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I. Introduction

The purpose of this report is to document the activities completed under Wisconsin Department of Natural Resources Grant Nos. NMH00000183 and NMI00000261. The project was designed to investigate the groundwater and surface water interactions in the Nine Springs watershed. The Nine Springs watershed, located in south-central Dane County, Wisconsin (Figure 1), serves as an excellent groundwater study area due to the large concentration of springs in the area, public concern over the susceptibility of these springs and the associated wetlands and unique wetland vegetation communites to ongoing development pressures, the existence of previously compiled background information on the wetlands and watershed hydrology (Bedford et al., 1974; Novitzki, 1978; WRM, 1990; Owen, 1995; WRM, 1996), and the existence of a calibrated regional groundwater flow model for Dane County (Krohelski et al., 1997).

The Nine Springs watershed is a sub-basin of the Yahara-Monona watershed. Nine Springs Creek flows east and discharges to Mud Lake north of Lake Waubesa. Two field sites within the Nine Springs watershed have been established as part of the study on the basis of wetland quality and proximity to major springs. The Gunflint Trail field site is located in the western part of the watershed (Figures 2 and 3) and represents one of the few remaining areas of high quality sedge and wet meadow. The wetland plant community is dominated by hummock sedge (*Carex strica*), but also includes some characteristic wet meadow and calcareous fen plant species. The margin of this wetland is, however, experiencing invasion by reed canary grass *(Phalaris arundinacea L.)* and some shrubs, which are often indicative of a lowered water table or human disturbance (Eggers and Reed, 1997; Bedford et al., 1974). There are several small spring complexes in addition to one large spring at this site.

The Syene Road field site is located south of Nine Springs Creek in the central part of the watershed (Figure 4). It contains both sedge meadow that is in transition from a high-quality to degraded state and severely degraded sedge and wet (fresh) meadow now dominated by reed canary grass (*Phalaris arundinacea L.*). There are several small springs and one large spring at the Syene Road site. An experimental wetland restoration project is also being developed on the degraded sedge meadow portion of the site (hereafter referred to as the experimental site or plot). This ongoing experimental project is being funded by the U.S. Geological Survey (USGS) and the Madison Metropolitan Sewerage District.

This report presents information gathered from June 1997 through June 1999. The data collected will also help to form the basis of two doctoral dissertations at the University of Wisconsin-Madison (Susan Swanson, Department of Geology and Geophysics and Michael Schwar, Department of Civil and Environmental Engineering) and peer-reviewed journal articles. The methods and results section of the report contains the data generated from several different aspects of the overall project. In the Discussion and Conclusions section, we summarize and interpret the major points relating to the results of the individual aspects of the project

II. Methods and Results

A. Well Installation and Stratigraphy

The Gunflint Trail site is instrumented with ten monitoring wells, which comprise three well nests (Table 1). Six additional water table wells and four mini-piezometer nests have also been installed within the wetland (Figure 3). During well installation, all materials were described and logged. In addition, in 1997 five vibracores were collected and two soil borings were drilled and described to further constrain site stratigraphy.

Table 1. Monitoring well construction details, Gunflint Trail site

Monitoring Wells	WDNR Number	Top of Casing (feet,amsl.)	Ground Surface (feet,amsl)	Outer Protective Casing (feet,amsl)	Elevation of Center of Screen	Date Installed	Casing Diameter (inches)	Well Depth (feet, btoc)	Well Depth (feet, bgs)	Screen Length (feet)
MW-1	JG502	868.94	867.02	none	866.13	7/31/97	2.0	3.5	1.6	1.4
MW-1A	JG503	870.21	867.80	870.55	865.21	7/18/97	1.5	7.5	5.09	5
MW-1B	JG504	869.40	867.26	869.49	852.20	7/16/97	1.5	18.8	17.3	3.2
MW-1C, with extension	JG511	873.25	869.00	none	829.82	1/29/98	2.0	45.9	42	5
without extension		871.32				7/98		44.0	40.1	
MW-2A	JG505	884.31	882.41	884.68	873.26	7/21/97	1.5	13.5	12.9	4.9
MW-2B	JG506	883.73	881.79	883.85	847.63	7/18/97	1.5	37.6	36.2	3
MW-3	JG507	868.23	866.68	none	865.88	9/26/97	2.0	3.1	2.3	1.5
MW-3A	JG508	869.62	867.04	869.76	860.12	7/21/97	1.25	12.0	10.6	5
MW-3B	JG509	869.57	867.05	869.73	831.37	7/22/97	1.25	39.5	36.8	2.6
MW-4B	JG510	876.05	873.54	876.18	838.25	7/22/97	1.25	39.1	36.5	2.6

The uplands surrounding the wetland area are composed of at least 50 feet of sandy diamicton (till), which is part of the Horicon Member of the Holy Hill Formation (Clayton and Attig, 1997). This till overlies the Cambrian-age Jordan sandstone. The bedrock surface gradually declines from the uplands to form a pre-glacial bedrock valley below the wetlands. At the margin of the wetland, one to three feet of peat overlies one to four feet of fine sandy silt (glacio-lacustrine material). Approximately 35-40 feet of till exist below the glacio-lacustrine material and above the weathered sandstone bedrock surface. Within the wetland area, peat and silt deposits thicken to approximately two to four feet and two to eight feet, respectively.

Eleven monitoring wells comprising four well nests have been installed at the Syene Road site in or at the margin of the wetlands (Table 2). Two well nests (MW5/A/B, MW6/A/B) are installed on the south side of the creek channel in the vicinity of the transitional wetlands south of Syene and McCoy Roads, one well nest (MW7/A/B) is installed near the experimental restoration plot, and one well nest (MW8A/8B) is installed on the north side of the Nine Springs Creek channel in the Dane County Parks Jenny and Kyle Preserve (Figure 4). During well installation, all materials were described and logged.

Table 2. Monitoring well construction details, Syene Road site

Monitoring Wells	WDNR Number	Top of Casing (feet,amsl.)	Ground Surface (feet,amsl.)	Elevation of Center of Screen	Installation Date	Casing Diameter (inches)	Well Depth (feet, btoc)	Well Depth (feet, bgs)	Screen Length (feet)
MW-5	JG518	875.48	873.38	871.53	6/16/98	1.5	4.95	2.9	2
MW-5A	JG512	877.27	874.02	857.91	5/19/98	2.0	21.86	18.7	5
MW-5B	JG513	879.48	874.08	836.84	5/20/98	2.0	45.14	39.7	5
MW-6	JG519	866.59	863.09	859.09	6/16/98	2.0	9.00	5.5	3
MW-6A	JG514	866.62	863.22	850.21	5/20/98	2.0	18.91	15.5	5
MW-6B	JG515	866.83	863.33	830.81	5/20/98	2.0	38.52	35.0	5
MW-7	JG520	862.01	859.01	852.46	6/26/98	2.0	10.55	7.6	2
MW-7A	JG516	862.14	859.09	831.83	5/21/98	2.0	32.81	29.8	5
MW-7B	JG517	862.25	859.07	789.93	5/21/98	2.0	74.82	71.6	5
MW-8A	JG521	NA	NA	NA	5/6/99	2.0	21.83	25.2	5
MW-8B	JQ701	NA	NA	NA	5/6/99	2.0	43.12	46.6	5

In addition, nine water table wells were installed in the experimental restoration plot and six soil cores were collected to determine the thickness of peat and the depth to glacio-lacustrine material in the experimental area. All monitoring wells at both field sites have been surveyed and referenced to mean sea level (NGVD-29).

In the transitional wetlands near Syene and McCoy Road, approximately one to five feet of peat has developed over one to three feet of fine sandy silt (glacio-lacustrine material) and 15-30 feet of sandy diamicton (till). Moving north towards Nine Springs Creek, approximately 10 feet of peat overlies the glacio-lacustrine material in the wetland area south of the creek channel, and the thicknesses of till and well-sorted medium sand (outwash) increase to over 60 feet as the depth to bedrock also increases.

B. Hydraulic Conductivity of Inorganic Materials

Following installation and development, slug tests were performed on all monitoring wells at both the Gunflint Trail and Syene Road field sites, and values of hydraulic conductivity were estimated for the unconsolidated, inorganic, surficial deposits and the weathered zones of the uppermost bedrock unit using the Hvorslev method (Hvorslev, 1951). The results of the slug tests are shown on Table 3. The hydraulic conductivity estimates for the till are very similar to, although slightly less than, previous estimates of hydraulic conductivity. The estimated hydraulic conductivity of the outwash is over two orders of magnitude greater than the geometric mean hydraulic conductivity value estimated by Swanson (1996). However, the Nine Springs estimate is based on only one slug test (MW7B), whereas Swanson's (1996) estimate was based on county-wide results from field tests. It is not surprising that the hydraulic conductivity estimates for the weathered bedrock zone differ at the two field sites because the degree of bedrock weathering of the uppermost unit is likely to vary spatially.

Table 3. Comparison of Nine Springs slug test results to previous hydraulic conductivity estimates

Source	Till	Outwash	Weathered Bedrock (GFT Site)	Weathered Bedrock (Syene Rd)
Nine Springs Study (slug tests)	5.4×10^{-4} cm/s (1.5 ft/d)	1.3×10^{-2} cm/s (37 ft/d)	1.1×10^{-4} cm/s (0.31 ft/d)	3.2×10^{-3} cm/s (9.1 ft/d)
Rayne, 1993 (slug tests)	2.4×10^{-4} cm/s (0.68 ft/d)	---	---	---
Swanson, 1996 (HYDPROP: database of values reported by consultants)	2.0×10^{-4} cm/s (0.57 ft/d)	5.0×10^{-4} cm/s (1.4 ft/d)	---	---

Note: Values represent geometric mean hydraulic conductivity values.

C. Hydraulic Properties of Degraded Sedge Meadow Peat

A well seepage test was used to evaluate the hydraulic characteristics of the partially decomposed peat in the degraded sedge meadow at the Syene Road experimental plot (Figure 4). The test was conducted by feeding water into a shallow water table well and measuring the response of the water table at seven observation wells within a three-meter radius of the source. Preliminary analysis of the results is discussed below. Further analysis of the data and use of results to model the hydrologic function of this degraded sedge meadow will be completed as part of the ongoing study funded by the USGS.

Test methodology. In early December 1998, eight 1.5-inch diameter shallow water table wells were installed in the Syene Road Experimental Plot (Figure 5). One well, the one to be used to introduce water, was placed in the center of the test area and six more of the wells were placed radially at a distance of one and three meters (3.28 – 9.84 feet) along northern, southeastern and southwestern axes (Figure 5). The eighth well was placed 0.5 meters (1.64 feet) south of the center well. The well screen at the center well was 0.9 m (2.95 feet) long; the other well screens were 0.6 m (1.97 feet) long. The wells were installed by pushing them into guide holes created using a 1-inch diameter soil auger. Pressure transducers (Global Water®, WL14) placed in each observation well monitored the change in water tables over the course of the experiment.

A 65.3 cm (25.7 inches) long, 17.6 cm (6.93 inches) radius steel barrel (Figure 6) was attached to the center well screen using a rubber connector and supported by three metal angle-irons (Figure 7). At the beginning of the test, at 15:09 on December 8, 1998, the barrel was filled to one foot depth and continually refilled when the water level dropped to 0.66 feet. Approximately 53 gallons (200 liters) of water were introduced in this way, at which point the water supply was refreshed and the process was repeated for an additional 53 gallons. Water levels were logged every minute until approximately 14:30 on December 9.

Results. As the experiment progressed, the rate of water infiltrating through the center well decreased (Figure 8). For the first part of the experiment the decrease in rate of infiltration was fairly constant, but for the final 26 gallons (100 liters) of infiltration the rate of decrease abruptly lessened. This suggests that the processes allowing water entry changed at this point, and may indicate a steady-state infiltration rate of approximately 0.53 gpm (2 liters/minute).

Most of the wells functioned well and provided meaningful data. The exception is the well at the one meter (3.28 feet) location of the southeastern transect, which was later found to have a substantially clogged well screen.

Wells located at the same radial distance from the injection well, but on different transects, showed similar but significantly different results (Figure 9 a-b). Part of the difference is apparently due to the presence of the existing horizontal groundwater gradient from south to north across the site and the flows accompanying that gradient. Comparison along the transects show, as expected, progressively delayed and muted response to the infiltrated water (Figure 10 a-c) (the single 0.5-meter (1.64-foot) well is assumed to be representative of all transects).

Unfortunately, the results of this experiment cannot be modeled using existing infiltration analyses. This is likely due to the failure of this site to approach the "ideal" conditions assumed for simplifying and generalizing the analysis. Conditions on this site that may have to be included for adequate modeling include the compressibility of the peat, the high water table and small unsaturated zone, and the south-to-north hydraulic gradient. We have not yet developed an infiltration model that appropriately describes this system.

D. Hydraulic Gradients

Semi-continuous measurements (every 30 minutes) of hydraulic head were recorded from September 1997 to November 1998, excluding winter months, at several well nests at both the Gunflint Trail and Syene Road sites using pressure transducers and data loggers. Water levels have also been hand-measured periodically at wells using an electric tape. The water level records for four well nests for selected periods during the summer of 1998 are included in Appendix A.

In general, groundwater within the watershed flows downward from the surrounding uplands and towards Nine Springs Creek and its associated wetlands where it discharges. Vertical hydraulic gradients range from downward gradients of approximately 0.08 in the upland recharge areas to upward gradients as high as 0.67 or more in the wetland discharge areas. Diurnal fluctuations in water levels due to evapotranspiration are apparent in all of the long-term records. The fluctuations continue through the summer months and gradually decline in magnitude through November. Use of these data will be further discussed in the following section.

E. Wetland Water Regime

The shallow water table dynamics of the Gunflint Trail sedge meadow and the Syene Road experimental site were investigated to compare the effects of drainage and the potential hydrologic factors that may influence plant community preservation and development at the sites.

Syene Road. On April 7, 1998, nine shallow water table wells were installed in the Syene Road experimental site (Figure 11). These 1.25-inch diameter PVC wells were pushed into one-inch auger holes to a depth of 3 to 4.3 feet, until the top of the well screens were just beneath the peat surface. The water levels in these wells were recorded at various intervals during the period the wetland remained unfrozen. Also, the water level in one well, X4, was continuously monitored from September 9 to December 1, 1998 using a pressure transducer.

Gunflint Trail. In June 1997, three minipiezometer nests were installed in a transect running from the edge of the Gunflint Trail sedge meadow into the site (MP 1, 2, 3; Figure 3). Of these nests, sites 1 and 3 included shallow PVC groundwater wells similar to those described above. For information on minipiezometer construction see Lee and Curry (1978). Additional groundwater wells (Figure 3) were installed during the summer of 1998 as part of Juli Thompson's undergraduate research project in the Department of Geology and Geophysics. The minipiezometer nests were monitored monthly or more frequently during the period when the wetland was not frozen. The water table wells were monitored continuously during the summer of 1998 using pressure transducers.

Results. At both sites the water table was at the ground surface after the spring thaw, but the hydrologic regimes of the two sites diverged as the summer progressed (Figure 12). Water levels on both sites declined during rain-free periods. At the Gunflint Trail site, the main mechanism for this decline appears to be daily evapotranspiration from the ground surface due to the daily fluctuations observable in the continuous water table records (Figure 13 and Appendix A, MW3A/B). Drainage appears to cause the reduced water table levels in the experimental site near Syene Road (Figure 14), and there is no evidence of a strong evapotranspiration influence in the hydrographs. The rate of drainage on this site appears to increase as the summer progresses.

Additionally, the site responses to storm events differ. The Gunflint Trail wells show an immediate water level rise at the start of storm events (Figure 15 and Appendix A, MW3A/B) indicative of a capillary fringe response wherein a small amount of rainfall fills the voids in a nearly saturated vadose zone above the water table (Heliotis and DeWitt, 1987). The Syene Road experimental site shows no such capillary fringe response, instead showing a delayed response typical of rainfall infiltrating through a relatively dry vadose zone or entering the site from offsite areas (Figure 15).

F. Geochemistry

Geochemical Sampling

Samples were collected from springs and selected monitoring wells at our two field sites, from selected residential wells within the watershed, and from one well (#9) at the WDNR Nevin Fish Hatchery (Figures 2 and 3). Residential wells were chosen on the basis of their proximity to the field sites, whether a well construction report and driller's log was on file at the Wisconsin Geologic and Natural History Survey, and whether the screened or open interval was relatively short (<50 feet) (Table 4). One residential well (Karls Niehaus) has an open interval of 184 feet, and was sampled during only one sampling event (August 1998). The well was removed from subsequent rounds because the open interval is greater than 50 feet.

Table 4. Private well sampling locations

Well Owner	Well Depth (feet)	Approx. Elev. (ft.amsl)	Screened or Open	Interval (feet)	Possible Elev. of Open Interval (ft.amsl)	Screened Material (from driller's log)
H&M	138	880-890	open	33	742-785	shalestone
Finch	144	870-880	open	25	726-761	soft and firm sandstone
Jones	100	900-910	open	37	800-847	sandstone
Church	214	860-870	screened	3	646-659	Sand and gravel
Eisele	245	1010-1020	open	42	765-817	sand rock
WDNR#9	171	850-870	open	35	679-734	sandstone
Karls Niehaus	312	890-900	open	184	578-772	sandstone

The first round of groundwater samples was collected in November of 1997, and sample locations were added to the quarterly sampling program as new wells were installed. Residential well sampling began in August of 1998 and was also conducted on a quarterly basis. All samples were analyzed at the State Laboratory of Hygiene for major cations (Mg^{+2}, Ca^{+2}, K^{+}, Na^{+}) and anions (NO_3^-, SO_4^{-2}, Cl^-). The laboratory also reported laboratory pH, conductivity, and total alkalinity results. In addition, pH, conductivity, temperature, total alkalinity, and dissolved oxygen were measured in the field at the time of sample collection. Alkalinity and dissolved oxygen were measured using Chemetrics colorimetric ampoules, which use a hydrochloric acid titrant with a pH indicator and an indigo carmine method, respectively. Geochemical results for all sampling rounds are summarized in tables in Appendix B.

Due to the similarity in composition between the unconsolidated deposits and the bedrock in the area, all waters are a calcium-magnesium bicarbonate type. Piper diagrams for each sampling event are shown in (Figure 16 a. through g.).

Nitrate (NO_3^-) and chloride (Cl^-) have proven to be especially useful as conservative environmental tracers and indicators of differing recharge areas and flow paths. Nitrate is often present at high concentrations in agricultural settings. Some of the springs and groundwater show temporal variations in nitrate concentration, most likely due to seasonal fertilizer application, whereas other waters show either elevated or very low, but consistent concentrations throughout the sampling period (Figure 17 a. and b.).

Chloride concentrations tend to be fairly consistent throughout the sampling period at all sample locations. At the Gunflint Trail site, concentrations range from approximately 3 to 40 mg/L (Figure 18a.) The shallow water table wells and/or wells in recharge areas have comparatively low Cl^- concentrations, and wells screened at the top of the bedrock surface and the Big Spring have higher Cl^- concentrations. The Peat Spring showed temporal variation in Cl^- concentration that ranged from 14.3 to 23.5 mg/L over the sampling period. At the Syene Road site, wells screened in till and at the top of the bedrock surface have Cl^- concentrations that are greater than 35 mg/L, whereas wells that are screened in outwash and till in a deeper portion of the bedrock valley have very low Cl^- concentrations; less than 5 mg/L (Figure 18b.). Since chloride is very mobile and conservative in groundwater systems, differences in the magnitude of the Cl^- concentrations could indicate whether or not the recharge area for a sample point has a source of chloride (i.e. road salt).

The chloride to sodium (Na^+) molar ratio for all samples collected is approximately 2:1 (Figure 19). This molar ratio could suggest (i) a source of chloride other than road salt (NaCl) exists in the system or (ii) sodium is involved in an exchange process which has the effect of lowering the amount of sodium in the system.

Other constituents or measures of constituents, such as potassium, sodium, sulfate, total dissolved solids, conductivity, and dissolved oxygen were less useful, but still provide some limited insight on possible differences in recharge areas and flow paths. Potassium (K^+) is usually a minor constituent in groundwater. Concentrations tended to be less than 3 mg/L at all sample locations with low to moderate variation at most sample locations throughout the year (COV<0.20) (Figure 20a. and b.). The exceptions are well numbers MW2A and MW2B (Figure 20a.). Samples collected from these locations have elevated concentrations of K^+, and show more temporal variation ($COV_{(MW2A)}$=0.53, $COV_{(MW2B)}$=0.22). MW2A and MW2B are located on a hillslope in a recharge area that was farmed through the 1997 agricultural season. The source of potassium is most likely agricultural fertilizers. The elevated and variable concentrations in these samples suggest significant sources of K^+ and short flow paths.

Most sample locations have sodium concentrations that range from 5-11 mg/L and that are relatively consistent throughout the sampling period (COV<0.06) (Figure 21a. and b.). The exceptions are wells MW7A, MW7B, and the church well, which have sodium concentrations that were less than 3.3 mg/L throughout the sampling period. Wells MW2A, MW3A, and the peat spring also have lower sodium concentrations (1.7-6.5 mg/L), but were somewhat less consistent throughout the sampling period (COV=0.07-0.40).

Sulfate (SO_4^{-2}) concentrations range from 5 to 55 mg/L within the study area and, for the most part, were variable throughout the sampling period (COV>0.30). The exceptions are well numbers MW7A, MW7B, and the residential well at the church. Sulfate concentrations were somewhat more consistent throughout the sampling period at these locations (COV<0.16) and ranged from 5 to 8 mg/L (Figure 22a. and b.).

Total dissolved solid (TDS) concentrations were calculated for each sampling point and sampling event by summing the concentrations of the major cations and anions (Figure 23a. and b.). TDS ranges from approximately 400 to 650 mg/L in the waters that were sampled, and tended to be very consistent throughout the sampling period (COV<0.04). TDS concentrations were slightly less consistent at wells MW2A, MW3A, and the Peat Spring (COV=0.08-0.09), and were consistently (COV<0.02) less than 460 mg/L at wells MW7A, MW7B, and at the church well.

Another general indication of the total dissolved inorganic constituents in groundwater is the water's capability to conduct an electrical current. Conductivity, in microsiemens (µS) or micromhos (µmhos), was measured in the field at the time of sample collection. Figures 24a. and b. show the variation in conductivity at the sampling points throughout the sampling period (COV=0.02-0.22). The lowest conductivity measurements were recorded in groundwater samples collected from MW7A, MW7B and the church well (444-696µS). All other samples showed higher conductivities (597-1188µS).

All samples showed high levels of dissolved oxygen (>4 mg/L). The only exception was MW7B, which had lower dissolved oxygen concentrations that ranged from 2-4 mg/L. Dissolved oxygen was not measured at any of the private residential wells because water passes through a pump.

Discussion and Grouping of Geochemical Results

On the basis of the geochemical sampling results, three "groups" of waters have been identified. Table 5 summarizes the geochemical characteristics of each of the groups and identifies the sampling locations that helped to define the groups. The geochemical characteristics (defined relative to the other two groups of waters) are also discussed below.

