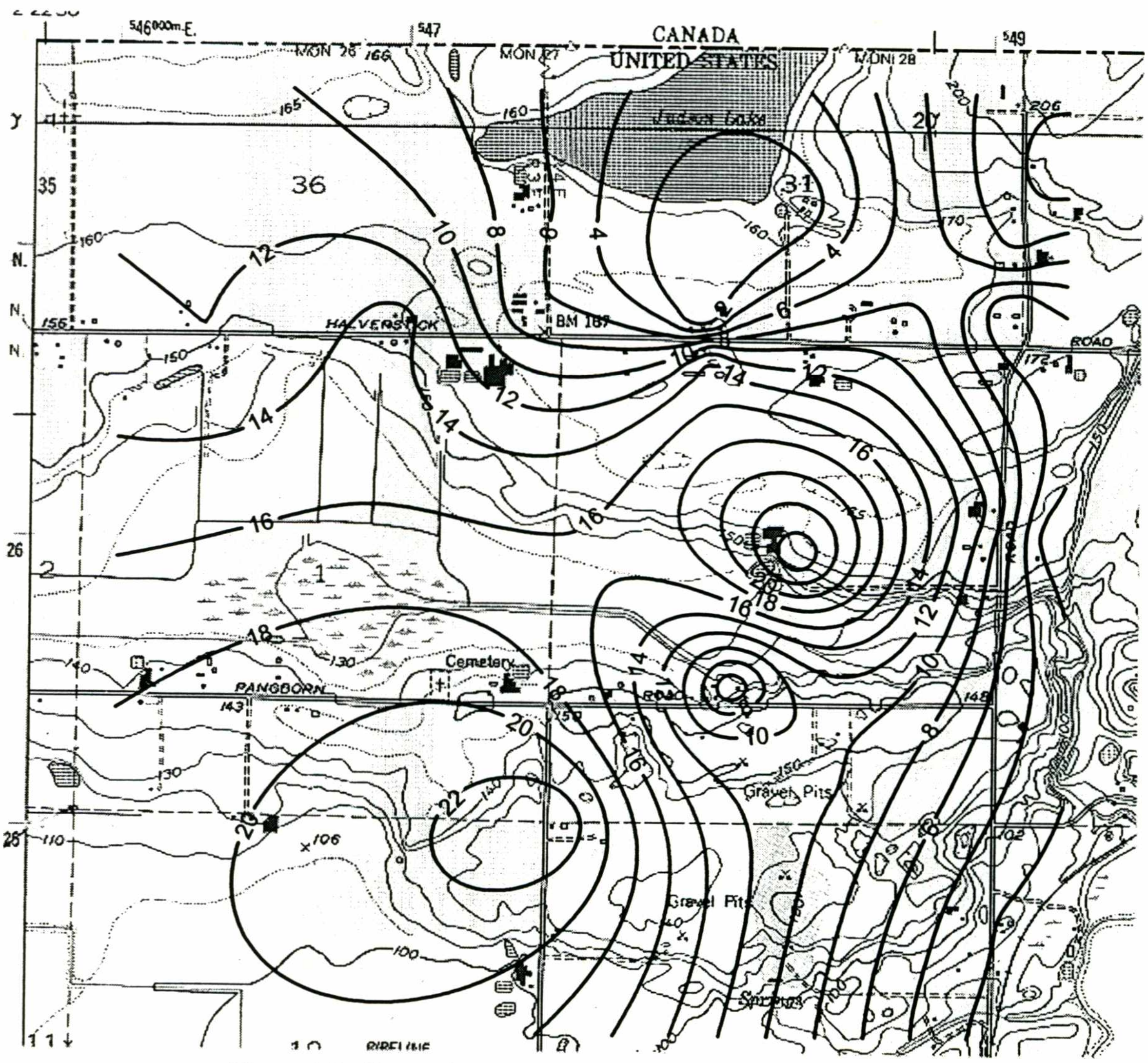


Figure 37. Two-Dimensional Nitrate Contours Winter 1998
Concentrations = mg/L

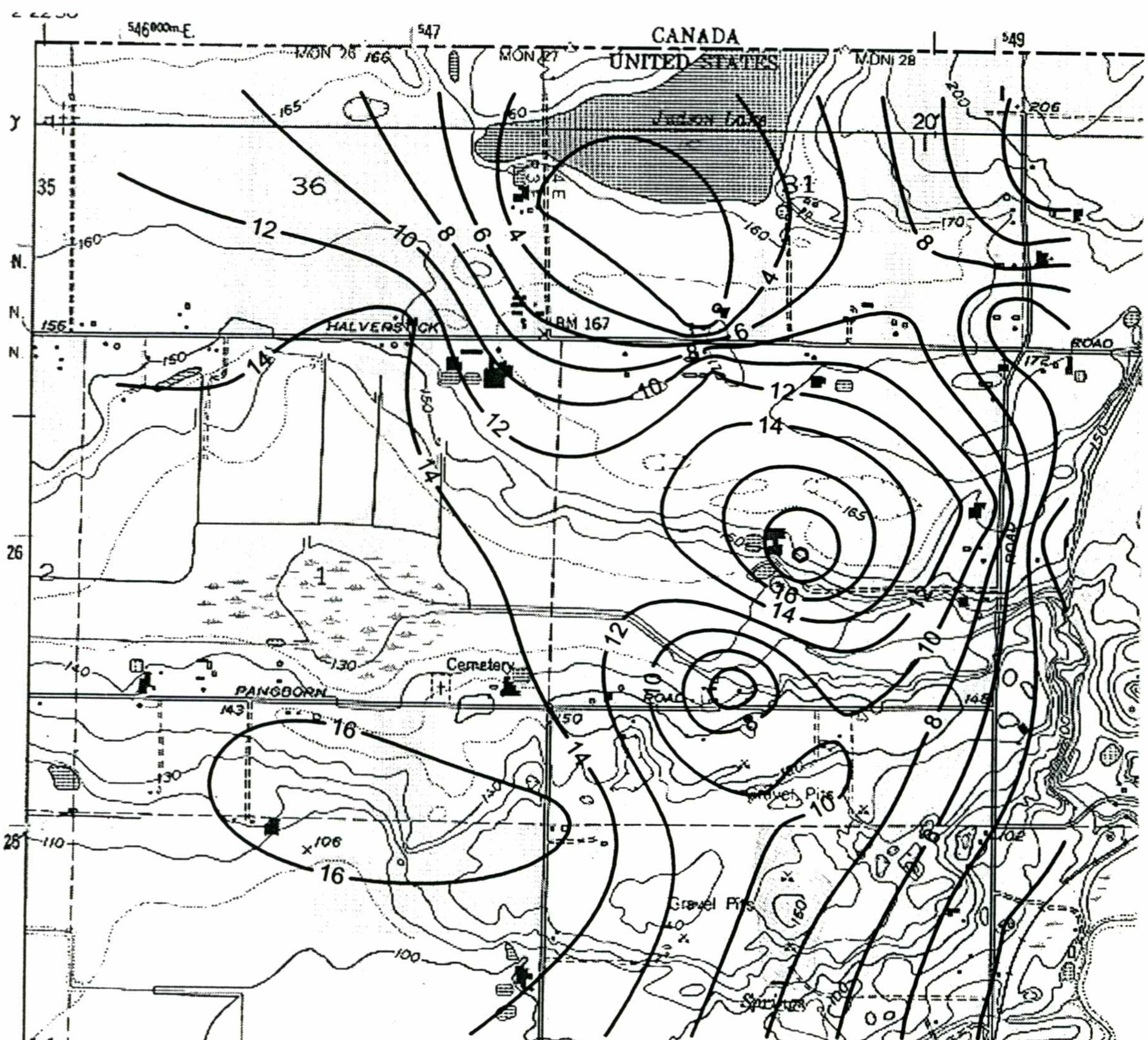


Figure 38. Two-Dimensional Nitrate Contours Spring 1998
Concentrations = mg/L

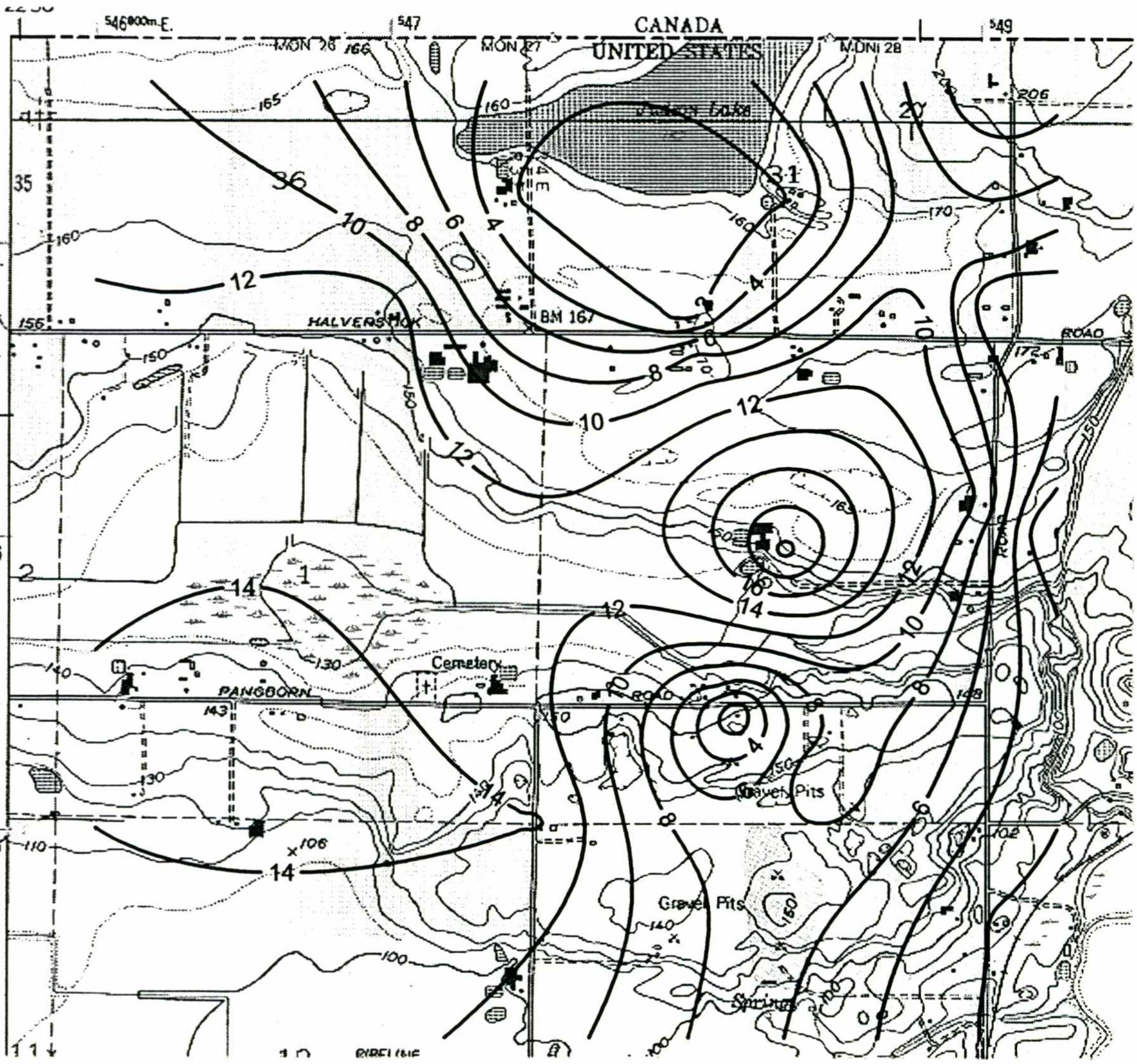


Figure 39. Two-Dimensional Nitrate Contours Summer 1998
Concentrations = mg/L

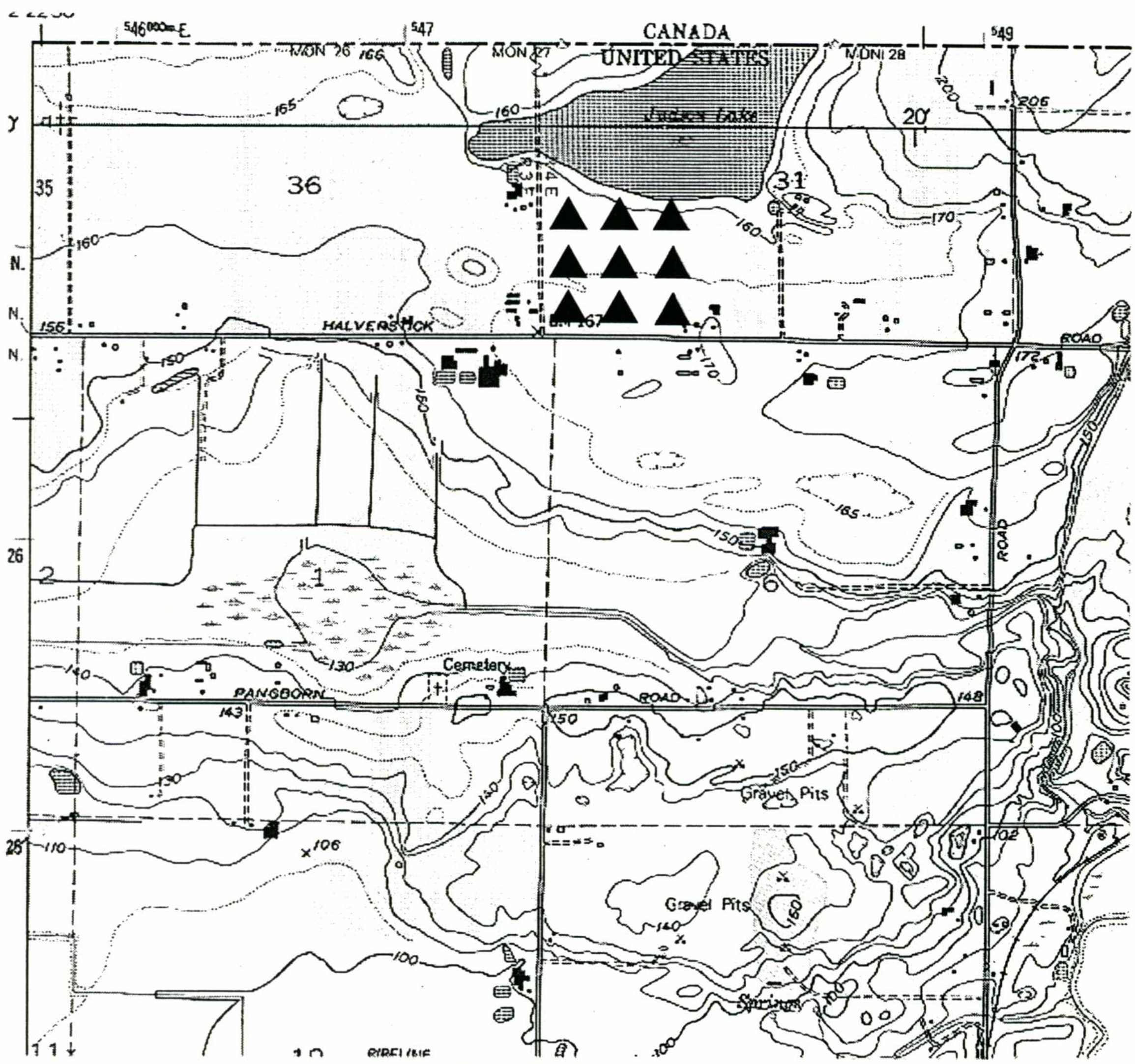


Figure 40. Scenario 1 - 50 mg/L Nitrate Spike Application Cells

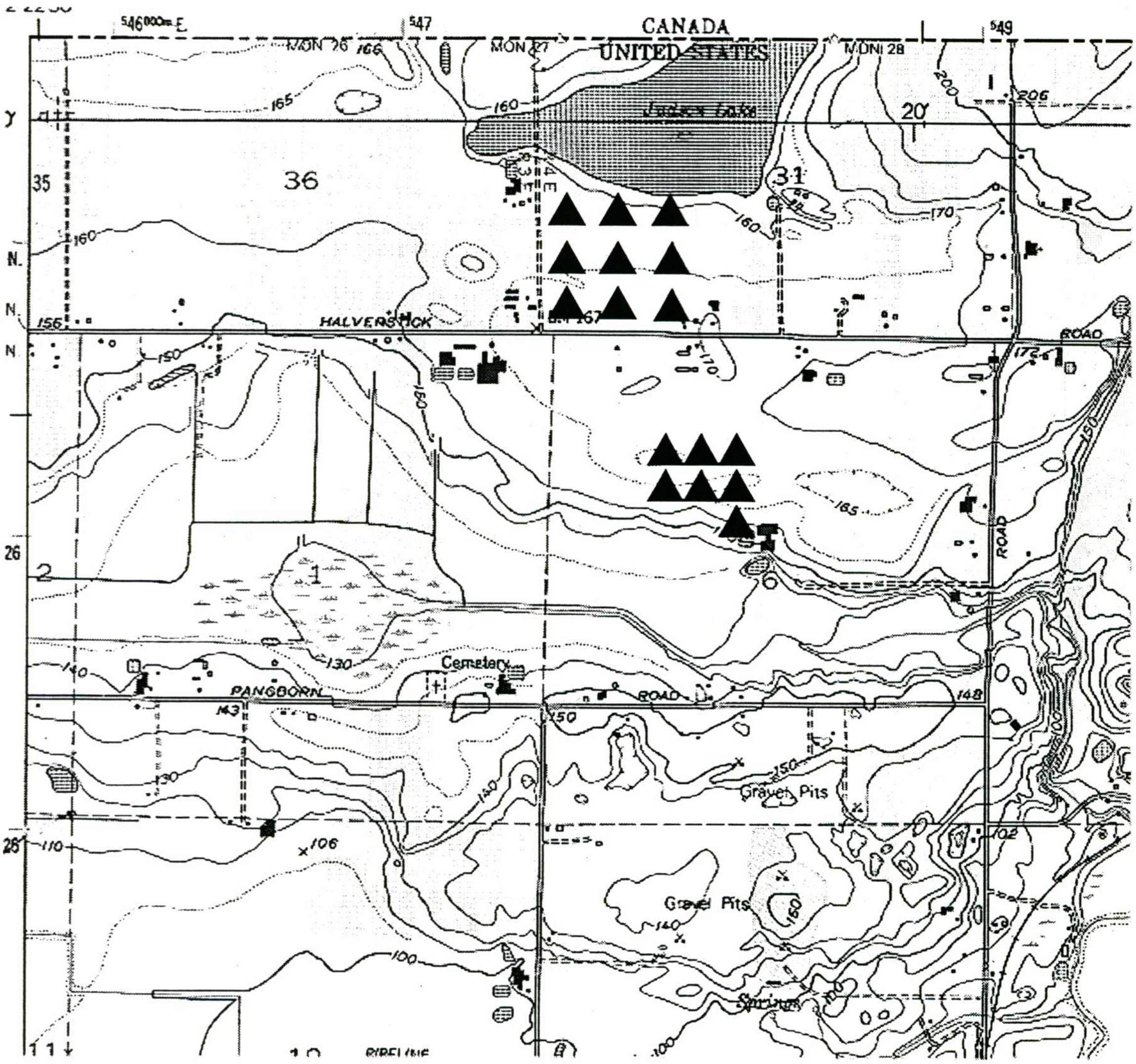


Figure 41. Scenario 2 - 50 mg/L Nitrate Spike Application Cells

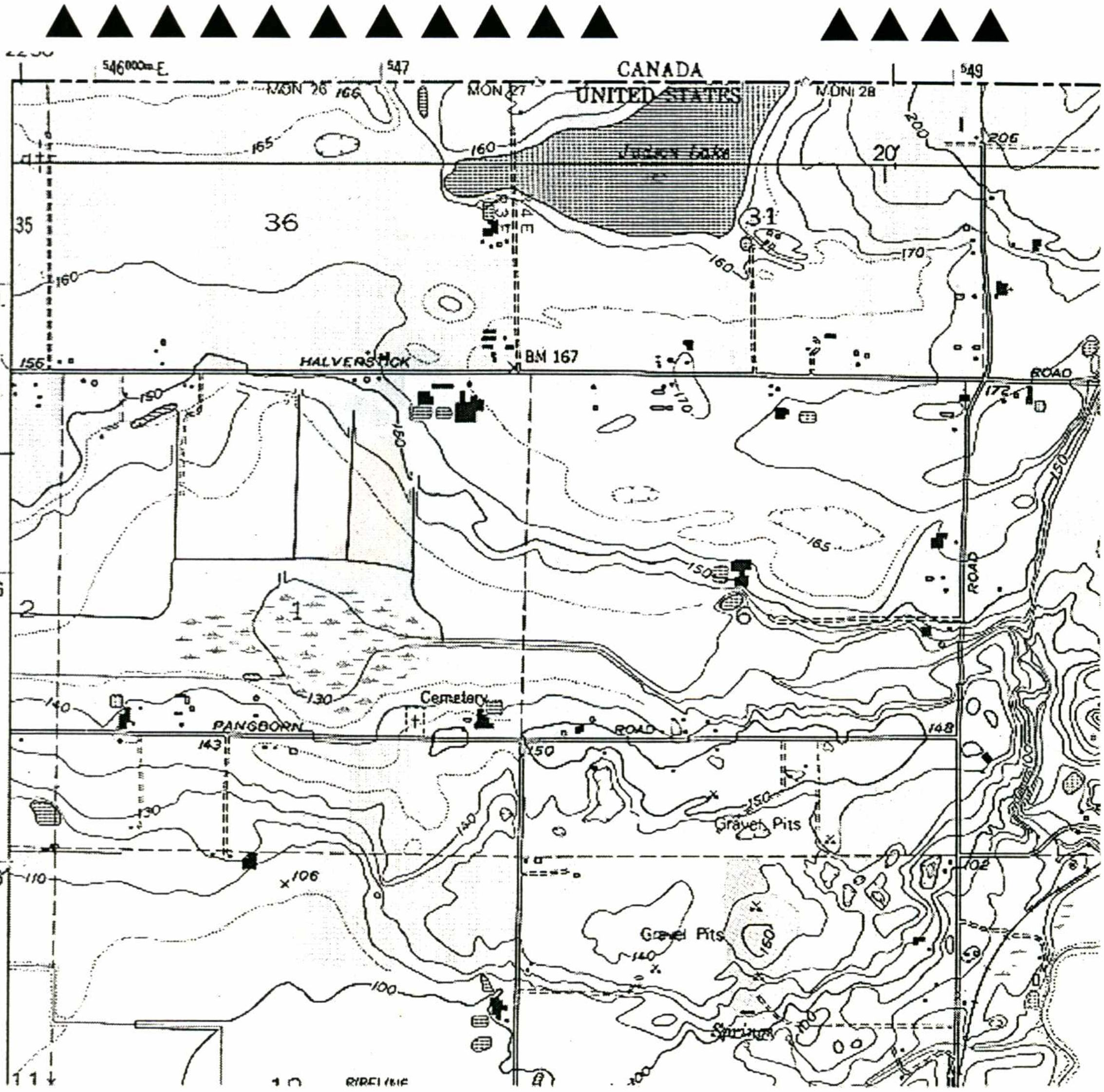


Figure 42. Scenario 3 - 50 mg/L Nitrate Spike Application Cells

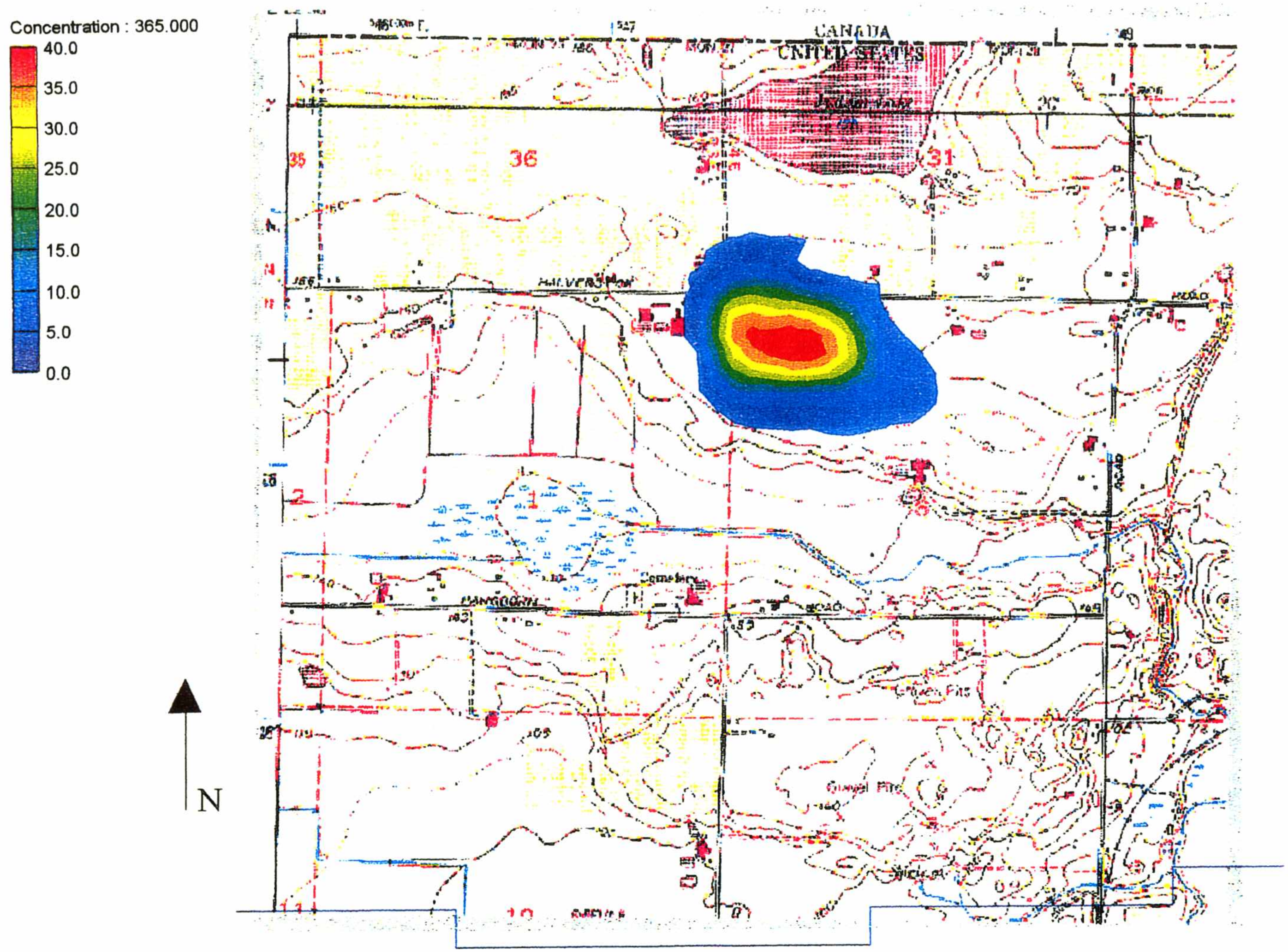


Figure 43. Scenario 1: 1 year nitrate contours (conductivity = 270 feet per day)