Table 5.
Geochemical Groups

Group I

Sampling Location	Nitrate, mg/L (Range in Concentration)	COV	Chloride, mg/L (Range in Concentration)	COV	Sulfate, mg/L (Range in Concentration)	COV	Potassium, mg/L (Range in Concentration)	COV
MW2A	6.25-28	0.45	3.5-9.2	0.40	12.1-55	0.39	19-78	0.53
MW2B	8.76-12.5	0.13	12.7-16.6	0.16	5.6-43	0.42	8.8-16	0.22
MW3A	3.21-14.8	0.39	7.1-10.7	0.18	8.1-41	0.64	0.6-1.2	0.28
Peat Spring	0.55-9.16	0.65	14.3-23.6	0.19	7-23	0.37	<0.3-1	0.58

Group II

Sampling Location	Nitrate, mg/L (Range in Concentration)	COV	Chloride, mg/L (Range in Concentration)	COV	Sulfate, mg/L (Range in Concentration)	COV	Potassium, mg/L (Range in Concentration)	COV
Big Spring	10.7-11.9	0.04	28.9-31.8	0.03	19-28	0.14	0.9-1	0.06
Nursery Spring	10.2-13	0.13	21.2-26.3	0.11	16-32	0.43	0.8-1.2	0.20
Syene Spring	9.83-10.3	0.02	36.9-38.4	0.02	7-27	0.58	1-1.1	0.06
MW4B	10.6-11.5	0.03	30.2-33.3	0.04	8-30	0.34	1.1-1.4	0.08
MW1C	9.7-10.9	0.05	34.8-40.5	0.06	7-27	0.55	1.7-3.1	0.26
MW5A	15.6-16.3	0.02	39.9-40.9	0.01	38-42	0.05	1.1-1.7	0.20
MW5B	9.68-10.8	0.06	36.5-37.4	0.01	18.7-28.1	0.20	1.3-1.6	0.11
MW6A	10.4-10.7	0.01	36.4-37.4	0.01	7-28	0.49	0.9-1.2	0.15
MW6B	10.3-10.9	0.03	36.1-37.1	0.01	7-28	0.49	1-1.2	0.09
Jones	9.48-10.4	0.05	35.6-35.8	0.00	12.8-27	0.36	0.7-1	0.18
H&M	12.2-12.8	0.03	32.1-34	0.03	30.4-32.8	0.04	1.1-1.2	0.05

Group III

Sampling Location	Nitrate, mg/L (Range in Concentration)	COV	Chloride, mg/L (Range in Concentration)	COV	Sulfate, mg/L (Range in Concentration)	COV	Potassium, mg/L (Range in Concentration)	COV
MW7A	2.22-2.37	0.03	2.4-3.1	0.11	5-7.4	0.16	0.9-1.4	0.20
MW7B	nd-0.16	---	0.9-1.4	0.32	5.9-8	0.14	1.1-1.3	0.07
Church Well	1.12-1.25	0.06	1.7-2	0.08	7-7	0.00	0.9-1	0.06

Exceptions

Sampling Location	Nitrate, mg/L (Range in Concentration)	COV	Chloride, mg/L (Range in Concentration)	COV	Sulfate, mg/L (Range in Concentration)	COV	Potassium, mg/L (Range in Concentration)	COV
MW3B	10.8-15.2	0.11	24-25.9	0.03	8.3-34	0.35	1.3-8.4	0.95
Finch	9.65-9.89	0.01	20.9-23	0.05	14.6-25	0.26	0.9-1.2	0.17
Eisele	17.4-18.5	0.04	21.2-22.1	0.02	29.6-30.8	0.02	0.6-1.2	0.39
WDNR#9	4.76-5.25	0.05	17.6-18.8	0.03	14-23	0.29	1.3-1.6	0.10

Table 5.
Geochemical Groups

Group I

Sampling Location	Sodium, mg/L (Range in Concentration)	COV	TDS, mg/L (Range in Concentration)	COV	Conductivity, microsiemens (Range in Conductivity)	COV	Dissolved Oxygen, mg/L (Range in Concentration)	COV
MW2A	1.7-6.5	0.40	593-743	0.09	751-1067	0.14	6-7	0.07
MW2B	5-6.2	0.07	588-617	0.02	819-971	0.07	6-7	0.09
MW3A	3.8-6.1	0.18	462-566	0.08	675-882	0.11	3.5-6	0.26
Peat Spring	4.8-6	0.10	396-529	0.09	614-847	0.12	7-11	0.24

Group II

Sampling Location	Sodium, mg/L (Range in Concentration)	COV	TDS, mg/L (Range in Concentration)	COV	Conductivity, microsiemens (Range in Conductivity)	COV	Dissolved Oxygen, mg/L (Range in Concentration)	COV
Big Spring	7.5-8	0.03	493-514	0.02	697-838	0.06	7-9	0.13
Nursery Spring	7.7-7.8	0.01	477-513	0.04	714-843	0.09	7-8	0.08
Syene Spring	13-14	0.04	518-544	0.02	815-855	0.02	7-8	0.08
MW4B	7.2-8	0.04	503-525	0.02	659-1188	0.22	6-7	0.09
MW1C	9.2-11	0.08	497-529	0.02	723-973	0.11	7-7	0.00
MW5A	12-12	0.00	562-577	0.01	815-943	0.06	5-7	0.18
MW5B	13-13	0.00	527-539	0.01	722-865	0.09	7-7	0.00
MW6A	13-13	0.00	518-545	0.02	815-865	0.03	5-8	0.23
MW6B	13-13	0.00	517-539	0.02	815-865	0.03	5-7	0.18
Jones	13-14	0.04	527-539	0.01	691-876	0.12	n.m.	—
H&M	9.2-9.3	0.01	521-525	0.00	680-866	0.12	n.m.	—

Group III

Sampling Location	Sodium, mg/L (Range in Concentration)	COV	TDS, mg/L (Range in Concentration)	COV	Conductivity, microsiemens (Range in Conductivity)	COV	Dissolved Oxygen, mg/L (Range in Concentration)	COV
MW7A	2.7-3.1	0.06	415-432	0.02	444-633	0.15	5-7	0.17
MW7B	3.3-3.3	0.00	443-455	0.01	504-696	0.14	2-4	0.33
Church Well	2.6-2.7	0.02	397-398	0.00	512-584	0.07	n.m.	—

Exceptions

Sampling Location	Sodium, mg/L (Range in Concentration)	COV	TDS, mg/L (Range in Concentration)	COV	Conductivity, microsiemens (Range in Conductivity)	COV	Dissolved Oxygen, mg/L (Range in Concentration)	COV
MW3B	8.3-9.2	0.04	533-559	0.02	719-1169	0.20	7-7	0.00
Finch	5.4-5.7	0.03	469-484	0.02	683-751	0.05	n.m.	—
Eisele	4.7-4.8	0.01	491-495	0.00	605-841	0.17	n.m.	—
WDNR#9	5.3-5.5	0.02	437-449	0.02	597-674	0.06	n.m.	—

Group I

Group I consists of monitoring wells MW2A, MW2B, and MW3A, and the peat spring. The geochemical characteristics of this group include (i) temporally variable nitrate concentrations, (ii) moderate chloride concentrations, (iii) variable, and in some cases (MW2A and MW2B), much higher potassium concentrations (iv) lower and somewhat more variable sodium concentrations, and (v) somewhat more variable TDS concentrations.

MW2A and MW2B are located in a recharge area and are screened in till. MW3A is located in an area that, depending on the time of the year, can be either a recharge or discharge area. It is also screened in till. High and variable nitrate and potassium concentrations suggest a direct source of these constituents, and MW2A and MW2B are located in a field that was farmed through the 1997 agricultural season. MW3A and the peat spring are located at the base of this field. The variability of the geochemistry results is probably due to the preservation of temporal, and in some cases seasonal, variations in constituents, which suggests that the water has short flow paths and residence times and is most likely part of a local flow system.

Group II

Group II consists of the big spring, nursery spring, and Syene spring, monitoring wells MW4B, MW1C, MW5A, MW5B, MW6A, and MW6B, and private wells Jones and H&M. The geochemical characteristics of this group include (i) elevated, but consistent nitrate concentrations, (ii) high and consistent chloride concentrations, and (iii) moderate and consistent sodium concentrations.

All of the monitoring wells in this group are in discharge areas. MW5A and MW6A are screened in till, but all other monitoring wells are screened at the top of the bedrock surface. MW5A and MW6A are located in an area where vertical upward gradients range from 0.1 to 0.2.

The two private wells (Jones and H&M) are drilled to varying depths. From the well construction reports, the wells appear to be open over 30-40 foot intervals in the upper 100 feet bedrock. The high nitrate and chloride concentrations suggest sources of these constituents in the recharge areas, most likely from fertilizers and road salt. It is likely that flow paths and residence times are longer than those for Group I because the temporal variations in nitrate and chloride concentration have been damped.

Group III

Group III consists of monitoring wells MW7A, MW7B, and the church well. The geochemical characteristics of this group include (i) low and consistent nitrate concentrations, (ii) low and consistent chloride concentrations, (iii) lower and somewhat more consistent sulfate concentrations, (iv) lower sodium concentrations, (v) lower TDS concentrations, (vi) lower conductivities, and (v) in some cases (MW7B), lower dissolved oxygen concentrations.

MW7B and the church well are screened in outwash that fills the preglacial bedrock valley below Nine Springs Creek. MW7A is screened in till. The low nitrate and chloride concentrations probably represent background levels of these constituents in regional groundwater. It is likely that either (i) fertilizer or road salt sources do not exist in the recharge area or (ii) elevated concentrations of nitrate and chloride, resulting from heavy use of fertilizers and road salt beginning in the 1930's, have not yet reached these locations due to long flow paths and residence times.

Exceptions

Exceptions to the groups defined above include monitoring well MW3B, and private wells Eisele, Finch, and WDNR#9. Monitoring well MW3B is screened in till, near the top of the bedrock surface at the Gunflint Trail Site. It is located in an area where groundwater gradients alternate between upward and downward, depending on the season and/or individual storm events (Figure 25). Therefore, it is not surprising that the groundwater shows some characteristics that are consistent with Group I (temporally variable nitrate concentrations) and some that are consistent with Group II (elevated, but consistent chloride concentrations).

The private wells (Eisele, Finch, and WDNR#9) are drilled to varying depths. From the well construction reports, the Eisele and Finch wells appear to be open over 25-40 foot intervals. The Finch well is completed in the upper 100 feet of bedrock and the Eisele well is completed at a depth over 200 feet into bedrock. Taking into account surface elevations, the Finch well is probably screened at a slightly deeper interval than the Eisele well. The sampling results from these two wells are very similar to the characteristics of Group II, with a few exceptions. Groundwater results from the Finch well show lower, but still consistent, chloride and sodium concentrations, and results from the Eisele well show higher, but still consistent, nitrate concentrations. The results suggest that there is a smaller source of sodium and chloride (road salt) in the recharge area for the Finch well. The Eisele well is located in a regional recharge area. The uplands in the Nine Springs watershed are primarily agricultural, therefore it is likely that the higher nitrate concentrations are a result of a direct source of nitrate from fertilizer; however, due to the depth of the well, no temporal variation in nitrate concentration is apparent.

The total depth of WDNR#9 is 171 feet; however, it is located at a slightly lower point on the landscape than the other private wells (see Table 4). Because the sedimentary bedrock units are relatively flat-lying in the area, dipping only 10-15 feet per mile (Cline, 1965), WDNR#9, which is a flowing well, may be open to an older, deeper bedrock unit. The groundwater chemistry of the water discharging from this well has lower nitrate, chloride, and sodium concentrations than those samples in Group II; however, the concentrations are higher than those detected in Group III. The water discharging from WDNR#9 may be a result of mixing of these two "groups" of waters.

Cluster Analysis

Cluster analysis has been widely applied in the biological sciences to classify objects into meaningful sets. It has been used less widely in hydrogeology, but can be useful when abundant data are available and clear hydrogeologic models have not yet been developed (Colby, 1993). We used a Q-mode cluster analysis with mean nitrate values for all sample locations to provide a check on the groupings and conceptual models of source waters discussed above. A Euclidean distance similarity coefficient was chosen and an unweighted pair group method with arithmetic averaging was used to perform the analysis in the statistical software, Statistica (StatSoft, Inc., 1997). The tree diagram or dendrogram that was constructed is shown in Figure 26. The linkage distances shown on the tree diagram are arbitrary distances; however, they represent the relative similarity between clusters of sampling locations.

The cluster analysis resulted in two clusters with linkage distances of less than 10, plus one outlier (MW2A). Both clusters also contain distinct clusters with linkage distances of less than five. These clusters are labeled A, B, and C on Figure 26. Two additional outliers result (Peat Spring and WDNR#9) when a linkage distance of less than 5 is used to define the clusters. Cluster C contains MW7A, the Church well, and MW7B, which corresponds to Group III discussed above. Cluster B contains most of the sampling locations included in Group II, with the exception of including the Finch well and MW2B and not including MW5A. Cluster A does not correspond well to Group I. While it contains MW3A, it also contains MW3B and the Eisele well (both considered exceptions above), but does not contain the Peat Spring, MW2A, and MW2B. Because the sampling points in Group I are mostly shallow monitoring points or wells that are in recharge areas, we believe that our conceptual model of the points representing locally-derived water with short flow paths and residence times is still valid. Because the cluster analysis used mean nitrate concentrations, it was unable to capture the variability in nitrate data, which was a deciding factor in grouping the sampling locations in Group I together.

G. Stable Isotopes

Samples were collected on a quarterly basis (since August of 1998) from springs and monitoring wells at the two field sites and from the residential wells in the vicinity of the site for analysis of stable isotopes of oxygen (^{18}O) and hydrogen (^{2}H). The samples were analyzed by mass spectrometry at the Southern Methodist University Stable Isotope Laboratory. The strong correlation between temperature and stable isotopes in meteoric waters provide a seasonal signal that can be used to date and distinguish waters. Isotopically lighter compositions are characteristic of winter precipitation, while isotopically heavier compositions are characteristic of summer precipitation. Shallow groundwater with short residence times often preserves this seasonal variation in isotopic composition, whereas variations are damped with longer flow paths and increased residence times (Clark and Fritz, 1997).

A local meteoric water line was developed for the area and is shown on Figure 27. Most of the data used in the plot, with the exception of three points, are monthly composite precipitation samples. For comparison, the global meteoric water line of Craig (1961) is also shown on the plot. Figures 28a-c show the results of each sampling round plotted with the local meteoric water line.

Results of the analyses suggest that stable isotopes provide another useful tool in distinguishing between local versus intermediate or regional sources of water within the watershed. In addition, the results support the groupings that have been distinguished on the basis of geochemical results. Because shallow groundwater with short residence times often preserves seasonal variations in isotopic composition, we may expect to see isotopic variation in samples collected from the locations in Group I described above, which was interpreted as locally-derived water with short flow paths and residence times. Figure 29 shows the variation in isotopic signature at each sampling location over the sampling period. The greatest variability in isotopic composition occurs in the samples collected MW2A and MW2B, which were included in Group I above. In addition, these results show isotopically lighter results in winter months (Dec) and isotopically heavier results in summer months (Aug).

H. Weir Data

Gunflint Trail

Springflow and rainfall were measured at Big Spring at the Gunflint Trail site beginning on Thursday July 2, 1998. On that day a Campbell CR10 datalogger was installed to continuously monitor output from a Stevens Type-III Pulse Generator water level meter and a Weather Measure Corporation Model P501 tipping bucket rain gage at that location. The water level reader measured the water surface elevation in a pool formed behind a polypropylene weir installed on Thursday May 21, 1998. Water levels in the pool were converted to flows over the trapezoidal notch in the weir using a stage-discharge relationship obtained from measured flows and extrapolated values from a theoretical weir equation.

Weir design. The Gunflint Trail weir was developed to measure the flow from the Big Spring (Figure 30), a continuous spring discharging into a 215 ft^2 (20 m^2) pool. Immediately downstream of the pool the spring discharge flows in a well-defined channel through the sedge meadow to the north. The weir site was chosen a short distance (approximately 39 feet) downstream of the pool, allowing the water to back into both the channel and the spring pool. At this point, the channel top width is about 3.9 feet (1.2 m), with nearly vertical banks in peat and clay soils. The bank height is 1.64 feet (0.5 m), with unobstructed water depth of about 0.46 feet (0.14 m) and probing indicated a depth of easy penetration of approximately 0.82 feet (0.25 m) beneath the channel bottom.

Based on observations, the maximum tailwater at this site was estimated to be 0.59 feet (0.18 m), so as to ensure adequate clearance the bottom of the weir plate was designed for an elevation of 0.82 feet (0.25 m) above the channel bottom. The assumed maximum and mean flows from the spring were 1.0 cfs and 0.3-0.35 cfs (0.028 and 0.01 cms), respectively, based in part on prior downstream flow measurements. A trapezoidal weir with sideslopes of 30 degrees, a crest length of 2.75 inches (7 cm) and height of 9.84 inches (25 cm) was found to be most sensitive to flows in this range. Larry Wheeler of the University of Wisconsin-Madison Hydraulics Lab constructed a weir plate out of polyvinyl chloride (PVC) to these dimensions, with a knife-edge crest and a 45-degree bevel (Bos, 1989).

The weir was obtained from Bob Schoen at United Plastic Fabricating, Inc. in Neenah, WI. It was crafted from a 0.5-inch (13 mm) thick piece of polypropylene (Figure 31) with the dimensions shown in Figure 32. The metal support pieces and weir plate as shown in Figure 32 were attached to the weir at the site and the holes sealed with silicone caulk.

Two fence post pounders were used to drive both vertical angle-irons simultaneously, and the weir was driven approximately 1.5 feet (47 cm) into the bottom of the spring channel (Figure 33). Several large rocks were placed downstream of the weir to provide a splash-block, and over time a 4.9-foot (1.5 m) long scour pool formed with a depth of approximately 9.1 inches (23 cm) at the face of the weir.

Water level monitoring. Water level behind the weir was recorded using a pulse generator attached to a float within a stilling well (Figure 34). The pulse-generator is designed to emit an electrical signal when the wheel to which it is attached moves 1/300 of a rotation; a separate signal is sent for each direction of motion. Vertical movement of the float causes movement of the float line, which rotates the wheel and generates a pulse. Each pulse represents a change in height of approximately 0.06 inches (1.5 mm). This design has the advantage that it only registers change in position; if the water level remains constant no signal is generated. There is relatively little potential for drift in this system and this provides confidence in long-period records that show little or no change over time.

The stilling well was built out of a 3.28-foot (1.0 m) length of 0.66-foot (20 cm) diameter PVC pipe. The length of pipe was sufficient to measure water levels well in excess of those that would overtop the weir and spill over the sides of the channel, flooding over the entire expanse of the wetland. Cement was used to weld a cap on the bottom of the pipe and a flange on the top. The flange was used to attach the weatherproof plastic case (Rubbermaid™) housing the pulse generator. Two 3.9-inch (10 cm) diameter holes were cut into the bottom of the case, one for the float line and the other for the counterweight line, and the case was attached to the flange with four bolt, nut and washer sets. Having two separate holes minimizes the chances of dropping the entire float/counterweight/line assembly into the stilling well during maintenance. When it is necessary to measure the water level in the well, the plastic case is removed and a point gage is placed across the top of the flange.

The stilling well was placed in the pool behind the weir, in part to insulate the plumbing from freezing and allow year-round operation (Olson, 1994). A portion of the bank and bottom was excavated and two fence posts were driven to secure the well in place. Two adjustable metal bands tie the well to the posts. A 3.9-foot (1.2 m) length of 2-inch (5 cm) diameter PVC pipe serves as the inlet from the middle of the weir pool to the stilling well. It was attached to the stilling well using a saddle fitting cemented around a 3.9-inch (10 cm) diameter hole drilled into the pipe using a hole saw. The saddle opening was necked down from 3.9-inch (10 cm) diameter to 1.96-inch (5 cm) diameter using an appropriate fitting, which was cemented to the inlet pipe. A 90-degree elbow on the end of the inlet was added to reduce the chances of clogging; it faced roughly downstream along the bottom of the weir pool.

Datalogger. A Campbell CR10 datalogger was attached to a fence post driven into the ground next to the stilling well (Figures 35 and 36). A 4.9-foot (1.5 m) metal rod was driven into the soil to ground the instrument and a Solarex MSX10 solar cell was used to keep the datalogger battery charged. The rain gage was mounted atop a round post within the pool, adjusted to ensure that it was level, and connected to the datalogger. Similarly, the wires from the water level meter were connected to the datalogger. Data collected by the CR10 was downloaded into a storage module using a CR10KD keypad, or directly into a laptop computer, but was not removed from the datalogger's memory. The datalogger's memory was configured so as to write over the oldest data when its storage capacity was full.

The datalogger program used was adapted from that developed by Olson (1994) and recorded changes in water level or rainfall intensity on a 1-minute basis (Appendix C). Also, battery voltage was read daily as a check on system function. Water level meter inputs entered the two pulse input channels: #1 for downward changes, #2 for upward (Appendix D). The rain gage input was read using a combination of a control port and an interrupt subroutine detailed and explained in Section 8.5 of the CR10 Operator's Manual (1994).

Calibration. Both the pulse generator-stilling well system and the rain gage were calibrated in the lab before installation. The water level monitoring equipment showed some evidence of lagging at the one-minute scale during both the rising and the falling water level tests, but the results equalized within a few minutes. The final pulse rate for both tests was very close to (but slightly less than) the theoretical rate of 200 pulses per foot of water level change (rising 199.7, falling 195.9 pulses per foot).

The response of the rain gage was tested under a series of artificial rainfall rates and was found to be consistent. The volume of water delivered from a spray bottle was estimated and then used to apply approximate rainfall totals of 0.1 and 1.0 in (2.5 and 25 mm) in 15- and 30-minute time periods, and 1.0 in (25 mm) in 60 minutes. Rainfall was applied approximately evenly over time. After adjusting for actual volume delivered (subtracting final volume in the bottle from initial volume), the relative response for each run was compared at 2-minute intervals. At all of the rainfall rates the response of the recorder was proportional to the rainfall delivered and did not show a significant lag over time (Figure 37). The calibration constant observed from this test was slightly higher for the lower intensity rainfalls than the higher, indicating that a larger proportion of the rainfall is not captured, but the difference was at the limit of experimental error. The volume-weighted average calibration factor was 0.0116 in/click (0.29 mm/click), as opposed to the factory calibration of 0.010. Because of the exposed nature of the gage, it is likely that the total rainfall recorded over the period of study was on the order of 5-10% less than the actual rainfall due to diminished efficiency during windy rainfall events (Rodda and Smith, 1986; Essery and Wilcock, 1991). The actual catch efficiency of this gage was not determined.

Syene Road

Flows were also measured immediately downstream of the largest spring on the Syene Road site. The continuous flow record began on Wednesday April 14, 1999 when a datalogger and water level recorder system similar to that at the Gunflint Trail site was installed. The water level reader measured the water surface elevation in a pool formed behind a polypropylene weir installed on Saturday March 20, 1999. Flow measurement at the Syene Road site was based on an 8-inch wide rectangular weir plate.

Weir design. The Syene Road weir was developed to measure the flow from the largest of several springs on the site (Figure 38). The spring discharges into a well-defined channel that arises in a few much smaller springs to the south and at least one subsurface drain outlet. The weir site was chosen to hold water within the walls of the existing channel and create a pool to facilitate flow measurement. The weir was again crafted using a piece of 0.5 inch (13 mm) thick polypropylene from United Plastic Fabricating, Inc., with the dimensions shown in Figure 39.

The weir was installed using a method similar to that described for the Gunflint Trail weir, with the exceptions that the Syene Road weir contains four angle-irons for pounding and that a plastic sheet was installed to reduce the risk of erosion at the weir. A polyethylene ground-cloth was placed over the streambed and the weir was driven 1.2 feet (37 cm) into the bottom of the spring channel (Figure 40). The ground-cloth extends approximately 4.9 feet (1.5 meters) downstream of the weir, and several large rocks were placed on the plastic to help dissipate energy of the flows coming over the weir.

Water level monitoring. Water level behind the weir was recorded using a pulse generator and stilling well system similar to that described for the Gunflint Trail site. A Campbell CR10X datalogger was installed beside the weir and stilling well to maintain a continuous record of water levels (Figure 41). The datalogger installation differed from that for the Gunflint Trail only in that a raingage was not installed at the Syene Spring site.

Spring Flow Results

The two weir records display similar and notable flow behaviors for the study springs. Both springs have stable flow regimes that exhibit little or no recession, even during long summer dry periods. The Big Spring at the Gunflint Trail site provides a constant flow of 0.33 cfs at all times of the year, with no measurable recession or fluctuation (Figures 42), and only short-lived high flows during rainfall events sufficient to cause surface runoff in its drainage basin (Figure 43). This lack of recession is unusual and has not been noted elsewhere in the scientific literature; the mechanism may be linked to the high and relatively constant heads in the underlying aquifer (Figure 44), but has not yet been ascertained. Similar results can be observed in the Syene Road Spring data (Figures 45a-c), which shows a constant flow of 0.16 cfs. The Syene Road data are complicated somewhat by the presence of drain tiles, which increase the surface flow response measured by the weir, but this does not seem to contribute to changes in between-event flows. A longer flow record at this site will be necessary to provide more conclusive results.

Precipitation Data

The tipping-bucket raingage located at the Gunflint Trail weir collected precipitation data through the course of the study. The CR10 datalogger was installed at the site on July 2, 1998 and the precipitation record extends from that date until June 30, 1999. The gage was removed from the field on December 7, 1998 and returned on April 15, 1999, so data were not collected for that time period. Tipping-bucket gages do not operate properly under the snow and ice conditions prevalent during that time.

Data were collected on a 1-minute basis and aggregated to provide 15-minute rainfall totals. Individual rainfall events were extracted from the data assuming that all events were separated by at least 8 hours of "dry weather", i.e.; lack of recorded rainfall. From July 3, 1998 to September 30, 1998 (the end of Water Year 1998) there were 13 precipitation events that had rainfall totals exceeding 0.20 inch (Table 6). Notably high intensity rainfall occurred during five of these events. Two short events, those on July 19 and on July 20, contained the most intense rainfalls during this period (0.50 and 0.43 inch in 15 minutes, respectively). High rainfall intensities were also noted during the July 3, August 4 and August 24 events.

Table 6. Gunflint Trail rain events exceeding 0.20 inch – WY 1998

Rainfall (inches)	Beginning of storm (CST)	End of Storm (CST)	Storm Length (Hours)
2.78	9/14/98 0:15	9/14/98 20:45	20.75
1.29	7/3/98 9:00	7/3/98 21:15	12.50
0.79	7/19/98 2:00	7/19/98 3:45	2.00
0.77	7/20/98 17:15	7/20/98 20:15	3.25
0.73	8/4/98 5:45	8/4/98 18:30	13.00
0.73	8/27/98 14:15	8/28/98 4:30	14.50
0.61	8/23/98 4:00	8/23/98 6:45	3.00
0.60	8/24/98 4:30	8/24/98 23:15	19.00
0.49	8/14/98 17:30	8/14/98 21:45	4.50
0.43	8/17/98 7:00	8/17/98 10:00	3.25
0.34	9/30/98 11:15	9/30/98 15:30	4.50
0.31	9/23/98 23:00	9/24/98 1:30	2.75
0.26	8/5/98 5:00	8/5/98 8:15	3.50

From October 1, 1998 through June 30, 1999, excepting the winter period noted above, there were 24 events during which the rainfall exceeded 0.20 inches (Table 7). The two largest events were long duration (34.5 and 31.25 hours) storms typical of frontal, as opposed to thunderstorm, activity. There were only four events during which rainfall exceeded 0.34 inches in a 15 minute period, but these events were all considerably more intense than the storms noted for the previous water year. The highest 15-minute rainfall (0.94 inch) occurred on June 10 and the storm on May 15 contained successive 15-minute rainfalls of 0.57 and 0.48 inches. The other high-intensity events occurred on June 6 and June 22.