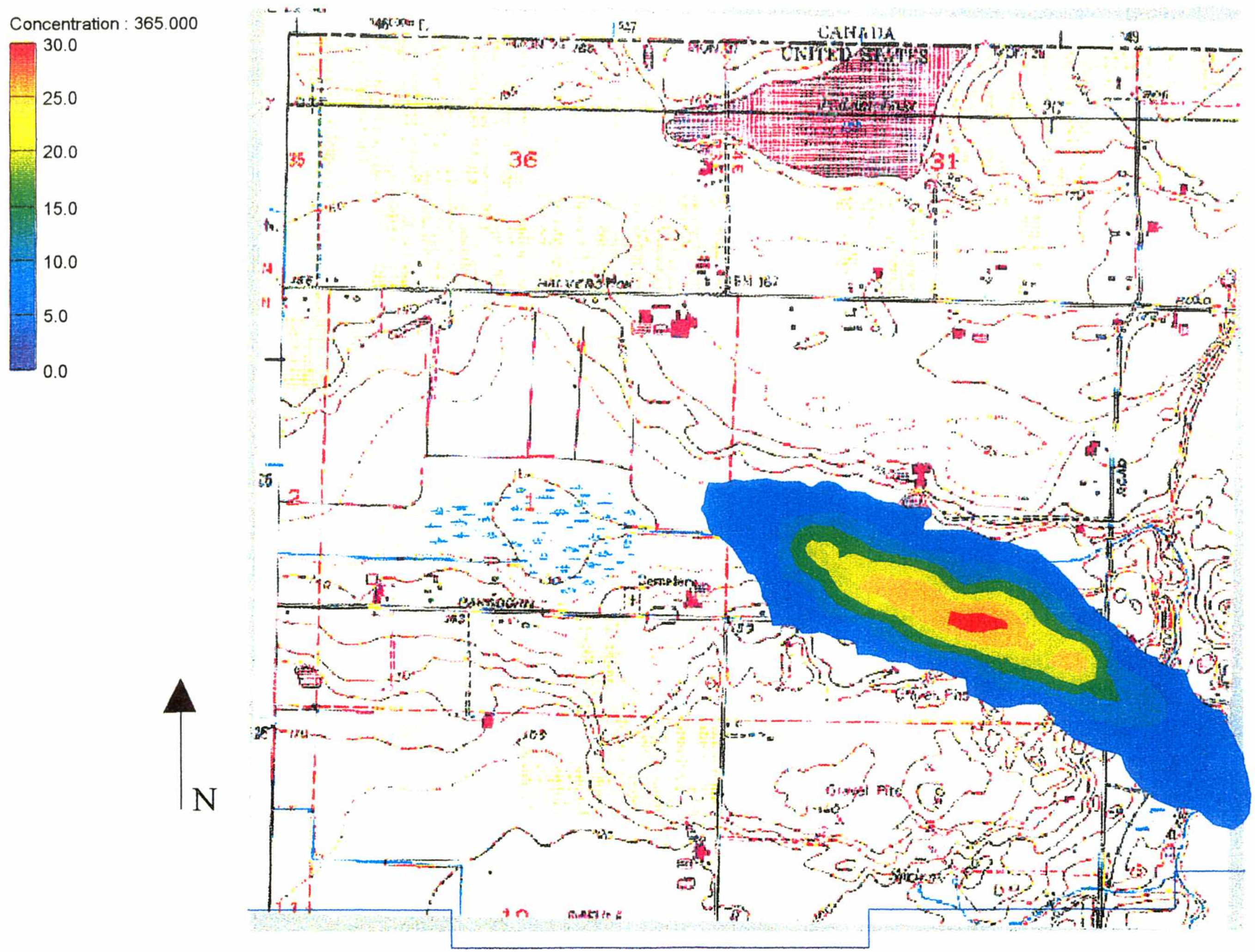


Figure 44. Scenario 1: 1 year nitrate contours (conductivity = 929 feet per day)

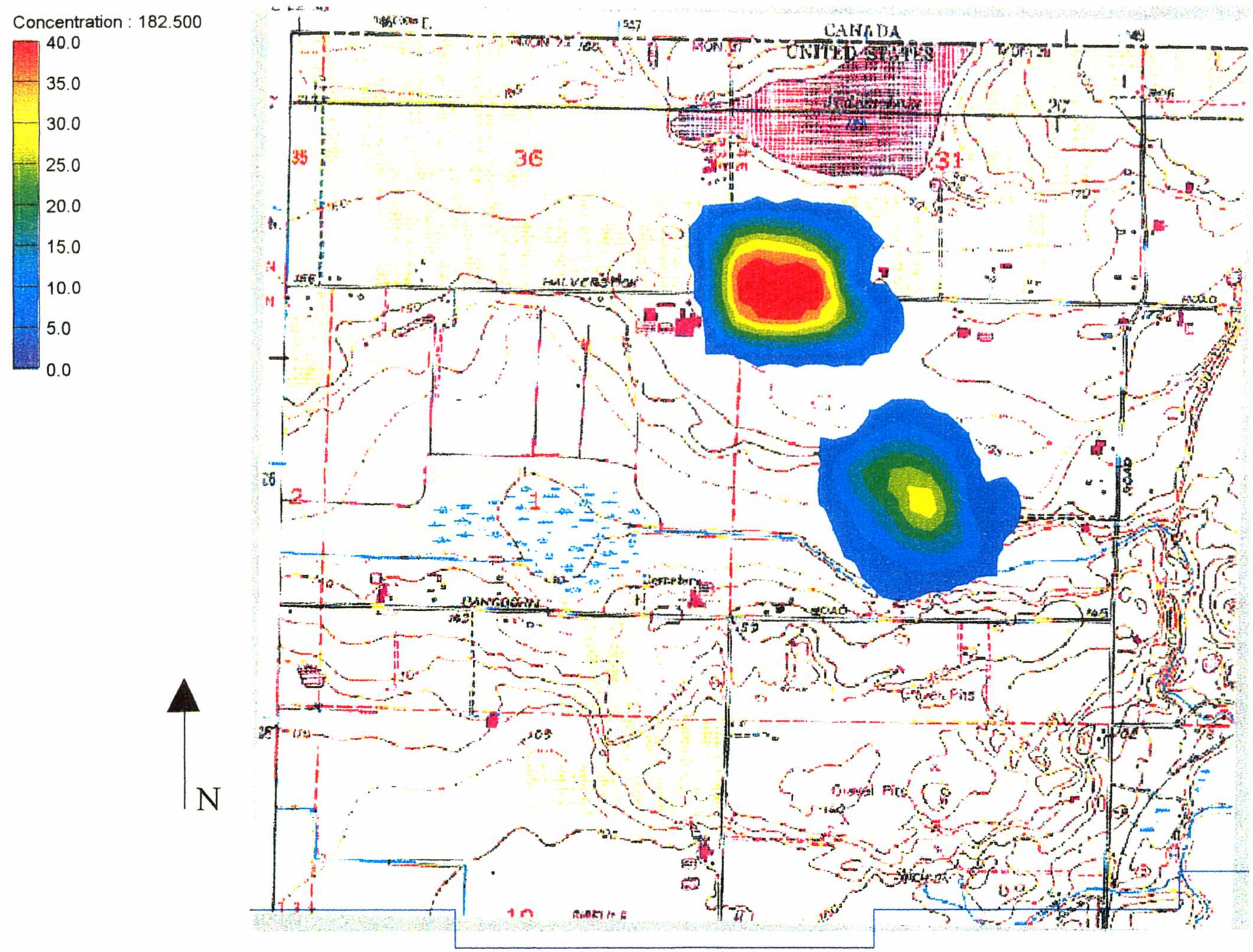


Figure 45. Scenario 2: 6 month nitrate contours (conductivity = 270 feet per day)

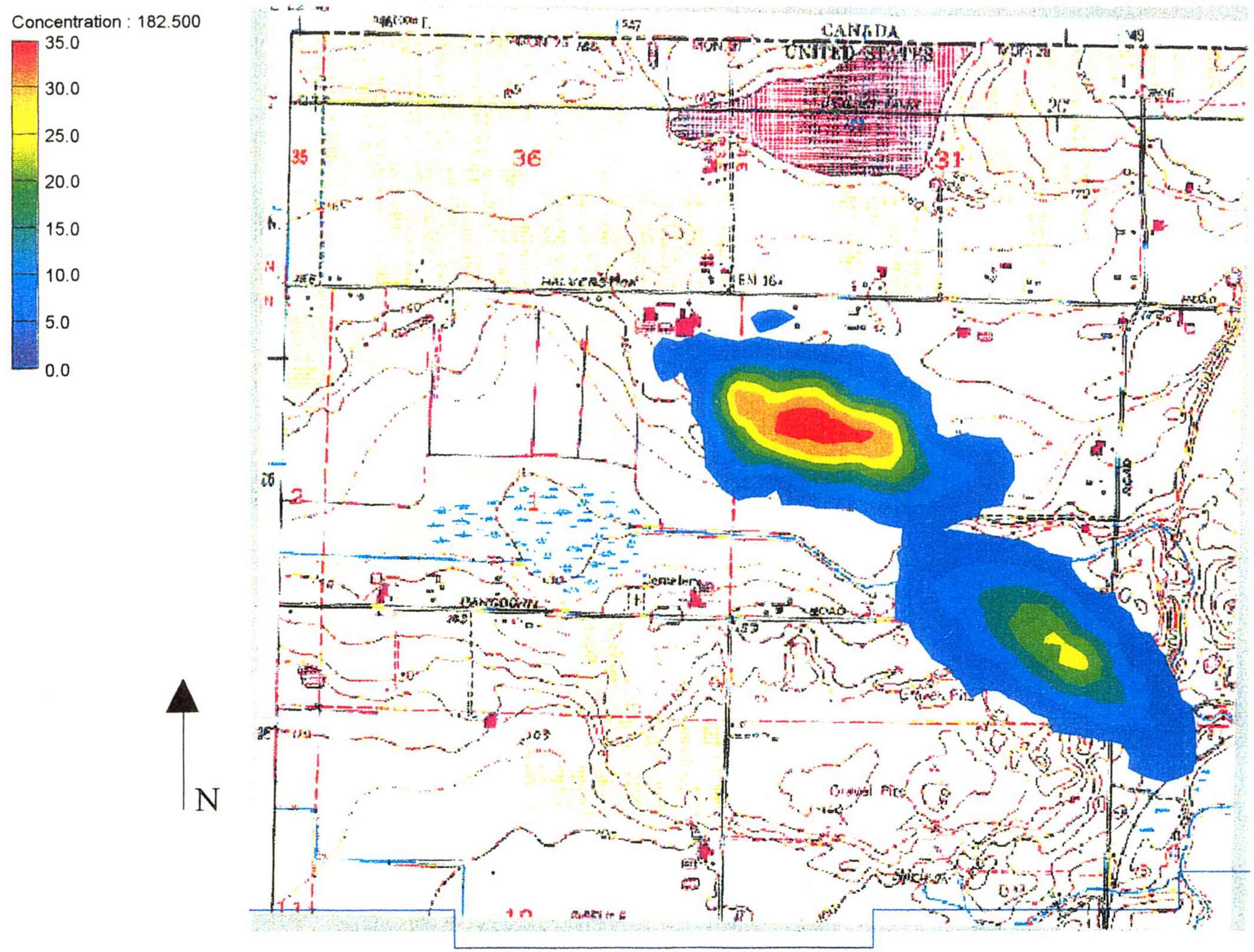


Figure 46. Scenario 2: 6 month nitrate contours (conductivity = 929 feet per day)

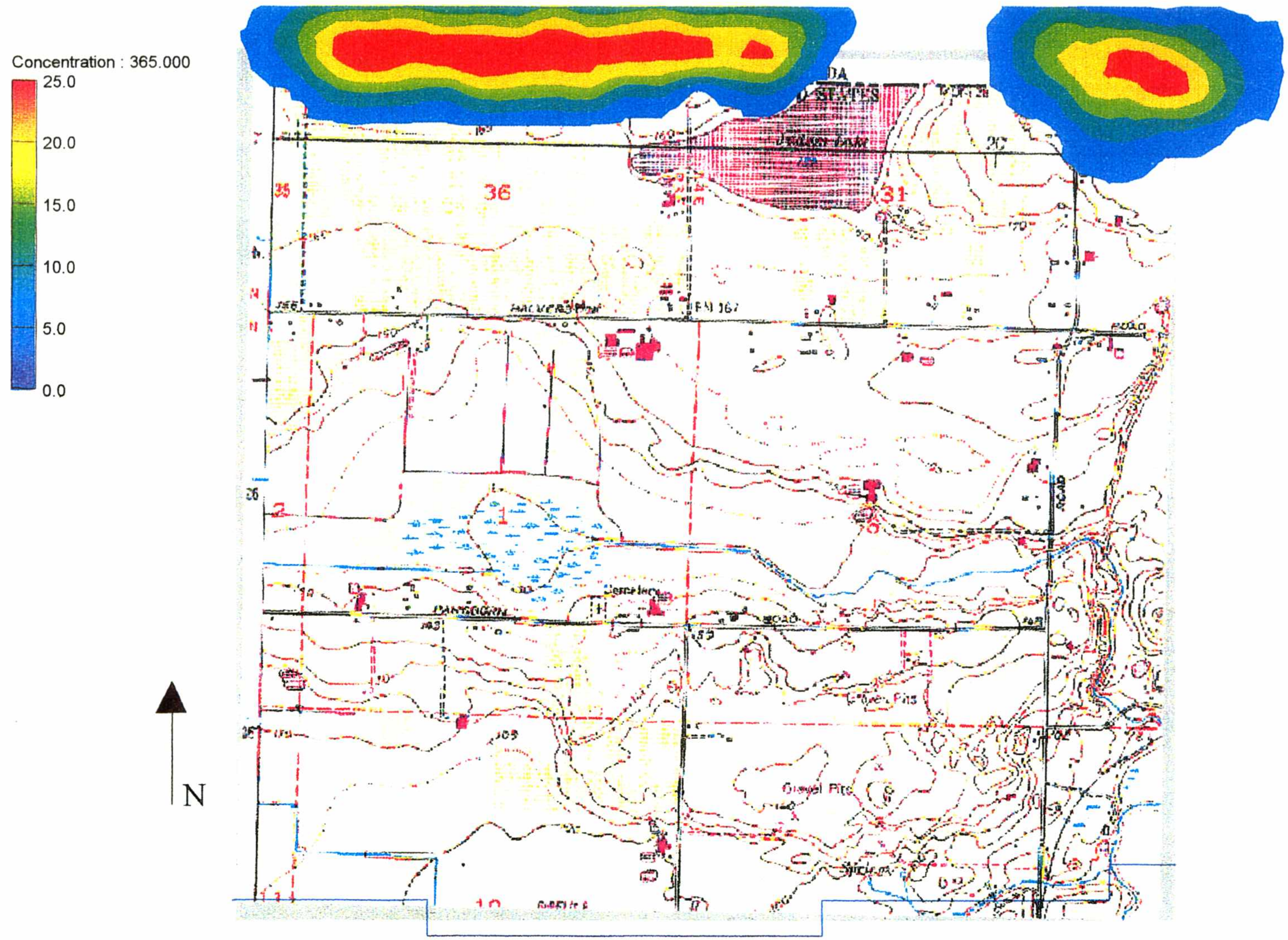


Figure 47. Scenario 3: 1 year nitrate contours (conductivity = 270 feet per day)

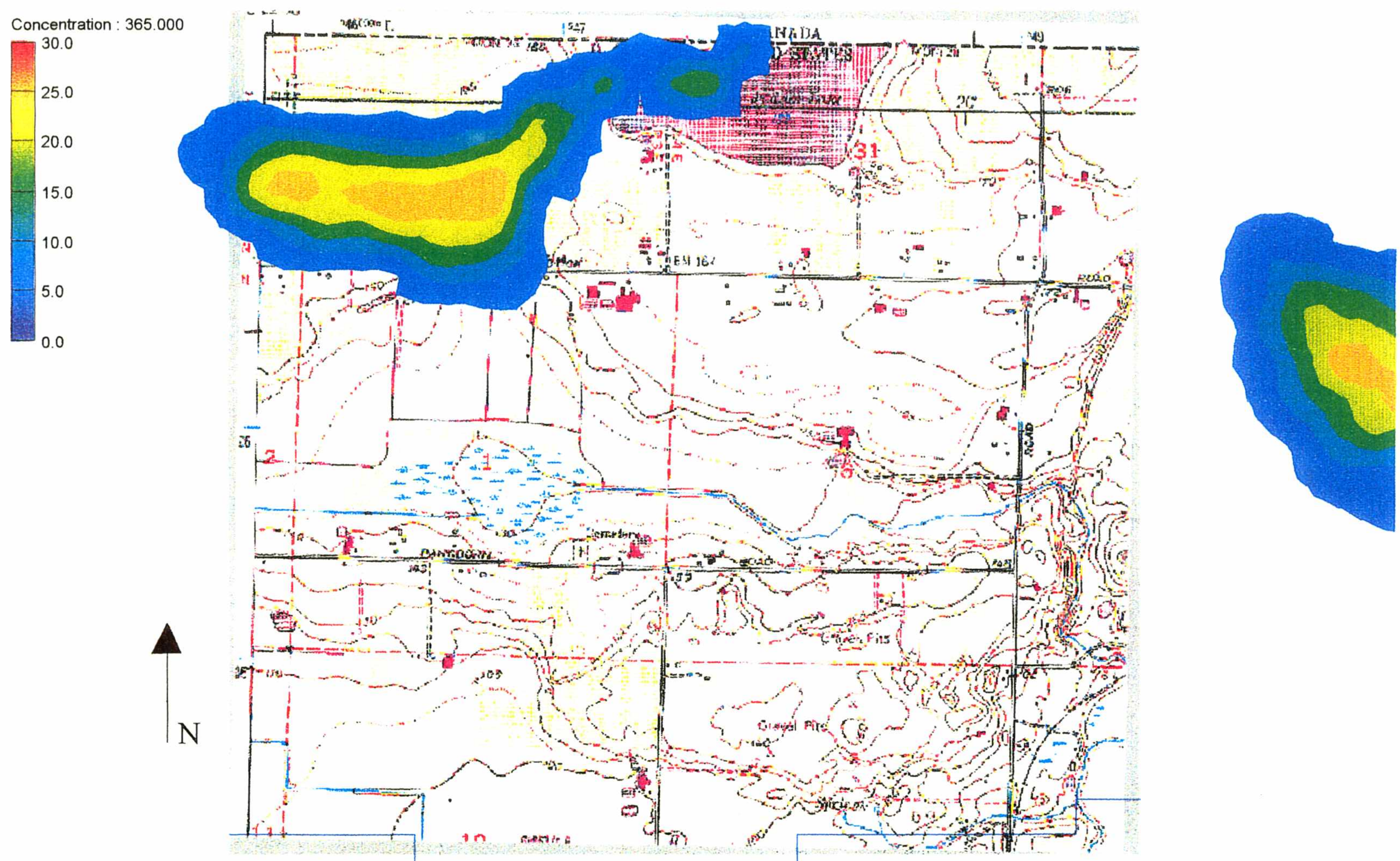


Figure 48. Scenario 3: 1 year nitrate contours (conductivity = 929 feet per day)

Appendices

APPPENDIX A. ASTM STANDARDS FOR SIEVE ANALYSES

APPENDIX A

ASTM PARTICLE SIZE DISTRIBUTION LIST

Boulders = Particles of rock that will not pass a 12 inch square opening.

Cobbles = Particles of rock that will pass a 12 inch square opening and be retained on a 3 inch U.S. standard sieve.

Gravel = Particles of rock that will pass a 3 inch sieve and be retained on a No. 4 U.S. standard sieve with the following subdivisions:
Coarse = passes 3 inch sieve and retained on 3/4 inch sieve.
Fine = passes 3/4 inch sieve and retained on No. 4 sieve.

Sand = Particles of rock that will pass a No. 4 sieve and be retained on a No. 200 U.S. standard sieve with the following subdivisions:
Coarse = passes No. 4 sieve and retained on No. 10 sieve.
Medium = passes No. 10 sieve and retained on No. 40 sieve.
Fine = passes No. 40 sieve and retained on No. 200 sieve.

Silt = Soil passing a No. 200 U.S. standard sieve that is nonplastic or very slightly plastic and that exhibits little or no strength when dry.

Clay = Soil passing a No. 200 U.S. standard sieve that can be made to exhibit plasticity (putty-like properties) within a range of water contents and that exhibits considerable strength when air dry.

APPPENDIX B. WATER LEVEL AND WATER QUALITY DATA

Well #	Type	Corrected SWL	T.Nitrogen	Nitrate+Nitrite	Nitrite	Ammonia	Chloride	pH	Cond	D.O.	Temp	Month	Day	Year
		feet	mg N/L	mg N/L	mg N/L	mg N/L	mg/L		umhos/cm	mg/L	C			
1	1	0.00	14.693	12.924	0.000	-0.001	-99.00	6.580	256.3	10.97	9.8	4	9	1997
2	1	19.33	17.156	15.958	0.000	-0.004	-99.00	6.341	193.1	9.50	10.1	4	9	1997
2	3	-99.00	18.375	16.809	0.001	-0.012	-99.00	-99	-99.0	-99	-99.0	4	9	1997
3	1	17.84	-0.042	0.009	0.000	0.047	-99.00	6.643	144.8	9.50	9.5	4	9	1997
4	1	18.92	3.148	3.060	0.001	-0.013	-99.00	5.947	70.5	11.40	10.4	4	9	1997
5	1	57.50	8.323	8.035	0.001	-0.010	-99.00	6.723	188.0	11.55	9.7	4	9	1997
5	2	-99.00	9.300	-99.000	-99.000	-99.000	-99.00	-99	-99.0	-99.00	-99.0	4	9	1997
6	1	46.17	13.237	11.366	0.001	-0.015	-99.00	6.585	181.8	11.66	8.3	4	9	1997
7	2	-99.00	-99.000	-99.000	-99.000	0.005	-99.00	-99	-99.0	-99.00	-99.0	4	9	1997
7	1	32.92	8.491	8.673	0.013	0.013	-99.00	6.316	179.1	10.16	9.1	4	9	1997
8	1	24.70	14.002	13.009	0.009	0.001	-99.00	6.032	159.3	10.98	10.3	4	9	1997
8	2	-99.00	-99.000	13.123	-99.000	-99	-99.00	-99	-99.0	-99	-99.0	4	9	1997
9	1	-99.00	27.519	26.674	0.004	-0.001	-99.00	5.726	262.8	10.40	12.5	4	10	1997
10	1	24.50	11.937	11.223	0.004	-0.004	-99.00	6.158	137.5	8.35	10.3	4	9	1997
11	1	45.04	1.777	1.621	0.007	0.094	-99.00	6.558	85.5	10.78	10.6	4	9	1997
12	1	37.95	0.249	0.012	0.003	0.397	-99.00	6.756	142.0	6.59	12.4	4	10	1997
13	1	-99.00	22.319	21.642	0.006	0.013	-99.00	5.909	248.4	8.25	11.1	4	10	1997
14	1	21.58	32.421	30.586	0.001	-0.011	-99.00	5.918	314.4	9.30	10.4	4	10	1997
15	1	9.50	2.712	2.375	0.001	-0.014	-99.00	6.345	98.8	5.55	8.2	4	10	1997
16	1	-99.00	5.412	5.295	0.001	-0.017	-99.00	6.129	105.6	7.30	12.0	4	10	1997
17	1	-99.00	9.891	9.729	0.001	-0.010	-99.00	6.534	177.7	3.20	8.8	4	10	1997
17	2	-99.00	10.195	-99.000	-99.000	-99	-99.00	-99	-99.0	-99	-99.0	4	10	1997
18	1	22.54	22.045	21.331	0.001	-0.017	-99.00	6.078	241.4	10.47	11.3	4	10	1997
18	3	-99.00	23.482	-99.000	0.001	-0.015	-99.00	-99	-99	-99	-99.0	4	10	1997
19	1	-99.00	2.930	3.098	0.001	-0.022	-99.00	6.997	102.6	12.47	9.0	4	10	1997
20	1	13.67	1.854	2.208	0.001	-0.019	-99.00	7.053	171.9	11.36	11.2	4	10	1997
20	2	-99.00	-99.000	2.228	-99.000	-99.000	-99.00	-99	-99	-99	-99	4	10	1997
21	1	14.75	-0.064	0.016	0.001	-0.004	-99.00	6.798	287.4	9.49	13.7	4	10	1997
1	1	0.00	13.391	13.593	0.001	0.005	-99.00	6.659	183.2	10.89	9.8	5	6	1997
2	1	20.15	17.685	16.396	0.002	-0.005	-99.00	6.390	193.0	8.15	10.0	5	6	1997
2	2	-99.00	18.213	16.376	-99.000	-99.000	-99.00	-99.000	-99.0	-99	-99.0	5	6	1997
3	1	19.52	-0.083	0.003	0.006	0.046	-99.00	6.716	160.2	1.54	10.7	5	6	1997
4	1	-99.00	1.879	1.914	0.001	-0.005	-99.00	5.966	60.3	4.3	10.1	5	6	1997
5	1	62.50	9.096	8.635	0.001	-0.007	-99.00	6.676	197.0	3.5	10.4	5	6	1997
6	1	47.17	12.912	12.022	0.000	-0.009	-99.00	6.553	201.2	8.56	11.0	5	6	1997
6	3	-99.00	12.281	11.522	0.001	-0.004	-99.00	-99	-99.0	-99	-99.0	5	6	1997
7	1	33.92	9.078	8.110	0.002	-0.007	-99.00	6.311	132.3	9.04	12.1	5	6	1997
8	1	26.00	7.046	6.669	0.004	0.001	-99.00	5.786	119.6	1.93	10.5	5	6	1997
8	2	-99.00	-99.000	-99.000	0.004	-99.000	-99.00	-99	-99.0	-99	-99.0	5	6	1997
9	1	-99.00	27.137	25.893	0.003	-0.005	-99.00	5.853	257.8	2.6	11.8	5	6	1997
10	1	25.73	13.863	12.573	0.005	-0.004	-99.00	6.140	150.0	7.89	11.9	5	6	1997
11	1	32.71	1.155	1.189	0.003	0.094	-99.00	6.479	84.1	3.61	10.6	5	6	1997
12	1	39.95	0.130	0.003	0.003	0.331	-99.00	6.768	140.3	1.36	11.3	5	6	1997
13	1	-99.00	23.149	25.476	0.001	-0.007	-99.00	5.985	271.9	10.39	10.4	5	6	1997
14	1	22.02	31.027	31.016	0.001	-0.004	-99.00	5.880	326.8	6.7	12.2	5	7	1997

Well #	Type	Corrected SWL feet	T.Nitrogen mg N/L	Nitrate+Nitrite mg N/L	Nitrite mg N/L	Ammonia mg N/L	Chloride mg/L	pH	Cond umhos/cm	D.O. mg/L	Temp C	Month	Day	Year
14	3	-99.00	-99.000	29.249	0.001	-0.007	-99.00	-99	-99	-99	-99.0	5	7	1997
15	1	24.10	2.839	2.605	0.001	-0.008	-99.00	6.107	76.2	4.06	11.6	5	7	1997
16	1	-99.00	5.956	5.904	0.001	-0.007	-99.00	6.115	109.6	8.03	12.5	5	7	1997
17	1	27.50	10.544	10.581	0.001	-0.007	-99.00	6.465	204.7	10.62	12.8	5	7	1997
17	2	-99.00	11.673	-99.000	-99.000	-99.000	-99.00	-99	-99	-99	-99.0	5	7	1997
18	1	24.36	27.100	24.826	0.002	-0.008	-99.00	6.046	270.0	8.35	13.8	5	7	1997
18	2	-99.00	-99.000	-99.000	0.002	-0.005	-99.00	-99	-99	-99	-99.0	5	7	1997
19	1	10.63	3.594	3.243	0.001	-0.008	-99.00	7.022	108.7	6.02	10.5	5	7	1997
19	2	-99.00	-99.000	3.173	-99.000	-99.000	-99.00	-99	-99	-99	-99.0	5	7	1997
20	1	13.30	2.183	2.272	0.001	-0.006	-99.00	7.038	180.7	7.43	12.4	5	7	1997
21	1	-99.00	-0.073	0.002	0.000	0.007	-99.00	6.776	272.2	3.32	12.2	5	6	1997
1	1	0.00	13.26	12.827	0.001	-0.001	-99.00	6.470	192.0	-99.00	14.4	6	11	1997
2	1	21.05	14.65	14.985	0.001	-0.003	-99.00	6.280	195.0	7.30	11.4	6	11	1997
2	2	-99.00	0.05	-99.000	0.002	-99.000	-99.00	-99.000	-99.0	-99.00	-99.0	6	11	1997
3	1	20.52	0.05	0.001	0.013	0.045	-99.00	6.530	153.0	1.60	12.6	6	11	1997
3	2	-99.00	-99.00	-99.00	-99.00	-0.006	-99.00	-99.00	-99.00	-99.00	-99.00	6	11	1997
3	8	-99.00	-0.12	0.005	-99.000	-0.002	-99.00	6.650	173.0	-99.00	16.7	6	11	1997
4	1	21.05	0.53	0.547	0.002	-0.004	-99.00	5.820	54.0	5.73	11.0	6	11	1997
4	2	-99.00	-99.00	-99.000	-99.000	-0.006	-99.00	-99.000	-99.0	-99.00	-99.0	6	11	1997
5	1	59.42	9.12	8.253	0.002	-0.008	-99.00	6.520	207.0	2.80	12.0	6	11	1997
6	1	48.10	11.39	11.334	0.002	-0.007	-99.00	6.430	214.0	4.64	12.0	6	11	1997
7	1	34.72	6.60	5.923	0.015	0.004	-99.00	6.290	127.0	3.37	12.5	6	11	1997
8	1	27.00	3.03	2.804	0.005	0.002	-99.00	5.790	96.6	2.16	11.5	6	11	1997
9	1	-99.00	17.43	16.920	0.002	-0.003	-99.00	5.800	208.0	2.24	12.4	6	11	1997
9	3	-99.00	19.02	18.581	-99.000	-0.006	-99.00	-99.000	-99.0	-99.00	-99.0	6	11	1997
9	4	-99.00	20.60	-99.000	-99.000	-99.000	-99.00	-99.000	-99.0	-99.00	-99.0	6	11	1997
10	1	26.53	12.44	10.973	0.006	-0.005	-99.00	6.030	159.0	4.31	14.0	6	11	1997
11	1	39.61	1.52	1.457	0.005	0.075	-99.00	6.340	92.0	1.66	11.8	6	11	1997
12	1	40.55	0.39	0.001	0.002	-99.000	-99.00	6.660	142.0	5.86	12.7	6	12	1997
13	1	-99.00	21.67	24.348	0.003	0.001	-99.00	5.890	262.0	5.31	11.2	6	11	1997
13	2	-99.00	-99.00	22.953	-99.000	-99.000	-99.00	-99.000	-99.0	-99.00	-99.0	6	11	1997
14	1	22.62	30.10	32.433	0.002	-0.001	-99.00	5.880	326.0	5.85	12.0	6	12	1997
14	2	-99.00	-99.00	-99.000	0.003	-99.000	-99.00	-99.000	-99.0	-99.00	-99.0	6	12	1997
15	1	24.80	2.27	2.484	0.002	-0.002	-99.00	6.050	78.5	4.97	11.0	6	12	1997
16	1	-99.00	6.92	7.352	0.003	-0.002	-99.00	6.060	116.0	-99.00	11.9	6	12	1997
16	3	-99.00	7.94	7.276	-99.000	-0.004	-99.00	-99.000	-99.0	-99.00	-99.0	6	12	1997
17	1	28.30	11.37	11.621	0.002	-0.002	-99.00	6.350	217.0	2.56	14.2	6	12	1997
17	2	-99.00	-99.00	-99.000	-99.000	-0.002	-99.00	-99.000	-99.0	-99.00	-99.0	6	12	1997
18	1	25.16	25.07	28.334	0.003	0.000	-99.00	6.040	276.0	6.32	11.5	6	12	1997
19	1	13.33	3.28	3.117	0.003	-0.002	-99.00	6.840	116.0	8.12	12.8	6	12	1997
19	2	-99.00	3.17	-99.000	-99.000	-99.000	-99.00	-99.000	-99.0	-99.00	-99.0	6	12	1997
20	1	13.90	2.28	2.335	0.002	-0.003	-99.00	6.980	179.0	7.23	11.8	6	12	1997
21	1	17.77	-0.15	0.004	0.002	0.002	-99.00	6.740	287.0	3.56	15.4	6	12	1997
21	2	-99.00	-99.00	0.003	-99.000	-99.000	-99.00	-99.000	-99.0	-99.00	-99.0	6	12	1997
22	1	-99.00	6.32	6.385	0.002	-0.003	-99.00	-99.000	-99.0	-99.00	-99.0	6	12	1997

Well #	Type	Corrected SWL	T.Nitrogen	Nitrate+Nitrite	Nitrite	Ammonia	Chloride	pH	Cond	D.O.	Temp	Month	Day	Year
		feet	mg N/L	mg N/L	mg N/L	mg N/L	mg/L		umhos/cm	mg/L	C			
1	1	4.00	11.90	11.048	0.000	-0.004	4.72	6.330	181.0	4.46	12.3	7	9	1997
1	2	-99.00	-99.00	-99.00	0.001	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	7	9	1997
2	1	21.85	15.40	14.453	0.000	0.001	4.83	6.390	189.0	10.00	10.5	7	9	1997
3	1	21.92	0.05	0.006	0.000	0.053	5.43	6.740	156.0	7.85	13.1	7	9	1997
4	1	22.55	0.14	0.291	0.000	-0.004	2.29	5.950	55.6	4.99	10.1	7	9	1997
4	2	-99.00	0.26	-99.000	-99.000	-99.000	-99.00	-99.000	-99.0	-99.00	-99.0	7	9	1997
5	1	60.72	9.38	8.484	0.000	-0.004	10.90	6.660	205.0	2.76	12.5	7	9	1997
5	3	-99.00	9.04	9.180	0.000	-0.004	-99.00	-99.000	-99.0	-99.00	-99.0	7	9	1997
6	1	49.10	12.40	12.916	0.000	0.000	9.47	6.530	215.0	7.82	12.1	7	9	1997
6	2	-99.00	12.80	-99.000	-99.000	-99.000	-99.00	-99.000	-99.0	-99.00	-99.0	7	9	1997
7	1	35.62	7.99	7.523	0.001	-0.001	3.00	6.340	134.0	9.41	13.3	7	9	1997
8	1	28.30	1.63	1.776	0.004	0.004	4.53	5.920	88.9	4.87	11.7	7	9	1997
8	2	-99.00	-99.00	-99.000	-99.000	0.000	-99.00	-99.000	-99.0	-99.00	-99.0	7	9	1997
9	1	-99.00	17.32	16.926	0.001	-0.004	12.30	5.890	200.0	6.50	11.7	7	9	1997
10	1	27.63	11.50	11.358	0.001	-0.004	2.33	6.130	161.0	5.50	14.4	7	9	1997
10	2	-99.00	-99.00	12.113	-99.000	-99.000	-99.00	-99.000	-99.0	-99.00	-99.0	7	9	1997
11	1	42.71	1.34	1.268	0.001	0.097	1.95	6.440	92.8	7.52	11.3	7	10	1997
12	1	41.95	0.27	0.016	0.000	0.371	3.73	6.760	138.0	1.77	11.5	7	10	1997
13	1	-99.00	18.70	18.518	0.000	-0.004	7.48	5.950	233.0	5.37	10.9	7	10	1997
14	1	22.92	31.00	29.493	0.000	-0.003	15.80	5.950	325.0	3.87	12.2	7	10	1997
15	1	25.10	2.60	2.355	0.000	-0.004	3.29	6.190	83.0	7.78	11.3	7	10	1997
15	2	-99.00	-99.00	-99.00	0.000	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	7	10	1997
16	1	-99.00	7.99	7.141	0.000	-0.004	3.89	6.080	126.0	9.28	11.4	7	10	1997
16	2	-99.00	-99.00	-99.000	-99.000	-0.002	-99.00	-99.000	-99.0	-99.00	-99.0	7	10	1997
17	1	-99.00	11.61	10.855	0.000	-0.004	9.56	6.400	223.0	2.30	14.2	7	10	1997
18	1	25.86	30.12	28.195	0.000	-0.004	11.20	5.990	290.0	7.70	10.9	7	10	1997
19	1	11.83	3.14	2.775	0.000	-0.004	2.82	6.920	110.0	7.64	12.7	7	10	1997
19	3	-99.00	4.26	2.955	0.000	-0.004	-99.00	-99.000	-99.0	-99.00	-99.0	7	10	1997
20	1	13.90	2.31	2.267	0.000	-0.004	6.62	7.050	181.0	9.21	12.1	7	10	1997
21	1	18.17	1.02	0.006	0.000	0.003	21.00	6.750	265.0	6.76	14.8	7	10	1997
21	2	-99.00	-99.00	0.000	-99.000	-99.000	-99.00	-99.000	-99.0	-99.00	-99.0	7	10	1997
23	1	-99.00	0.17	0.229	0.001	0.003	-99.00	-99.000	-99.0	-99.00	-99.0	7	10	1997
1	1	5.13	10.35	10.609	0.000	0.002	4.65	6.220	185.9	3.27	15.4	8	13	1997
1	3	-99.00	11.46	10.740	0.000	-0.006	-99.00	-99.000	-99.0	-99.00	-99.0	8	13	1997
2	1	23.05	15.13	14.797	0.000	-0.001	4.90	6.285	193.3	7.32	11.0	8	13	1997
3	1	23.62	0.12	0.008	0.000	0.046	5.10	6.540	148.0	5.75	15.6	8	13	1997
3	5	-99.00	-99.00	0.007	-99.000	0.047	-99.00	-99.000	-99.0	-99.00	-99.0	8	13	1997
4	1	34.45	-0.23	0.210	0.000	-0.004	2.78	5.760	66.6	3.30	15.2	8	13	1997
5	1	62.52	9.63	9.357	0.000	0.003	10.90	6.590	216.0	3.10	14.1	8	13	1997
5	2	-99.00	9.29	-99.000	-99.000	-99.000	-99.00	-99.000	-99.0	-99.00	-99.0	8	13	1997
6	1	50.75	12.27	11.943	0.000	-0.006	9.44	6.428	222.0	9.40	13.4	8	13	1997
6	2	-99.00	-99.00	-99.000	-99.000	-0.005	9.52	-99.000	-99.0	-99.00	-99.0	8	13	1997
7	1	37.12	8.69	8.633	0.003	0.002	3.16	6.330	142.4	3.83	14.1	8	13	1997
8	1	29.70	0.58	1.539	0.004	0.006	4.18	5.910	89.7	2.35	12.7	8	13	1997
9	1	-99.00	17.86	16.945	0.001	-0.003	13.00	5.817	228.0	10.10	14.1	8	13	1997

Well #	Type	Corrected SWL	T.Nitrogen	Nitrate+Nitrite	Nitrite	Ammonia	Chloride	pH	Cond	D.O.	Temp	Month	Day	Year
		feet	mg N/L	mg N/L	mg N/L	mg N/L	mg/L		umhos/cm	mg/L	C			
9	2	-99.00	-99.00	17.229	0.001	-99.000	-99.00	-99.000	-99.0	-99.00	-99.0	8	13	1997
10	1	29.13	12.89	12.244	0.003	0.001	2.39	6.060	167.5	6.20	15.9	8	13	1997
11	1	45.51	3.42	3.305	0.002	0.118	2.20	6.396	116.3	8.76	15.0	8	13	1997
12	1	43.05	0.42	0.003	0.000	0.347	3.68	6.620	141.0	9.67	14.0	8	14	1997
12	2	-99.00	0.36	-99.000	-99.000	-99.000	-99.00	-99.000	-99.0	-99.00	-99.0	8	14	1997
13	1	-99.00	12.54	14.022	0.001	-0.006	6.21	5.979	208.0	10.80	11.4	8	14	1997
13	3	-99.00	12.60	14.136	-99.000	-0.002	-99.00	-99.000	-99.0	-99.00	-99.0	8	14	1997
14	1	-99.00	26.90	28.693	0.001	0.002	15.00	-99.000	-99.0	-99.00	-99.0	8	14	1997
14	2	-99.00	-99.00	-99.000	0.000	-0.005	-99.00	-99.000	-99.0	-99.00	-99.0	8	14	1997
15	1	25.90	2.82	3.150	0.000	0.000	4.84	6.139	106.0	4.24	11.7	8	14	1997
16	1	-99.00	8.58	8.750	0.000	-0.005	5.57	6.036	150.0	4.65	13.5	8	14	1997
17	1	29.10	11.67	11.057	0.000	-0.007	8.95	6.355	226.0	2.35	16.2	8	14	1997
17	2	-99.00	-99.00	-99.000	-99.000	-99.000	9.05	-99.000	-99.0	-99.00	-99.0	8	14	1997
18	1	27.42	29.84	31.772	0.001	-0.006	10.80	5.930	308.2	5.30	12.0	8	14	1997
18	2	-99.00	32.99	31.403	-99.000	-99.000	-99.00	-99.000	-99.0	-99.00	-99.0	8	14	1997
19	1	12.83	2.32	2.764	0.000	-0.008	2.58	6.880	118.0	6.47	17.3	8	14	1997
20	1	14.58	1.76	2.207	0.000	-0.008	6.61	7.077	189.9	6.14	13.8	8	14	1997
21	1	18.87	0.06	0.007	0.000	-0.003	24.30	6.662	298.6	0.06	19.6	8	14	1997
22	1	-99.00	5.31	5.307	0.000	0.007	2.03	-99.000	-99.0	-99.00	-99.0	8	14	1997
23	1	11.60	-99.00	0.358	0.000	-0.008	4.55	5.816	37.6	10.06	14.9	8	13	1997
24	1	17.38	1.38	0.171	0.014	0.585	-99.00	6.870	209.8	0.98	18.0	8	13	1997
1	1	5.67	11.61	10.972	0.001	0.007	4.53	6.435	181.4	-99.00	13.5	9	16	1997
2	1	25.05	15.88	14.981	0.000	-0.003	4.31	6.453	195.0	-99.00	10.7	9	16	1997
3	1	25.17	0.05	0.014	0.000	0.050	5.01	6.663	141.7	-99.00	14.7	9	16	1997
4	1	26.05	0.00	0.066	0.000	0.004	3.25	5.882	75.3	-99.00	14.1	9	16	1997
5	1	63.92	10.19	9.830	0.000	-0.001	10.90	6.685	274.7	-99.00	11.7	9	16	1997
5	3	-99.00	10.54	10.065	0.000	-0.004	9.34	-99.000	-99.0	-99.00	-99.0	9	16	1997
6	1	51.88	12.70	12.061	0.000	0.001	3.17	6.548	215.1	-99.00	12.0	9	16	1997
6	2	-99.00	12.56	-99.000	-99.000	-99.000	-99.00	-99.000	-99.0	-99.00	-99.0	9	16	1997
7	1	38.21	9.42	9.217	0.000	0.005	3.37	6.394	184.6	-99.00	11.8	9	16	1997
7	2	-99.00	-99.00	9.237	-99.000	-99.000	13.10	-99.000	-99.0	-99.00	-99.0	9	16	1997
8	1	31.00	0.41	0.387	0.002	0.000	2.34	5.985	108.6	-99.00	11.4	9	16	1997
8	2	-99.00	-99.00	-99.000	-99.000	-0.001	-99.00	-99.000	-99.0	-99.00	-99.0	9	16	1997
9	1	-99.00	17.01	16.601	0.001	0.001	13.10	5.925	203.4	-99.00	12.0	9	16	1997
10	1	30.13	11.84	11.023	0.001	0.003	2.34	6.163	201.8	-99.00	13.5	9	16	1997
11	1	46.13	2.80	1.618	0.002	0.116	2.08	6.532	106.7	-99.00	11.3	9	16	1997
12	1	43.42	0.24	0.004	0.000	0.370	3.35	6.683	135.6	-99.00	11.7	9	16	1997
13	1	-99.00	11.44	12.433	0.000	0.001	5.69	6.436	192.7	-99.00	10.9	9	16	1997
13	2	-99.00	-99.00	12.518	-99.000	-99.000	-99.00	-99.000	-99.0	-99.00	-99.0	9	16	1997
14	1	23.96	27.37	27.771	0.000	0.006	14.50	5.967	312.3	-99.00	12.2	9	16	1997
15	1	26.46	3.46	2.031	0.000	0.002	5.73	6.256	119.5	-99.00	10.7	9	16	1997
16	1	-99.00	10.19	10.402	0.001	-0.001	6.65	6.093	161.2	-99.00	10.9	9	16	1997
16	2	-99.00	-99.00	-99.000	0.001	-99.000	-99.00	-99.000	-99.0	-99.00	-99.0	9	16	1997
17	1	31.00	10.08	10.315	0.000	-0.005	8.17	6.436	214.8	-99.00	15.3	9	16	1997
17	2	-99.00	-99.00	-99.000	0.000	-99.000	-99.00	-99.000	-99.0	-99.00	-99.0	9	16	1997

Well #	Type	Corrected SWL feet	T.Nitrogen mg N/L	Nitrate+Nitrite mg N/L	Nitrite mg N/L	Ammonia mg N/L	Chloride mg/L	pH	Cond umhos/cm	D.O. mg/L	Temp C	Month	Day	Year
17	3	-99.00	-99.00	10.434	-99.000	-99.000	-99.00	-99.000	-99.0	-99.00	-99.0	9	16	1997
18	1	28.17	28.87	30.323	0.000	0.001	10.70	6.093	283.7	-99.00	11.1	9	16	1997
18	2	-99.00	30.45	-99.000	-99.000	0.004	-99.00	-99.000	-99.0	-99.00	-99.0	9	16	1997
19	1	25.58	2.45	1.472	0.000	-0.005	2.37	6.948	111.8	-99.00	16.2	9	16	1997
19	2	-99.00	-99.00	-99.000	-99.000	-99.000	2.24	-99.000	-99.0	-99.00	-99.0	9	16	1997
20	1	14.58	2.03	1.253	0.000	-0.008	6.52	7.046	178.0	-99.00	10.9	9	16	1997
21	1	19.29	-0.01	0.009	0.000	0.003	28.10	6.752	295.7	-99.00	15.2	9	16	1997
22	1	-99.00	4.37	4.735	0.000	-0.006	-99.00	-99.000	-99.0	-99.00	-99.0	9	16	1997
23	1	-99.00	-0.03	0.183	0.001	0.014	1.70	5.908	47.4	-99.00	11.6	9	16	1997
1	1	5.67	11.01	10.683	0.001	-0.004	4.61	6.160	180.0	6.96	13.5	10	7	1997
1	2	-99.00	10.67	-99.000	-99.000	-99.000	-99.00	-99.000	-99.0	-99.00	-99.0	10	7	1997
2	1	24.25	15.44	15.059	0.001	-0.004	4.38	6.312	187.7	10.27	10.2	10	7	1997
3	1	29.00	0.06	0.018	0.002	0.040	4.98	6.387	126.6	6.78	11.6	10	7	1997
4	1	-99.00	0.10	0.040	0.002	-0.004	3.53	5.861	79.2	6.83	14.2	10	7	1997
4	2	-99.00	-99.00	-99.000	0.002	-99.000	-99.00	-99.000	-99.0	-99.00	-99.0	10	7	1997
5	1	64.67	10.68	10.195	0.001	-0.004	10.75	6.550	195.6	13.18	-99.0	10	8	1997
6	1	52.42	12.27	12.260	0.007	-0.004	9.41	6.421	201.8	14.00	10.6	10	8	1997
6	2	-99.00	-99.00	-99.000	-99.000	-99.000	9.44	-99.000	-99.0	-99.00	-99.0	10	8	1997
7	1	38.72	11.22	9.468	0.001	0.000	3.45	6.079	129.9	11.08	10.3	10	8	1997
7	2	-99.00	-99.00	-99.000	-99.000	-0.004	-99.00	-99.000	-99.0	-99.00	-99.0	10	8	1997
7	3	-99.00	9.48	9.757	0.001	-0.003	-99.00	-99.000	-99.0	-99.00	-99.0	10	8	1997
8	1	31.42	0.96	0.627	0.003	-0.004	3.44	5.885	77.1	0.53	11.1	10	7	1997
8	2	-99.00	-99.00	0.556	-99.000	-99.000	-99.00	-99.000	-99.0	-99.00	-99.0	10	7	1997
9	1	-99.00	18.02	15.992	0.005	-0.003	13.01	5.846	191.6	10.17	11.0	10	7	1997
10	1	30.59	11.59	11.547	0.002	-0.004	2.37	6.045	152.4	5.62	13.5	10	7	1997
11	1	47.38	3.25	2.737	0.006	0.100	2.28	6.377	102.8	6.25	10.8	10	7	1997
11	2	42.62	-99.00	-99.000	-99.000	-99.000	-99.00	-99.000	-99.0	-99.00	-99.0	10	7	1997
11	6	-99.00	3.09	2.696	-99.000	0.060	-99.00	-99.000	-99.0	-99.00	-99.0	10	8	1997
12	1	-99.00	0.32	-0.013	0.002	0.386	3.47	-99.000	-99.0	-99.00	-99.0	10	8	1997
12	2	-99.00	-99.00	-99.000	0.002	-99.000	-99.00	-99.000	-99.0	-99.00	-99.0	10	8	1997
13	1	-99.00	11.70	11.570	0.012	0.016	6.09	5.926	188.4	7.95	11.5	10	7	1997
14	1	24.22	28.97	30.397	0.000	-0.004	14.52	5.876	309.1	7.98	11.7	10	7	1997
15	1	26.08	4.05	4.240	0.000	-0.004	5.78	5.920	128.5	9.96	11.9	10	7	1997
15	2	-99.00	4.24	-99.000	-99.000	-99.000	-99.00	-99.000	-99.0	-99.00	-99.0	10	7	1997
15	3	-99.00	4.13	4.233	0.001	-0.004	-99.00	-99.000	-99.0	-99.00	-99.0	10	7	1997
16	1	-99.00	11.44	12.299	0.001	-0.004	7.20	5.750	175.5	9.21	12.5	10	7	1997
17	1	29.33	11.25	11.643	0.001	-0.004	8.46	6.278	209.2	1.93	14.1	10	7	1997
17	7	-99.00	11.24	11.474	-99.000	-99.000	-99.00	-99.000	-99.0	-99.00	-99.0	10	7	1997
18	1	27.96	30.71	32.346	0.003	-0.004	10.88	5.930	279.9	10.56	11.4	10	7	1997
18	2	-99.00	-99.00	-99.000	0.001	-99.000	10.61	-99.000	-99.0	-99.00	-99.0	10	7	1997
19	1	13.00	3.60	2.620	0.000	-0.002	2.30	5.440	99.1	6.41	12.9	10	8	1997
19	2	-99.00	-99.00	2.571	-99.000	-99.000	-99.00	-99.000	-99.0	-99.00	-99.0	10	8	1997
20	1	14.10	2.63	2.298	0.000	-0.004	6.34	6.936	169.6	3.37	10.6	10	8	1997
21	1	19.33	0.24	0.008	0.000	0.002	21.55	6.629	266.7	5.32	15.8	10	7	1997
22	1	-99.00	3.62	3.633	0.000	-0.004	-99.00	-99.000	-99.0	-99.00	-99.0	10	7	1997