Table 7. Gunflint Trail rain events exceeding 0.20 inch – WY 1999

Rainfall (inches)	Beginning of storm (CST)	End of Storm (CST)	Storm Length (Hours)
4.90	4/21/99 19:45	4/23/99 6:00	34.50
3.04	11/9/98 15:30	11/10/98 22:30	31.25
2.39	5/16/99 16:00	5/17/99 1:15	9.50
1.82	10/5/98 1:45	10/5/98 18:30	17.00
1.42	6/10/99 16:30	6/10/99 18:00	1.75
1.39	10/17/98 3:15	10/18/98 1:15	22.25
1.38	6/13/99 0:15	6/13/99 9:45	9.75
1.16	6/6/99 14:15	6/7/99 1:15	11.25
1.06	5/6/99 5:15	5/6/99 18:45	13.75
1.06	6/1/99 18:45	6/2/99 7:00	12.50
0.95	6/22/99 16:00	6/22/99 20:30	4.75
0.61	10/2/98 17:15	10/3/98 20:30	27.50
0.58	4/27/99 12:45	4/27/99 21:15	8.75
0.57	6/30/99 22:30	7/1/99 6:15	7:45
0.44	10/27/98 3:00	10/27/98 22:00	19.25
0.41	4/20/99 12:30	4/20/99 16:15	4.00
0.39	5/23/99 4:00	5/23/99 7:00	3.25
0.27	6/11/99 20:45	6/12/99 2:00	5.50
0.26	5/11/99 21:45	5/12/99 3:00	5.50
0.26	6/4/99 10:30	6/4/99 11:30	1.25
0.26	6/23/99 10:15	6/23/99 15:15	5.25
0.21	5/4/99 17:15	5/5/99 9:00	16.00
0.21	5/17/99 21:30	5/18/99 8:45	11.50
0.21	5/21/99 14:00	5/22/99 0:15	10.50

Rainfall totals measured at the Gunflint Trail site consistently exceeded the totals measured at Dane County Regional Airport (DCRA) for Water Year 1999, although not for WY 1998. A double-mass plot comparing the two rainfall records shows that Gunflint Trail rainfall overestimated DCRA rainfall by 47% (Figure 46), suggesting a systematic error in the Gunflint Trail data. However, a recalibration exercise did not support this suggestion. Systematic errors in rainfall data generally result in reduced rainfall catch efficiency, or underestimation of actual rainfall. Further analysis of the DCRA record relative to other rainfall records is necessary to determine if there is some error in that data.

I. Groundwater Modeling

Regional groundwater flow models are an important tool with which to address regional land-use planning and water-supply questions, but they often lack the resolution to assess the complexities of local groundwater flow. Regional models can, however, provide a valuable starting point for more detailed and precise watershed-scale models. Using the telescopic mesh refinement (TMR) approach, a localized groundwater flow model can be created from a regional model. The resulting localized model has a smaller model domain than the regional model and increased grid resolution. A smaller model domain is used because it is difficult to justify the regional use of finer grid spacing, since data point density often decreases outside the local area of interest. The increased grid resolution (or finer grid spacing) is necessary in order to incorporate the more detailed hydrogeologic information available for local study areas. Problems can arise in designing a model grid for a local study area because a model domain must be large enough to correctly represent the regional groundwater input to the system. The telescopic mesh refinement approach allows the use of the smaller model domain because the localized model boundary conditions are defined of the basis of the regional model hydraulic head or flow results. Therefore, connection to the regional flow system is maintained, even though a smaller model domain is used (Ward et al., 1987).

Using the TMR approach and the Dane County regional groundwater flow model (Krohelski et al., 1997), which uses the U.S. Geological Survey modular groundwater modeling code (MODFLOW, McDonald and Harbaugh, 1988), a localized model for the Nine Springs area was created. The purpose of the refinement process was to create a model that could more *precisely* represent the distribution of hydraulic heads in the vicinity of the Nine Springs watershed. The modeling results, used in association with the physical database compiled as part of the project, provide an improved understanding of potential effects of increases in municipal pumping.

The model grid for the Nine Springs model is shown in Figure 47. This refined MODFLOW model has 125 columns, 101 rows, and three layers. The three layers correspond to those defined for the Dane County model (layer 3: the Mt. Simon sandstone; layer 2: the Upper Paleozoic bedrock units; layer 1: the unconsolidated surficial materials) (see Krohelski et al., 1997). The variable grid spacing ranges from approximately 164 to 656 feet, which was reduced from the 1,312-foot grid spacing used in the county-scale model. Using the TMR approach, two sets of specified-flow boundary conditions were defined for the Nine Springs model on the basis of steady-state flow conditions from the county-scale model. The boundary conditions represent flow conditions under (i) current (1995) municipal and high capacity well pumping levels and (ii) proposed (2020) pumping levels.

Because the model grid spacing was reduced throughout the model domain, improvements in the distribution of river nodes, representing the Madison lakes and Nine Springs Creek could be made. In addition, river conductance terms were updated in the nodes representing Nine Springs Creek so as to better represent the dimensions of the creek and therefore, the conductance of the river-bed sediment in each river node.

The distribution of unlithified hydraulic conductivity values in layer 1 was updated using an overlay of the geomorphic settings initially used to define the distribution of surficial materials in the county-scale model (Swanson, 1996; Krohelski et al., 1997). In addition, the distributions of bedrock elevations for both layers 2 and 3, representing the uppermost bedrock surface and the top of the Mt. Simon sandstone, respectively, were refined.

As previously stated, two sets of specified flow boundary conditions were created for the Nine Springs model, corresponding to two flow conditions:

i. flow conditions under current (1995) pumping levels

ii. flow conditions under proposed (2020) pumping levels

Following refinement of the model parameters discussed above, the Nine Springs model was run under steady-state conditions using the first set of boundary conditions. In order to confirm that the refined information had been properly incorporated, the hydraulic head distribution generated by the Nine Springs model was compared to the hydraulic head distribution (for the Nine Springs area) that was generated by the county-scale model under current (1995) pumping levels. For the purposes of the study, a detailed calibration of the Nine Springs model was not necessary because the model adequately reproduced the coarser hydraulic head distribution from the calibrated county-scale model. The Nine Springs model was then run using the proposed (2020) pumping levels including the pumping levels for proposed wells, as compiled for the Dane County Hydrologic Modeling and Management Program (Dane County RPC, 1997).

In order to compare the results of the two steady-state model runs, maps of the approximate Nine Springs ground-watershed boundaries were generated (Figures 48 and 49). The ground-watershed boundaries were generated using the particle-tracking code MODPATH (Polluck, 1994). MODPATH was used in association with the MODFLOW model output to track imaginary particles backwards from Nine Springs Creek up-gradient to the points where they enter the groundwater flow system (i.e. the water table). Figure 50 shows the approximate ground-watershed boundaries under the two pumping scenarios in order to illustrate the approximate reduction in areal extent of the ground-watershed under the future pumping scenario.

To quantify the effects of the change in pumping scheme, we compared the groundwater discharge to Nine Springs Creek under current pumping levels to the discharge under future pumping levels. The groundwater discharge to each river node representing Nine Springs Creek is shown on Figure 51. Under the proposed pumping scenario, discharge to Nine Springs Creek decreases by approximately 15% at each river node. In the lower (eastern) reaches of the creek, Figure 51 shows negative discharge in some river nodes. In these nodes, groundwater does not discharge to the creek. The creek acts as a losing stream in these nodes under the proposed pumping scenario, whereas the creek is simulated, for the most part, as a gaining stream under current pumping levels.

Cumulative modeled stream flow (cfs) at four points along the creek (Figure 52) is shown on Table 8. Results from synoptic baseflow surveys at the same four points are also included on the Table 8. The modeled flows are less that the observed flows. However, as previously mentioned the Nine Springs model was not recalibrated beyond the county-scale model calibration. Therefore, the model has not been calibrated to include a significant volume of flow discharging from the wells at the WDNR Nevin Fish Hatchery (approximately 2 to 3 cfs). Therefore, the results presented below are intended for comparative purposes and should not be used as precise quantitative predictions of flow loss.

Table 8. Cumulative flow (cfs) at four points along Nine Springs Creek

Location	Measured Baseflow (cfs)	Cumulative Modeled Flow (cfs) under Current Pumping Levels	Cumulative Modeled Flow (cfs) under Proposed Pumping Levels
Triple Junction	1.2 +	0.59	0.51
Nursery Spring Channel	2.1 +	0.91	0.78
Syene Road	3.3	1.72	1.47
Discharge to Mud Lake	5.0	2.82	2.28

Notes: + indicates flow greater than estimated value. Accurate measurements could not be made due to creek channel obstructions.

The model predicts that approximately 0.5 cfs of baseflow to the creek would be lost under the proposed pumping scheme, which is approximately 18% of the modeled flow under current pumping levels. In addition, ½ of the loss of flow occurs by the Syene Road location, which is only ¼ of the distance to the discharge point at Mud Lake. Most of the remaining high quality wetlands also occur along, and in the vicinity of, the upper ¼ reaches of the creek.

III. Discussion and Conclusions

A. Comparative Wetland Hydrology

Two wetlands that have supported sedge meadow communities in historic times were contrasted as part of this study. The Syene Road experimental site at times supported a productive wetland community, as shown by the 8.2 to 9.8-foot (2.5 to 3.0-meter) thick peat layer remaining, but was drained for agricultural purposes between 1906 and 1910 (Frolik, 1941). This site is now dominated by reed canary grass and exhibits very little sedge meadow character. In contrast, the sedge meadow at the Gunflint Trail site was never successfully drained and retains a relatively healthy sedge meadow community. It is likely that the hydrologic regimes at the two sites always differed somewhat, due to their differing peat thicknesses, proximity of the confining silt layer and distance to adjacent uplands; however, it is believed that the existing sedge meadow provides a reasonably good surrogate for the pre-drainage regime of the degraded site.

The hydrologic regime of the drained wetland at the Syene Road experimental site shows qualitative differences with that observed in the relatively healthy sedge meadow on the Gunflint Trail site. Drainage has lowered water levels, reduced the ability of the peat to retain water after storm events and altered the peat structure so that the capillary fringe of the wetland has been reduced or eliminated. The result is a system in which the upper layers of the peat are significantly drier through most of the growing season, which may provide the conditions favoring the domination by the exotic reed canary grass.

Gunflint Trail hydrology. Water tables on the Gunflint Trail site are at the ground surface in the spring season, and even though they may drop during dry periods, they quickly respond to rain events and remain high until evapotranspiration removes enough water to lower the water tables. Seepage inflows appear to be much smaller than evapotranspiration losses during the growing season. A capillary fringe extends 0.5 feet (0.15 m) above the water table and extends the zone in which plant roots would be exposed to saturated or near-saturated conditions to the soil surface during all but the driest periods.

Experimental site (Syene Road) hydrology. Early in the growing season, the experimental site retains high water table levels. Drainage from the site is slow and water levels fall only after relatively long dry periods. Water table levels and topography indicate that the groundwater on the site drains toward Nine Springs Creek, which has been ditched to a level considerably lower than the surface of the wetland. This flow is believed to occur largely through macropores in the peat and subsurface tile drains. As the summer progresses the drainage from the wetland to the creek occurs more quickly, possibly due to temperature effects within the peat and possibly due to lower tailwater levels downstream.

Evapotranspiration, which clearly affects the water table at the Gunflint Trail site, is not obvious in water table records from the experimental site, but may cause a significant loss of water from the wetland. The lack of an evaporation signal is probably related to the lack of a capillary fringe response in this wetland, which is apparent in the hydrograph of the September 14, 1998 storm (Figure 15). If the plants in this wetland do not draw water from the groundwater table or a capillary fringe extending above the water table, fluctuations due to evapotranspiration may not be visible in the water table record.

Hydrologic effects of drainage. Subsurface drainage has resulted in water table levels in the Syene Road site that are considerably lower than those on the Gunflint Trail site. The water levels decline more quickly in the summer time, resulting in much shorter times in which the water table remains near the surface in the growing season. Additionally, the area above the water table that maintains near saturated conditions is considerably reduced in the drained (tiled) wetland, likely due to structural changes in the peat brought about by increased aeration of the upper levels after drainage. The net result is that after early season flooding the water content in the rooting zone is lower in the drained wetland than in the undrained sedge meadow through most of the growing season. Instead of the nearly saturated conditions that tend to occur in the upper 0.5 feet (0.15 m) of the undrained sedge meadow, the drained wetland has much drier soils for essentially the entire summer. These relatively drier late growing season soil conditions may be a key to the dominance of reed canary grass in the drained wetland, and its lack of dominance in the undrained wetland.

B. Groundwater Flow

On the basis of the geochemical and isotopic results, it appears that both local groundwater flow through the unconsolidated surficial materials and intermediate groundwater flow through the shallow bedrock units are critical to the maintenance of the wetlands and springs in the Nine Springs watershed. We are less able to determine the relative importance of regional groundwater input to the system. Unfortunately, we had very few sampling points where we could monitor groundwater that may have a regional geochemical signature (geochemical Group III). However, we expect that regional groundwater does have an important, but as yet undetermined role in the Nine Springs system. A significant result that indicates that the regional flow system may play an important role in the Nine Springs system is that both of the large springs that were monitored have stable flow regimes that exhibit little or no measurable recession at all times of the year, even during long summer dry periods. Further study will be necessary to confirm our findings and conclusions regarding the source of groundwater discharging to the Nine Springs wetlands and springs.

Groundwater modeling results suggest that the proposed 2020 pumping scheme may result in a reduction of the volume of groundwater discharging to Nine Springs Creek. The model is not capable of simulating the response of the wetland water table and/or individual springs. However, on the basis of our comparitive hydrology discussion, any reduction in the volume of groundwater discharging to the wetland system may have detrimental effects on the diversity and/or restoration potential of the wetland vegetative communities, particularly in the areas where subsurface drainage has already resulted in water table levels that are considerably lower than those in the undrained (untiled) wetlands.

References

Bedford, B.L., Zimmerman, E.H., and Zimmerman, J.H., 1974, The Wetlands of Dane County, Wisconsin, Dane County Regional Planning Commission and the Wisconsin Department of Natural Resources, Madison, WI, 1052p.

Bos, M.G., Editor, 1989, Discharge Measurement Structures, Third Revised Edition. International Institute for Land Reclamation and Improvement. Wageningen, The Netherlands.

Bradbury, K.R., Swanson, S.K., Krohelski, J.T., and Fritz, A.K., 1996, Hydrogeology of Dane County, Wisconsin, Wisconsin Geological and Natural History Survey Information Circular XXX, (in preparation).

Clark I.D. and Fritz P., 1997, Environmental Isotopes in Hydrogeology, Lewis Publishers, New York, 328p.

Clayton, L. and Attig, J.W., 1997, Pleistocene geology of Dane County, Wisconsin, Wisconsin Geological and Natural History Survey Bulletin 95, 64p.

Cline, D.R., 1965, Geology and ground-water resources of Dane County, Wisconsin, U.S. Geological Survey Water Supply Paper 1779-U, 64p.

Colby, N.D., 1993, The use of 2-way cluster analysis as a tool for delineating trends in hydrogeologic units and development of a conceptual model, *in* International Ground Water Modeling Center (IGWMC), Proceedings of the 1993 Ground Water Modeling Conference, 91-100, Golden, CO: IGWMC, Colorado School of Mines.

Craig, H., 1961, Isotopic Variations in Meteoric Waters, Science, Vol. 133, pp. 1702-1703.

CR10 Measurement and Control Module Operator's Manual. Revision 3/94. 1994. Campbell Scientific, Inc. Logan, UT.

Dane County Regional Planning Commission (RPC), August 1997, Evaluation of Alternative Management Strategies, Dane County Regional Hydrologic Study, 41p. plus appendices.

Eggers, S.D. and Reed, D.M., 1997, Wetland Plants and Plant Communities of Minnesota and Wisconsin, U.S. Army Corps of Engineers, St. Paul District, 263p.

Essery, C. I. and Wilcock, D.N., 1991, The variation in rainfall catch from standard UK Meteorological Office raingauges: a twelve year case study. Hydrological Sciences Journal 36: 23-34.

Frolik, A.K., 1941, Vegetation on the peat lands of Dane County, Wisconsin. Ecological Monographs 11: 117-140.

Heliotis, F.D. and Dewitt, C.B., 1987, Rapid watertable responses to rainfall in a northern peatland ecosystem, Water Resources Bulletin 23: 1011-1016.

Hvorslev, M.J., 1951, Time lag and soil permeability in groundwater observations, U.S. Army Corps of Engineers Waterways Experimental Station Bulletin 36, Vicksburg, MA, 50p.

Krohelski, J.T., Bradbury, K.R., Hunt, R.J., and Swanson, S.K., 1997, Numerical simulation of groundwater flow in Dane County, Wisconsin, Wisconsin Geological and Natural History Survey Bulletin 9x, in press.

Latkovich, V. J. and Leavesley, G.H., 1993, Automated Data Acquisition and Transmission. In: Handbook of Hydrology. Edited by David R. Maidment. McGraw-Hill, Inc., New York NY.

Lee, D.P. and Cherry, J.A., 1978, A field exercise on groundwater flow using seepage meters and mini-piezometers, Journal of Geological Education 27: 6-10.

McDonald, M.G., and Harbaugh, A.W., 1988, A modular three dimensional finite-difference ground-water flow model: U.S. Geological Survey Techniques of Water Resources Investigations, book 6, chap. A1, 579p.

Novitzki, R.P., 1978, Hydrology of the Nevin Wetland near Madison, Wisconsin, U.S. Geological Survey, Water Resources Investigation 78-48, 25p.

Olson, D.E., 1994, An investigation of runoff in the Garfoot Creek Watershed, Dane County, Wisconsin: Implications for recharge in the Driftless Region. M.S. Independent Study Report, University of Wisconsin - Madison.

Owen, C.R., 1995, Water budget and flow patterns in an urban wetland, Journal of Hydrology, Vol. 169, pp. 171-187.

Polluck, D.W., 1994, MODPATH a particle tracking postprocessing model for, Version 3, U.S. Geological Survey Open File Report 94-463.

Rayne, T.W., 1993, Variability of hydraulic conductivity in sandy till: The effects of scale and methodology: Madison, University of Wisconsin, Department of Geology and Geophysics, Ph.D. Dissertation, 134p.

Rodda, J.C. and Smith, S.W, 1986, The significance of the systematic error in rainfall measurement for assessing wet deposition. Atmospheric Environment 20: 1059-1064.

StatSoft, Inc., 1997, STATISTICA for Windows [Computer program manual]. Tulsa, OK: StatSoft, Inc., 2300 East 14th Street, Tulsa, OK 74104.

Swanson, S.K., 1996, A Comparison of Two Methods Used to Estimate Groundwater Recharge in Dane County, Wisconsin: Madison, University of Wisconsin, Department of Geology and Geophysics, M.S. Thesis, 123p.

Ward, D.S., Buss, D.R., Mercer, J.W., and Hughes, S.S., 1987, Evaluation of a groundwater corrective action at the Chem-Dyne hazardous waste site using a telescopic mesh refinement modeling approach, Water Resources Research, Vol. 23, No. 4, pp. 603-617.

Water Resources Management Practicum (WRM), 1990, Urban Wetlands in the Yahara-Monona Watershed: Functional Classification and Management Alternatives, University of Wisconsin-Madison Institute of Environmental Studies, Madison, WI, 255p.

Water Resources Management Practicum (WRM), 1996, The Nine Springs Watershed and Environmental Corridor, A Water Resources Management Study, University of Wisconsin-Madison Institute of Environmental Studies, Madison, WI, 204p.

Figures

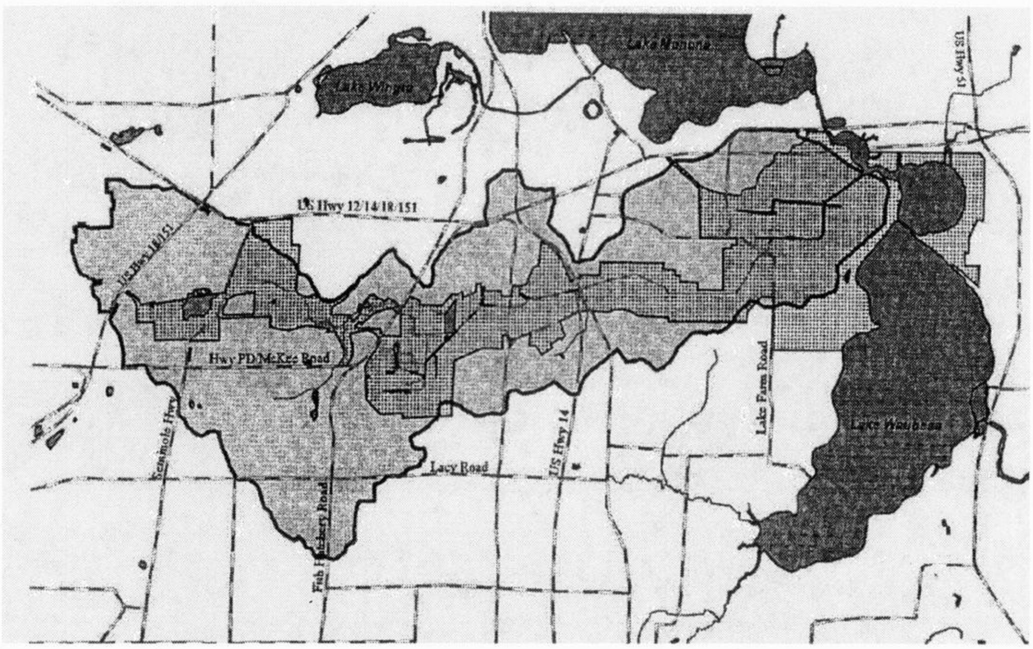


Figure 1. Location map of Nine Springs watershed
(Adapted from WRM, 1996)

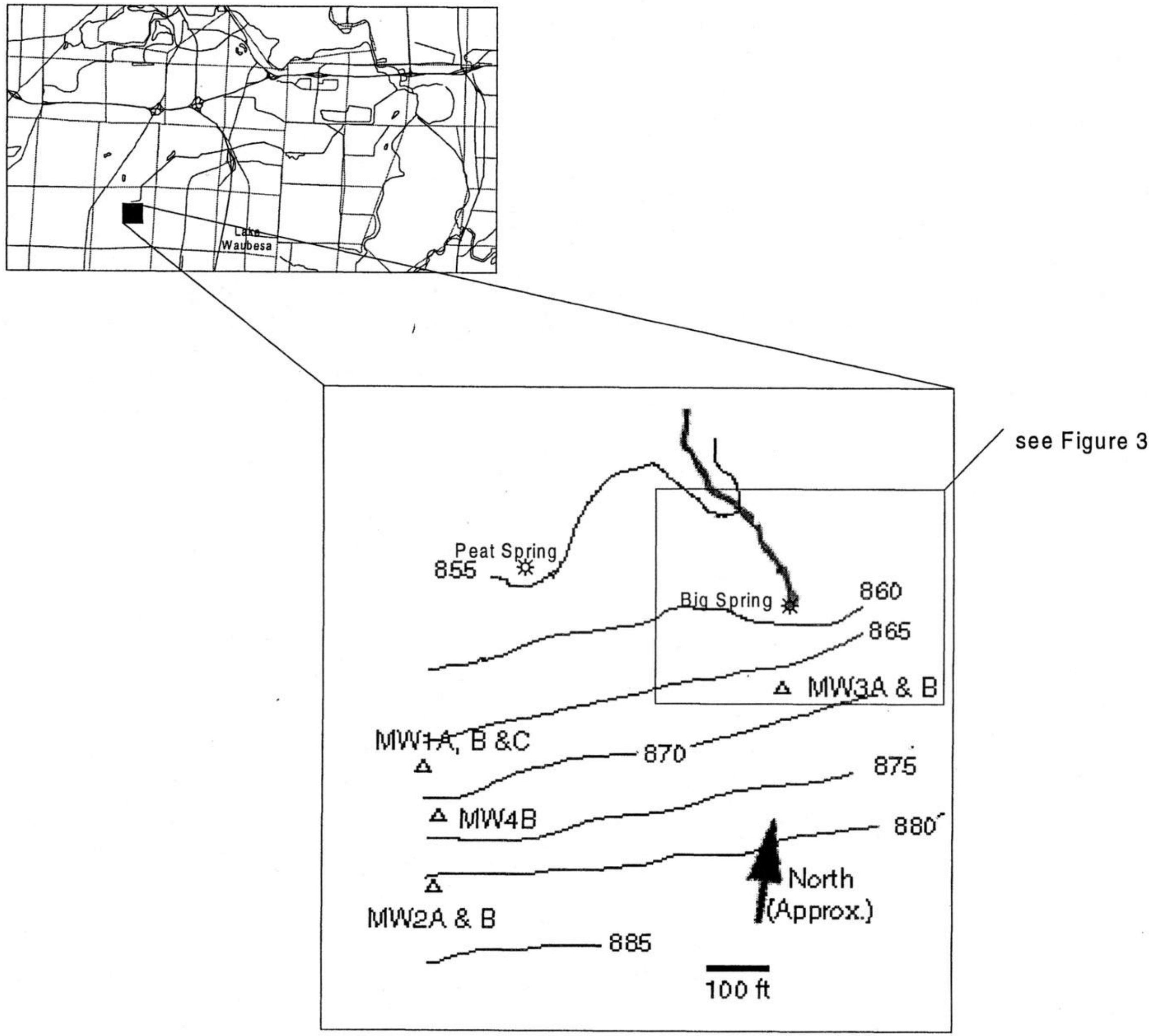


Figure 2. Gunflint Trail site map

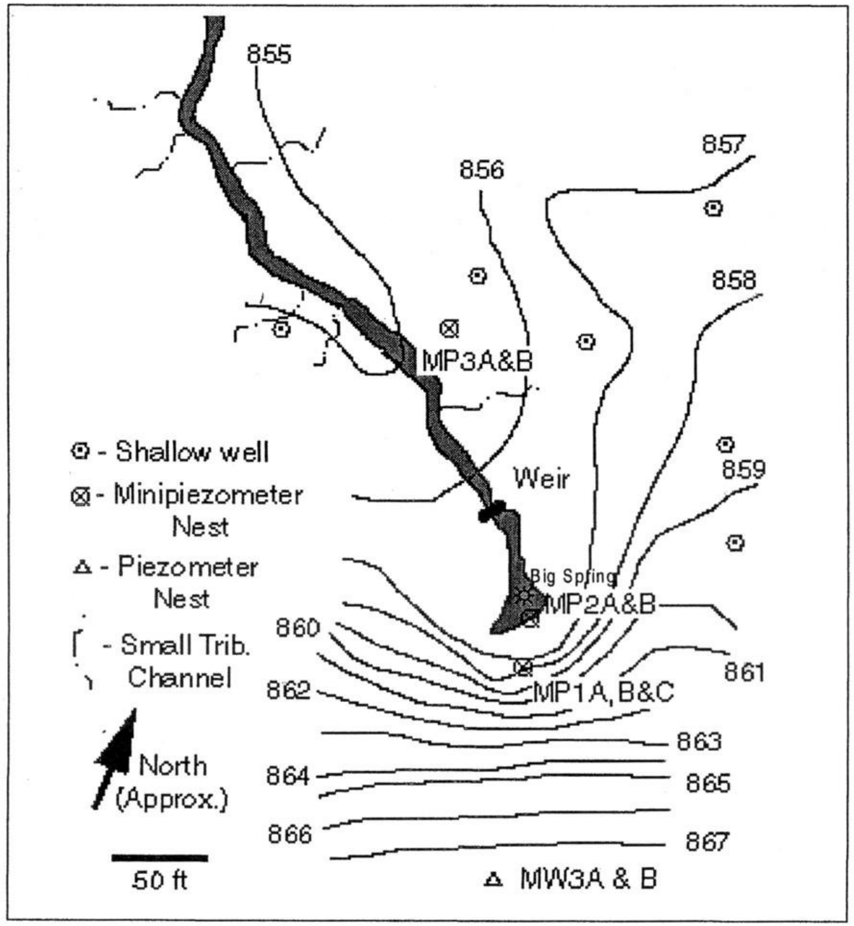


Figure 3. Gunflint Trail site wetland instrumentation

Figure 4. Syene Road site map

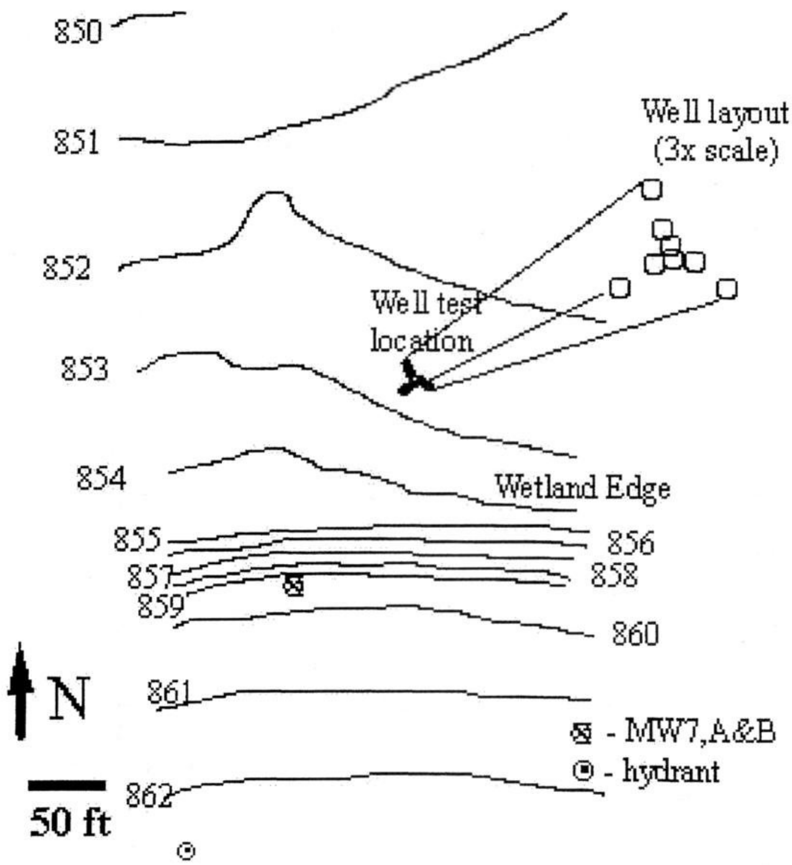


Figure 5. Well test layout

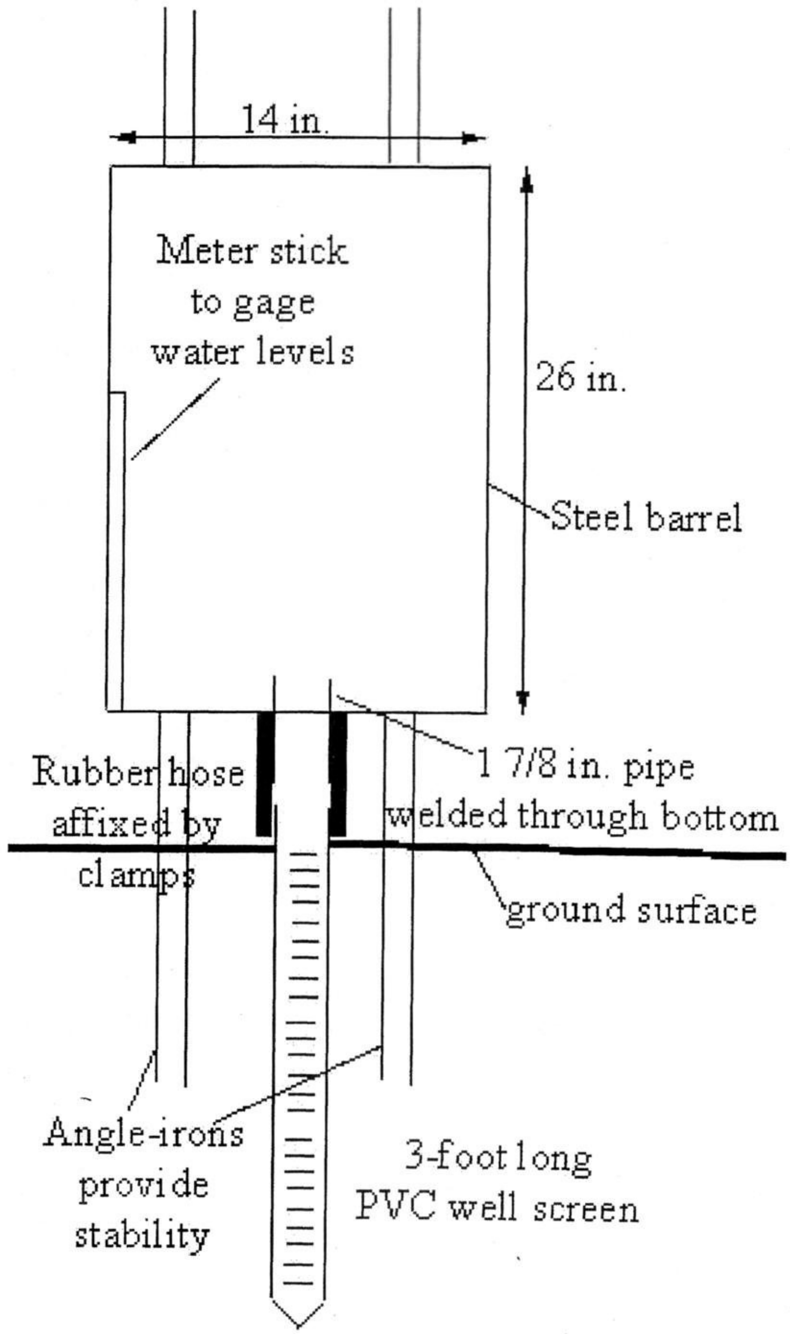


Figure 6. Water infiltration system diagram

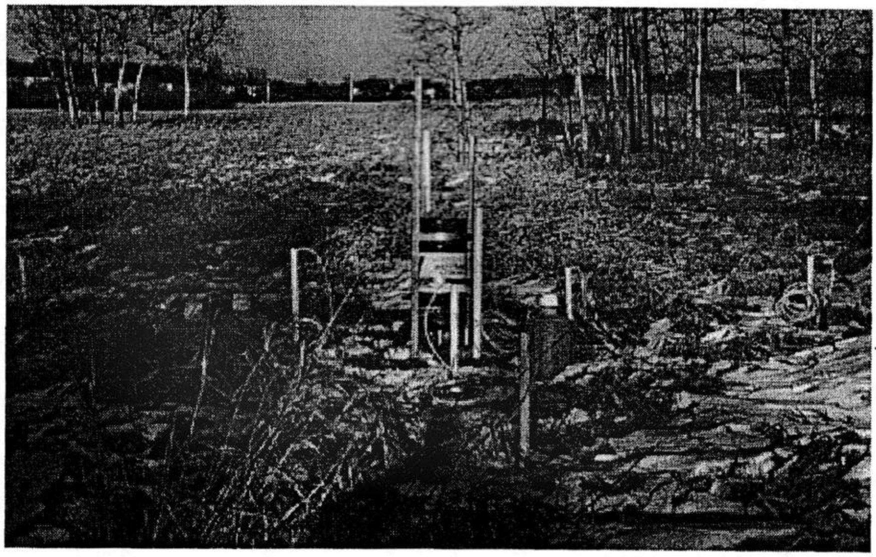


Figure 7. Photograph of well test setup

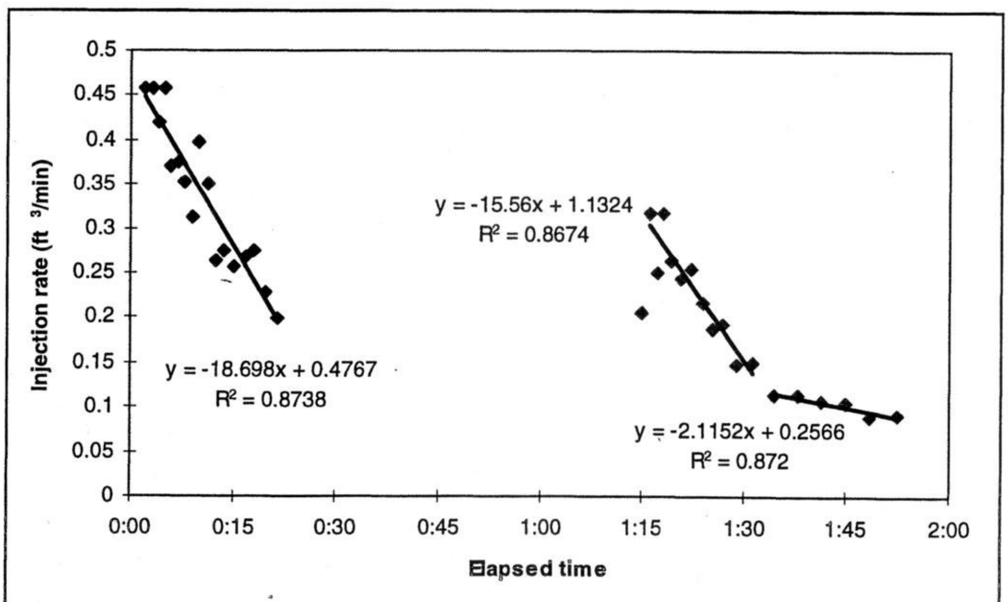


Figure 8. Water infiltration rate during well test

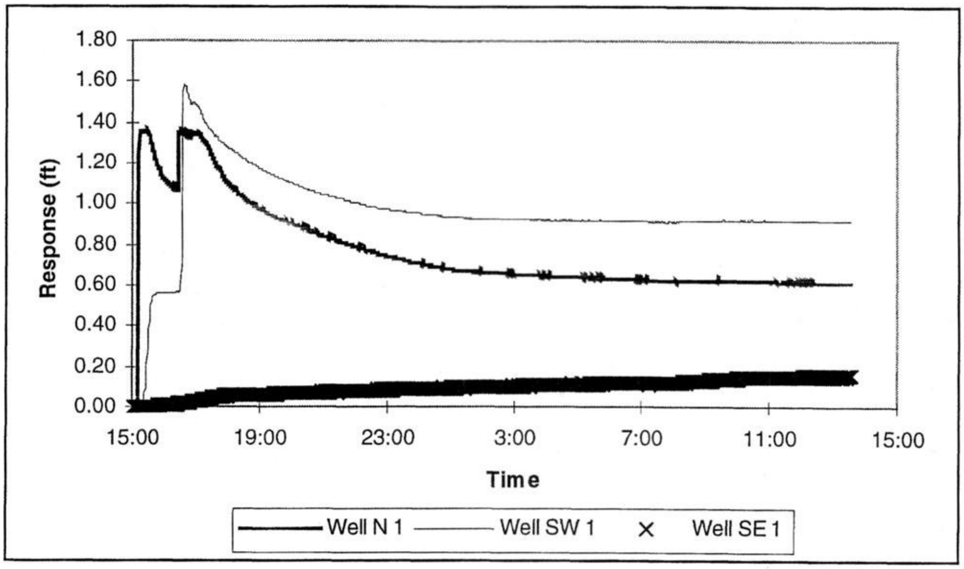


Figure 9a. Water levels in wells one meter from source

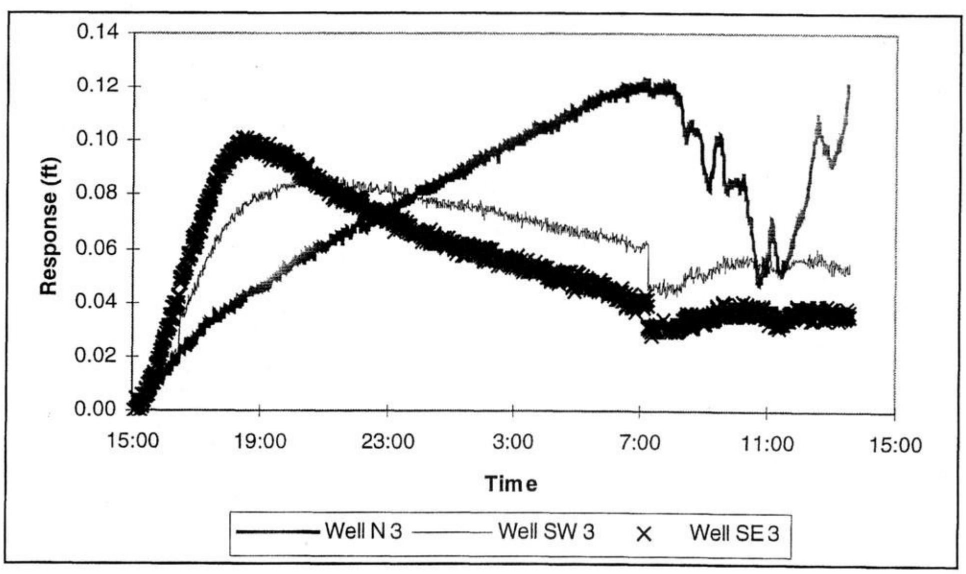


Figure 9b. Water levels in wells three meters from source

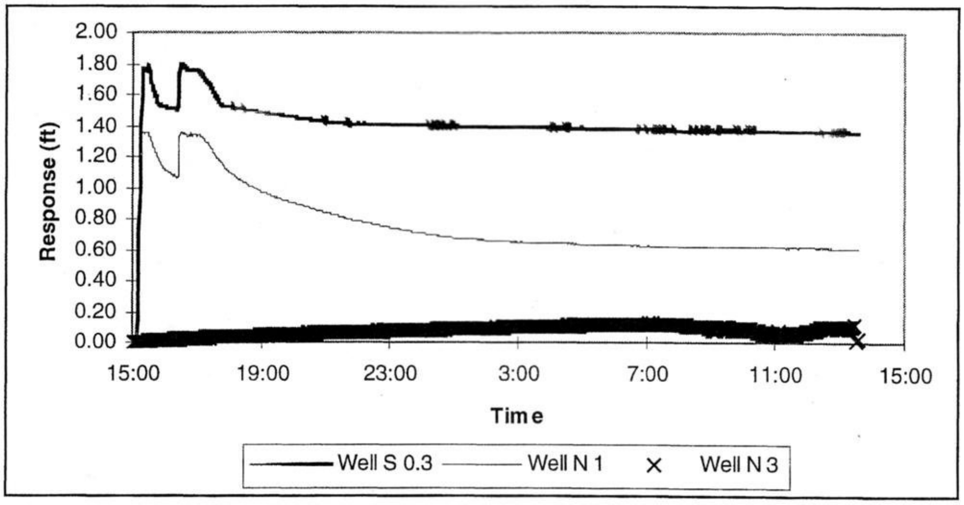


Figure 10a. Water levels in north transect

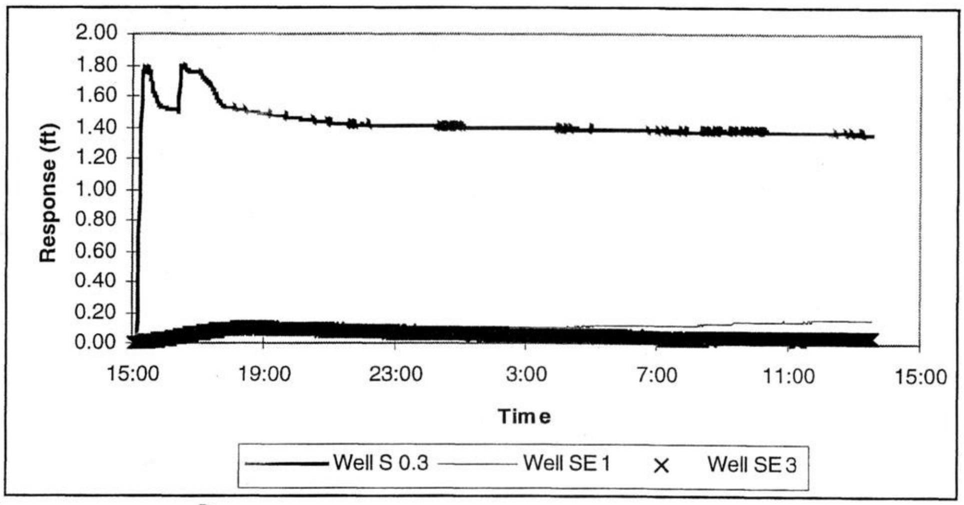


Figure 10b. Water levels in southeast transect

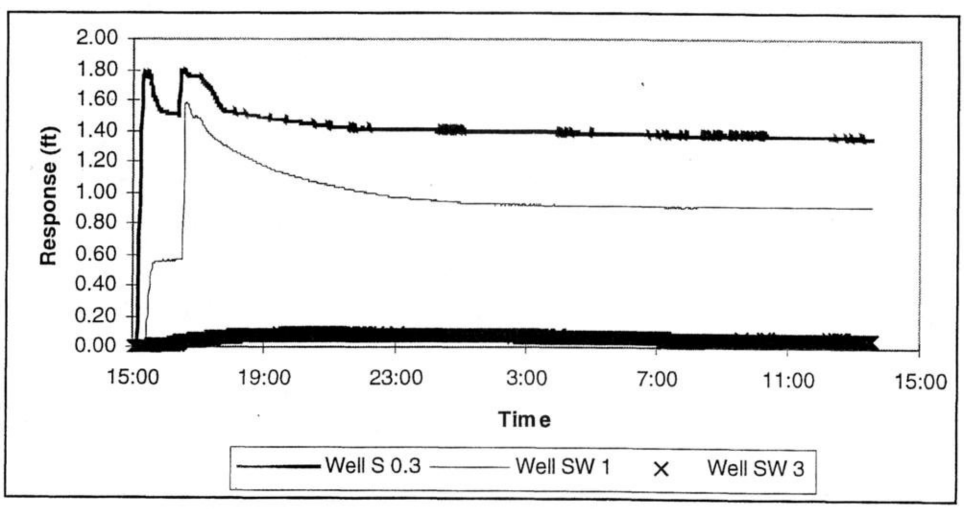


Figure 10c. Water levels in southwest transect

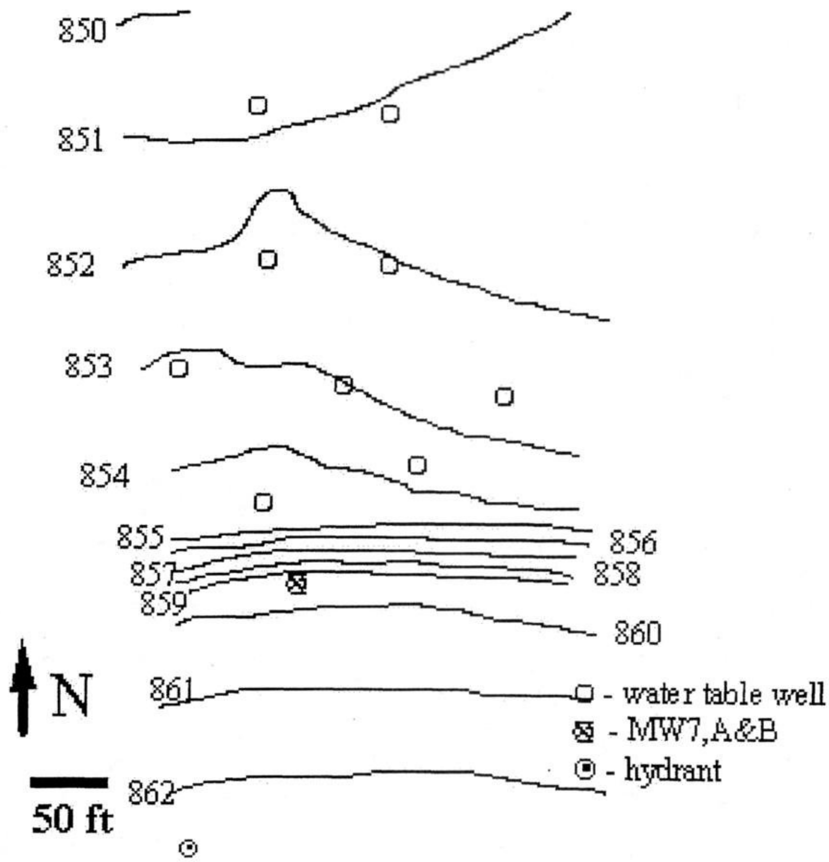


Figure 11. Syene Road experimental site wells

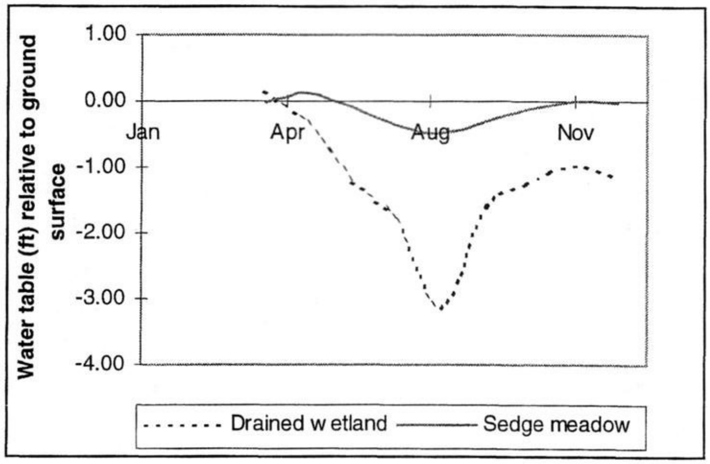


Figure 12. Average water table levels in two wetlands

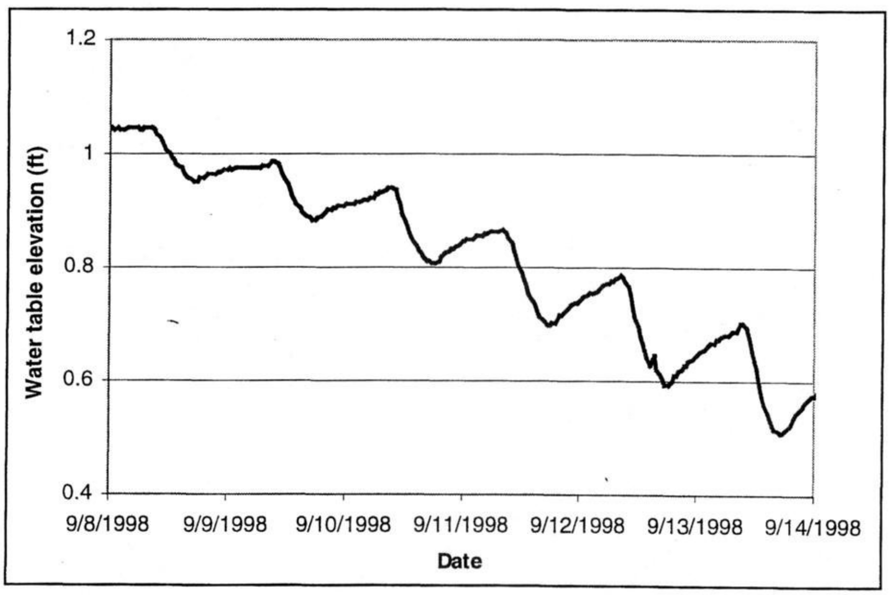


Figure 13. Gunflint Trail daily water table fluctuations

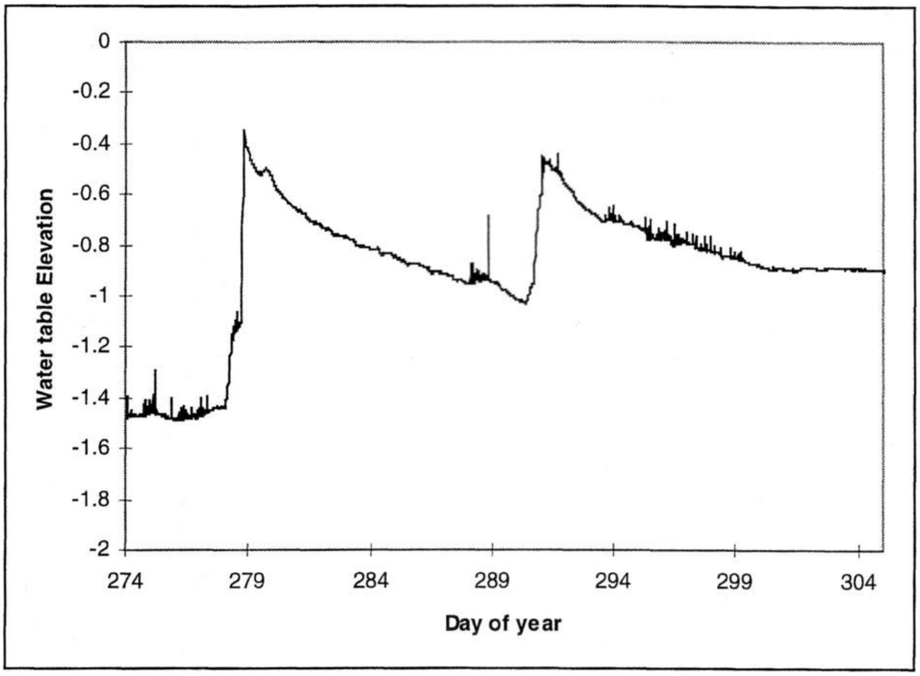


Figure 14. Water table recovery from two October storm events at Syene Road experimental site