Well #	Type	Corrected SWL feet	T.Nitrogen mg N/L	Nitrate+Nitrite mg N/L	Nitrite mg N/L	Ammonia mg N/L	Chloride mg/L	pH	Cond umhos/cm	D.O. mg/L	Temp C	Month	Day	Year
23	1	12.82	0.46	0.182	0.000	0.004	1.87	5.747	37.9	7.58	13.7	10	7	1997
24	1	-99.00	28.39	28.728	0.001	-0.004	-99.00	-99.000	-99.0	-99.00	-99.0	10	7	1997
1	1	5.25	10.33	9.762	0.004	0.006	4.65	5.860	179.7	4.80	12.4	11	10	1997
1	3	-99.00	10.02	10.735	0.004	0.003	-99.00	-99.000	-99.0	-99.00	-99.0	11	10	1997
2	1	24.00	15.11	14.809	0.004	0.003	3.99	6.133	191.9	14.29	10.7	11	10	1997
2	2	-99.00	-99.00	15.116	-99.000	-99.000	-99.00	-99.000	-99.0	-99.00	-99.0	11	10	1997
3	1	25.25	0.07	0.005	0.002	0.042	4.92	6.379	124.6	13.21	10.5	11	10	1997
3	2	-99.00	-99.00	-99.000	-99.000	-99.000	4.89	-99.000	-99.0	-99.00	-99.0	11	10	1997
4	1	-99.00	0.31	0.241	0.004	0.003	3.22	5.688	75.0	0.52	12.8	11	10	1997
5	1	65.58	11.17	10.465	0.002	0.003	10.77	6.558	201.6	10.48	10.9	11	10	1997
6	1	53.17	12.30	12.105	0.002	0.003	9.33	6.336	207.0	10.30	10.9	11	10	1997
6	2	-99.00	-99.00	-99.000	0.002	-99.000	-99.00	-99.000	-99.0	-99.00	-99.0	11	10	1997
7	1	39.33	10.98	9.424	0.002	0.003	3.19	6.238	129.2	10.30	10.0	11	11	1997
8	1	31.10	0.55	0.441	0.004	0.003	3.29	5.794	73.2	13.13	10.6	11	10	1997
8	2	-99.00	-99.00	-99.000	-99.000	0.004	-99.00	-99.000	-99.0	-99.00	-99.0	11	10	1997
9	1	-99.00	16.27	15.182	0.003	0.003	12.69	5.728	187.2	0.68	10.2	11	10	1997
10	1	30.93	11.26	10.766	0.004	0.003	2.11	6.050	144.0	6.04	10.8	11	11	1997
10	2	-99.00	11.04	-99.000	-99.000	0.003	-99.00	-99.000	-99.0	-99.00	-99.0	11	11	1997
11	1	40.81	2.22	2.173	0.004	0.119	2.11	6.508	98.3	14.20	9.5	11	11	1997
12	1	43.85	0.30	0.013	0.008	0.329	3.18	7.009	133.5	0.18	11.2	11	10	1997
13	1	-99.00	10.85	11.180	0.006	0.004	5.71	6.047	180.7	8.60	10.9	11	10	1997
13	2	-99.00	-99.00	10.687	-99.000	-99.000	-99.00	-99.000	-99.0	-99.00	-99.0	11	10	1997
14	1	24.17	28.45	27.124	0.002	0.003	13.41	5.998	302.8	10.30	10.6	11	11	1997
14	2	-99.00	-99.00	-99.000	-99.000	0.003	-99.00	-99.000	-99.0	-99.00	-99.0	11	11	1997
15	1	30.60	6.17	-99.000	0.002	0.003	6.11	5.904	137.5	10.10	9.8	11	11	1997
16	1	-99.00	11.78	12.039	0.006	0.018	6.57	5.508	174.7	2.46	11.7	11	10	1997
16	2	-99.00	-99.00	-99.000	0.006	0.017	-99.00	-99.000	-99.0	-99.00	-99.0	11	10	1997
17	1	29.30	10.70	10.844	0.002	0.003	7.94	6.046	192.3	2.02	10.8	11	10	1997
17	2	-99.00	-99.00	-99.000	-99.000	-99.000	7.92	-99.000	-99.0	-99.00	-99.0	11	10	1997
18	1	21.56	28.90	29.903	0.003	0.003	10.53	5.906	270.6	10.32	10.5	11	11	1997
18	3	-99.00	30.20	31.315	0.004	0.003	-99.00	-99.000	-99.0	-99.00	-99.0	11	11	1997
19	1	13.03	2.46	2.442	0.002	0.003	1.98	6.510	97.1	4.97	11.6	11	10	1997
20	1	13.60	2.06	2.202	0.002	0.003	6.37	6.515	170.8	10.93	10.1	11	10	1997
21	1	24.37	0.03	0.011	0.002	0.003	18.77	6.540	258.6	0.24	14.0	11	10	1997
22	1	-99.00	3.73	3.835	0.002	0.003	-99.00	-99.000	-99.0	-99.00	-99.0	11	11	1997
22	2	-99.00	3.87	-99.000	-99.000	-99.000	-99.00	-99.000	-99.0	-99.00	-99.0	11	11	1997
23	1	-99.00	0.24	0.174	0.003	0.033	1.88	5.545	33.2	8.25	10.8	11	10	1997
24	1	-99.00	25.46	25.847	0.002	0.003	-99.00	-99.000	-99.0	-99.00	-99.0	11	11	1997
1	1	4.84	1.27	10.385	0.001	0.003	5.13	5.978	174.8	5.88	11.5	12	10	1997
2	1	23.45	15.05	14.601	0.002	0.003	4.32	-99.000	189.3	8.90	10.7	12	10	1997
3	1	24.62	0.09	0.009	0.004	0.042	5.05	-99.000	136.3	8.28	12.7	12	10	1997
4	1	-99.00	0.93	0.834	0.004	0.002	3.58	5.514	78.1	1.00	12.4	12	10	1997
5	1	66.02	11.17	11.068	0.001	0.001	10.94	5.800	195.3	11.90	8.8	12	10	1997
6	1	53.50	12.36	12.277	0.000	-0.001	9.38	5.700	197.3	7.89	8.9	12	10	1997
7	1	39.32	9.47	9.863	0.000	-0.001	3.18	-99.000	129.7	9.05	9.6	12	10	1997

Well #	Type	Corrected SWL feet	T.Nitrogen mg N/L	Nitrate+Nitrite mg N/L	Nitrite mg N/L	Ammonia mg N/L	Chloride mg/L	pH	Cond umhos/cm	D.O. mg/L	Temp C	Month	Day	Year
7	2	-99.00	10.28	-99.000	-99.000	-99.000	-99.00	-99.000	-99.0	-99.00	-99.0	12	10	1997
7	3	-99.00	9.86	9.903	0.001	-0.001	-99.00	-99.000	-99.0	-99.00	-99.0	12	10	1997
8	1	30.70	0.34	0.415	0.004	-0.001	3.59	5.680	71.8	12.71	9.8	12	10	1997
9	1	-99.00	14.48	14.719	0.002	0.001	11.71	5.720	176.8	12.84	9.9	12	10	1997
9	2	-99.00	-99.00	14.923	-99.000	-99.000	-99.00	-99.000	-99.0	-99.00	-99.0	12	10	1997
10	1	30.63	9.92	10.135	0.000	0.003	2.36	5.926	132.7	12.60	8.2	12	10	1997
10	2	-99.00	-99.00	-99.000	0.000	0.004	2.39	-99.000	-99.0	-99.00	-99.0	12	10	1997
11	1	43.88	1.53	1.613	0.016	0.095	2.34	-99.000	98.6	7.45	10.3	12	11	1997
12	1	43.55	0.24	0.009	0.009	0.337	3.37	-99.000	127.2	8.11	10.0	12	11	1997
13	1	-99.00	10.22	10.179	0.001	-0.001	6.12	-99.000	176.3	4.58	10.4	12	11	1997
13	3	-99.00	10.37	10.663	0.001	0.000	-99.00	-99.000	-99.0	-99.00	-99.0	12	11	1997
14	1	23.92	26.57	27.608	0.001	-0.001	13.45	-99.000	283.5	10.02	9.6	12	11	1997
14	2	-99.00	-99.00	27.665	-99.000	-99.000	13.49	-99.000	-99.0	-99.00	-99.0	12	11	1997
15	1	24.90	4.35	4.319	0.001	-0.001	4.28	-99.000	112.8	4.04	8.0	12	11	1997
16	1	-99.00	10.74	10.768	0.004	0.004	6.23	-99.000	153.2	8.71	9.2	12	11	1997
17	1	28.60	10.41	10.567	0.001	0.001	8.07	-99.000	170.1	3.53	6.7	12	11	1997
17	2	-99.00	10.74	-99.000	-99.000	-99.000	-99.00	-99.000	-99.0	-99.00	-99.0	12	11	1997
18	1	25.76	26.84	26.543	0.001	0.006	10.51	-99.000	246.5	6.14	-99.0	12	11	1997
18	2	-99.00	-99.00	-99.000	-99.000	0.007	-99.00	-99.000	-99.0	-99.00	-99.0	12	11	1997
19	1	12.93	2.19	2.355	0.001	-0.001	2.19	6.400	84.7	6.54	8.1	12	11	1997
20	1	13.60	1.91	2.130	0.000	-0.001	6.60	-99.000	166.7	10.70	9.6	12	11	1997
21	1	18.97	-0.01	0.013	0.001	0.002	19.36	-99.000	256.0	0.46	12.3	12	11	1997
21	2	-99.00	-99.00	-99.000	0.001	-99.000	-99.00	-99.000	-99.0	-99.00	-99.0	12	11	1997
22	1	-99.00	4.18	4.047	0.000	-0.001	-99.00	-99.000	-99.0	-99.00	-99.0	12	11	1997
23	1	-99.00	0.35	0.308	0.000	0.036	-99.00	-99.000	-99.0	-99.00	-99.0	12	11	1997
24	1	-99.00	25.52	24.773	0.001	0.000	-99.00	-99.000	-99.0	-99.00	-99.0	12	11	1997
1	1	3.82	12.650	12.035	0.001	0.000	4.81	6.223	160.4	5.51	8.3	1	14	1998
1	2	-99.00	-99.000	-99	0.001	-99.000	-99.00	-99	-99.0	-99.00	-99.0	1	15	1998
2	1	21.85	13.810	13.847	0.001	0.001	4.05	6.210	178.8	5.34	9.9	1	15	1998
2	2	-99.00	-99.000	-99	-99.000	-99.000	4.14	-99	-99.0	-99.00	-99.0	1	15	1998
3	1	22.62	0.040	0.003	0.001	0.044	4.86	6.662	110.4	0.26	7.6	1	14	1998
4	1	23.55	2.300	2.143	0.003	0.001	2.66	5.885	82.4	6.74	13.5	1	14	1998
5	1	64.42	10.710	10.759	0.001	0.001	10.83	6.459	190.3	6.12	7.9	1	15	1998
6	1	52.00	13.410	13.069	0.000	0.000	9.28	6.426	194.6	5.34	8.4	1	15	1998
7	1	37.62	10.150	9.689	0.003	0.002	2.79	6.167	126.7	4.00	9.1	1	15	1998
7	2	-99.00	-99.000	9.848	-99.000	-99.000	-99.00	-99.000	-99.0	-99.00	-99.0	1	15	1998
8	1	30.60	1.110	1.028	0.001	0.000	3.81	5.909	76.900	7.77	9.5	1	14	1998
9	1	-99.00	13.821	13.031	0.001	0.000	10.13	5.912	156.6	0.82	9.4	1	14	1998
9	2	-99.00	-99.000	-99	-99.000	0.001	-99.00	-99.000	-99.0	-99.00	-99.0	1	14	1998
11	1	39.11	2.440	1.488	0.003	0.122	2.10	6.504	96.4	2.37	9.6	1	15	1998
12	1	42.08	0.250	0.003	0.000	0.318	3.11	6.701	121.6	7.09	8.8	1	15	1998
13	1	-99.00	9.190	9.784	0.001	0.000	6.08	5.915	173.6	3.92	9.9	1	15	1998
13	4	-99.00	9.680	-99	-99.000	0.001	-99.00	-99.000	-99.0	-99.00	-99.0	1	15	1998
13	3	-99.00	9.730	9.747	0.001	0.000	-99.00	-99.000	-99.0	-99.00	-99.0	1	15	1998
14	1	22.92	24.950	24.672	0.001	0.000	11.90	5.835	258.6	3.85	8.3	1	15	1998

Well #	Type	Corrected SWL	T.Nitrogen	Nitrate+Nitrite	Nitrite	Ammonia	Chloride	pH	Cond	D.O.	Temp	Month	Day	Year
		feet	mg N/L	mg N/L	mg N/L	mg N/L	mg/L		umhos/cm	mg/L	C			
14	2	-99.00	24.978	24.434	-99	-99.000	12.20	-99.000	-99.0	-99	-99.0	1	15	1998
15	1	23.17	3.160	3.246	0.001	0.001	2.37	6.018	95.4	7.19	6.9	1	15	1998
15	2	-99.00	-99.000	-99	-99.000	0.002	-99.00	-99.000	-99.0	-99.00	-99.0	1	15	1998
16	1	-99.00	8.780	8.931	0.006	0.006	5.06	5.910	147.7	8.26	9.8	1	15	1998
17	1	26.70	10.760	10.679	0.001	0.000	-99.00	6.404	162.5	2.75	4.0	1	15	1998
17	3	-99.00	10.730	10.653	0.001	0.002	-99.00	-99.000	-99.0	-99.00	-99.0	1	15	1998
18	1	23.29	23.500	22.791	0.002	0.010	10.30	6.150	223.3	5.33	8.4	1	14	1998
19	1	12.03	2.110	2.184	0.001	0.000	1.97	7.073	78.1	6.18	5.4	1	14	1998
19	2	-99.00	-99.000	-99	0.001	-99	-99.00	-99.000	-99.0	-99.00	-99.0	1	14	1998
20	1	13.20	1.960	2.164	0.001	0.000	6.33	7.135	161.8	7.10	8.3	1	14	1998
21	1	17.97	-0.010	0.011	0.001	0.000	21.03	6.645	255.7	0.34	10.8	1	14	1998
22	1	-99.00	4.330	4.499	0.001	0.000	-99.00	-99	-99	-99.00	-99.0	1	15	1998
23	1	-99.00	0.900	0.796	0.002	0.072	-99.00	5.860	42.4	6.65	8.3	1	14	1998
23	2	-99.00	0.880	-99	-99	-99	-99.00	-99.000	-99.0	-99.00	-99.0	1	14	1998
1	1	3.22	13.277	13.686	0.002	0.002	5.24	6.262	167.2	7.26	9.5	2	4	1998
1	2	-99.00	-99	13.029	-99.000	-99.000	-99.00	-99	-99	-99	-99	2	4	1998
2	1	20.75	14.228	14.904	0.001	0.000	4.03	6.036	181.3	5.30	10.5	2	5	1998
2	2	-99.00	13.995	-99.000	-99.000	-99.000	-99.00	-99	-99	-99	-99	2	5	1998
3	1	21.02	0.054	0.031	0.001	0.041	4.80	6.385	122.3	2.22	10.3	2	4	1998
4	1	22.35	1.849	2.036	0.002	0.000	2.42	5.773	83.4	2.60	-99.0	2	4	1998
4	2	-99.00	-99	-99.000	0.002	-99.000	-99.00	-99	-99	-99	-99	2	4	1998
5	1	62.52	11.178	11.310	0.001	0.000	10.88	6.394	200.5	3.30	9.5	2	5	1998
6	1	50.30	13.896	13.818	0.001	0.000	9.23	6.674	197.5	5.33	9.1	2	4	1998
7	1	36.22	8.988	9.632	0.002	0.000	2.73	6.042	127.1	3.94	9.8	2	5	1998
8	1	27.60	-99	-99.000	-99.000	-99.000	-99.00	-99.000	-99.0	-99.00	-99.0	2	4	1998
8	2	-99.00	-99	-99.000	-99.000	-99.000	-99.00	-99	-99	-99	-99	2	4	1998
9	1	-99.00	12.577	12.450	0.001	0.000	10.24	5.688	160.2	1.40	10.1	2	5	1998
9	2	-99.00	11.663	-99.000	-99.000	0.000	-99.00	-99	-99	-99	-99	2	5	1998
9	3	-99.00	10.847	13.656	0.001	0.000	-99.00	-99	-99	-99	-99	2	5	1998
10	1	27.53	7.816	9.065	0.001	0.002	2.29	5.859	122.9	5.86	8.7	2	5	1998
10	2	-99.00	-99	-99.000	-99.000	-99.000	2.36	-99	-99	-99	-99	2	5	1998
11	1	37.81	1.837	1.983	0.007	0.114	2.12	6.719	98.8	4.62	10.1	2	4	1998
12	1	40.75	0.312	0.031	0.002	0.333	3.07	6.805	125.2	0.76	10.0	2	4	1998
13	1	-99.00	8.92	9.656	0.020	0.020	4.98	5.746	160.5	4.16	9.9	2	5	1998
14	1	22.22	23.08	25.483	0.001	0.000	11.69	5.694	252.7	4.30	9.3	2	5	1998
14	2	-99.00	-99	-99.000	-99.000	0.000	-99.00	-99	-99	-99	-99	2	5	1998
15	1	23.00	3.046	3.387	0.001	0.000	1.84	6.463	88.0	4.78	6.5	2	4	1998
16	1	-99.00	6.791	7.966	0.003	0.004	3.94	6.537	134.6	4.40	9.6	2	4	1998
17	1	26.50	10.068	10.271	0.001	0.000	7.74	6.229	170.5	3.20	6.8	2	5	1998
17	2	-99.00	-99	9.919	-99.000	-99.000	-99.00	-99	-99	-99	-99	2	5	1998
18	1	20.36	20.761	21.736	0.002	0.004	10.44	5.846	222.3	4.81	9.9	2	5	1998
19	1	11.23	3.592	2.166	0.001	0.000	2.02	6.871	82.8	7.18	7.0	2	4	1998
19	3	-99.00	1.211	2.318	0.002	0.000	-99.00	-99	-99	-99	-99	2	4	1998
20	1	13.10	1.865	2.226	0.001	0.000	6.18	6.758	165.4	8.51	9.0	2	4	1998
20	2	-99.00	-99	-99.000	-99.000	-99.000	6.30	-99	-99	-99	-99	2	4	1998

Well #	Type	Corrected SWL feet	T.Nitrogen mg N/L	Nitrate+Nitrite mg N/L	Nitrite mg N/L	Ammonia mg N/L	Chloride mg/L	pH	Cond umhos/cm	D.O. mg/L	Temp C	Month	Day	Year
21	1	17.67	-0.026	0.031	0.004	0.039	15.04	6.886	242.9	0.36	11.0	2	4	1998
21	2	-99.00	-99	-99.000	0.004	-99.000	-99.00	-99	-99	-99	-99	2	4	1998
22	1	-99.00	4.491	4.592	0.001	0.000	-99.00	-99.000	-99.0	-99.00	-99.0	2	4	1998
23	1	-99.00	0.813	0.788	0.001	0.013	-99.00	6.472	40.7	9.24	7.4	2	5	1998
1	1	3.75	13.370	12.710	0.002	0.007	5.38	6.252	167.3	5.44	9.2	3	4	1998
2	1	21.65	14.918	13.993	0.001	0.005	4.18	6.180	185.9	6.08	9.9	3	4	1998
2	2	-99.00	-99.000	14.413	-99	-99.000	-99.00	-99	-99	-99	-99	3	4	1998
3	1	22.12	0.067	0.007	0.003	0.050	4.82	6.491	125.5	3.77	10.4	3	4	1998
4	1	-99.00	3.514	3.575	0.003	0.004	2.20	5.700	88.5	2.48	14.0	3	4	1998
5	1	61.48	11.229	10.871	0.001	0.003	10.76	6.511	201.5	3.46	8.9	3	4	1998
7	1	36.12	8.921	8.365	0.002	0.007	3.09	6.166	125.7	5.96	9.8	3	5	1998
7	2	-99.00	8.668	-99.000	-99	-99.000	-99.00	-99	-99	-99	-99	3	5	1998
7	3	-99.00	8.840	8.398	-99	0.010	-99.00	-99	-99	-99	-99	3	5	1998
8	1	28.40	0.621	0.619	0.001	0.004	3.11	5.874	72.1	1.27	10.2	3	4	1998
8	2	-99.00	-99.000	-99.000	-99	-99.000	3.09	-99	-99	-99	-99	3	4	1998
8	3	-99.00	0.622	-99.000	-99	0.005	-99.00	-99	-99	-99	-99	3	4	1998
9	1	-99.00	12.432	11.766	0.002	0.003	10.37	5.707	160.2	1.23	10.2	3	4	1998
10	1	28.03	8.637	8.545	0.002	0.009	2.54	6.049	125.8	4.84	9.3	3	4	1998
10	2	-99.00	-99.000	7.879	-99	-99.000	-99.00	-99	-99	-99	-99	3	4	1998
11	1	38.04	0.222	1.983	0.003	0.115	2.53	6.329	99.7	1.30	10.8	3	4	1998
12	1	41.35	0.319	0.005	0.001	0.355	3.21	6.715	119.3	2.57	9.6	3	4	1998
12	2	-99.00	-99.000	-99.000	0.0013	-99.000	-99.00	-99	-99	-99	-99	3	4	1998
13	1	-99.00	9.422	9.397	0.056	0.005	5.76	5.981	174.2	5.81	10.2	3	4	1998
14	1	22.92	22.919	20.789	0.001	0.007	11.07	5.936	252.0	5.68	9.2	3	4	1998
15	1	24.00	3.275	3.816	0.001	0.003	2.29	5.958	82.1	4.30	6.3	3	4	1998
16	1	-99.00	7.172	6.700	0.003	0.007	4.05	5.909	134.4	4.10	9.6	3	4	1998
17	1	27.20	11.379	10.035	0.001	0.007	8.43	6.371	177.8	7.20	6.4	3	4	1998
18	1	23.79	18.211	16.642	0.002	0.009	10.59	6.087	210.7	5.70	9.7	3	5	1998
18	2	-99.00	-99.000	-99.000	-99	0.013	-99.00	-99	-99	-99	-99	3	5	1998
19	1	11.17	2.984	2.411	0.001	0.005	2.43	6.832	83.4	5.57	7.2	3	4	1998
19	2	-99.00	1.787	0.656	-99	-99	2.40	-99	-99	-99	-99	3	4	1998
20	1	13.25	2.018	2.170	0.001	0.008	6.52	7.045	167.9	9.45	9.8	3	5	1998
21	1	18.07	-0.061	0.014	0.001	0.009	23.60	6.719	256.5	2.97	11.6	3	4	1998
22	1	-99.00	6.760	6.418	0.001	0.005	-99.00	-99	-99	-99	-99.0	3	4	1998
23	1	-99.00	0.725	0.658	0.001	0.016	-99.00	-99	-99	-99	-99.0	3	4	1998
26	1	-99.00	7.114	7.073	0.005	0.017	21.20	-99	-99	-99	-99	3	5	1998
1	1	4.02	13.794	13.846	0.001	0.001	5.77	6.037	176.0	7.15	10.1	4	8	1998
1	2	-99.00	-99.000	-99.000	-99.000	-0.003	-99.000	-99.000	-99.000	-99.000	-99.000	4	8	1998
2	1	21.95	15.023	14.494	0.001	0.005	22.34	6.046	235.9	6.16	10.4	4	8	1998
2	2	-99.00	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	4	8	1998
2	3	-99.00	14.135	14.711	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	4	8	1998
3	1	22.52	-0.007	0.010	0.001	0.043	4.69	6.485	136.2	7.56	12.6	4	8	1998
3	2	-99.00	-99.000	-99.000	0.001	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	4	8	1998
4	1	-99.00	6.497	6.611	0.002	-0.003	2.37	5.633	110.9	3.37	14.3	4	8	1998
5	1	61.92	12.259	12.087	0.001	-0.003	11.04	6.447	206.6	3.99	9.8	4	8	1998