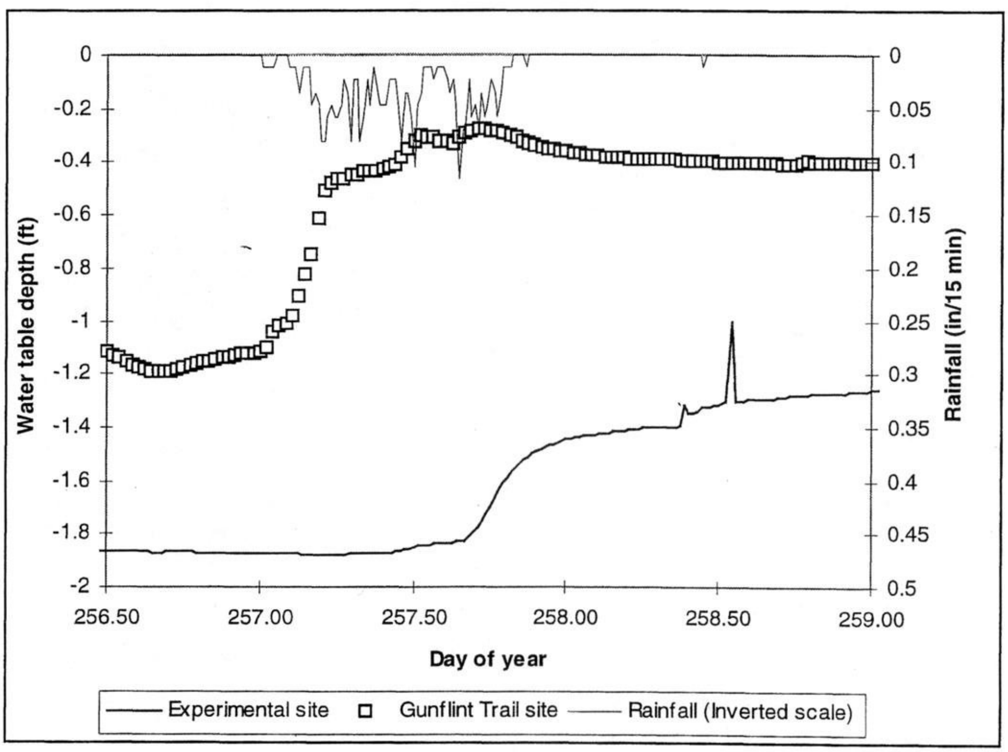


Figure 15. Water table response to September 14, 1998 storm event

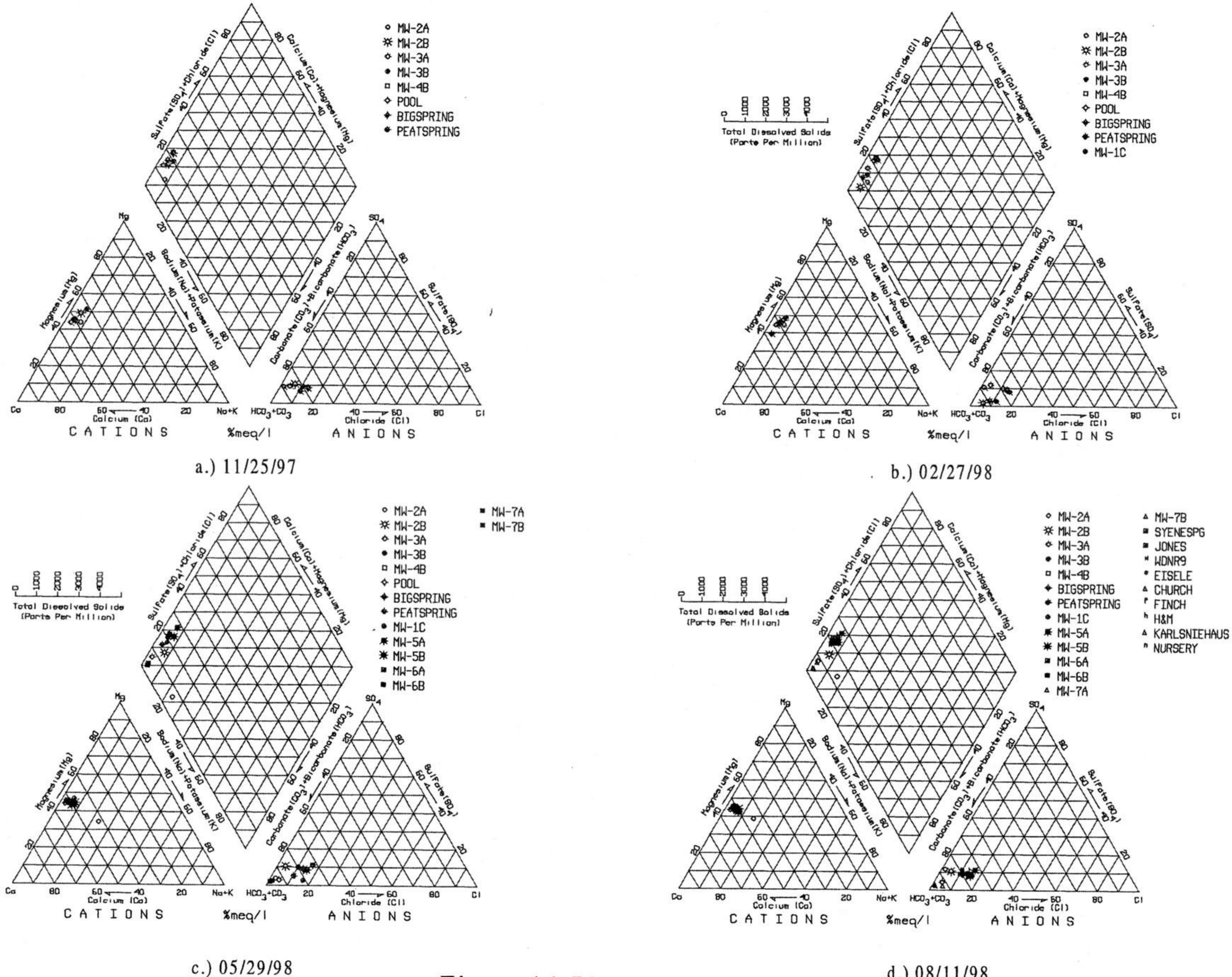
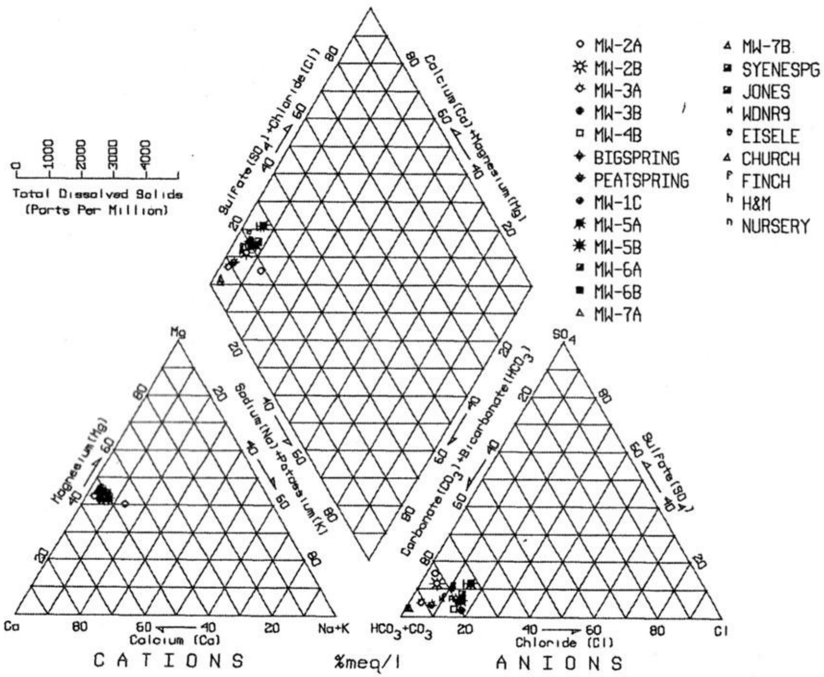
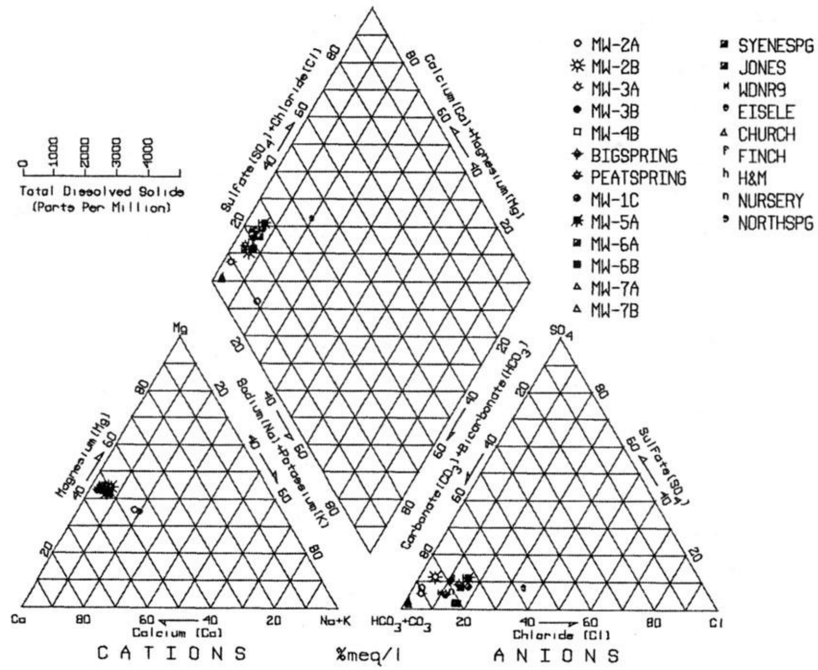


Figure 16. Piper Diagrams



e.) 12/16/98



f.) 03/11/98

Figure 16 (continued). Piper Diagrams

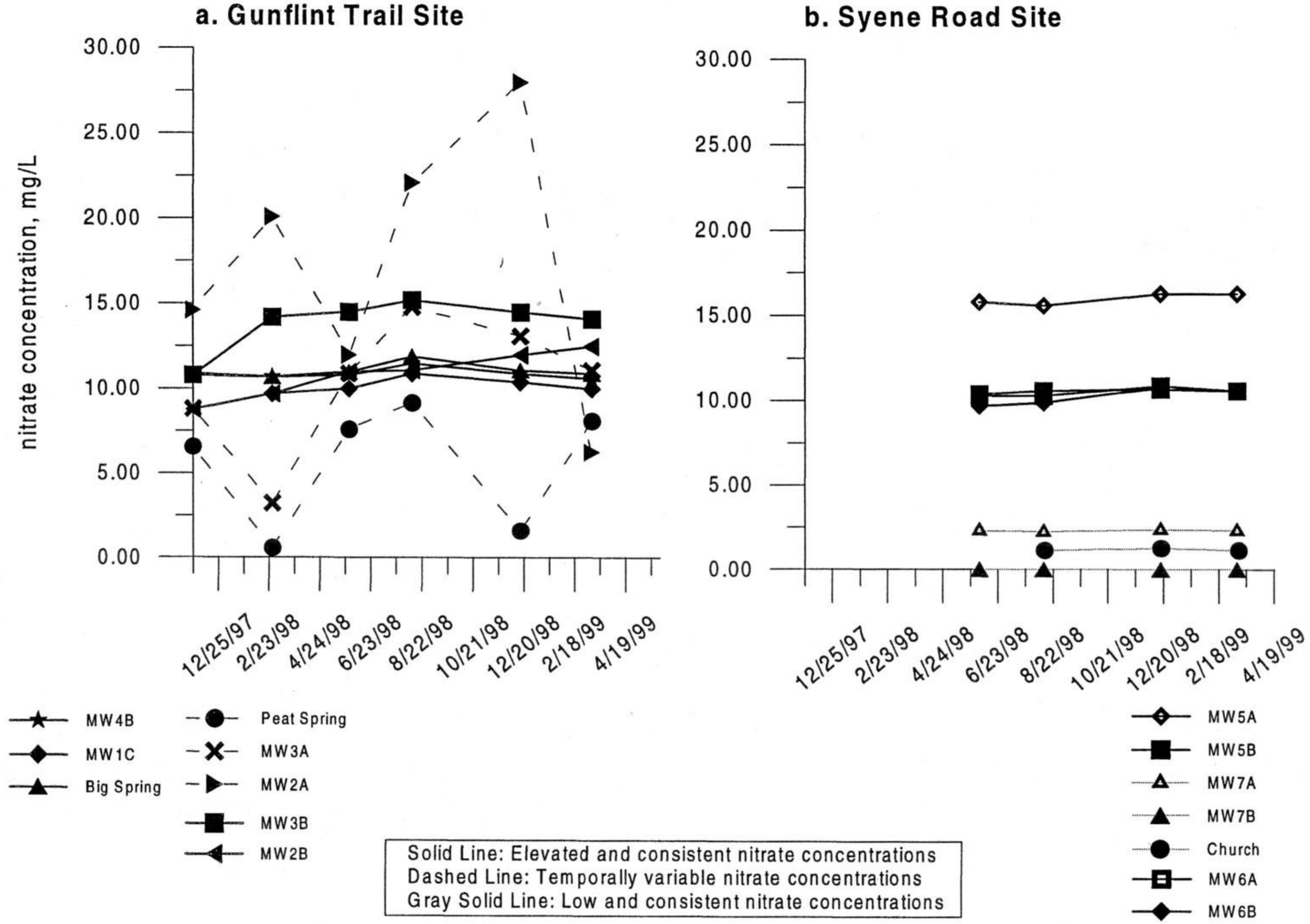


Figure 17a-b. Nitrate Results

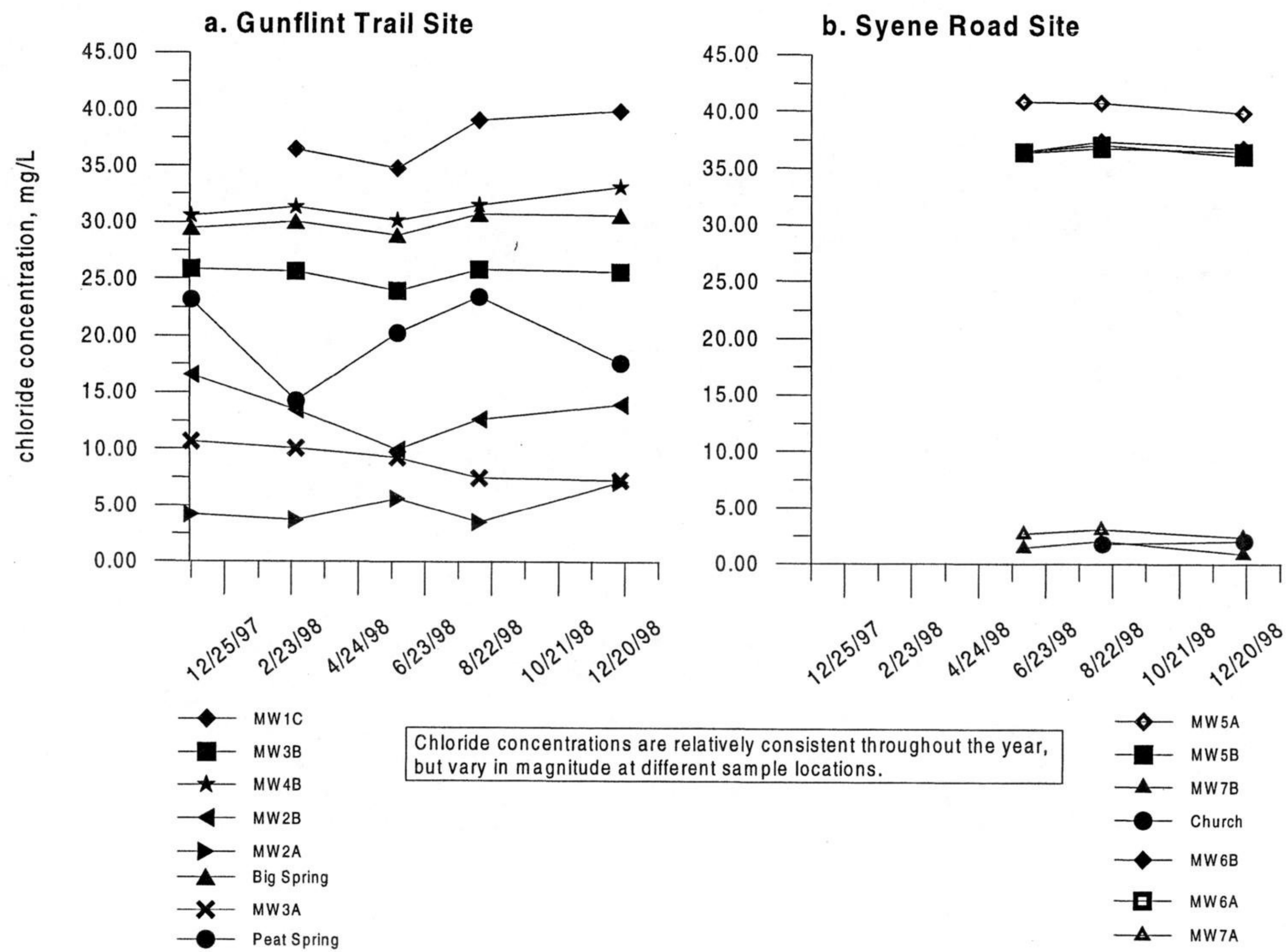


Figure 18a-b. Chloride Results

Figure 19. Molar Ratio of Chloride to Sodium

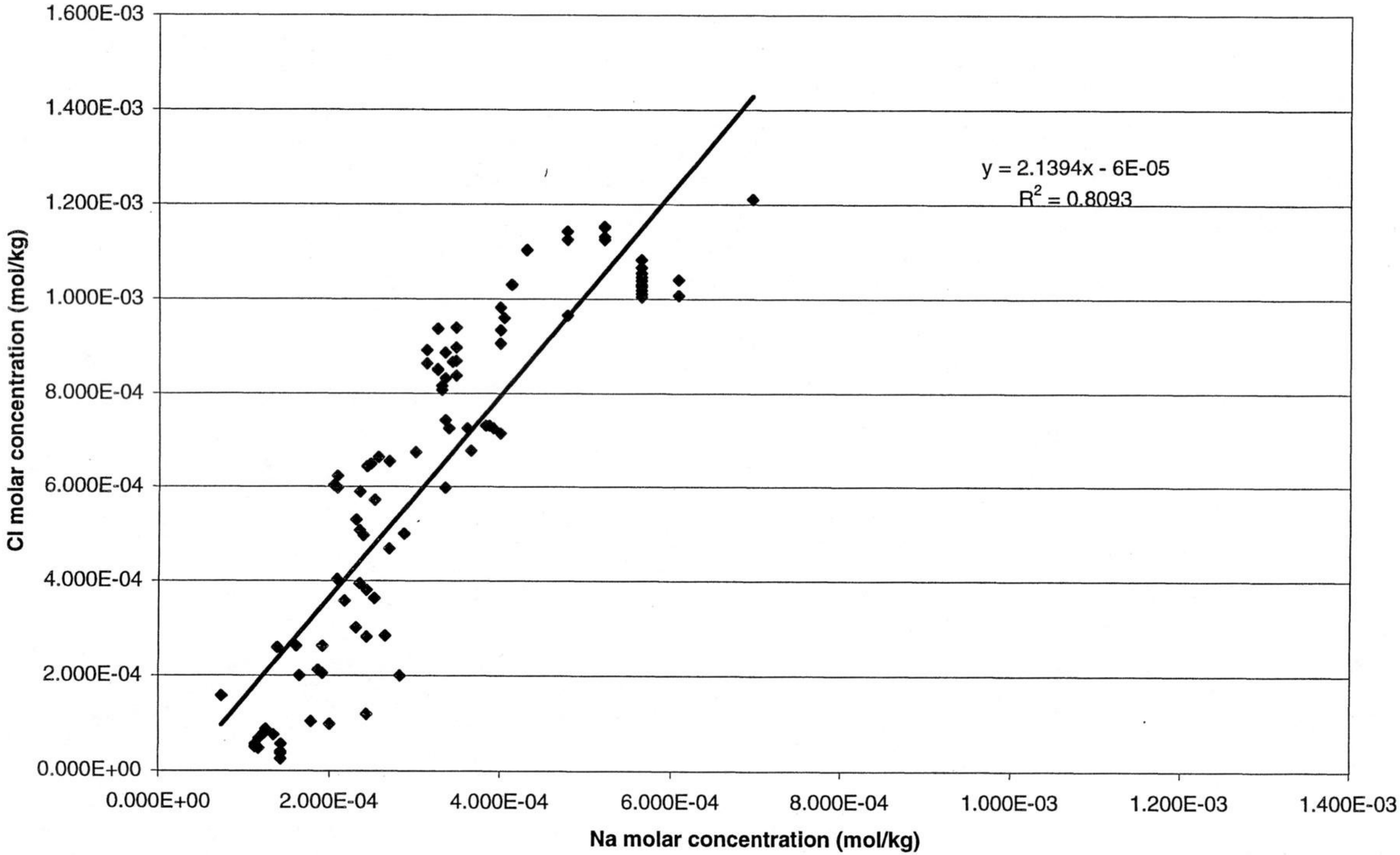


Figure 20a. K concentrations (mg/L), Gunflint Trail site

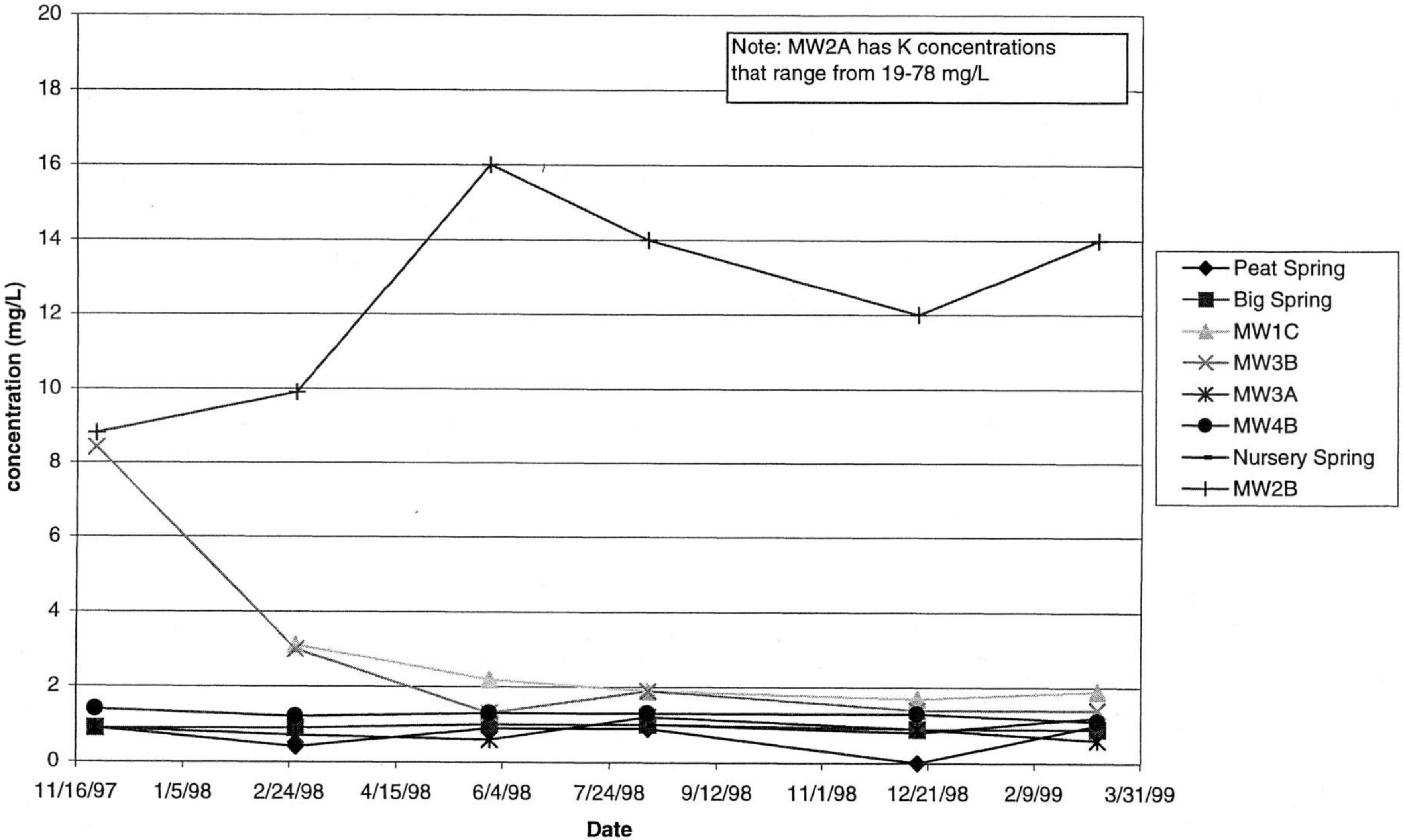


Figure 20b. K concentrations (mg/L), Syene Road site

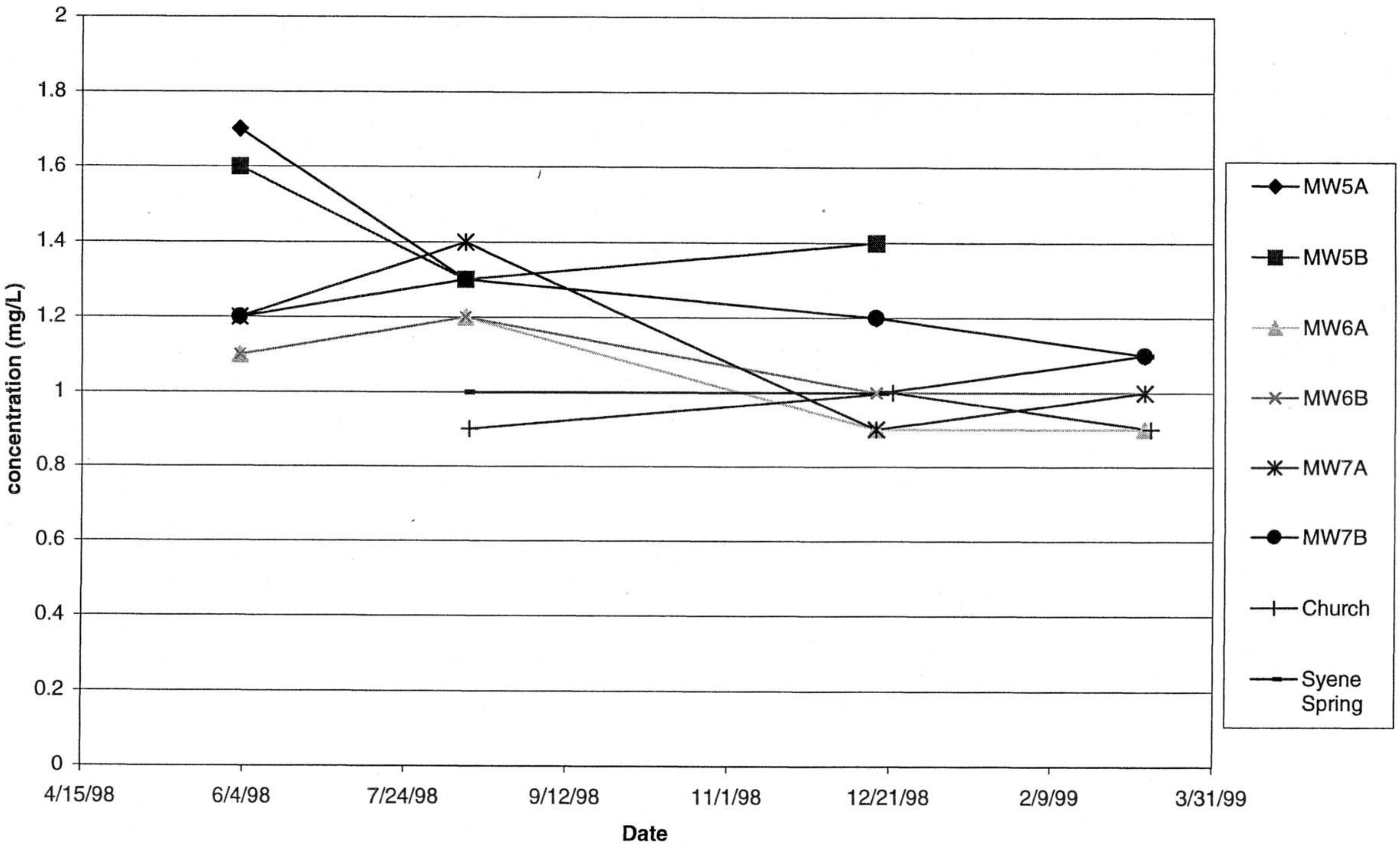


Figure 21a. Na concentrations (mg/L) Gunflint Trail site

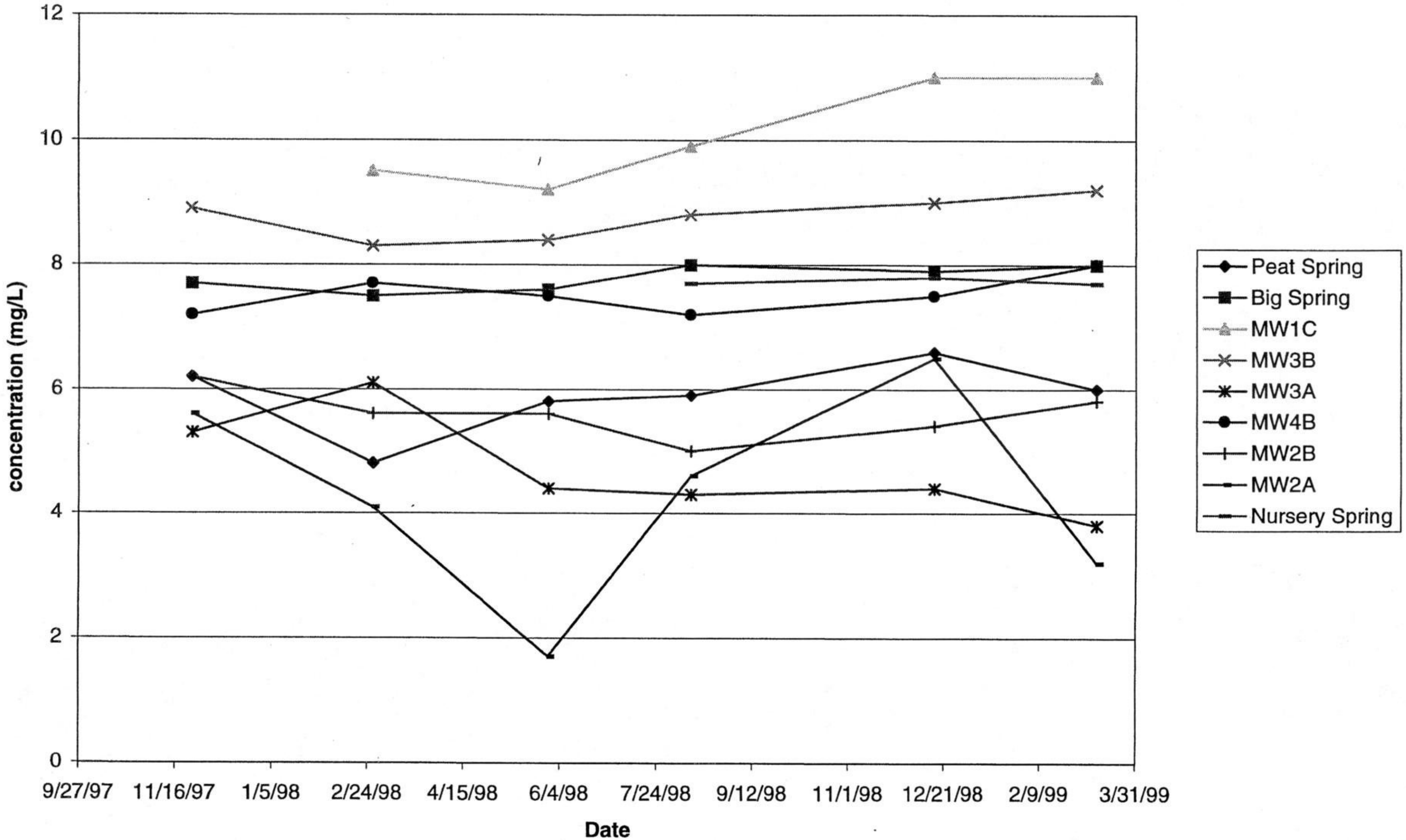


Figure 21b. Na concentrations (mg/L), Syene Road site

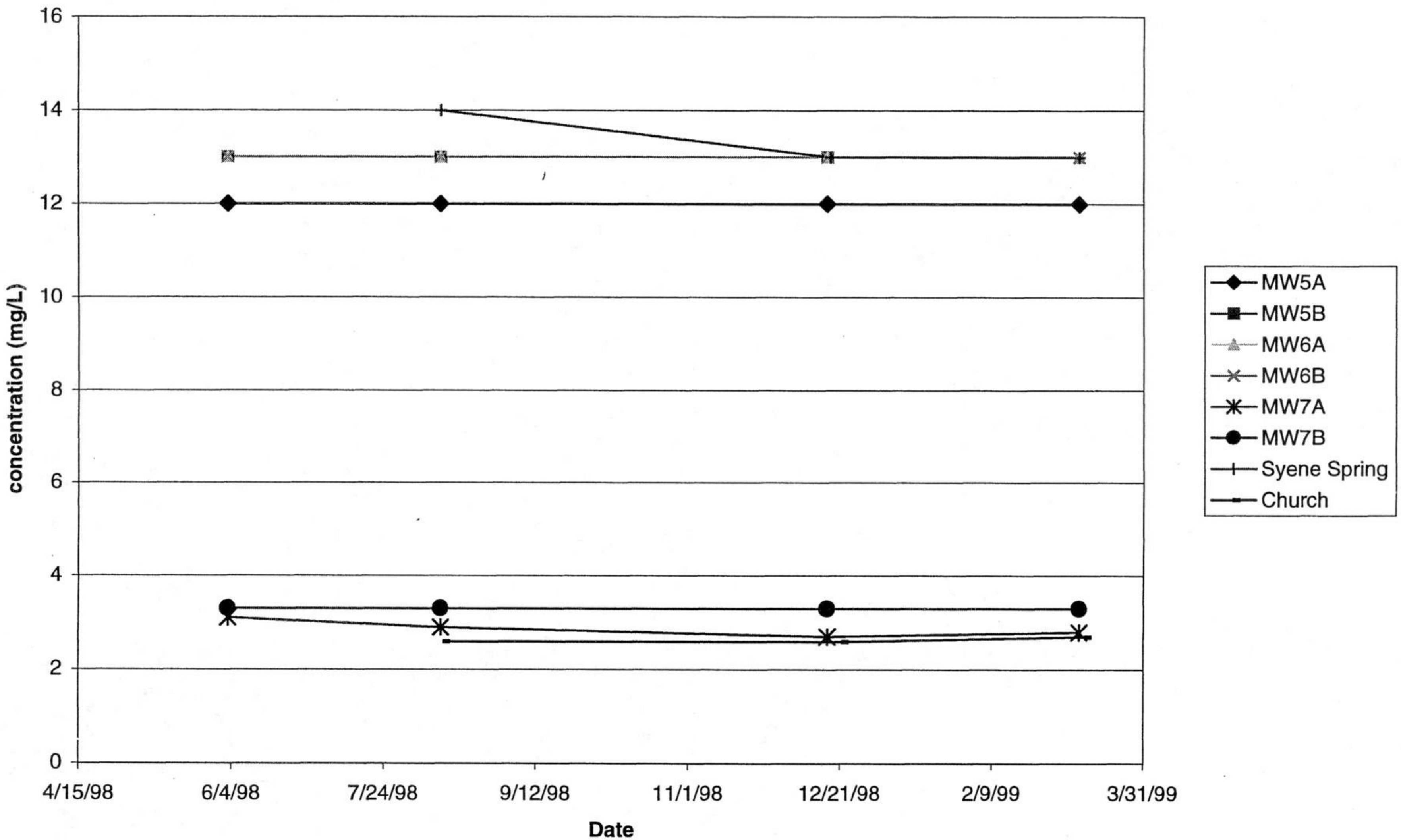


Figure 22a. Sulfate concentrations (mg/L), Gunflint Trail site