Well #	Type	Corrected SWL feet	T.Nitrogen mg N/L	Nitrate+Nitrite mg N/L	Nitrite mg N/L	Ammonia mg N/L	Chloride mg/L	pH	Cond umhos/cm	D.O. mg/L	Temp C	Month	Day	Year
6	1	50.10	13.782	13.714	0.001	0.048	9.62	6.456	210.8	4.87	10.2	4	8	1998
6	2	-99.00	-99.000	13.234	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	4	8	1998
7	1	-99.00	8.796	9.349	0.001	-0.003	3.23	6.365	135.8	5.83	10.7	4	8	1998
7	2	-99.00	-99.000	-99.000	-99.000	-0.003	-99.000	-99.000	-99.000	-99.000	-99.000	4	8	1998
8	1	28.60	0.759	0.775	0.001	-0.003	2.58	5.884	72.6	8.52	10.5	4	8	1998
8	2	-99.00	-99.000	0.778	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	4	8	1998
9	1	-99.00	11.460	11.318	0.001	-0.001	10.72	5.837	158.5	5.90	10.8	4	8	1998
10	1	28.33	8.826	8.443	0.001	0.005	2.24	6.203	133.3	4.91	10.2	4	8	1998
10	2	-99.00	-99.000	-99.000	-99.000	-99.000	2.24	-99.000	-99.000	-99.000	-99.000	4	8	1998
10	3	-99.00	-99.000	-99.000	-99.000	-0.003	-99.000	-99.000	-99.000	-99.000	-99.000	4	8	1998
11	1	38.31	1.308	1.549	0.005	0.090	2.18	6.425	96.8	7.20	10.9	4	8	1998
12	1	42.73	0.199	0.008	0.001	0.349	2.86	6.605	120.6	0.39	10.2	4	8	1998
13	1	-99.00	10.919	11.733	0.001	-0.003	5.29	5.962	188.0	6.73	10.7	4	8	1998
14	1	23.32	19.497	19.426	0.001	-0.003	10.65	6.041	249.1	4.41	10.6	4	8	1998
14	2	-99.00	27.036	-99.000	0.001	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	4	8	1998
15	1	24.46	2.999	3.224	0.001	-0.003	2.25	5.989	85.5	4.50	8.8	4	8	1998
16	1	-99.00	8.032	8.106	0.002	-0.003	3.71	5.981	146.9	7.34	12.4	4	8	1998
17	1	27.60	10.007	11.487	0.001	-0.003	8.31	6.468	191.7	7.95	9.5	4	8	1998
17	3	-99.00	10.231	11.162	0.001	-0.003	-99.000	-99.000	-99.000	-99.000	-99.000	4	8	1998
18	1	24.46	16.346	18.540	0.001	-0.003	10.88	6.048	211.2	6.88	10.5	4	8	1998
18	2	-99.00	16.804	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	4	8	1998
19	1	11.66	1.814	2.312	0.001	-0.003	2.05	6.941	89.0	7.90	12.3	4	8	1998
19	2	-99.00	-99.000	-99.000	0.001	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	4	8	1998
20	1	13.66	1.829	2.349	0.001	-0.003	6.28	6.985	175.2	7.03	10.7	4	8	1998
20	2	-99.00	-99.000	-99.000	-99.000	-99.000	6.23	-99.000	-99.000	-99.000	-99.000	4	8	1998
21	1	-99.00	-0.036	0.013	0.001	-0.003	21.11	6.781	254.8	0.40	11.1	4	8	1998
22	1	-99.00	8.658	9.187	0.001	-0.003	3.37	-99.000	-99.000	-99.000	-99.000	4	8	1998
23	1	-99.00	1.589	1.697	0.001	-0.003	1.53	-99.000	-99.000	-99.000	-99.000	4	8	1998
26	1	-99.00	6.967	7.746	0.004	-0.003	13.57	-99.000	-99.000	-99.000	-99.000	4	8	1998
1	1	4.82	12.034	14.219	0.001	-0.007	5.78	5.866	178.0	5.21	11.0	5	7	1998
2	1	22.75	13.358	15.317	0.001	-0.011	3.98	5.600	186.7	7.20	10.5	5	7	1998
2	3	-99.00	14.001	13.389	0.001	-0.013	-99.000	-99.000	-99.000	-99.000	-99.000	5	7	1998
3	1	23.42	-0.051	-0.002	0.001	0.036	4.86	6.572	139.6	-99.00	13.8	5	7	1998
4	1	-99.00	2.808	3.793	0.002	-0.011	2.96	5.535	93.8	2.80	14.6	5	7	1998
5	1	62.42	10.881	13.088	0.001	-0.014	11.10	6.010	217.0	5.57	11.0	5	7	1998
6	1	50.70	11.839	14.063	0.001	0.005	9.63	7.000	219.6	4.38	11.0	5	7	1998
6	3	-99.00	13.366	14.436	0.001	-0.014	-99.000	-99.000	-99.000	-99.000	-99.000	5	7	1998
6	4	-99.00	-99.000	-99.000	-99.000	-0.013	-99.000	-99.000	-99.000	-99.000	-99.000	5	7	1998
7	1	37.17	8.346	9.527	0.001	-0.012	3.59	5.500	132.5	4.31	10.7	5	7	1998
7	2	-99.00	-99.000	-99.000	-99.000	-0.013	-99.000	-99.000	-99.000	-99.000	-99.000	5	7	1998
8	1	29.42	1.003	1.151	0.001	-0.013	2.51	5.500	75.2	6.31	11.2	5	7	1998
8	2	-99.00	1.248	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	5	7	1998
9	1	-99.00	9.085	10.608	0.001	-0.014	10.31	5.454	160.0	1.19	11.3	5	7	1998
10	1	28.83	7.584	9.042	0.001	-0.002	2.30	5.680	140.6	4.83	12.0	5	7	1998
11	1	38.96	1.310	2.121	0.006	0.085	2.52	5.870	102.7	1.23	11.5	5	7	1998

Well #	Type	Corrected SWL feet	T.Nitrogen mg N/L	Nitrate+Nitrite mg N/L	Nitrite mg N/L	Ammonia mg N/L	Chloride mg/L	pH	Cond umhos/cm	D.O. mg/L	Temp C	Month	Day	Year
12	1	42.25	0.106	-0.004	0.001	0.338	2.98	6.201	122.9	4.63	11.9	5	7	1998
13	1	-99.00	9.315	11.928	0.001	-0.006	5.83	6.326	190.8	3.88	10.8	5	7	1998
13	2	-99.00	-99.000	-99.000	-99.000	-0.008	-99.000	-99.000	-99.000	-99.000	-99.000	5	7	1998
14	1	23.52	18.051	21.114	0.001	-0.012	10.85	5.628	256.1	3.73	11.8	5	7	1998
14	2	-99.00	-99.000	20.654	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	5	7	1998
15	1	25.30	2.430	3.156	0.001	-0.012	3.13	5.651	95.7	4.18	10.7	5	7	1998
16	1	-99.00	7.075	8.719	0.001	-0.011	4.31	6.488	144.6	4.12	12.0	5	7	1998
17	1	28.30	9.487	10.619	0.001	-0.011	8.03	6.859	207.5	4.52	13.1	5	7	1998
18	1	25.38	14.163	14.440	0.001	-0.012	10.34	6.573	209.5	3.80	11.4	5	7	1998
18	2	-99.00	-99.000	14.649	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	5	7	1998
19	1	12.17	1.726	2.182	0.000	-0.013	2.24	6.132	89.7	6.39	10.6	5	7	1998
19	2	-99.00	1.430	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	5	7	1998
20	1	14.10	2.004	2.283	0.000	-0.014	6.51	6.945	178.8	3.41	11.2	5	7	1998
21	1	18.47	-0.034	0.002	0.000	-0.006	22.16	6.435	287.6	0.70	15.5	5	7	1998
22	1	-99.00	1.672	4.340	0.000	-0.013	-99.000	-99.000	-99.000	-99.000	-99.000	5	7	1998
23	1	-99.00	1.646	0.170	0.001	-0.005	-99.000	-99.000	-99.000	-99.000	-99.000	5	7	1998
26	1	-99.00	6.650	7.566	0.003	-0.007	12.50	-99.000	-99.000	-99.000	-99.000	5	7	1998
1	1	5.67	11.698	12.293	0.000	-0.003	5.53	-99.000	180.9	4.9	11.9	6	16	1998
1	2	-99.00	-99.000	12.750	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	6	16	1998
2	1	24.15	13.516	14.024	0.000	0.004	4.08	-99.000	186.5	4.6	11.2	6	16	1998
3	1	25.25	-0.064	0.020	0.000	0.044	4.72	-99.000	136.8	1.7	13.2	6	16	1998
4	1	-99.00	1.431	2.284	0.003	-0.005	3.10	-99.000	82.4	1.6	14.0	6	16	1998
5	1	64.08	13.112	13.833	0.000	0.009	11.18	-99.000	226.1	3.0	11.3	6	16	1998
5	2	-99.00	13.112	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	6	16	1998
7	1	28.22	8.420	9.346	0.000	0.000	3.91	-99.000	135.8	4.0	11.5	6	16	1998
7	2	-99.00	-99.000	-99.000	-99.000	-99.000	4.06	-99.000	-99.000	-99.000	-99.000	6	16	1998
8	1	-99.00	1.306	1.367	0.000	-0.006	2.45	-99.000	74.0	1.7	11.0	6	16	1998
9	1	-99.00	7.820	8.810	0.003	-0.003	9.14	-99.000	147.4	2.7	12.1	6	16	1998
9	2	-99.00	-99.000	-99.000	-99.000	0.000	-99.000	-99.000	-99.000	-99.000	-99.000	6	16	1998
9	3	-99.00	7.895	8.608	0.001	-0.007	-99.000	-99.000	-99.000	-99.000	-99.000	6	16	1998
10	1	30.23	7.473	7.928	0.000	-0.003	2.39	-99.000	131.4	4.3	10.7	6	16	1998
11	1	39.81	2.043	2.402	0.002	0.156	2.58	-99.000	-99.000	-99.000	-99.000	6	16	1998
12	1	43.70	0.151	0.007	0.002	0.312	2.79	-99.000	119.9	0.4	12.0	6	16	1998
13	1	-99.00	9.522	10.705	0.000	-0.001	6.87	-99.000	189.3	3.5	11.5	6	16	1998
13	3	-99.00	9.938	10.652	0.003	0.004	-99.000	-99.000	-99.000	-99.000	-99.000	6	16	1998
13	2	-99.00	-99.000	-99.000	-99.000	-0.001	-99.000	-99.000	-99.000	-99.000	-99.000	6	16	1998
14	1	24.22	18.260	20.657	0.000	-0.012	10.30	-99.000	256.2	4.6	12.2	6	16	1998
15	1	26.20	3.970	4.293	0.000	0.000	4.53	-99.000	118.0	2.6	10.9	6	16	1998
16	1	-99.00	8.253	9.813	0.002	0.004	5.89	-99.000	164.2	5.4	12.3	6	16	1998
17	1	-99.00	9.459	10.594	0.006	-0.002	8.22	-99.000	223.4	2.4	15.1	6	16	1998
17	2	-99.00	9.089	-99.000	-99.000	-99.000	8.07	-99.000	-99.000	-99.000	-99.000	6	16	1998
18	1	26.56	10.687	13.382	0.000	0.002	9.68	-99.000	203.0	4.5	11.3	6	16	1998
19	1	12.83	1.650	2.194	0.000	-0.001	2.17	-99.000	95.8	6.3	13.1	6	16	1998
20	1	14.30	1.575	2.398	0.000	-0.007	6.27	-99.000	182.0	3.1	11.5	6	16	1998
20	2	-99.00	-99.000	2.352	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	6	16	1998

Well #	Type	Corrected SWL	T.Nitrogen	Nitrate+Nitrite	Nitrite	Ammonia	Chloride	pH	Cond	D.O.	Temp	Month	Day	Year
		feet	mg N/L	mg N/L	mg N/L	mg N/L	mg/L		umhos/cm	mg/L	C			
21	1	19.17	-0.106	0.012	0.000	-0.005	23.21	-99.000	288.4	2.3	15.0	6	16	1998
22	1	-99.00	6.623	7.238	0.000	-0.002	-99.000	-99.000	-99.000	-99.000	-99.000	6	16	1998
23	1	-99.00	1.088	0.119	0.000	0.003	-99.000	-99.000	-99.000	-99.000	-99.000	6	16	1998
26	1	-99.00	7.075	8.053	0.001	-0.002	11.87	-99.000	-99.000	-99.000	-99.000	6	16	1998
1	1	6.12	12.839	12.192	0.002	0.010	5.71	5.836	192.300	5.280	15.200	7	18	1998
2	1	24.75	13.816	12.737	0.001	0.011	3.91	5.546	186.3	5.47	11.5	7	18	1998
3	1	26.12	0.159	0.002	0.008	0.036	4.98	6.328	151.0	0.23	14.5	7	18	1998
4	1	-99.00	1.705	1.817	0.003	0.005	3.19	5.474	82.8	3.43	15.0	7	18	1998
5	1	65.38	14.373	13.620	0.000	0.001	11.24	6.320	236.8	3.28	12.5	7	18	1998
5	3	-99.00	13.636	14.181	0.001	0.004	-99.000	-99.000	-99.000	-99.000	-99.000	7	18	1998
7	1	39.22	9.369	8.673	0.000	0.002	4.19	5.988	137.9	4.18	12.2	7	18	1998
7	2	-99.00	-99.000	8.700	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	7	19	1998
8	1	31.83	1.237	1.107	0.000	0.002	2.46	5.612	71.9	5.47	11.7	7	18	1998
8	2	-99.00	1.105	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	7	19	1998
9	1	-99.00	8.242	7.437	0.005	-0.001	7.73	5.682	140.8	1.06	12.8	7	18	1998
10	1	31.03	11.173	10.630	0.001	0.002	2.70	5.755	146.9	5.48	12.9	7	18	1998
10	2	-99.00	-99.000	-99.000	-99.000	-99.000	2.73	-99.000	-99.000	-99.000	-99.000	7	19	1998
11	1	54.21	3.725	3.484	0.006	0.133	2.59	6.183	113.9	4.35	12.4	7	18	1998
12	1	44.15	0.260	0.003	0.000	0.308	2.85	6.497	124.4	0.18	13.2	7	18	1998
13	1	-99.00	9.980	9.582	0.001	0.003	6.78	5.788	188.400	4.2	12.40	7	18	1998
13	2	-99.00	-99.000	-99.000	-99.000	0.008	-99.000	-99.000	-99.000	-99.000	-99.000	7	19	1998
14	1	24.67	20.535	19.730	0.001	0.004	9.92	5.812	275.2	4.35	14.7	7	18	1998
15	1	26.80	6.060	5.930	0.001	0.068	5.81	5.941	140.9	4.45	12.9	7	19	1998
16	1	-99.00	10.507	10.400	0.010	0.009	6.93	5.100	179.8	4.50	14.1	7	19	1998
16	2	-99.00	-99.000	-99.000	-99.000	0.005	-99.000	-99.000	-99.000	-99.000	-99.000	7	19	1998
17	1	29.58	9.177	9.309	0.009	0.010	6.94	6.279	218.5	5.48	17.3	7	19	1998
17	2	-99.00	8.338	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	7	19	1998
18	1	27.36	13.762	13.781	0.001	0.009	9.24	-99.000	210.1	5.58	13.4	7	19	1998
18	3	-99.00	12.312	13.486	0.001	0.001	-99.000	-99.000	-99.000	-99.000	-99.000	7	19	1998
19	1	13.35	1.918	2.049	0.005	0.011	2.24	6.630	99.9	5.87	16.5	7	19	1998
19	2	-99.00	-99.000	1.961	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	7	19	1998
20	1	14.56	2.392	2.433	0.001	0.003	6.41	6.678	180.7	3.48	12.2	7	19	1998
20	2	-99.00	-99.000	-99.000	-99.000	-99.000	6.36	-99.000	-99.000	-99.000	-99.000	7	19	1998
21	1	19.62	-0.114	0.011	0.001	0.002	21.11	6.400	333.4	0.55	17.0	7	18	1998
22	1	-99.00	5.419	5.977	0.000	0.008	-99.000	-99.000	-99.000	-99.000	-99.000	7	18	1998
23	1	-99.00	1.229	1.430	0.001	0.017	-99.000	-99.000	-99.000	-99.000	-99.000	7	18	1998
26	1	-99.00	5.347	6.470	0.010	0.004	-99.000	-99.000	-99.000	-99.000	-99.000	7	19	1998
27	1	-99.00	-0.050	0.045	0.011	0.065	-99.000	-99.000	-99.000	-99.000	-99.000	7	19	1998
1	1	7.50	12.888	12.592	0.001	-0.002	5.96	-99.000	188.5	3.76	14.8	8	12	1998
2	1	25.81	13.045	13.376	0.001	0.037	3.9	-99.000	181.2	4.46	11.1	8	12	1998
2	3	-99.00	13.513	12.855	0.001	-0.019	-99.000	-99.000	-99.000	-99.000	-99.000	8	12	1998
2	2	-99.00	-99.000	12.96	-99	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	8	12	1998
3	1	27.22	-0.048	0.018	0.005	0.03	4.91	-99.000	154.6	0.29	15.8	8	12	1998
4	1	-99.00	1	1.763	0.001	-0.01	3.19	-99.000	81.8	2.55	15.9	8	12	1998
4	2	-99.00	-99.000	-99	-99	-0.013	-99.000	-99.000	-99.000	-99.000	-99.000	8	12	1998

Well #	Type	Corrected SWL	T.Nitrogen	Nitrate+Nitrite	Nitrite	Ammonia	Chloride	pH	Cond	D.O.	Temp	Month	Day	Year
		feet	mg N/L	mg N/L	mg N/L	mg N/L	mg/L		umhos/cm	mg/L	C			
5	1	56.82	15.057	15.18	0.001	0.09	11.47	-99.000	240.8	3.34	13.1	8	12	1998
5	2	-99.00	-99.000	-99	0.001	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	8	12	1998
7	1	42.92	7.189	7.943	0.002	-0.005	4.43	-99.000	133.7	3.67	13.1	8	12	1998
8	1	33.00	1.18	1.155	0.001	-0.016	2.76	-99.000	78.5	-99.000	14.7	8	12	1998
9	1	-99.00	5.702	6.37	0.001	-0.019	6.75	-99.000	131.1	1.04	12.4	8	12	1998
9	2	-99.00	5.395	-99	-99	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	8	12	1998
10	1	32.13	11.469	11.44	0.002	-0.01	2.77	-99.000	149.8	4.57	13.4	8	12	1998
10	2	-99.00	-99.000	-99	-99	-99.000	2.79	-99.000	-99.000	-99.000	-99.000	8	13	1998
11	1	42.21	5.474	5.389	0.01	0.143	2.48	-99.000	128.6	2.68	13.4	8	12	1998
12	1	45.65	0.236	0.006	0.001	0.41	2.88	-99.000	126.1	0.31	14.4	8	12	1998
13	1	-99.00	8.37	9.5	0.002	-0.01	7.46	-99.000	187.3	3.22	12.8	8	12	1998
14	1	25.02	20.861	21.027	0.001	-0.019	9.81	-99.000	271.2	4.03	14.5	8	12	1998
15	1	27.10	7.137	7.398	0.001	0.017	6.66	-99.000	162.3	4.83	14.4	8	12	1998
17	1	-99.00	8.779	9.032	0.002	-0.016	-99	-99.000	224.1	2.46	18.9	8	13	1998
17	3	-99.00	8.79	9.179	0.002	-0.019	-99.000	-99.000	-99.000	-99.000	-99.000	8	13	1998
18	1	28.56	15.082	14.703	0.001	-0.014	8.14	-99.000	210.2	3.76	12.7	8	13	1998
19	1	13.89	1.582	2.117	0.001	-0.018	2.09	-99.000	94.4	4.93	14	8	13	1998
19	2	-99.00	1.894	-99	-99	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	8	13	1998
20	1	14.80	1.98	2.307	0.001	-0.017	6.28	-99.000	185.9	4.26	12.4	8	13	1998
20	2	-99.00	-99.000	-99	0.001	-99.000	6.36	-99.000	-99.000	-99.000	-99.000	8	13	1998
21	1	20.47	-0.081	0.017	0.004	0.036	17.44	-99.000	299.3	0.54	19.3	8	12	1998
22	1	-99.00	5.32	5.334	0.001	-0.019	-99.000	-99.000	-99.000	-99.000	-99.000	8	12	1998
23	1	-99.00	2.023	1.925	0.003	-0.003	-99.000	-99.000	-99.000	-99.000	-99.000	8	12	1998
26	1	-99.00	10.624	10.143	0.004	-0.016	7.69	-99.000	-99.000	-99.000	-99.000	8	13	1998
28	1	-99.00	12.877	12.545	0.087	0.126	9.65	-99.000	235.1	0.63	16.6	8	13	1998
28	2	-99.00	-99.000	12.85	-99	0.144	-99.000	-99.000	-99.000	-99.000	-99.000	8	13	1998
1	1	8.48	13.176	12.010	0.003	0.008	5.87	-99	185.1	3.90	15.0	9	16	1998
1	2	-99.00	-99.00	11.971	-99.00	-99.00	-99.00	-99	-99.00	-99.00	-99.00	9	16	1998
2	1	-99.00	16.030	12.889	0.001	0.011	4.21	-99	188.4	2.73	11.1	9	16	1998
3	1	28.61	-0.020	-0.007	0.003	0.039	4.73	-99	136.6	0.41	13.0	9	16	1998
3	2	-99.00	-99.00	-99.00	0.003	-99.00	-99.00	-99	-99.00	-99.00	-99.00	9	16	1998
4	1	-99.00	1.558	1.571	0.003	0.004	3.14	-99	80.3	3.33	15.8	9	16	1998
5	1	-99.00	16.327	15.158	0.002	0.051	11.82	-99	243.6	3.90	12.7	9	16	1998
7	1	41.71	8.492	8.417	0.002	0.009	4.50	-99	135.4	3.34	12.7	9	16	1998
8	1	49.25	0.866	0.876	0.002	0.011	2.80	-99	70.3	0.84	12.1	9	16	1998
9	1	-99.00	5.063	5.192	0.015	0.008	5.83	-99	118.4	1.04	12.2	9	16	1998
10	1	48.50	11.501	11.164	0.002	0.014	2.53	-99	147.0	4.16	12.4	9	16	1998
10	2	-99.00	-99.00	-99.00	-99.00	0.017	2.49	-99	-99.00	-99.00	-99.00	9	16	1998
10	3	-99.00	12.552	11.482	0.012	0.009	-99.00	-99	-99.00	-99.00	-99.00	9	16	1998
11	1	48.19	6.894	3.195	0.012	0.064	2.27	-99	128.0	2.95	12.9	9	16	1998
12	1	46.56	0.210	-0.001	0.002	0.332	2.81	-99	118.3	0.85	12.9	9	16	1998
13	1	-99.00	8.814	8.719	0.003	0.016	9.21	-99	194.8	2.95	13.0	9	16	1998
13	2	-99.00	9.889	-99.00	-99.00	-99.00	-99.00	-99	-99.00	-99.00	-99.00	9	16	1998
14	1	25.94	19.135	18.446	0.002	0.006	10.21	-99	262.2	3.25	13.3	9	16	1998
15	1	27.79	8.336	8.359	0.002	0.004	7.35	-99	169.4	1.77	12.8	9	16	1998

Well #	Type	Corrected SWL feet	T.Nitrogen mg N/L	Nitrate+Nitrite mg N/L	Nitrite mg N/L	Ammonia mg N/L	Chloride mg/L	pH	Cond umhos/cm	D.O. mg/L	Temp C	Month	Day	Year
17	1	30.77	9.277	9.246	0.003	0.004	6.75	-99	209.9	2.75	17.2	9	17	1998
17	2	-99.00	-99.00	-99.00	0.002	-99.00	-99.00	-99	-99.00	-99.00	-99.00	9	16	1998
18	1	29.48	15.601	14.051	0.004	0.007	6.09	-99	194.8	2.74	11.9	9	17	1998
18	2	-99.00	15.650	-99.00	-99.00	-99.00	-99.00	-99	-99.00	-99.00	-99.00	9	16	1998
19	1	14.35	1.855	2.122	0.002	0.005	1.93	-99	95.7	3.66	16.2	9	17	1998
20	1	15.06	2.331	2.501	0.002	0.011	6.51	-99	179.0	2.73	11.7	9	17	1998
20	2	-99.00	-99.00	2.496	-99.00	-99.00	6.42	-99	-99.00	-99.00	-99.00	9	17	1998
21	1	21.25	-0.066	0.003	0.005	0.049	17.32	-99	317.5	0.41	17.3	9	17	1998
22	1	-99.00	4.917	5.065	0.002	0.007	-99.00	-99	-99.00	-99.00	-99.00	9	16	1998
22	2	-99.00	-99.00	-99.00	-99.00	0.009	-99.00	-99	-99.00	-99.00	-99.00	9	16	1998
23	1	-99.00	1.891	1.835	0.004	0.020	-99.00	-99	-99.00	-99.00	-99.00	9	16	1998
26	1	-99.00	12.391	11.504	0.007	0.012	7.97	-99	-99.00	-99.00	-99.00	9	17	1998
28	1	-99.00	14.201	13.455	0.136	0.219	10.15	-99	223.6	3.31	12.0	9	16	1998
28	3	-99.00	14.344	13.515	0.002	0.173	-99.00	-99	-99.00	-99.00	-99.00	9	16	1998
1	1	8.42	13.091	12.042	0.001	0.031	5.69	-99	178.0	2.83	13.2	10	14	1998
2	1	27.17	16.204	13.810	0.000	0.006	4.13	-99	182.4	2.90	10.3	10	14	1998
3	1	28.69	0.046	-0.022	0.007	0.033	4.75	-99	147.3	3.20	11.2	10	14	1998
4	1	-99.00	0.887	1.761	0.001	0.001	3.14	-99	78.8	2.56	14.3	10	14	1998
5	1	-99.00	17.268	16.137	0.003	0.213	11.51	-99	237.5	2.02	11.4	10	14	1998
5	2	-99.00	-99.00	16.188	-99.00	-99.00	-99.00	-99	-99.00	-99.00	-99.00	10	14	1998
7	1	37.27	10.473	8.692	0.001	0.003	4.42	-99	131.3	2.32	10.8	10	14	1998
7	2	-99.00	8.339	-99.00	-99.00	-99.00	-99.00	-99	-99.00	-99.00	-99.00	10	14	1998
8	1	34.58	0.946	0.959	0.001	0.003	2.97	-99	68.4	0.84	10.4	10	14	1998
9	1	-99.00	5.165	5.348	0.003	0.007	5.73	-99	113.6	2.87	11.3	10	14	1998
10	1	34.08	11.501	11.906	0.000	0.013	2.31	-99	146.0	3.42	10.8	10	14	1998
10	3	-99.00	11.271	12.025	0.001	0.009	2.28	-99	-99.00	-99.00	-99.00	10	14	1998
10	2	-99.00	-99.00	-99.00	-99.00	-99.00	2.31	-99	-99.00	-99.00	-99.00	10	15	1998
11	1	43.94	5.602	5.089	0.012	0.096	2.20	-99	118.4	2.83	11.4	10	14	1998
11	2	-99.00	-99.00	-99.00	-99.00	0.100	-99.00	-99	-99.00	-99.00	-99.00	10	14	1998
12	1	46.77	0.249	-0.001	0.000	0.685	2.86	-99	115.3	0.35	11.3	10	14	1998
12	2	-99.00	-99.00	-99.00	0.000	-99.00	-99.00	-99	-99.00	-99.00	-99.00	10	14	1998
13	1	-99.00	6.507	8.771	0.000	0.007	8.31	-99	182.6	2.21	10.8	10	14	1998
14	1	26.08	18.842	19.880	0.000	0.008	9.81	-99	260.1	2.02	11.8	10	14	1998
15	1	28.06	8.299	9.195	0.001	0.014	7.49	-99	170.7	1.18	11.0	10	15	1998
15	2	-99.00	-99.00	9.066	-99.00	-99.00	-99.00	-99	-99.00	-99.00	-99.00	10	15	1998
17	1	31.83	9.651	9.782	0.001	0.004	6.93	-99	198.4	1.29	12.9	10	15	1998
17	2	-99.00	-99.00	-99.00	-99.00	0.017	-99.00	-99	-99.00	-99.00	-99.00	10	15	1998
18	1	29.63	15.324	14.994	0.001	0.007	5.99	-99	198.1	1.54	11.5	10	15	1998
18	2	-99.00	15.904	-99.00	-99.00	-99.00	-99.00	-99	-99.00	-99.00	-99.00	10	15	1998
19	1	14.39	1.265	1.912	0.004	0.011	1.90	-99	86.2	1.64	11.8	10	15	1998
20	1	14.75	1.951	2.410	0.000	0.005	6.05	-99	176.6	1.46	11.1	10	15	1998
20	3	-99.00	2.023	2.429	0.000	0.019	6.00	-99	-99.00	-99.00	-99.00	10	15	1998
20	2	-99.00	-99.00	-99.00	-99.00	-99.00	6.20	-99	-99.00	-99.00	-99.00	10	15	1998
21	1	21.67	-0.077	0.015	0.017	0.059	23.93	-99	309.0	2.18	13.6	10	14	1998
22	1	-99.00	4.239	5.557	0.000	0.012	-99.00	-99	-99.00	-99.00	-99.00	10	14	1998

Well #	Type	Corrected SWL feet	T.Nitrogen mg N/L	Nitrate+Nitrite mg N/L	Nitrite mg N/L	Ammonia mg N/L	Chloride mg/L	pH	Cond umhos/cm	D.O. mg/L	Temp C	Month	Day	Year
22	2	-99.00	-99.00	-99.00	0.000	-99.00	-99.00	-99	-99.00	-99.00	-99.00	10	15	1998
23	1	-99.00	1.603	1.667	0.001	0.013	-99.00	-99	-99.00	-99.00	-99.00	10	14	1998
26	1	-99.00	6.296	6.685	0.039	0.043	-99.00	-99	-99.00	-99.00	-99.00	10	15	1998
28	1	-99.00	12.819	14.143	0.053	0.061	9.48	-99	227.7	0.27	12.7	10	15	1998
1	1	9.10	12.471	12.080	0.001	0.000	6.04	6.275	182.5	4.96	11.7	11	10	1998
2	1	27.46	13.488	13.066	0.000	0.022	4.67	6.321	195.5	5.65	10.0	11	10	1998
3	1	29.17	0.078	-0.005	0.028	0.029	4.93	6.854	142.3	0.12	9.6	11	10	1998
3	3	-99.00	0.095	-0.005	0.0166	0.020	-99.00	-99.00	-99.00	-99.00	-99.00	11	10	1998
4	1	-99.00	1.420	1.765	0.003	0.000	2.92	5.786	78.0	9.80	13.8	11	10	1998
4	2	-99.00	-99.00	-99.00	-99.00	0.013	-99.00	-99.00	-99.00	-99.00	-99.00	11	10	1998
5	1	-99.00	13.263	14.921	0.001	0.316	11.80	6.612	228.2	3.37	10.1	11	10	1998
7	1	43.69	8.242	9.206	0.001	0.026	4.21	6.341	129.9	5.21	10.6	11	10	1998
8	1	35.92	1.669	1.685	0.001	-0.002	3.29	5.898	75.9	0.72	10.0	11	10	1998
8	2	-99.00	1.592	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	11	10	1998
9	1	-99.00	5.972	6.521	0.002	0.002	6.01	5.913	120.7	1.18	10.7	11	10	1998
10	1	34.46	12.575	12.320	0.001	0.001	1.96	5.967	140.5	6.63	10.1	11	10	1998
10	2	-99.00	-99.00	-99.00	-99.00	-0.002	1.98	-99.00	-99.00	-99.00	-99.00	11	10	1998
11	1	44.46	4.820	5.068	0.016	0.073	2.02	6.314	115.4	4.25	11.2	11	10	1998
11	2	-99.00	-99.00	-99.00	0.0163	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	11	10	1998
12	1	47.21	0.216	-0.001	0.001	0.038	2.55	6.772	112.0	0.13	10.4	11	10	1998
13	1	-99.00	7.936	8.939	0.001	0.003	8.02	6.078	180.1	4.11	10.7	11	10	1998
14	1	26.31	17.859	19.645	0.000	0.003	9.95	6.225	250.2	5.50	10.6	11	10	1998
14	2	-99.00	-99.00	-99.00	-99.00	-0.004	-99.00	-99.00	-99.00	-99.00	-99.00	11	10	1998
15	1	28.02	9.280	9.856	0.000	0.003	7.96	6.150	172.3	1.68	9.8	11	10	1998
17	1	60.75	9.271	10.030	0.001	0.011	7.09	6.427	181.1	2.18	9.9	11	11	1998
18	1	-99.00	14.116	15.162	0.007	0.004	6.31	6.241	190.2	5.20	10.2	11	11	1998
18	2	-99.00	-99.00	15.162	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	11	11	1998
19	1	14.46	1.388	3.283	0.005	0.014	1.67	7.008	79.3	6.03	10.0	11	11	1998
19	3	-99.00	1.432	1.508	0.004	0.031	-99.00	-99.00	-99.00	-99.00	-99.00	11	11	1998
20	1	14.50	1.989	1.868	0.000	0.008	6.20	7.251	171.7	3.09	10.2	11	11	1998
20	2	-99.00	-99.00	2.451	-99.00	-99.00	6.10	-99.00	-99.00	-99.00	-99.00	11	11	1998
21	1	-99.00	-0.023	0.008	0.000	0.000	39.17	6.540	336.2	0.21	12.2	11	11	1998
21	2	-99.00	-99.00	-99.00	0.000	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	11	11	1998
22	1	-99.00	6.857	7.050	0.000	0.000	-99.00	-99.00	-99.00	-99.00	-99.00	11	10	1998
22	2	-99.00	6.891	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	11	11	1998
23	1	-99.00	1.612	2.393	0.001	0.021	-99.00	-99.00	-99.00	-99.00	-99.00	11	10	1998
26	1	-99.00	5.076	5.447	0.054	0.026	15.66	-99.00	-99.00	-99.00	-99.00	11	11	1998
28	1	-99.00	14.233	13.890	0.028	0.027	-99.00	6.289	210.4	0.45	10.1	11	11	1998
1	1	6.29	11.644	12.051	0.006	0.001	6.49	6.064	183.3	3.82	11.2	12	10	1998
2	1	25.38	14.006	13.602	0.001	-0.001	5.44	6.218	195.5	5.58	10.5	12	10	1998
3	1	27.08	0.071	-0.012	0.008	0.024	4.92	6.591	133.4	0.20	8.9	12	10	1998
4	1	-99.00	2.030	1.366	0.002	0.000	2.82	5.680	84.4	0.65	13.0	12	10	1998
4	2	-99.00	-99.00	-99.00	-99.00	0.002	-99.00	-99.00	-99.00	-99.00	-99.00	12	10	1998
5	1	-99.00	12.979	13.860	0.001	0.028	11.71	6.553	218.0	3.62	9.2	12	10	1998
7	1	42.98	9.281	9.455	0.004	0.001	3.95	6.353	128.8	4.84	9.7	12	10	1998

Well #	Type	Corrected SWL feet	T.Nitrogen mg N/L	Nitrate+Nitrite mg N/L	Nitrite mg N/L	Ammonia mg N/L	Chloride mg/L	pH	Cond umhos/cm	D.O. mg/L	Temp C	Month	Day	Year
8	1	33.21	-99.00	3.065	0.001	0.001	3.82	5.798	83.0	0.87	9.6	12	10	1998
8	2	-99.00	0.045	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	12	10	1998
8	3	-99.00	1.328	3.067	0.002	-0.002	3.80	-99.00	-99.00	-99.00	-99.00	12	10	1998
9	1	-99.00	5.804	5.750	0.000	-0.006	5.67	5.861	116.0	1.25	10.6	12	10	1998
9	2	-99.00	-99.00	5.664	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	12	10	1998
10	1	33.67	-99.00	11.749	0.001	0.005	1.75	6.009	138.1	7.50	9.5	12	10	1998
11	1	44.08	3.431	2.726	0.032	0.050	2.19	6.410	111.5	1.65	10.4	12	10	1998
11	2	-99.00	-99.00	-99.00	-99.00	-99.00	2.17	-99.00	-99.00	-99.00	-99.00	12	10	1998
12	1	41.38	0.313	-0.004	0.001	0.316	2.60	6.623	108.9	0.23	9.6	12	10	1998
13	1	-99.00	6.352	8.362	0.001	-99.000	7.22	6.056	170.5	4.84	10.0	12	10	1998
14	1	25.31	-99.00	18.185	0.001	-0.003	9.39	6.067	233.1	3.55	9.3	12	10	1998
14	2	-99.00	-99.00	-99.00	0.0007	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	12	10	1998
15	1	25.69	7.148	7.655	0.002	-0.003	5.00	6.377	136.3	4.53	8.3	12	11	1998
17	1	29.46	9.332	10.301	0.004	0.003	7.41	6.553	173.5	1.67	7.1	12	11	1998
18	1	-99.00	13.674	14.738	0.003	0.000	6.66	6.353	186.3	5.78	9.3	12	11	1998
19	1	13.65	1.415	1.856	0.002	0.014	1.63	6.722	81.5	6.56	8.7	12	11	1998
19	2	-99.00	1.560	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	12	11	1998
20	1	13.29	2.423	2.345	0.001	0.004	6.14	6.935	170.3	2.60	9.4	12	11	1998
21	1	21.04	0.041	0.014	0.015	0.034	24.71	6.801	274.7	0.12	10.2	12	11	1998
21	3	-99.00	1.379	0.017	0.0182	0.034	24.60	-99.00	-99.00	-99.00	-99.00	12	11	1998
21	2	-99.00	-99.00	-99.00	-99.00	-99.00	24.80	-99.00	-99.00	-99.00	-99.00	12	11	1998
22	1	-99.00	-99.00	9.030	0.001	-0.009	-99.00	-99.00	-99.00	-99.00	-99.00	12	10	1998
22	2	-99.00	-99.00	-99.00	0.0013	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	12	11	1998
23	1	-99.00	1.227	1.370	0.003	0.001	-99.00	-99.00	-99.00	-99.00	-99.00	12	10	1998
23	2	-99.00	-99.00	-99.00	-99.00	0.003	-99.00	-99.00	-99.00	-99.00	-99.00	12	11	1998
26	1	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	12	11	1998
28	1	-99.00	12.104	13.457	0.028	0.021	9.64	6.503	210.1	0.4	9.3	12	11	1998
28	2	-99.00	-99.00	13.424	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	12	11	1998
1	1		9.252	9.770	0.002	-0.013	4.37	6.044	148.2	7.17	8.7	1	18	99
1	2		9.372	-99.000	-99.000	-99.000	-99	-99	-99	-99	-99	1	19	99
2	1		12.729	13.723	0.002	-0.021	5.37	6.174	191.5	7.57	10.7	1	18	99
2	3		9.441	13.859	0.002	-0.018	5.60	-99	-99	-99	-99	1	18	99
3	1		0.030	-0.005	0.002	0.014	4.69	6.934	134.6	0.16	7.9	1	18	99
4	1		1.192	1.436	0.003	-0.015	1.95	5.913	70.6	3.66	14.0	1	18	99
5	1		12.130	13.745	0.002	0.001	11.95	6.645	215.6	3.14	8.3	1	18	99
7	1		4.508	5.524	0.003	-0.021	3.95	6.383	113.0	1.88	9.8	1	18	99
8	1		3.170	3.614	0.003	-0.019	4.24	5.860	88.6	1.46	9.7	1	18	99
8	2		-99.000	3.543	-99.000	-99.000	-99	-99	-99	-99	-99	1	18	99
9	1		3.765	4.143	0.005	0.032	4.76	5.917	107.3	1.07	10.3	1	18	99
9	2		-99.000	-99.000	0.006	-99.000	4.77	-99	-99	-99	-99	1	19	99
10	1		10.291	11.254	0.003	-0.011	2.32	5.941	141.7	6.85	9.8	1	18	99
11	1		0.230	-0.015	0.010	0.053	2.54	6.416	92.9	0.50	10.4	1	18	99
11	2		-99.000	-99.000	-99.000	0.057	-99.00	-99	-99	-99	-99	1	19	99
12	1		0.277	-0.007	0.003	0.272	2.71	6.730	108.4	0.24	9.5	1	18	99
13	1		7.505	8.801	0.002	-0.013	6.90	6.108	165.9	5.20	10.1	1	18	99

Well #	Type	Corrected SWL feet	T.Nitrogen mg N/L	Nitrate+Nitrite mg N/L	Nitrite mg N/L	Ammonia mg N/L	Chloride mg/L	pH	Cond umhos/cm	D.O. mg/L	Temp C	Month	Day	Year
14	1		17.031	20.174	0.002	-0.013	10.27	6.064	237.7	3.70	9.0	1	18	99
14	2		19.806	-99.000	-99.000	-99.000	-99.00	-99	-99	-99	-99	1	19	99
15	1		-99.000	-99.000	-99.000	-99.000	-99.00	-99	-99	-99	-99	1	18	99
17	1		9.418	10.999	0.002	-0.009	8.24	6.551	178.5	1.62	6.4	1	19	99
17	2		-99.000	-99.000	0.002	-99.000	-99.00	-99	-99	-99	-99	1	19	99
17	3		4.462	10.864	0.002	-0.012	8.00	-99	-99	-99	-99	1	19	99
18	1		13.103	15.503	0.002	-0.014	5.90	6.067	185.0	5.59	9.4	1	19	99
19	1		1.674	1.784	0.003	-0.014	1.74	6.795	74.4	6.80	7.5	1	19	99
20	1		2.339	2.503	0.002	-0.016	6.20	6.988	164.2	3.21	8.7	1	18	99
20	2		-99.000	2.388	-99	-99.000	-99.00	-99	-99	-99	-99	1	19	99
21	1		0.047	0.011	0.002	-0.017	51.57	6.836	381.5	0.14	9.9	1	18	99
22	1		8.528	10.306	0.002	-0.015	-99.00	-99	-99	-99	-99	1	18	99
22	2		-99.000	-99.000	-99	-0.017	-99.00	-99	-99	-99	-99	1	19	99
23	1		1.989	2.250	0.002	-0.014	-99.00	-99	-99	-99	-99	1	18	99
26	1		-99.000	-99.000	-99.000	-99.000	-99.00	-99	-99	-99	-99	1	19	99
28	1		7.471	11.644	0.075	0.078	8.58	6.201	201.2	0.38	9.1	1	19	99
28	2		-99.000	-99.000	-99	-99.000	8.63	-99	-99	-99	-99	1	19	99

SWL = Static Water Level
D.O. = Dissolved Oxygen
Temp C = Temperature in degrees Celsius
Cond = Conductivity

APPPENDIX C.   WELL LOGS USED IN GEOLOGIC CROSS SECTIONS

Well ID	T	R	Sec.	1/4 1/4 Sec.	Depth (feet)	Drilling Company	Date Completed	Casing Size	Casing Material
A1	41N	3E	36	SE SE	92	Hayes Drilling	9/22/83	6 inch	Metal
A2	41N	3E	36	SE SE	34	Don Mulka	5/11/51	36 inch	Concrete
A3	40N	3E	1	NE NE	65	Livermore & Sons	7/18/73	6 inch	Metal
A4	40N	3E	1	NE NE	78	Hayes Drilling	6/22/81	8 inch	Metal
A5	40N	3E	1	NE NE	24	Don Mulka	3/11/47		
A6	40N	3E	1	SW SE	15	Riggs	1958	core sample	
A7	40N	4E	6	SW SW	59	B&C Well Drilling	7/29/90	6 inch	Metal
A8	40N	3E	1	SE SE	26	Don Mulka			
9A	40N	3E	12	NE NE	80	B&C Well Drilling	4/16/88	10 inch	Metal
10A	40N	3E	12	NE NE	100	Hayes Drilling	9/27/73	10 inch	Metal
11A	40N	3E	12	SE NE	120	Hayes Drilling	6/21/82	8 inch	Metal
B1	40N	3E	1	SE SW	96	B&C Well Drilling	7/7/92	10 inch	Metal
B2	40N	3E	1	SE SW	30	Harold Zruncken	9/1/53		
B3	40N	4E	6	SW NE	80	Hayes Drilling	9/2/94	8 inch	Metal
C1	41N	3E	36	SW SW	26	Don Mulka	4/18/56	36 inch	Concrete
C2	40N	3E	1	part of NW	50	Holt Drilling	4/9/87	8 inch	Metal
C3	40N	3E	1	NW NW	40	Hayes Drilling	4/28/86	8 inch	Metal
C4	40N	3E	1	NE NW	60	Hayes Drilling	4/25/86	8 inch	Metal
C5	41N	4E	31	SE SW	55	Bezona Well Serv.	6/17/95	8 inch	Metal
C6	40N	4E	6	NE NW	71	Livermore & Sons	6/17/73	6 inch	Metal
C7	40N	4E	6	NW NE	77	Hayes Drilling	11/1/73	6 inch	Metal
C8	40N	4E	6	NW NE	73	Hayes Drilling	12/1/70	10 inch	Metal
C9	41N	4E	31	SW SE	75	B&C Well Drilling	6/19/53	8 inch	Metal
C10	41N	4E	31	SW SE	50	B&C Well Drilling	3/5/87	6 inch	Metal
C11	41N	4E	31	SE SE	71	Livermore & Sons	11/29/51	8 inch	Metal

C12	40N	4E	31	SE SE	69	Hayes Drilling	12/1/69	6 inch	Metal
C13	41N	4E	32	SW SW	78.5	Hayes Drilling	10/20/87	6 inch	Metal
D1	40N	4E	7	NE NW	20	B&C Well Drilling	9/3/87	36 inch	Concrete
D2	40N	4E	7	NW NE	78	Hayes Drilling	11/30/88	8 inch	Metal
D3	40N	4E	7	NE NE	28	Hayes Drilling	5/1/73	6 inch	Metal
E1	41N	4E	32	NW SW	400	Hayes Drilling	9/25/81	6 inch	Metal
E2	41N	4E	32	NW SW	99	B&C Well Drilling	5/21/90	8 inch	Metal
E3	41N	4E	31	SE SE	77	Bezona Well Serv.	12/13/74	6 inch	Metal
E4	40N	4E	5	NW NW	95	Hayes Drilling	7/18/79	8 inch	Metal
E5	40N	4E	6	NE NE	78	Hayes Drilling	9/2/94	6 inch	Metal
E6	40N	4E	6	NE NE	83	Hayes Drilling	6/17/71	10 inch	Metal
E7	40N	4E	5	NW NW	77	Hayes Drilling	7/22/88	8 inch	Metal
E8	40N	4E	5	SW NW	140	Hayes Drilling	7/20/87	8 inch	Metal
E9	40N	4E	5	SW NW	57	B&C Well Drilling	8/19/94	6 inch	Metal
E10	40N	4E	5	SW SW	86			6 inch	Metal
E11	40 N	4E	5	NW SW	39	Hayes Drilling	8/3/73	6 inch	Metal
E12	40N	4E	7	NE NE	90	Hayes Drilling	2/26/87	6 inch	Metal

APPPENDIX D. SIEVE SAMPLE DATA

Sieve Analysis **Sample # 1**

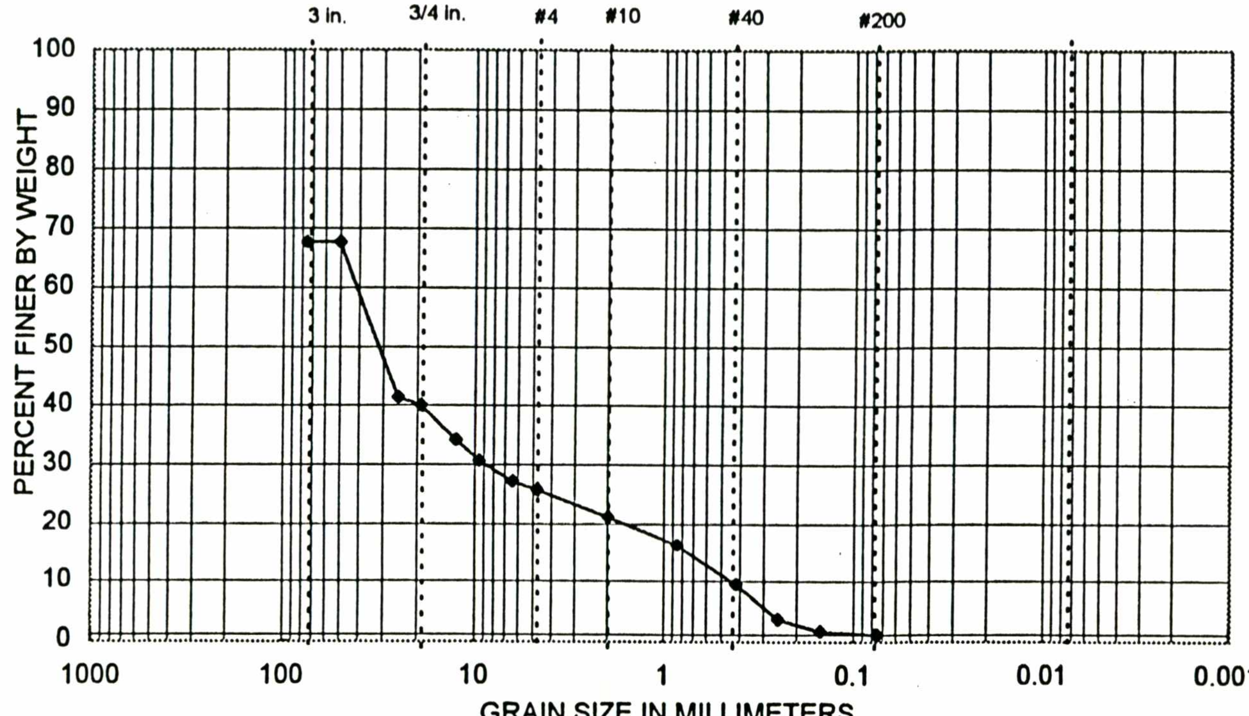
2/4/98

Sieve #	Wt. Dish &Soil	Wt. Soil	Sum Retained	% Retained	Cum % Retained	% finer					Sample:
DISH	204.6										
3"	891.2	686.6	686.6	32.4	32.4	67.6	32.4	% cobbles	32.4	% cobbles	cobbles
2"	891.2	0.0	0.0	0.0	32.4	67.6					
1"	1450.2	559.0	1245.6	26.3	58.7	41.3					
3/4"	1478.6	28.4	1274.0	1.3	60.0	40.0	27.7	% crs grvl			crs grvl
1/2"	1602.7	124.1	1398.1	5.8	65.9	34.1					
3/8"	1675.1	72.4	1470.5	3.4	69.3	30.7					
1/4"	1747.5	72.4	1542.9	3.4	72.7	27.3					
#4	1778.5	31.0	1573.9	1.5	74.2	25.8	14.1	% fi grvl	41.8	% grvl	fi grvl
#10	1875.8	97.3	1671.2	4.6	78.8	21.2	4.6	% crs snd			crs snd
#20	1980.4	104.6	1775.8	4.9	83.7	16.3					
#40	2126.0	145.6	1921.4	6.9	90.6	9.4	11.8	% me snd			me snd
#60	2251.3	125.3	2046.7	5.9	96.5	3.5					
#100	2292.3	41.0	2087.7	1.9	98.4	1.6					
#200	2304.9	12.6	2100.3	0.6	99.0	1.0	8.4	% fi snd	24.8	% snd	fi snd
>200	2326.2	21.3	2121.6	1.0	100.0	0.0	1.0	% slt or cl	1.0	% slt or cl	silt
wet	0.0										clay
		total	2121.6		100.0						