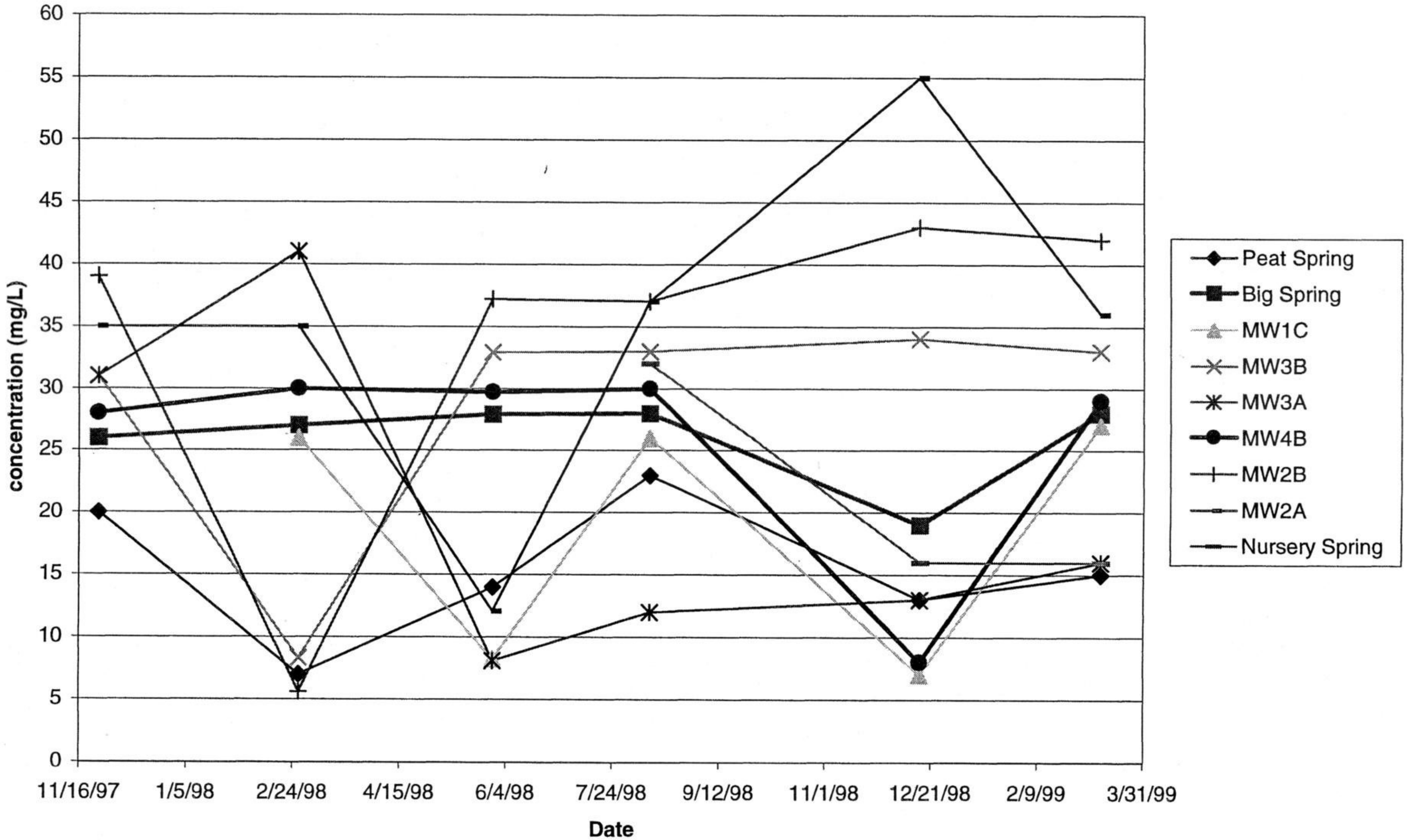


Figure 22b. Sulfate concentrations (mg/L), Syene Road site

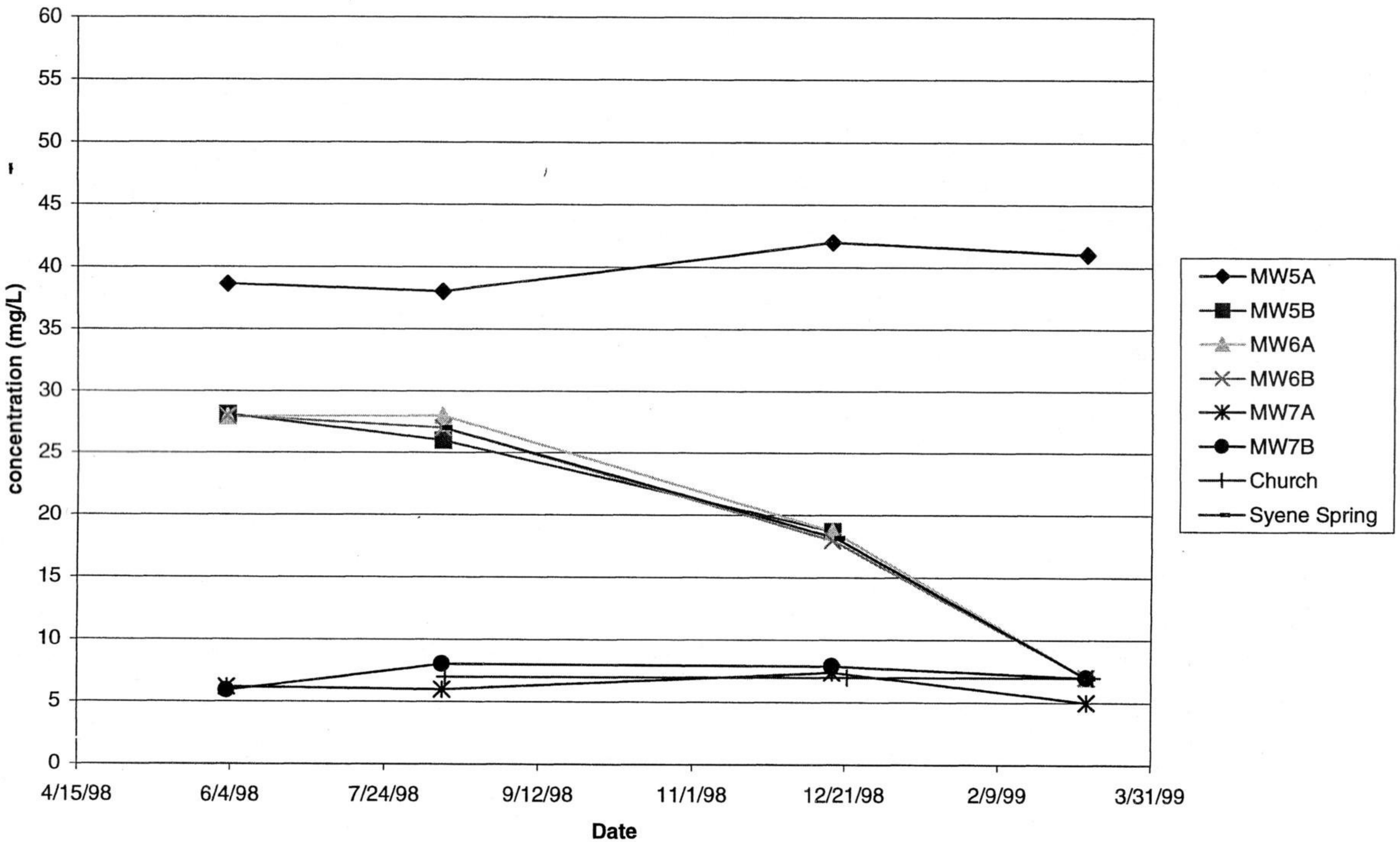


Figure 23a. TDS concentrations (mg/L), Gunflint Trail site

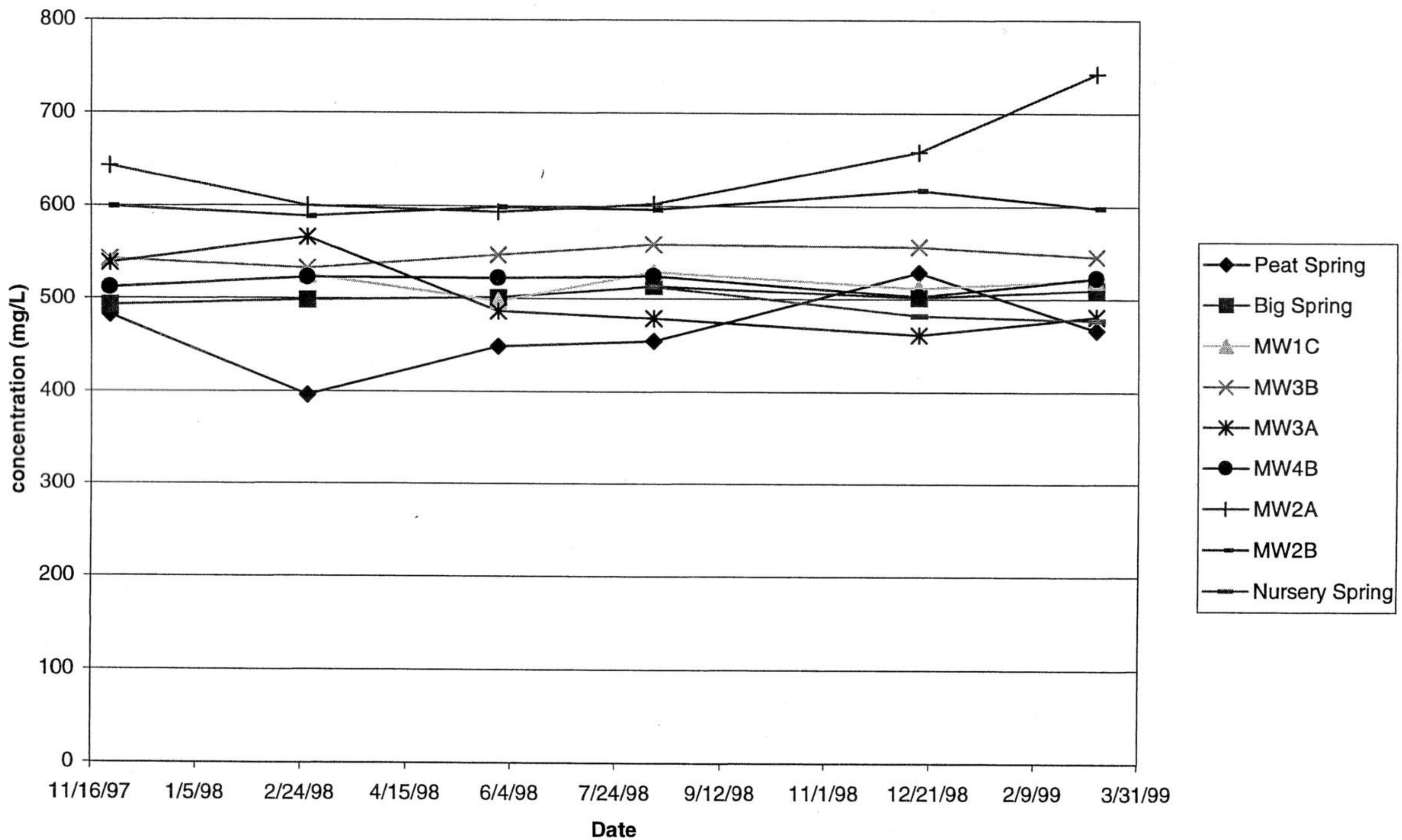


Figure 23b. TDS concentrations (mg/L), Syene Road site

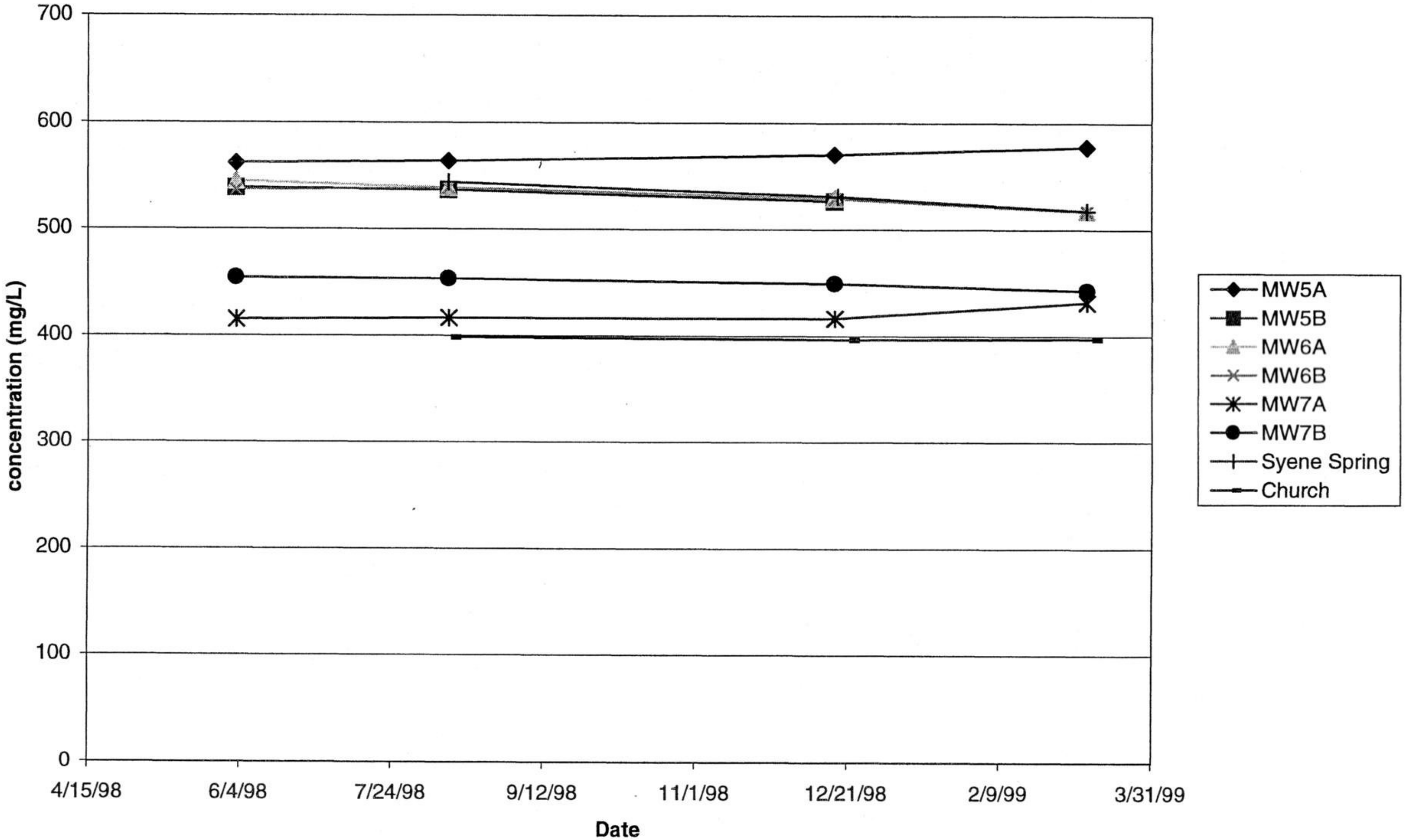


Figure 24a. Conductivity (uS) results, Gunflint Trail site

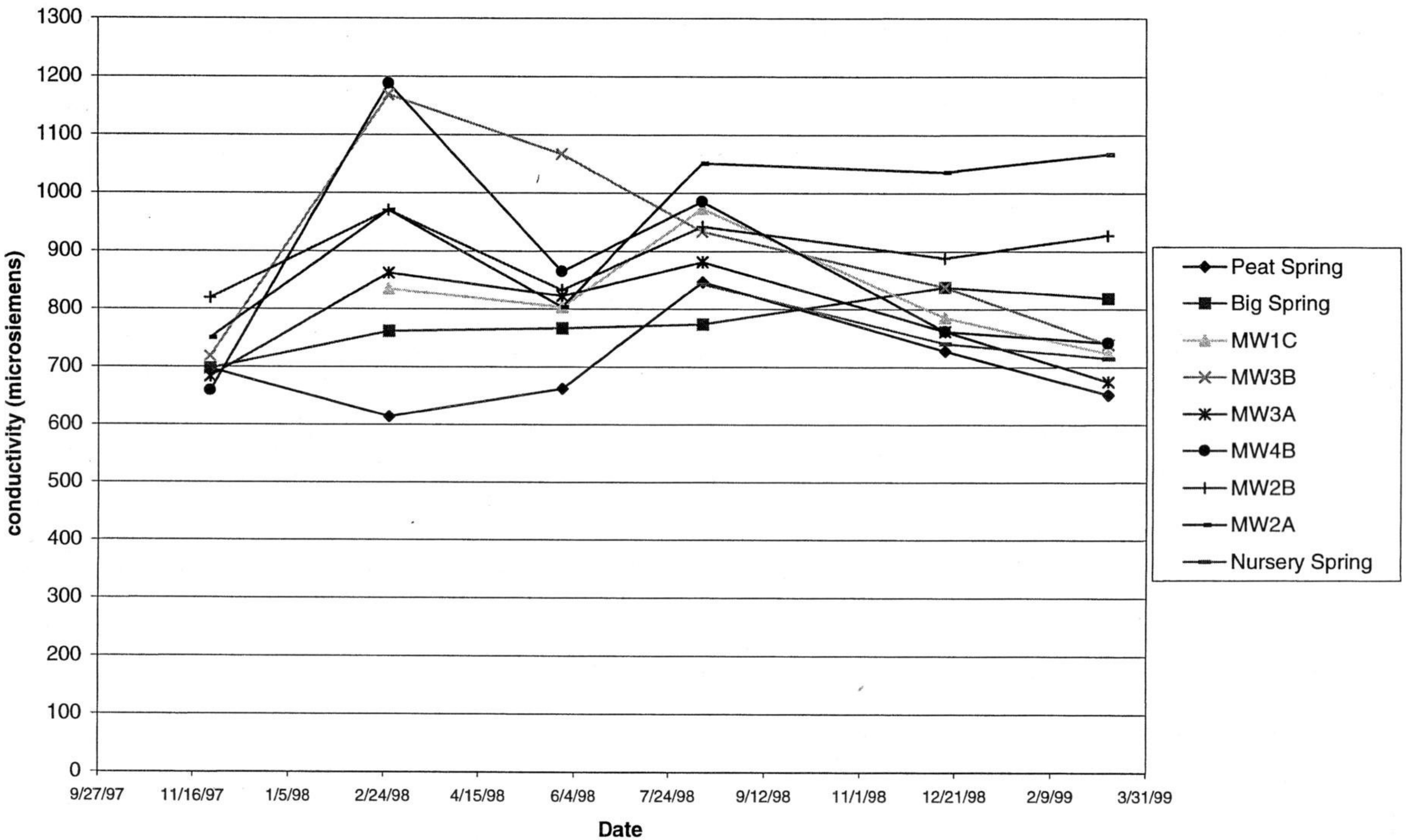
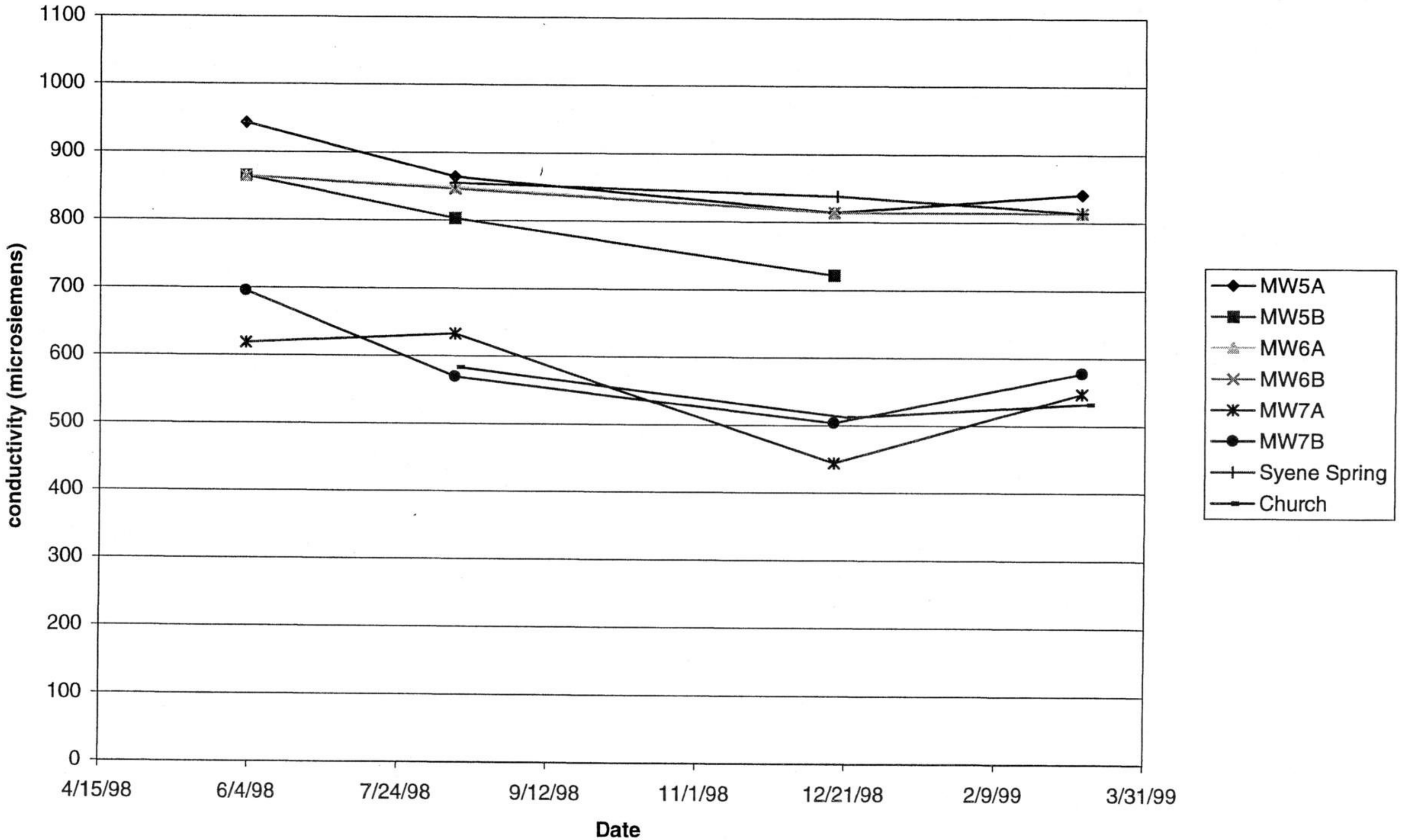


Figure 24b. Conductivity (uS) results, Syene Road site



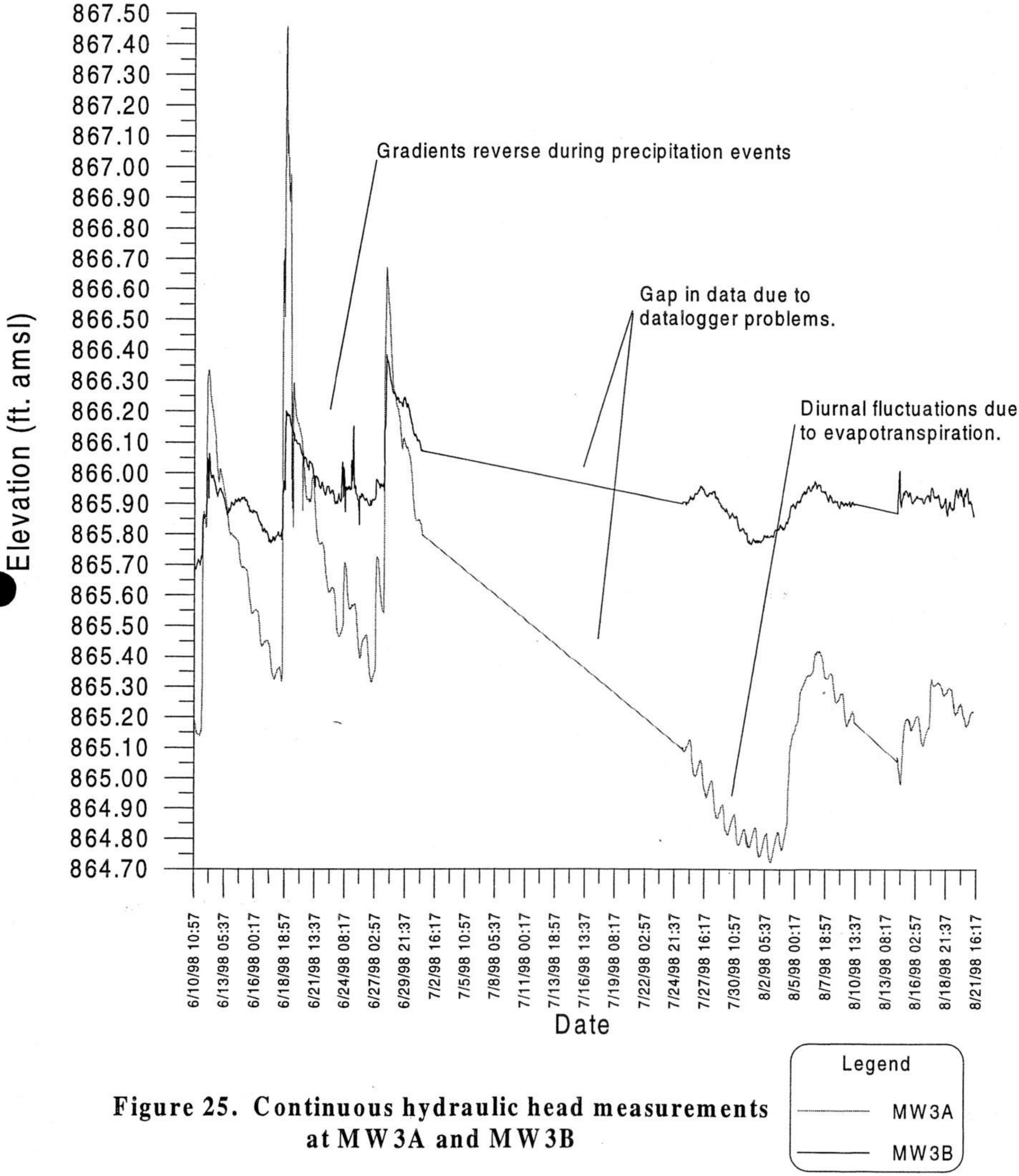


Figure 25. Continuous hydraulic head measurements at MW3A and MW3B

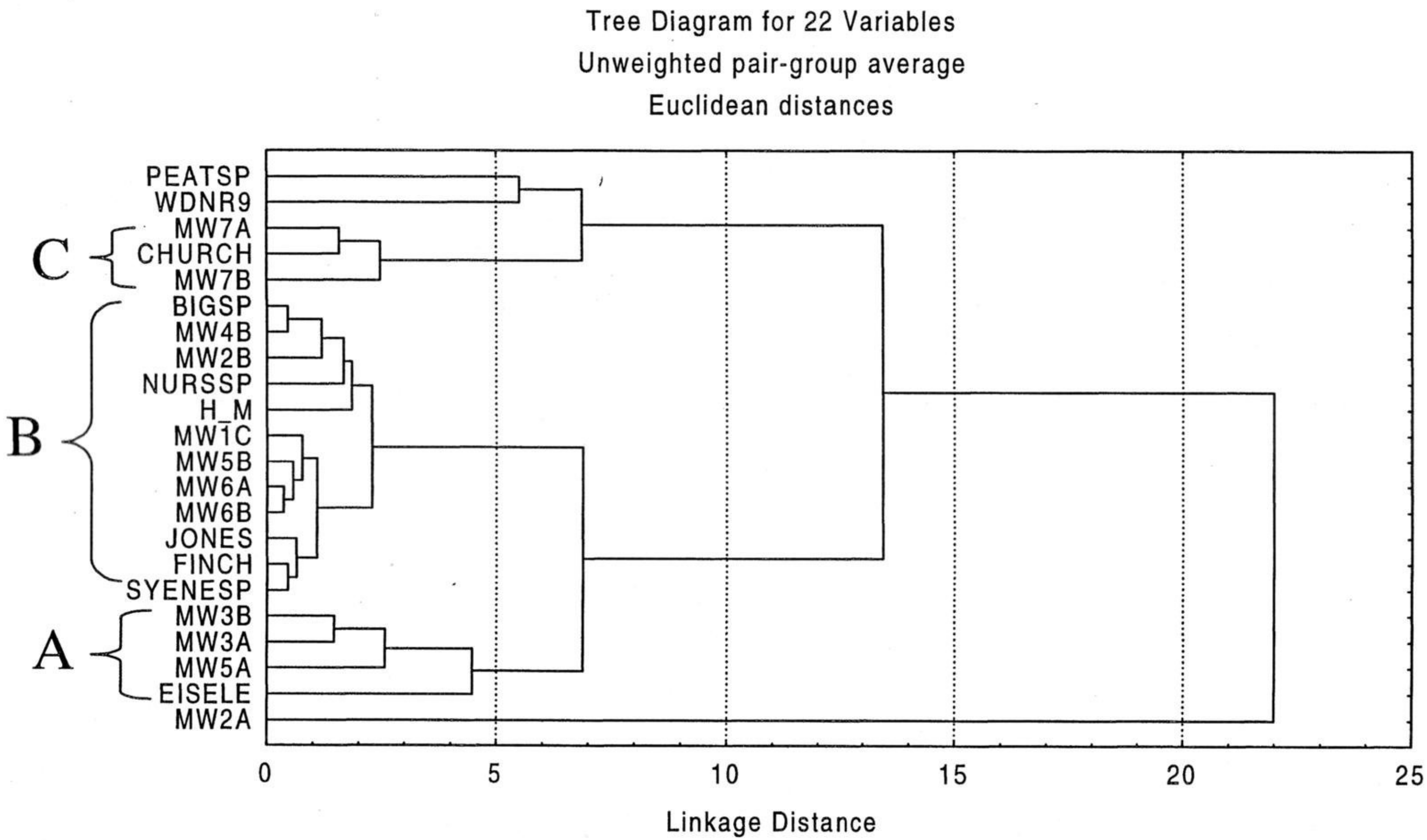
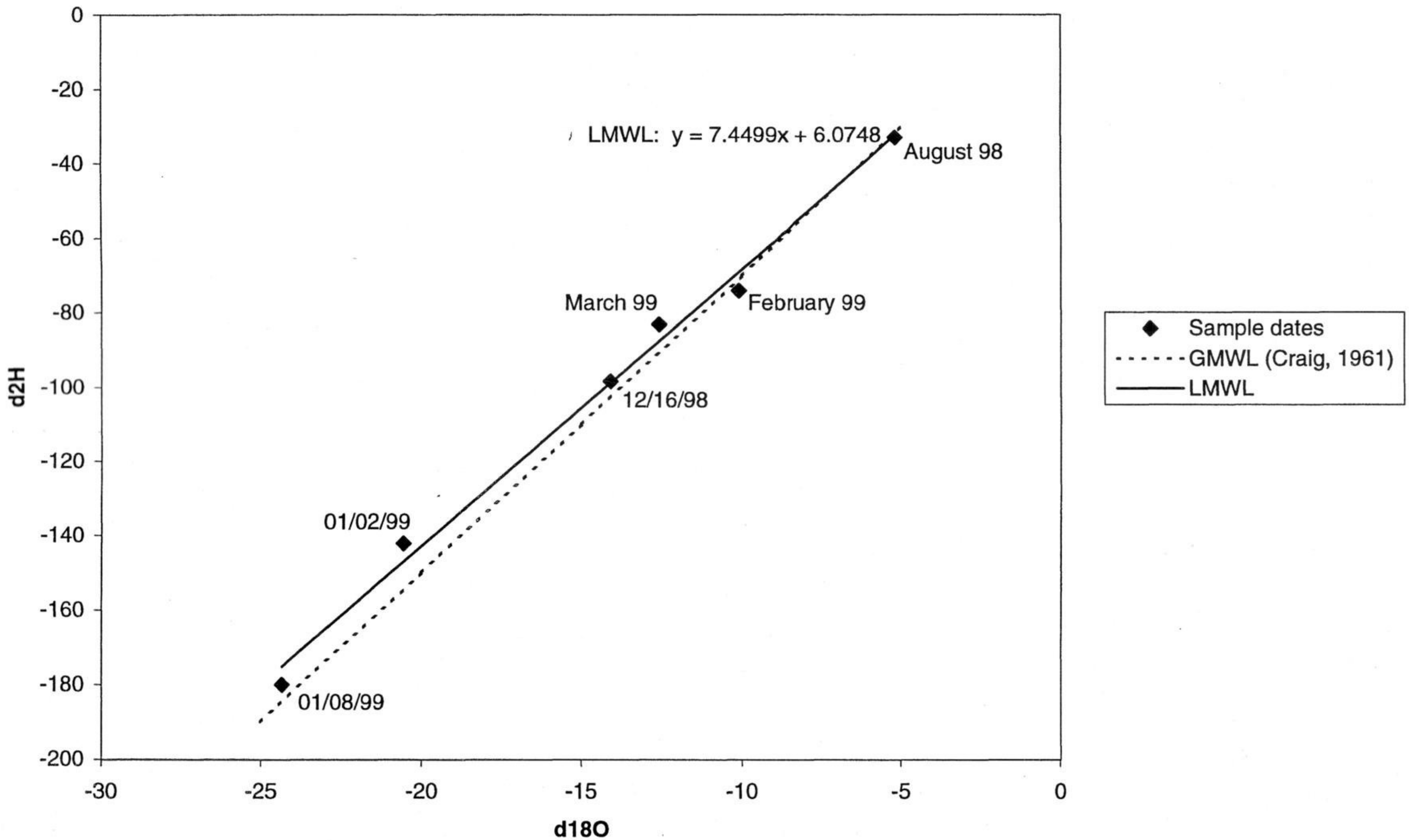