Sample: # 1

US	Metric	%
3"	75	67.6
2"	50	67.6
1"	25	41.3
3/4	19	40.0
1/2"	12.5	34.1
3/8"	9.5	30.7
1/4"	6.35	27.3
#4	4.75	25.8
#10	1.981	21.2
#20	0.85	16.3
#40	0.42	9.4
#60	0.25	3.5
#100	0.15	1.6
#200	0.075	1.0
>200	0.0075	

Sample # 1 Taken 2-4-98 Approximately 10 - 12 feet deep



COBBLES	COARSE GRAVEL	FINE GRAVEL	CRS SAND	MEDIUM SAND	FINE SAND	SILT	CLAY

GP	Poorly graded GRAVEL with sand

Sieve Analysis **Sample # 2**

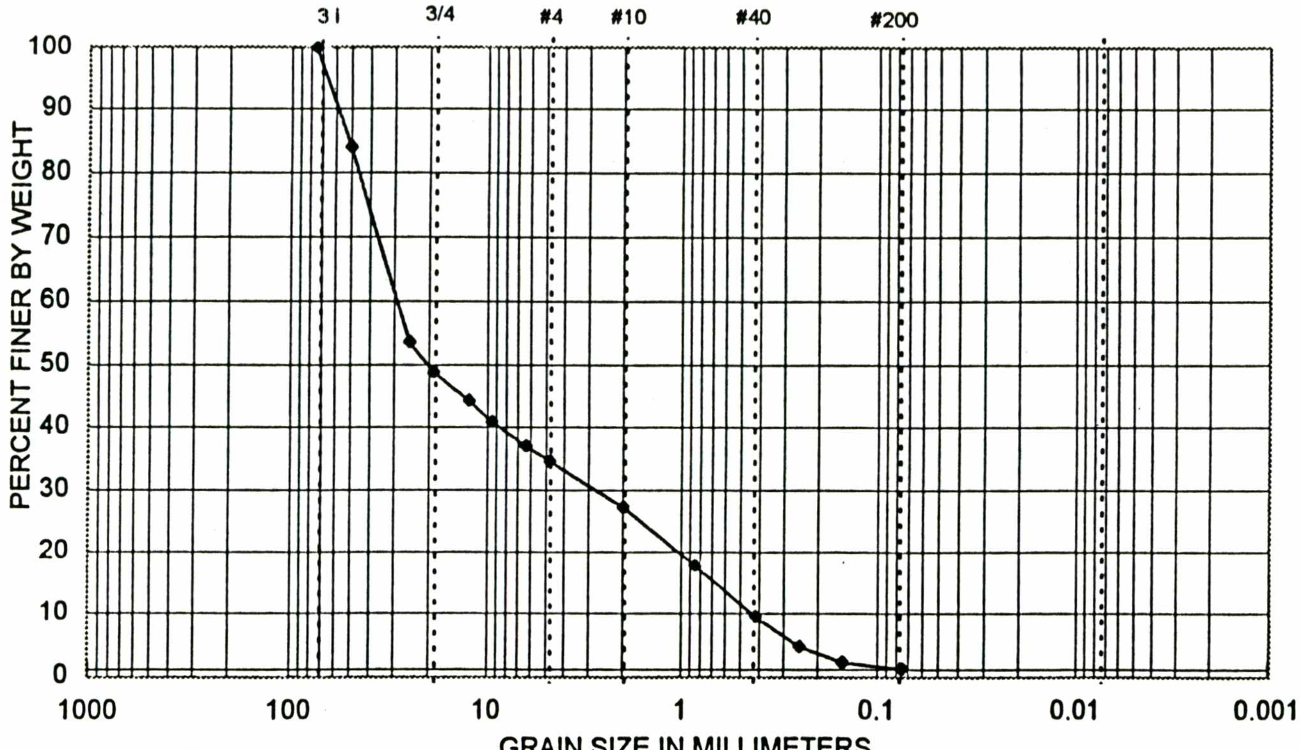
2/4/98

Sieve #	Wt. Dish &Soil	Wt. Soil	Sum Retained	% Retained	Cum % Retained	% finer			
DISH	204.2								
3"	204.2	0.0	0.0	0.0	0.0	100.0	0.0 % cobbles	0.0 % cobbles	cobbles
2"	525.9	321.7	0.0	16.0	16.0	84.0			
1"	1133.9	608.0	929.7	30.3	46.3	53.7			
3/4"	1231.1	97.2	1026.9	4.8	51.2	48.8	51.2 % crs grvl		crs grvl
1/2"	1322.2	91.1	1118.0	4.5	55.7	44.3			
3/8"	1391.7	69.5	1187.5	3.5	59.2	40.8			
1/4"	1470.0	78.3	1265.8	3.9	63.1	36.9			
#4	1517.6	47.6	1313.4	2.4	65.4	34.6	14.3 % fi grvl	65.4 % grvl	fi grvl
#10	1663.3	145.7	1459.1	7.3	72.7	27.3	7.3 % crs snd		crs snd
#20	1852.7	189.4	1648.5	9.4	82.1	17.9			
#40	2020.8	168.1	1816.6	8.4	90.5	9.5	17.8 % me snd		me snd
#60	2117.6	96.8	1913.4	4.8	95.3	4.7			
#100	2167.3	49.7	1963.1	2.5	97.8	2.2			
#200	2188.9	21.6	1984.7	1.1	98.9	1.1	8.4 % fi snd	33.5 % snd	fi snd
>200	2211.0	22.1	2006.8	1.1	100.0	0.0	1.1 % slt or cl	1.1 % slt or cl	silt
wet	0.0								clay
		total	2006.8		100.0				

Sample: # 2

US	Metric	%
3"	75	100.0
2"	50	84.0
1"	25	53.7
3/4	19	48.8
1/2"	12.5	44.3
3/8"	9.5	40.8
1/4"	6.35	36.9
#4	4.75	34.6
#10	1.981	27.3
#20	0.85	17.9
#40	0.42	9.5
#60	0.25	4.7
#100	0.15	2.2
#200	0.075	1.1
>200	0.0075	

Sample # 2 Taken 2-4-98 Approximately 5 - 10 feet deep



COBBLES	COARSE GRAVEL	FINE GRAVEL	CRS SAND	MEDIUM SAND	FINE SAND	SILT	CLAY

GP	Poorly graded GRAVEL with sand

Sieve Analysis **Sample # 3**

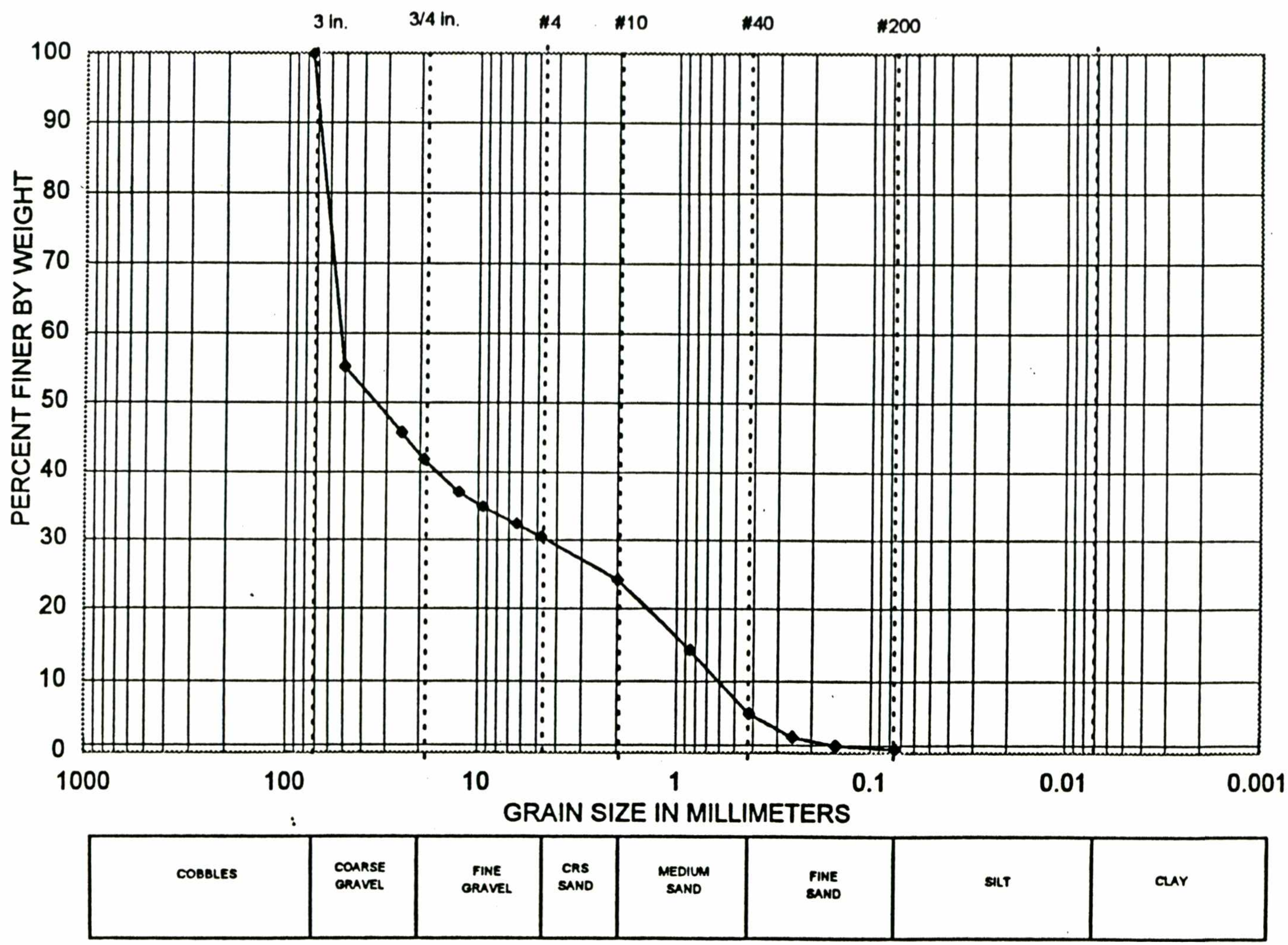
2/4/98

Sieve #	Wt. Dish &Soil	Wt. Soil	Sum Retained	% Retained	Cum % Retained	% finer			
DISH	202.0								
3"	202.0	0.0	0.0	0.0	0.0	100.0	0.0 % cobbles	0.0 % cobbles	cobbles
2"	1133.5	931.5	0.0	44.8	44.8	55.2			
1"	1329.6	196.1	1127.6	9.4	54.3	45.7			
3/4"	1409.7	80.1	1207.7	3.9	58.1	41.9	58.1 % crs grvl		crs grvl
1/2"	1510.0	100.3	1308.0	4.8	63.0	37.0			
3/8"	1554.2	44.2	1352.2	2.1	65.1	34.9			
1/4"	1607.1	52.9	1405.1	2.5	67.6	32.4			
#4	1648.0	40.9	1446.0	2.0	69.6	30.4	11.5 % fi grvl	69.6 % grvl	fi grvl
#10	1777.5	129.5	1575.5	6.2	75.8	24.2	6.2 % crs snd		crs snd
#20	1983.3	205.8	1781.3	9.9	85.8	14.2			
#40	2166.9	183.6	1964.9	8.8	94.6	5.4	18.7 % me snd		me snd
#60	2235.9	69.0	2033.9	3.3	97.9	2.1			
#100	2261.0	25.1	2059.0	1.2	99.1	0.9			
#200	2269.4	8.4	2067.4	0.4	99.5	0.5	4.9 % fi snd	29.9 % snd	fi snd
>200	2279.2	9.8	2077.2	0.5	100.0	0.0	0.5 % slt or cl	0.5 % slt or cl	silt
wet	0.0								clay
		total	2077.2		100.0				

Sample: # 3

US	Metric	%
3"	75	100.0
2"	50	55.2
1"	25	45.7
3/4	19	41.9
1/2"	12.5	37.0
3/8"	9.5	34.9
1/4"	6.35	32.4
#4	4.75	30.4
#10	1.981	24.2
#20	0.85	14.2
#40	0.42	5.4
#60	0.25	2.1
#100	0.15	0.9
#200	0.075	0.5
>200	0.0075	

Sample # 3 Taken 2-4-98 Approximately 2-4 feet deep



Sieve Analysis **Sample # 4**

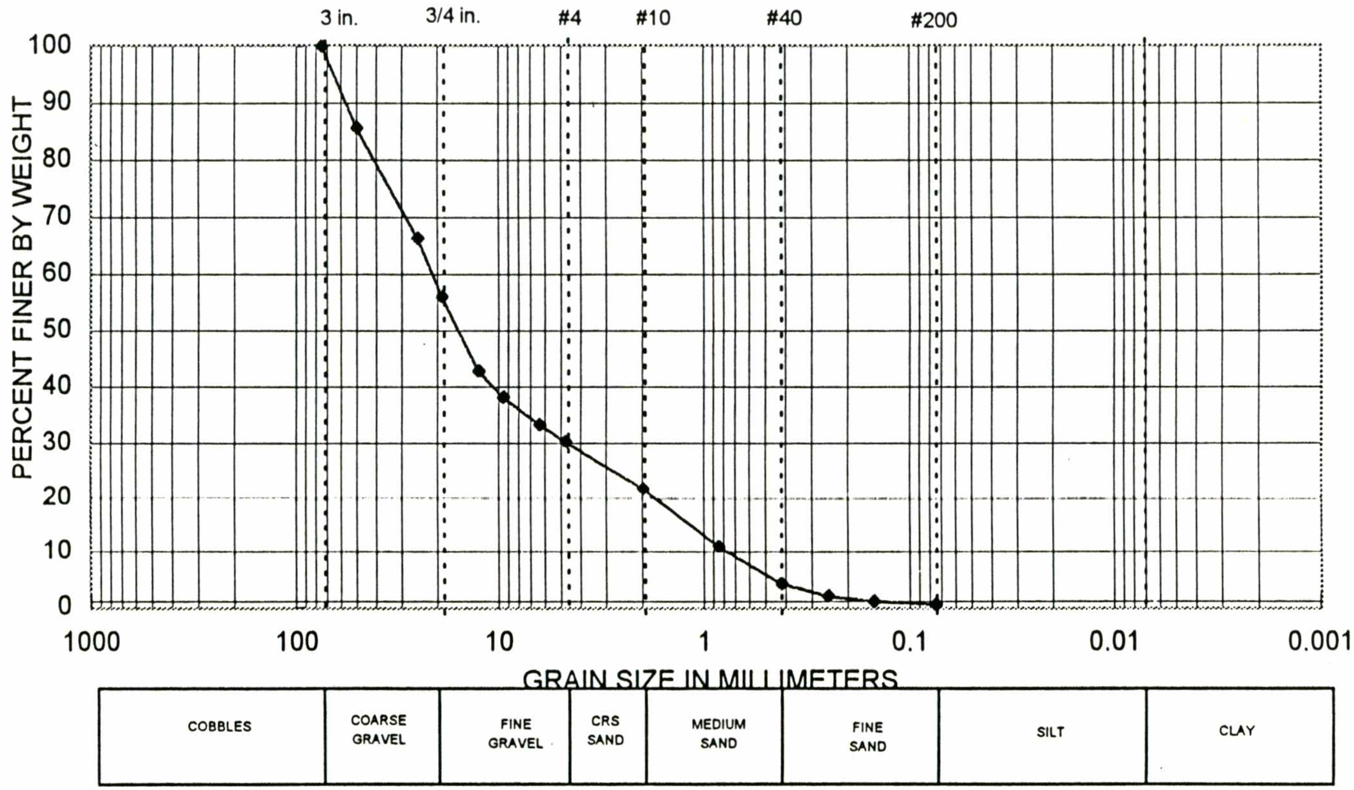
12/18/97

Sieve #	Wt. Dish &Soil	Wt. Soil	Sum Retained	% Retained	Cum % Retained	% finer						Sample:
DISH	204.3											
3"	204.3	0.0	0.0	0.0	0.0	100.0	0.0	% cobbles	0.0	% cobbles	cobbles
2"	596.0	391.7	0.0	14.4	14.4	85.6					
1"	1120.4	524.4	916.1	19.3	33.7	66.3					
3/4"	1400.4	280.0	1196.1	10.3	44.0	56.0	44.0	% crs grvl			crs grvl
1/2"	1757.1	356.7	1552.8	13.1	57.1	42.9					
3/8"	1885.7	128.6	1681.4	4.7	61.9	38.1					
1/4"	2016.1	130.4	1811.8	4.8	66.7	33.3					
#4	2098.9	82.8	1894.6	3.0	69.7	30.3	25.7	% fi grvl	69.7	% grvl	fi grvl
#10	2333.1	234.2	2128.8	8.6	78.3	21.7	8.6	% crs snd			crs snd
#20	2624.4	291.3	2420.1	10.7	89.1	10.9					
#40	2808.9	184.5	2604.6	6.8	95.9	4.1	17.5	% me snd			me snd
#60	2867.3	58.4	2663.0	2.1	98.0	2.0					
#100	2894.4	27.1	2690.1	1.0	99.0	1.0					
#200	2909.4	15.0	2705.1	0.6	99.6	0.4	3.7	% fi snd	29.8	% snd	fi snd
>200	2921.4	12.0	2717.1	0.4	100.0	0.0	0.4	% slt or cl	0.4	% slt or cl	silt
wet	0.0						-100.0	% Moisture			clay
		total	2717.1		100.0						

Sample: # 4

US	Metric	%
3"	75	100.0
2"	50	85.6
1"	25	66.3
3/4	19	56.0
1/2"	12.5	42.9
3/8"	9.5	38.1
1/4"	6.35	33.3
#4	4.75	30.3
#10	1.981	21.7
#20	0.85	10.9
#40	0.42	4.1
#60	0.25	2.0
#100	0.15	1.0
#200	0.075	0.4
>200	0.0075	

Sample #4 12-18-98 Approximately 20 feet deep



GW	Well graded GRAVEL with sand

Sieve Analysis **Sample # 5**

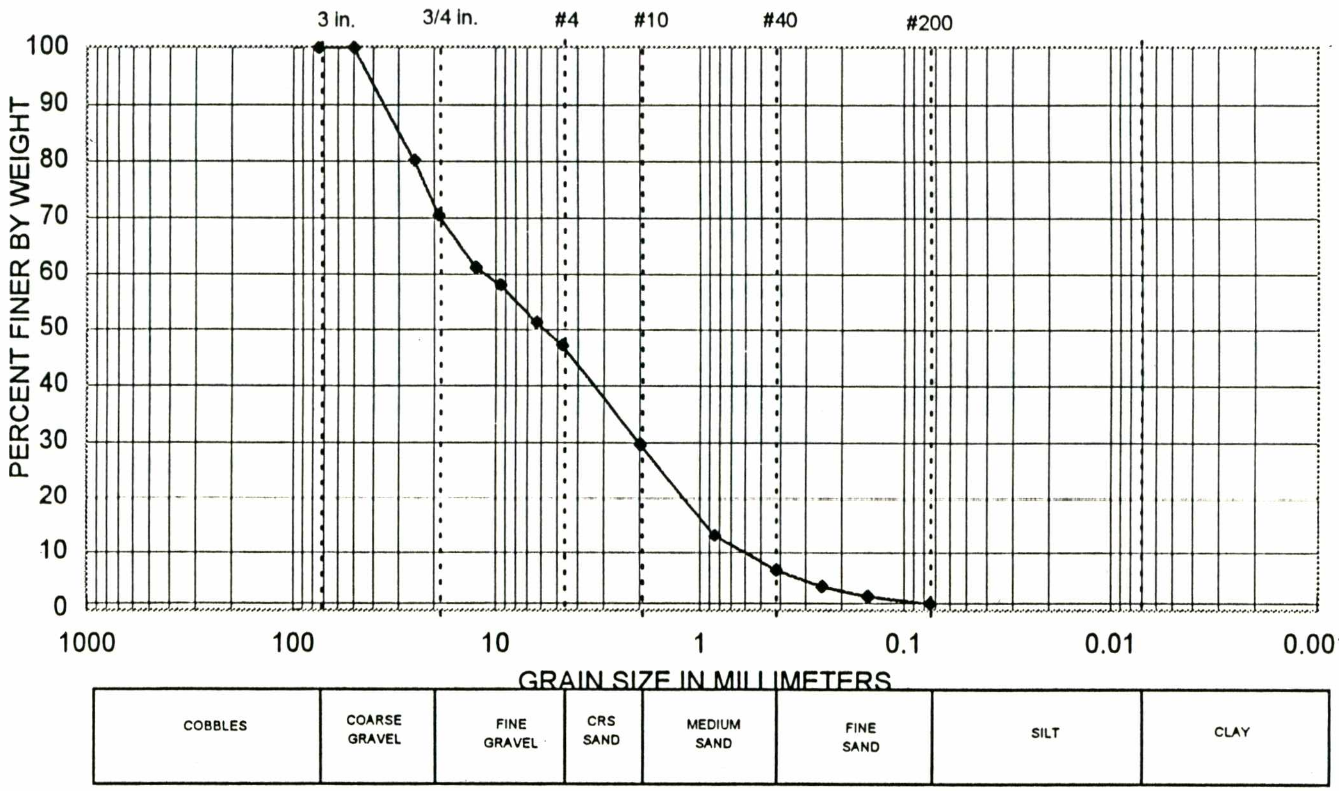
12/18/97

Sieve #	Wt. Dish &Soil	Wt. Soil	Sum Retained	% Retained	Cum % Retained	% finer			
DISH	204.4								
3"	204.4	0.0	0.0	0.0	0.0	100.0	0.0 % cobbles	0.0 % cobbles	cobbles
2"	204.4	0.0	0.0	0.0	0.0	100.0			
1"	349.2	144.8	144.8	19.9	19.9	80.1			
3/4"	420.0	70.8	215.6	9.7	29.6	70.4	29.6 % crs grvl		crs grvl
1/2"	487.2	67.2	282.8	9.2	38.8	61.2			
3/8"	510.7	23.5	306.3	3.2	42.0	58.0			
1/4"	559.4	48.7	355.0	6.7	48.7	51.3			
#4	589.8	30.4	385.4	4.2	52.9	47.1	23.3 % fi grvl	52.9 % grvl	fi grvl
#10	716.4	126.6	512.0	17.4	70.3	29.7	17.4 % crs snd		crs snd
#20	837.4	121.0	633.0	16.6	86.9	13.1			
#40	883.1	45.7	678.7	6.3	93.2	6.8	22.9 % me snd		me snd
#60	903.9	20.8	699.5	2.9	96.0	4.0			
#100	917.2	13.3	712.8	1.8	97.8	2.2			
#200	926.0	8.8	721.6	1.2	99.0	1.0	5.9 % fi snd	46.1 % snd	fi snd
>200	933.0	7.0	728.6	1.0	100.0	0.0	1.0 % slt or cl	1.0 % slt or cl	silt
wet	0.0						-100.0 % Moisture		clay
		total	728.6		100.0				

Sample: # 5

US	Metric	%
3"	75	100.0
2"	50	100.0
1"	25	80.1
3/4	19	70.4
1/2"	12.5	61.2
3/8"	9.5	58.0
1/4"	6.35	51.3
#4	4.75	47.1
#10	1.981	29.7
#20	0.85	13.1
#40	0.42	6.8
#60	0.25	4.0
#100	0.15	2.2
#200	0.075	1.0
>200	0.0075	

Sample # 5 12-18-98 Approximately 20 - 25 feet deep



GP	Poorly graded GRAVEL with sand

Sieve Analysis **Sample # 6**

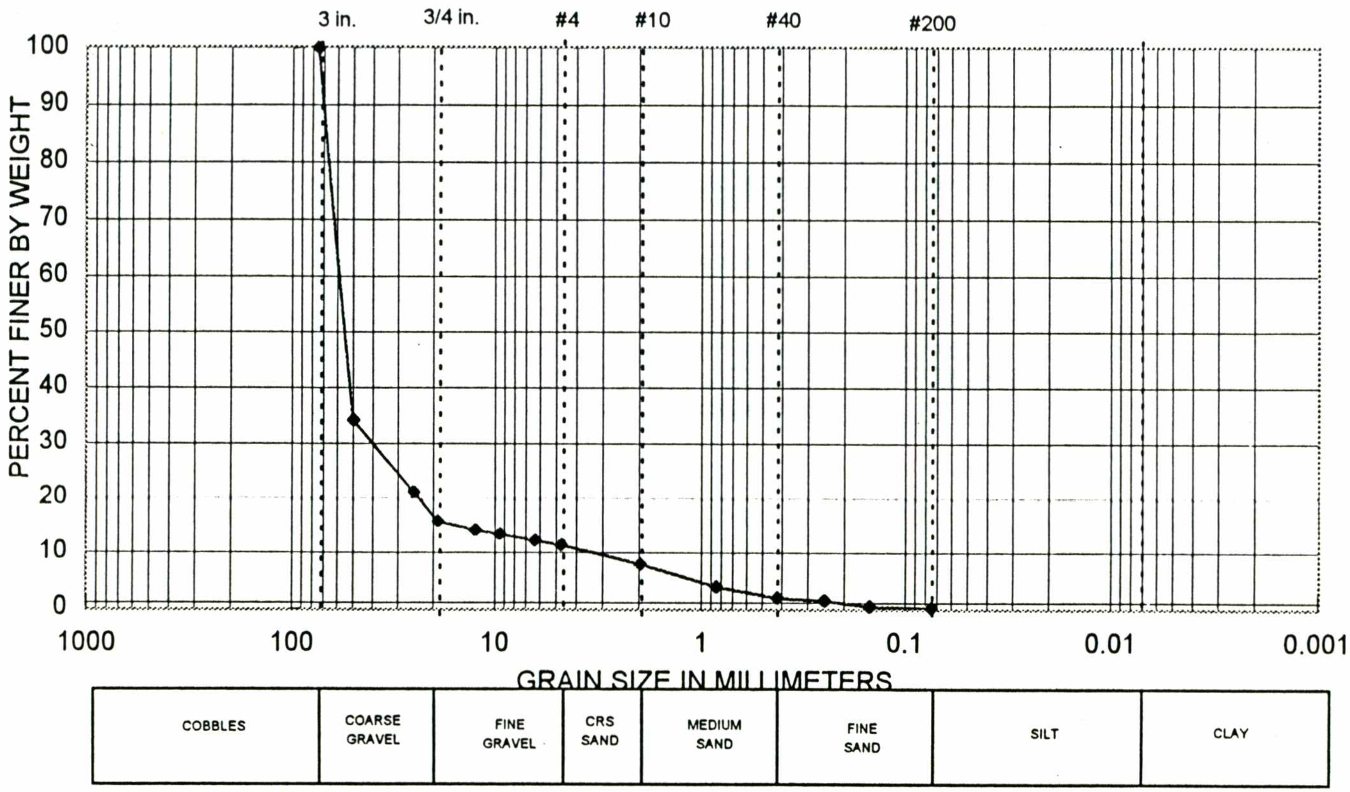
12/18/97

Sieve #	Wt. Dish &Soil	Wt. Soil	Sum Retained	% Retained	Cum % Retained	% finer			
DISH	202.0								
3"	202.0	0.0	0.0	0.0	0.0	100.0	0.0 % cobbles	0.0 % cobbles	cobbles
2"	1806.2	1604.2	0.0	65.8	65.8	34.2			
1"	2126.8	320.6	1924.8	13.1	78.9	21.1			
3/4"	2260.0	133.2	2058.0	5.5	84.4	15.6	84.4 % crs grvl		crs grvl
1/2"	2299.7	39.7	2097.7	1.6	86.0	14.0			
3/8"	2315.2	15.5	2113.2	0.6	86.6	13.4			
1/4"	2344.1	28.9	2142.1	1.2	87.8	12.2			
#4	2363.8	19.7	2161.8	0.8	88.6	11.4	4.3 % fi grvl	88.6 % grvl	fi grvl
#10	2449.6	85.8	2247.6	3.5	92.1	7.9	3.5 % crs snd		crs snd
#20	2548.9	99.3	2346.9	4.1	96.2	3.8			
#40	2594.8	45.9	2392.8	1.9	98.1	1.9	6.0 % me snd		me snd
#60	2607.8	13.0	2405.8	0.5	98.6	1.4			
#100	2632.9	25.1	2430.9	1.0	99.7	0.3			
#200	2638.2	5.3	2436.2	0.2	99.9	0.1	1.8 % fi snd	11.3 % snd	fi snd
>200	2641.1	2.9	2439.1	0.1	100.0	0.0	0.1 % slt or cl	0.1 % slt or cl	silt
wet	0.0						-100.0 % Moisture		clay
		total	2439.1		100.0				

Sample: # 6

US	Metric	%
3"	75	100.0
2"	50	34.2
1"	25	21.1
3/4	19	15.6
1/2"	12.5	14.0
3/8"	9.5	13.4
1/4"	6.35	12.2
#4	4.75	11.4
#10	1.981	7.9
#20	0.85	3.8
#40	0.42	1.9
#60	0.25	1.4
#100	0.15	0.3
#200	0.075	0.1
>200	0.0075	

Sample # 6 12-18-98 Approximately 20 - 25 feet deep



GP	Poorly graded GRAVEL

Sieve Analysis **Sample: # 7**

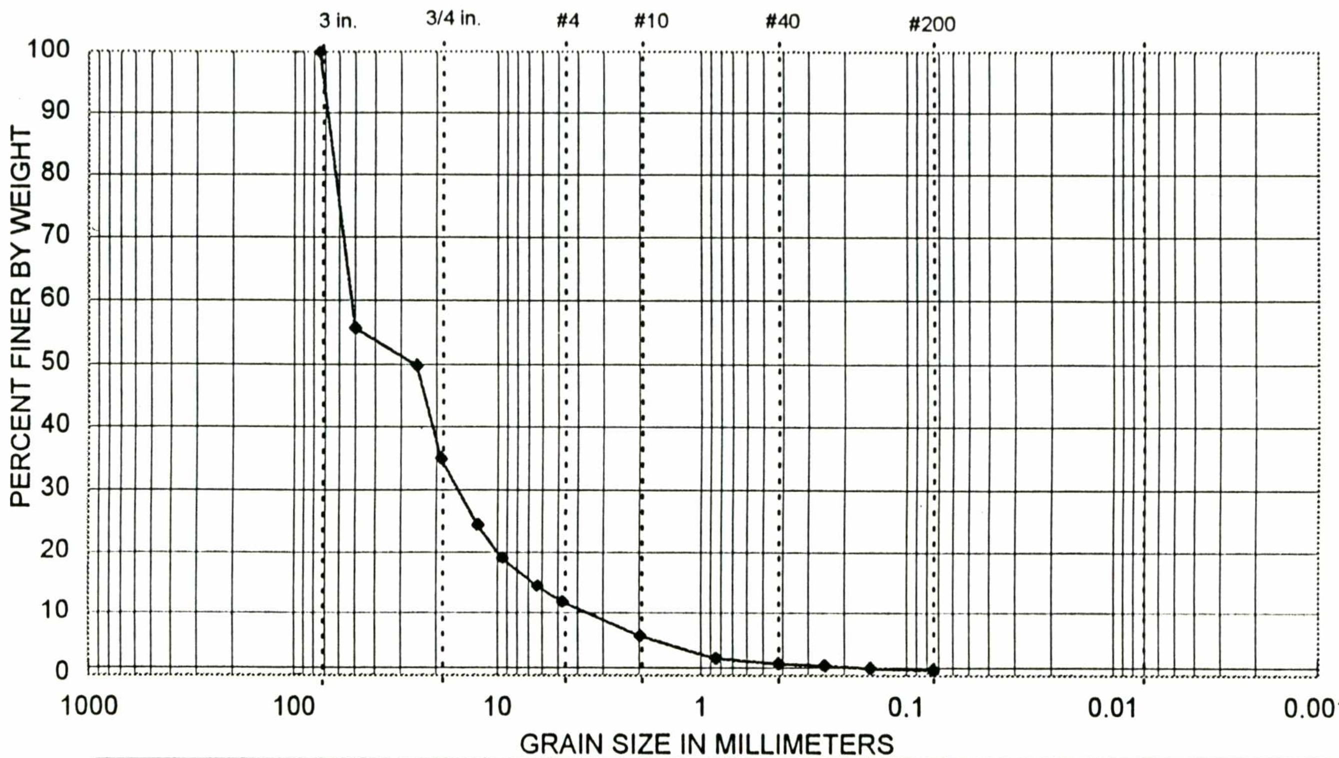
12/18/97

Sieve #	Wt. Dish &Soil	Wt. Soil	Sum Retained	% Retained	Cum % Retained	% finer			
DISH	202.0								
3"	202.0	0.0	0.0	0.0	0.0	100.0	0.0 % cobbles	0.0 % cobbles	cobbles
2"	465.8	263.8	0.0	44.3	44.3	55.7			
1"	501.3	35.5	299.3	6.0	50.2	49.8			
3/4"	590.3	89.0	388.3	14.9	65.2	34.8	65.2 % crs grvl		crs grvl
1/2"	652.5	62.2	450.5	10.4	75.6	24.4			
3/8"	685.1	32.6	483.1	5.5	81.1	18.9			
1/4"	712.4	27.3	510.4	4.6	85.7	14.3			
#4	727.6	15.2	525.6	2.6	88.2	11.8	23.0 % fi grvl	88.2 % grvl	fi grvl
#10	761.2	33.6	559.2	5.6	93.9	6.1	5.6 % crs snd		crs snd
#20	782.6	21.4	580.6	3.6	97.5	2.5			
#40	788.0	5.4	586.0	0.9	98.4	1.6	4.5 % me snd		me snd
#60	789.8	1.8	587.8	0.3	98.7	1.3			
#100	792.0	2.2	590.0	0.4	99.0	1.0			
#200	793.7	1.7	591.7	0.3	99.3	0.7	1.0 % fi snd	11.1 % snd	fi snd
>200	797.7	4.0	595.7	0.7	100.0	0.0	0.7 % slt or cl	0.7 % slt or cl	silt
wet	0.0						-100.0 % Moisture		clay
		total	595.7		100.0				

Sample: # 7

US	Metric	%
3"	75	100.0
2"	50	55.7
1"	25	49.8
3/4	19	34.8
1/2"	12.5	24.4
3/8"	9.5	18.9
1/4"	6.35	14.3
#4	4.75	11.8
#10	1.981	6.1
#20	0.85	2.5
#40	0.42	1.6
#60	0.25	1.3
#100	0.15	1.0
#200	0.075	0.7
>200	0.0075	

Sample # 7 12-18-98 Approximately 3 feet deep



COBBLES	COARSE GRAVEL	FINE GRAVEL	CRS SAND	MEDIUM SAND	FINE SAND	SILT	CLAY

GW	Well graded GRAVEL

Sieve Analysis **Sample: # 8**

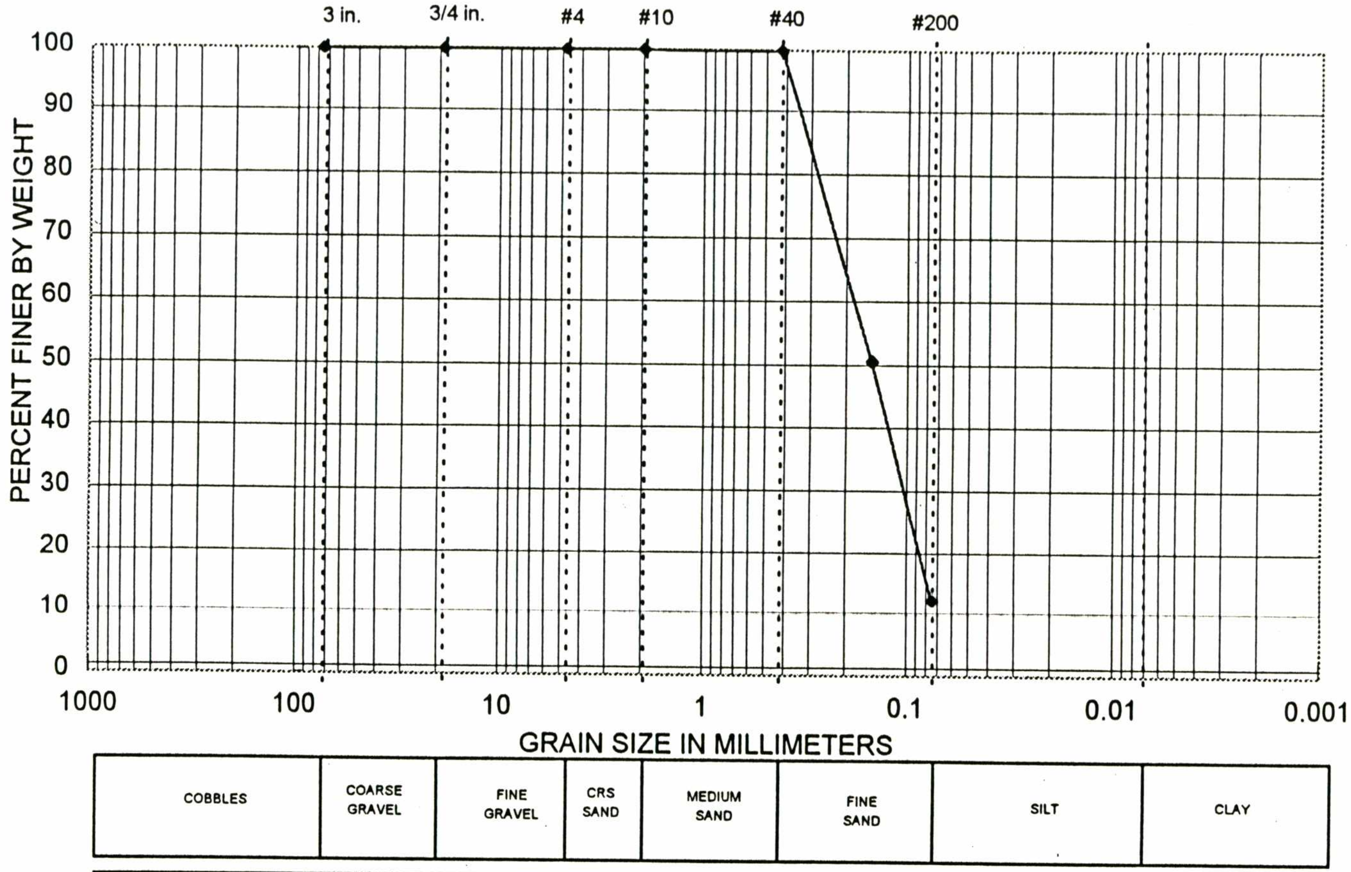
12/18/97

Sieve #	Wt. Dish &Soil	Wt. Soil	Sum Retained	% Retained	Cum % Retained	% finer					Sample:
DISH	204.3										
3"	204.3	0.0	0.0	0.0	0.0	100.0	0.0	% cobbles	0.0	% cobbles	cobbles
3/4"	204.3	0.0	0.0	0.0	0.0	100.0	0.0	% crs grvl			crs grvl
#4	204.3	0.0	0.0	0.0	0.0	100.0	0.0	% fi grvl	0.0	% grvl	fi grvl
#10	204.3	0.0	0.0	0.0	0.0	100.0	0.0	% crs snd			crs snd
#40	204.6	0.3	0.3	0.1	0.1	99.9	0.1	% me snd			me snd
#100	338.2	133.6	133.9	49.4	49.6	50.4					
#200	441.9	103.7	237.6	38.4	87.9	12.1	87.8	% fi snd	87.9	% snd	fi snd
>200	474.5	32.6	270.2	12.1	100.0	0.0	12.1	% slt or cl	12.1	% slt or cl	silt
wet	0.0						-100.0	% Moisture			clay
		total	270.2		100.0						

Sample: # 8

US	Metric	%
3"	75	100.0
3/4	19	100.0
#4	4.75	100.0
#10	1.981	100.0
#40	0.42	99.9
#100	0.15	50.4
#200	0.075	12.1
>200	0.0075	

Sample # 8 12/18/97 approximately 20 feet deep



SP-SM	Poorly graded SAND with Silt

Sieve Analysis **Sample: # 9**

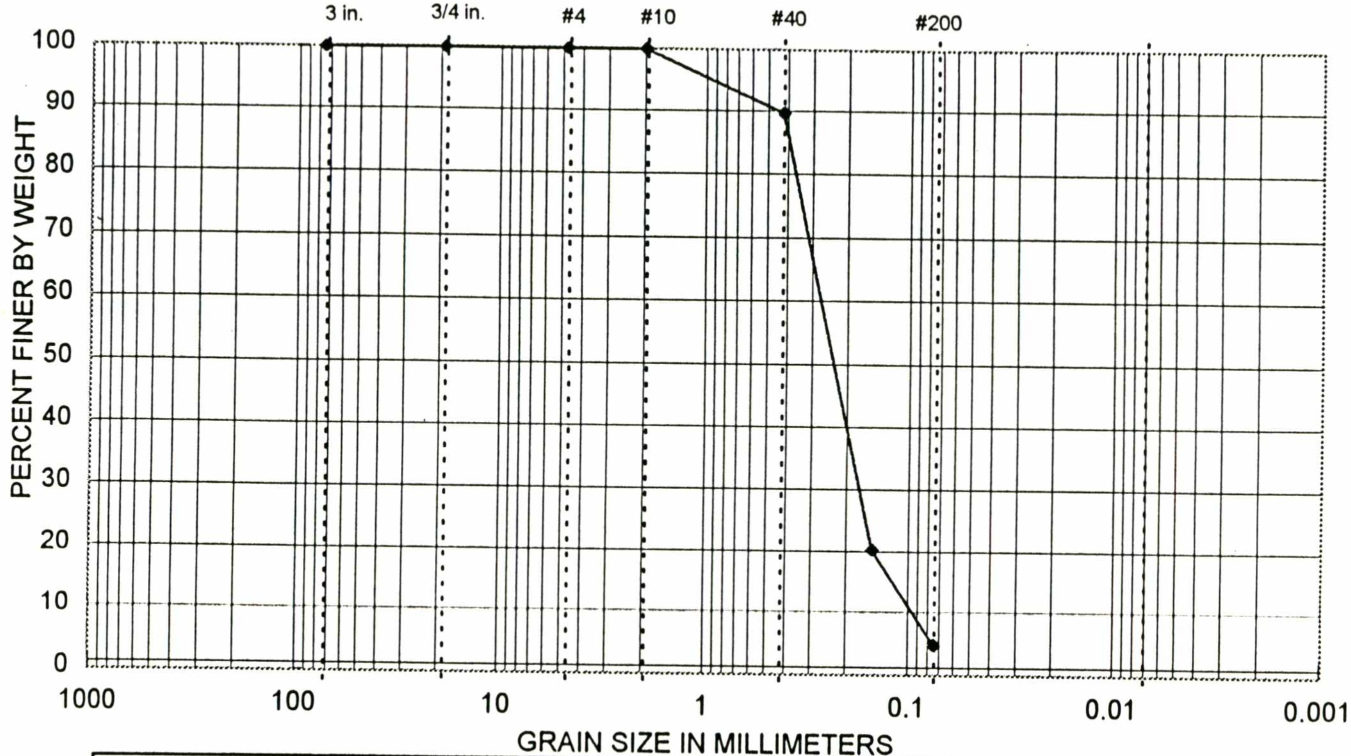
12/18/97

Sieve #	Wt. Dish &Soil	Wt. Soil	Sum Retained	% Retained	Cum % Retained	% finer					
DISH	204.3										
3"	204.3	0.0	0.0	0.0	0.0	100.0	0.0	% cobbles	0.0	% cobbles	cobbles
3/4"	204.3	0.0	0.0	0.0	0.0	100.0	0.0	% crs grvl			crs grvl
#4	204.3	0.0	0.0	0.0	0.0	100.0	0.0	% fi grvl	0.0	% grvl	fi grvl
#10	204.4	0.1	0.1	0.0	0.0	100.0	0.0	% crs snd			crs snd
#40	237.8	33.4	33.5	10.3	10.4	89.6	10.3	% me snd			me snd
#100	462.4	224.6	258.1	69.5	79.9	20.1					
#200	512.6	50.2	308.3	15.5	95.4	4.6	85.0	% fi snd	95.4	% snd	fi snd
>200	527.5	14.9	323.2	4.6	100.0	0.0	4.6	% slt or cl	4.6	% slt or cl	silt
wet	0.0						-100.0	% Moisture			clay
		total	323.2		100.0						

Sample: # 9

US	Metric	%
3"	75	100.0
3/4	19	100.0
#4	4.75	100.0
#10	1.981	100.0
#40	0.42	89.6
#100	0.15	20.1
#200	0.075	4.6
>200	0.0075	

Sample # 9 12/18/97 Aprroximately 20 feet deep



COBBLES	COARSE GRAVEL	FINE GRAVEL	CRS SAND	MEDIUM SAND	FINE SAND	SILT	CLAY

SP	Poorly graded SAND

Sieve Analysis **Sample: # 10**

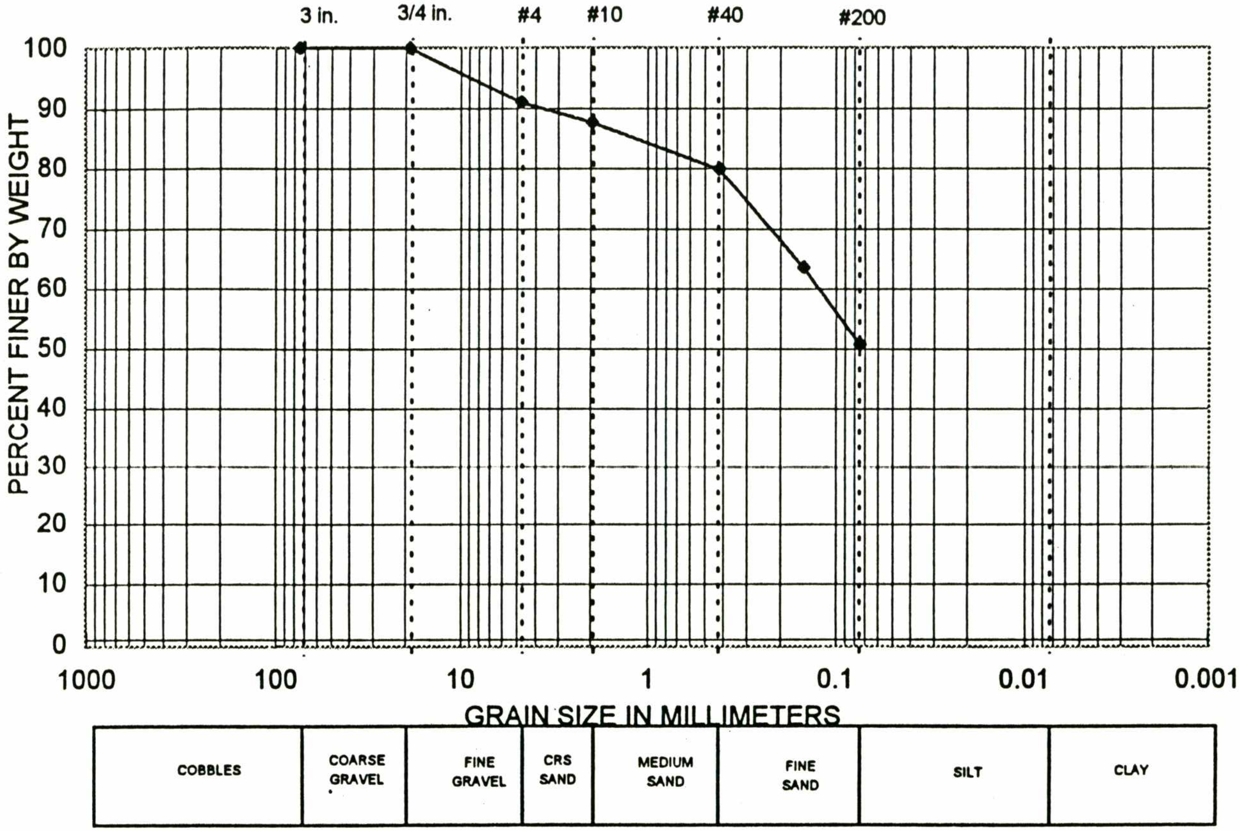
2/4/98

Sieve #	Wt. Dish &Soil	Wt. Soil	Sum Retained	% Retained	Cum % Retained	% finer				
DISH	86.1									
3"	86.1	0.0	0.0	0.0	0.0	100.0	0.0	% cobbl	0.0	% cobbl
3/4"	86.1	0.0	0.0	0.0	0.0	100.0	0.0	% crs grvl		
#4	117.0	30.9	30.9	9.0	9.0	91.0	9.0	% fi grvl	9.0	% grvl
#10	128.6	11.6	42.5	3.4	12.3	87.7	3.4	% crs snd		
#40	155.3	26.7	69.2	7.7	20.1	79.9	7.7	% me snd		
#100	211.6	56.3	125.5	16.3	36.4	63.6				
#200	256.0	44.4	169.9	12.9	49.2	50.8	29.2	% fi snd	40.3	% snd
>200	431.2	175.2	345.1	50.8	100.0	0.0	50.8	% slt or	50.8	% slt or
wet	0.0									
		total	345.1		100.0					

Sample: # 10

	US	Metric	%
cobbles	3"	75	100.0
crs grvl	3/4	19	100.0
fi grvl	#4	4.75	91.0
crs snd	#10	1.981	87.7
me snd	#40	0.42	79.9
	#100	0.15	63.6
fi snd	#200	0.075	50.8
silt	>200	0.0075	
clay			

Sample #10 Taken 2-4-98 Approximately 25 feet deep



MC	Silt and Clay