Figure 26. Tree diagram for cluster analysis

Figure 27. Local meteoric water line (LMWL), Nine Springs watershed



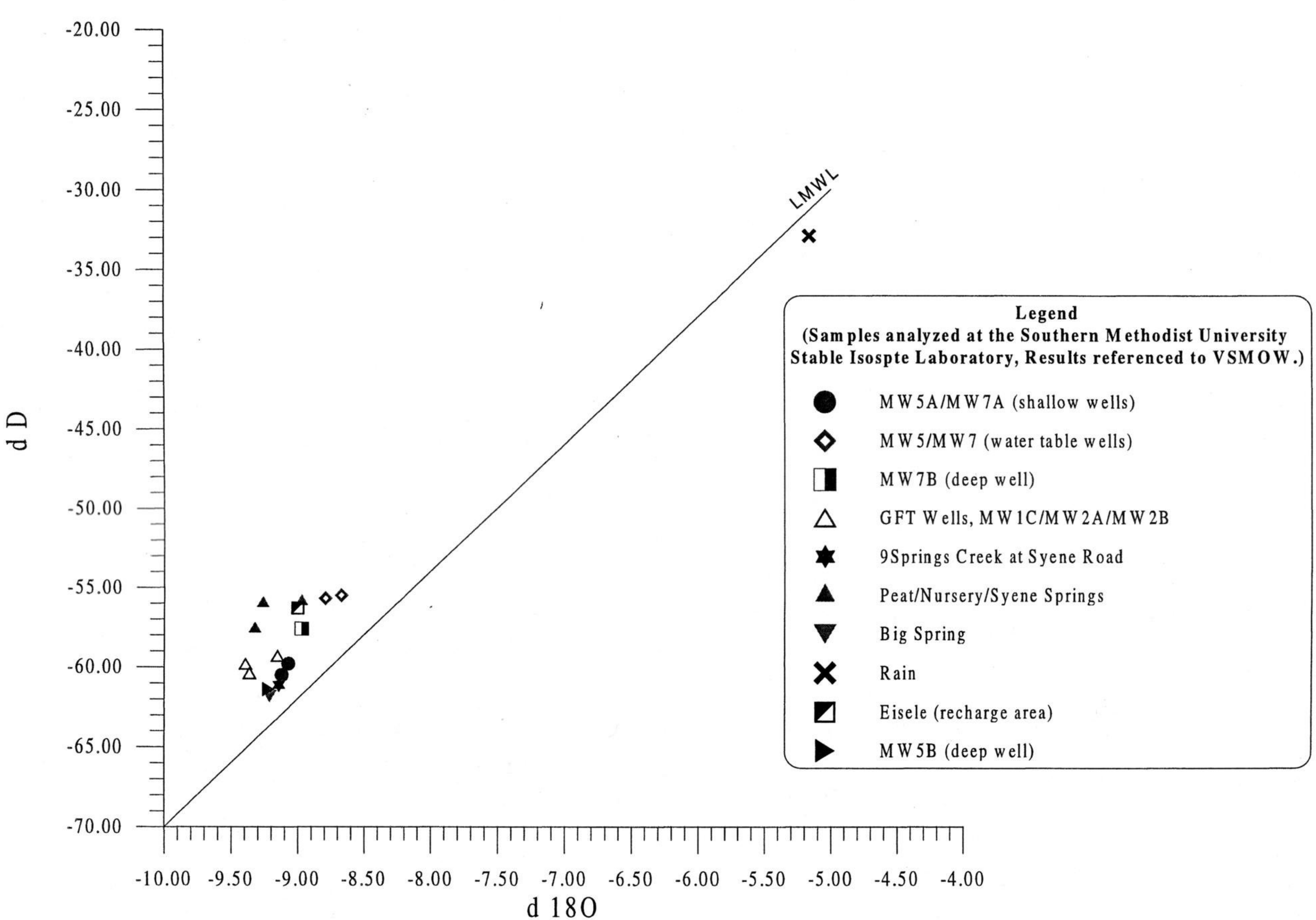


Figure 28a. Stable isotope results, 08/98

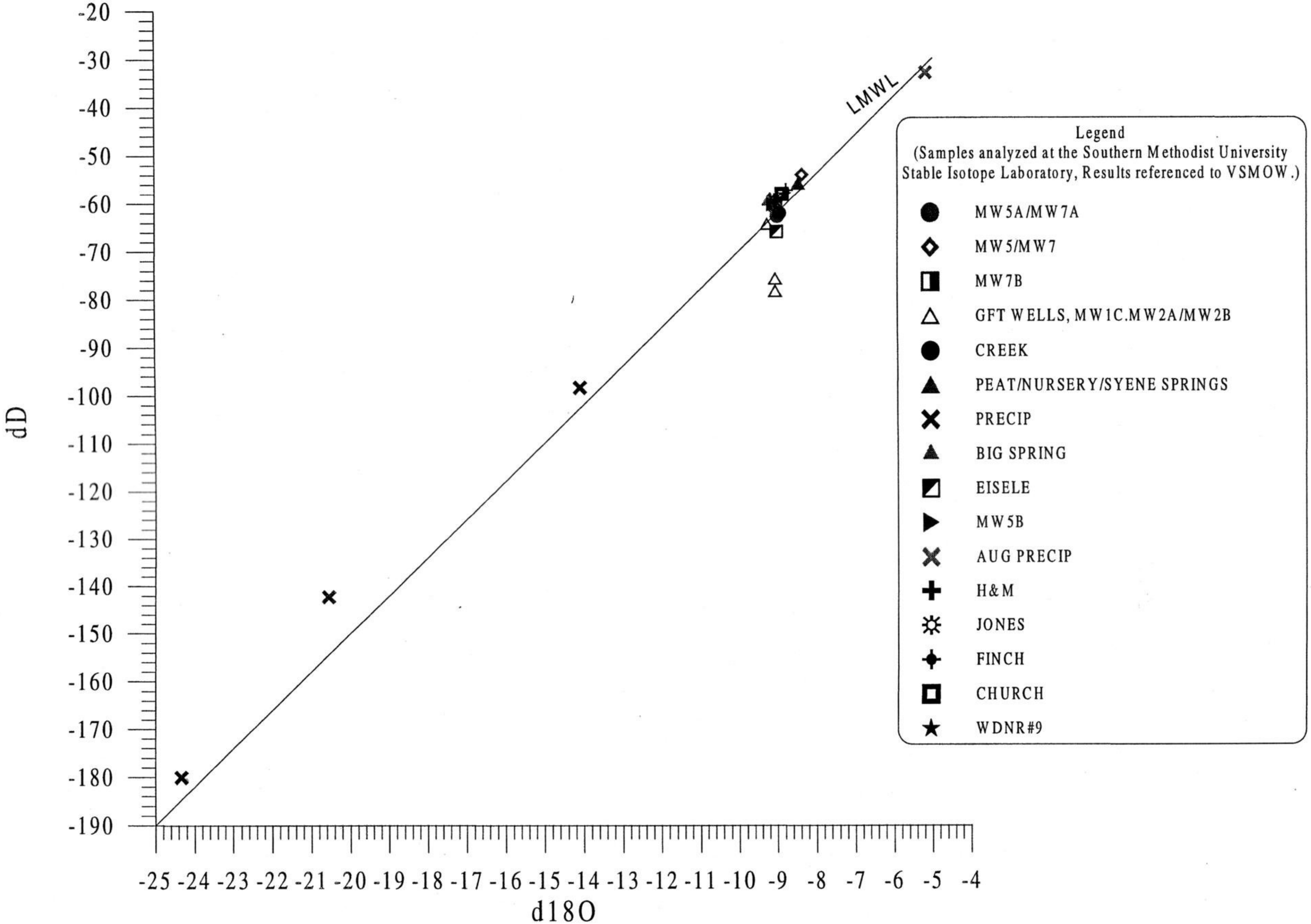


Figure 28b. Stable isotope results, 12/98

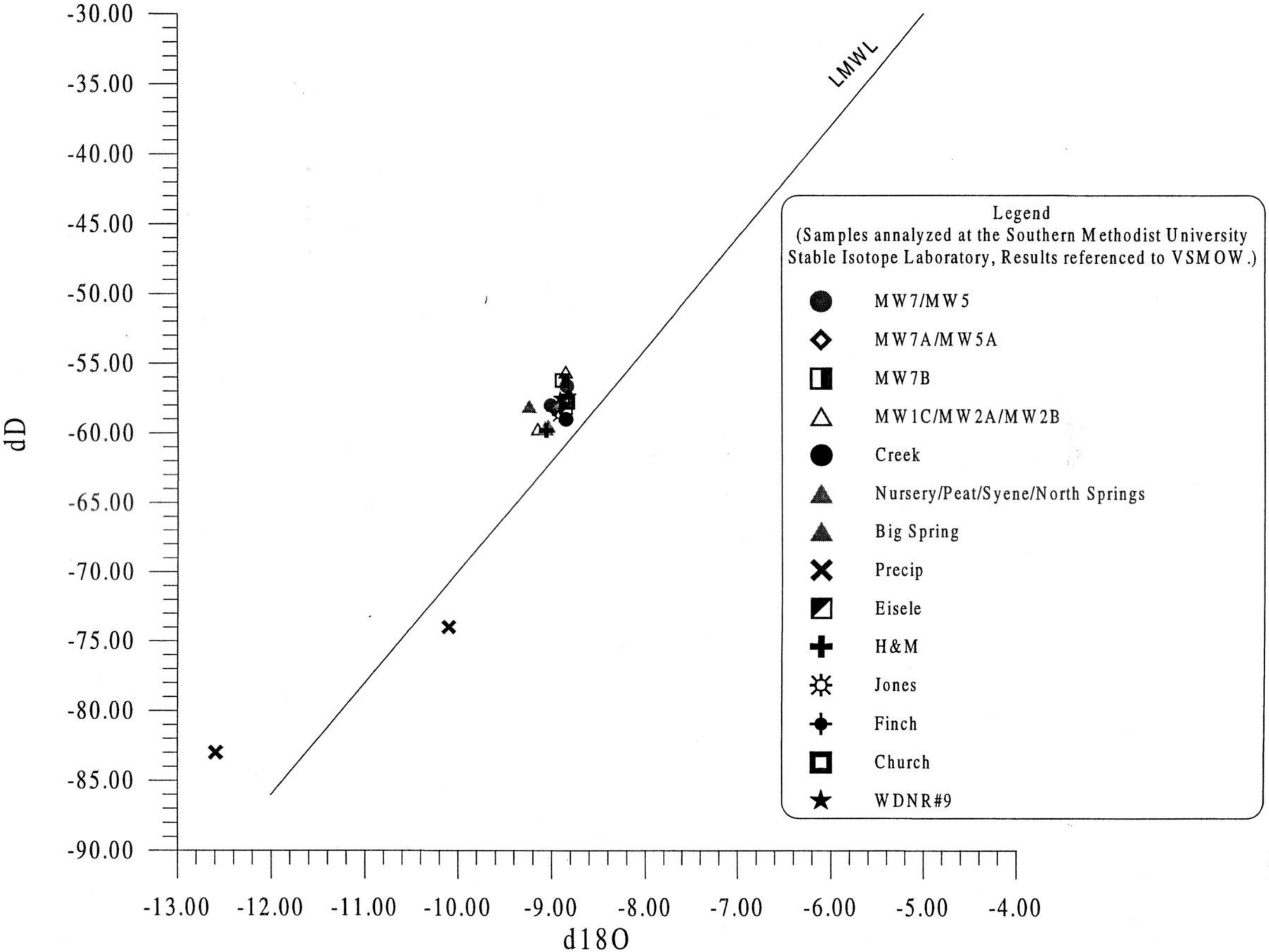


Figure 28c. Stable isotope results, 03/99

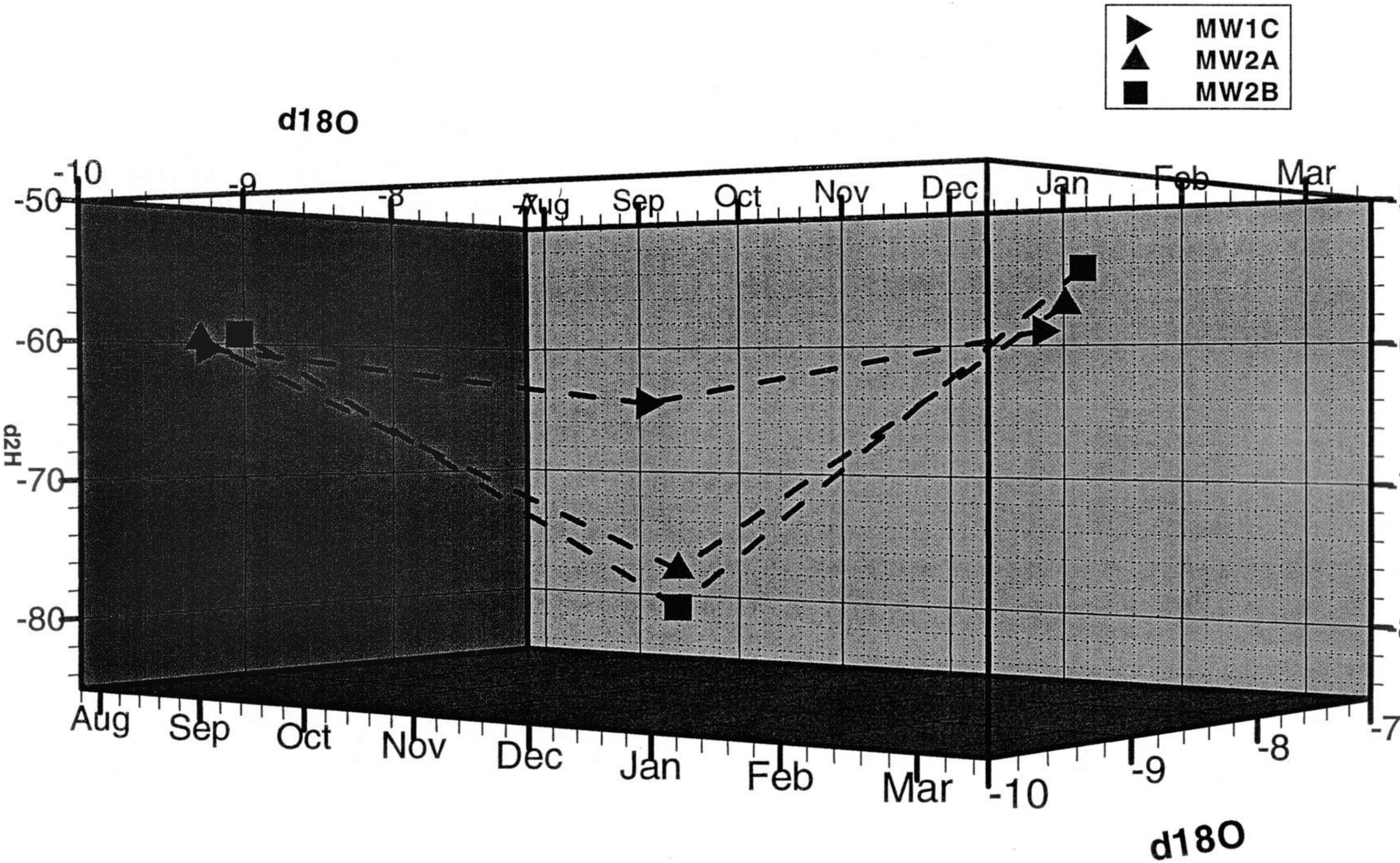


Figure 29a. Variation in isotopic composition

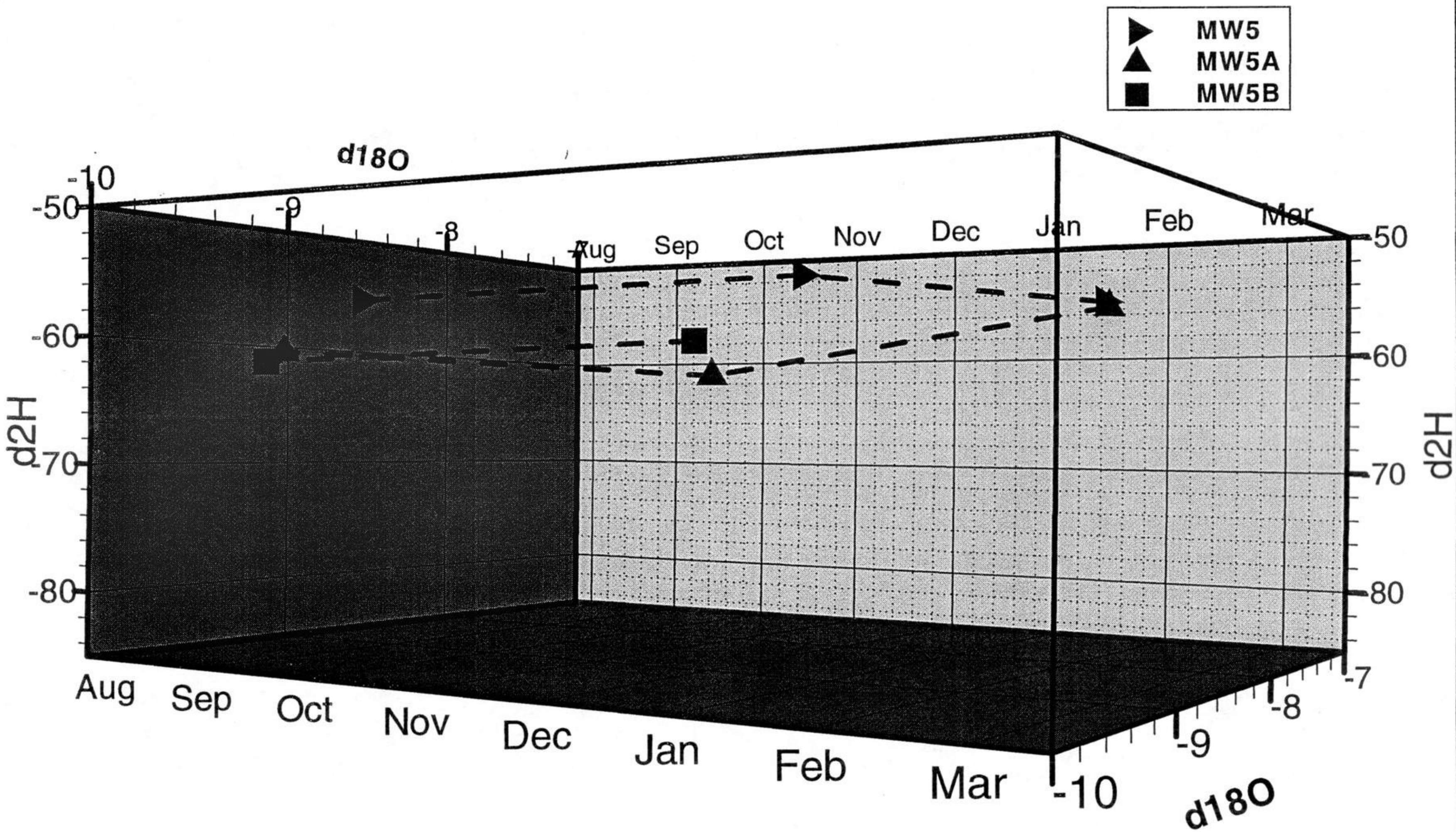


Figure 29b. Variation in isotopic composition

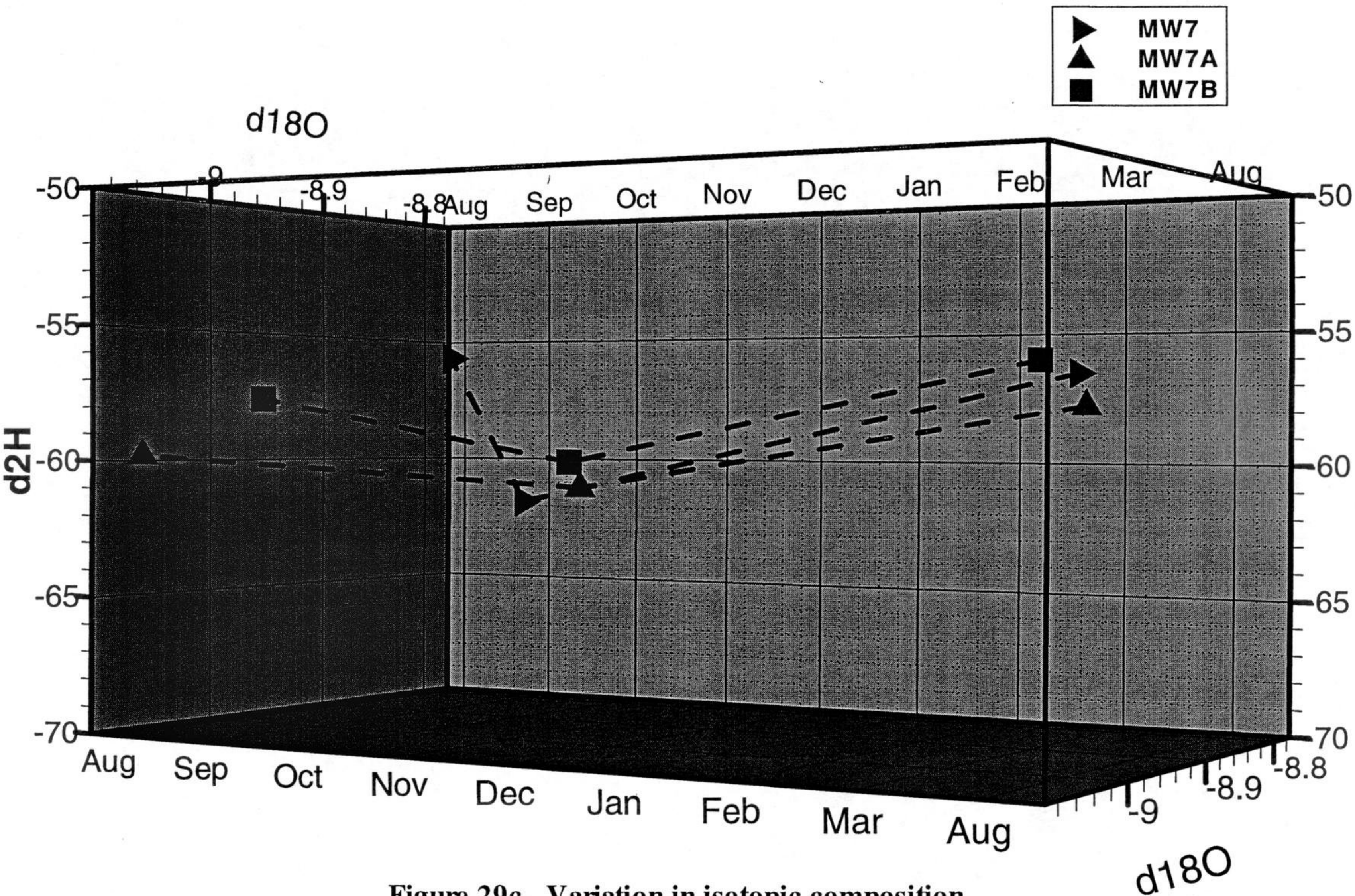


Figure 29c. Variation in isotopic composition

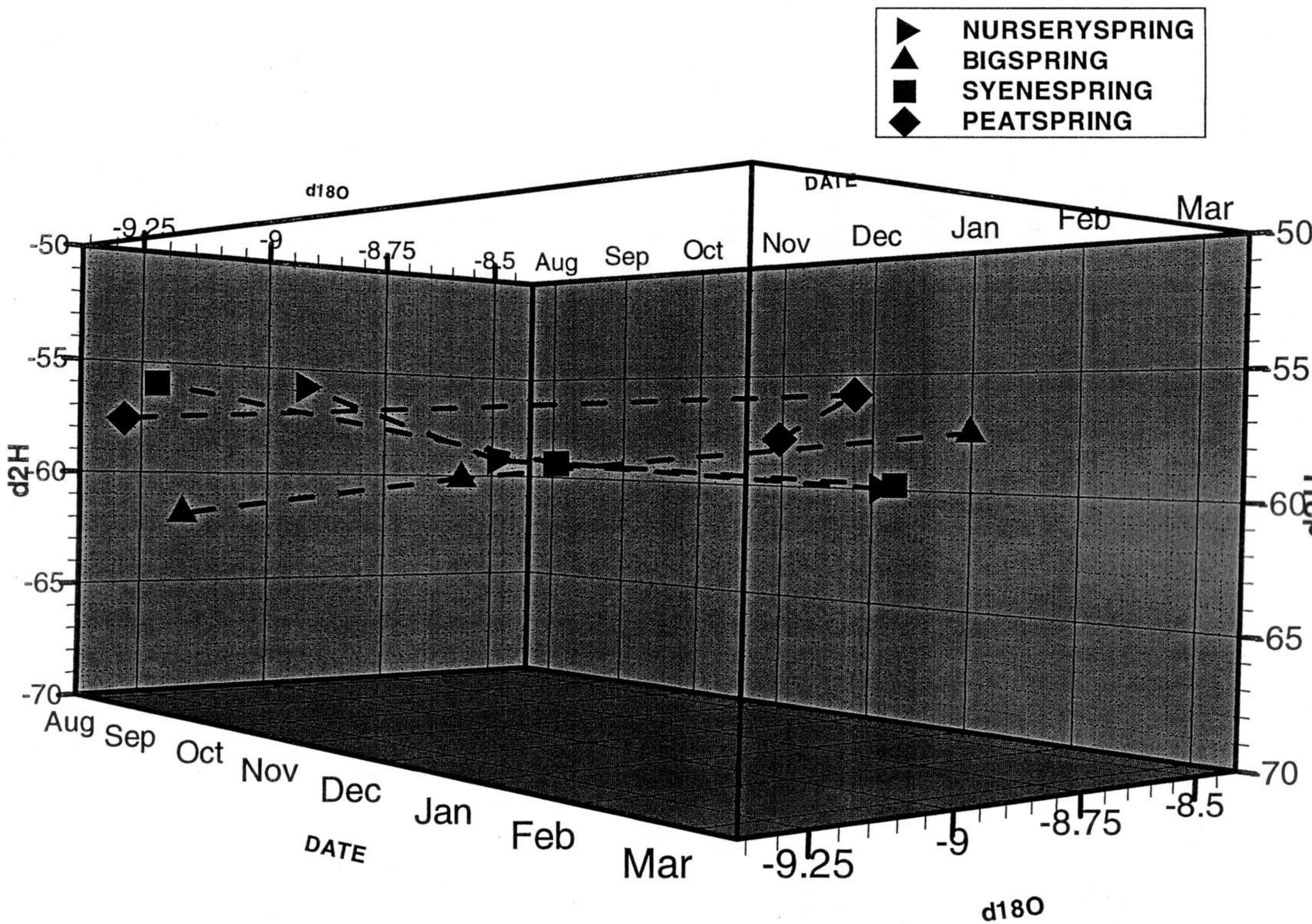


Figure 29d. Variation in isotopic composition

Figure 30. View of the Big Spring pool from the southwest

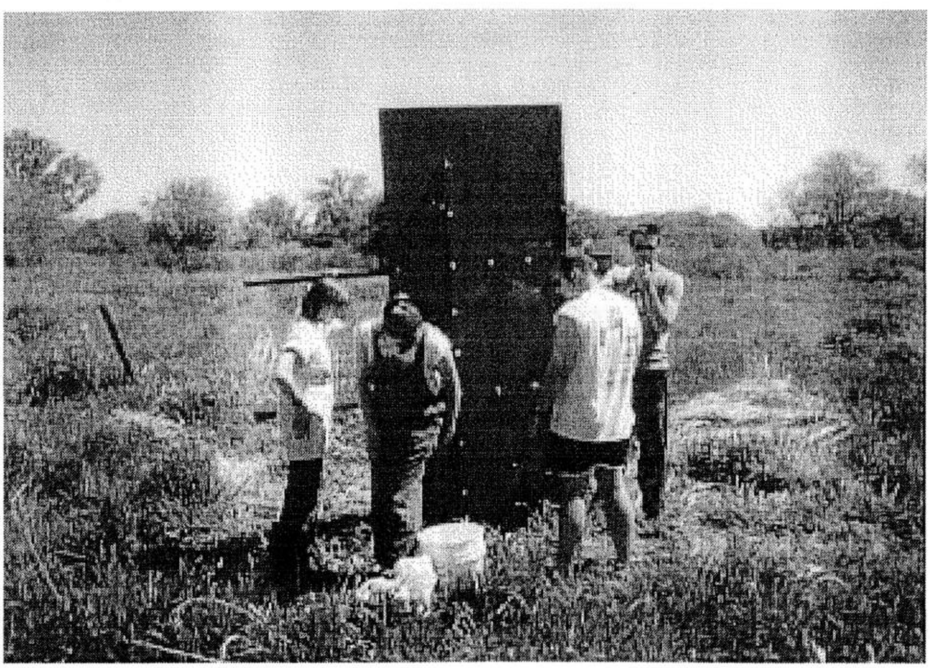


Figure 31. Photograph of Gunflint Trail weir

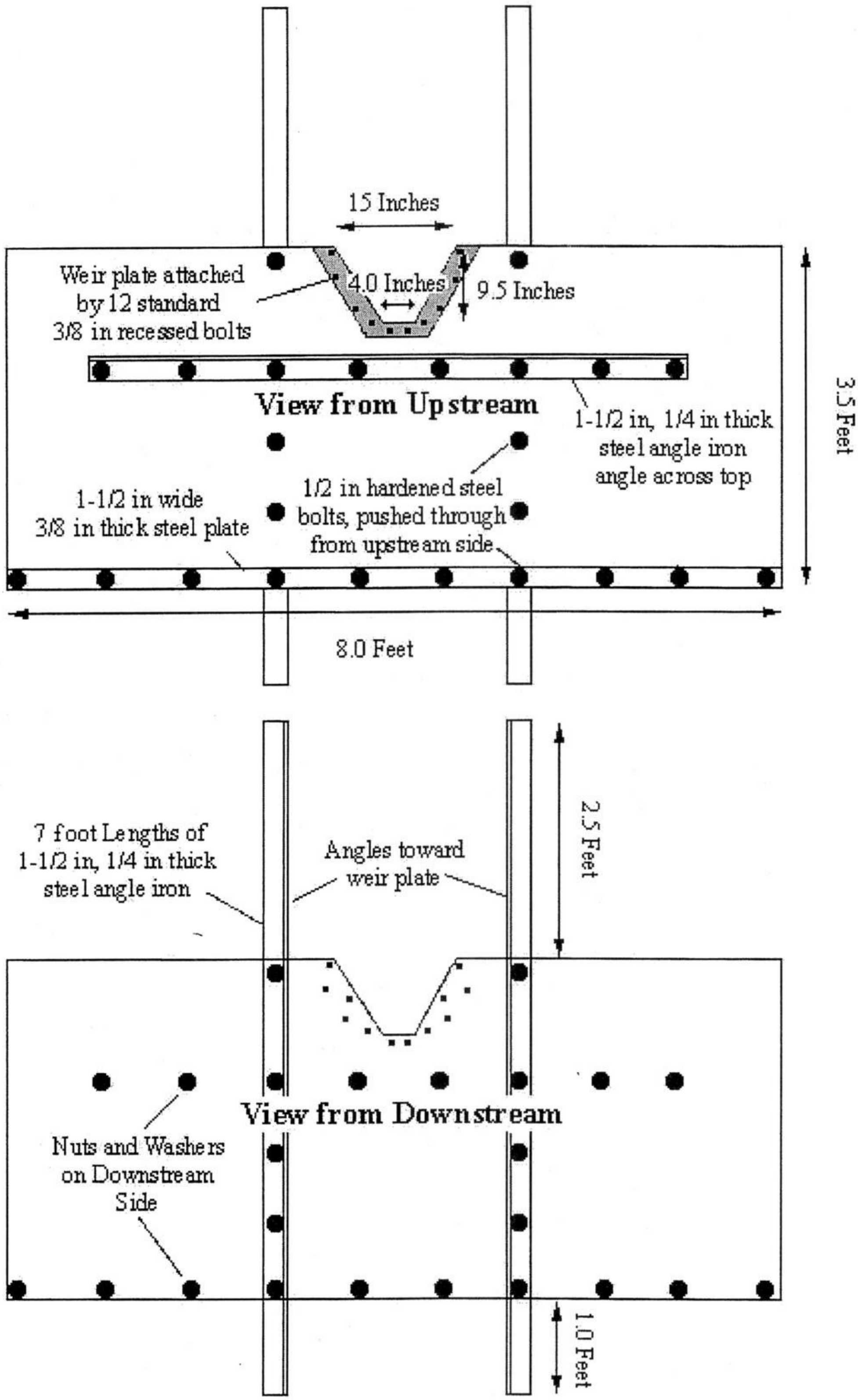


Figure 32. Diagram of Gunflint Trail weir

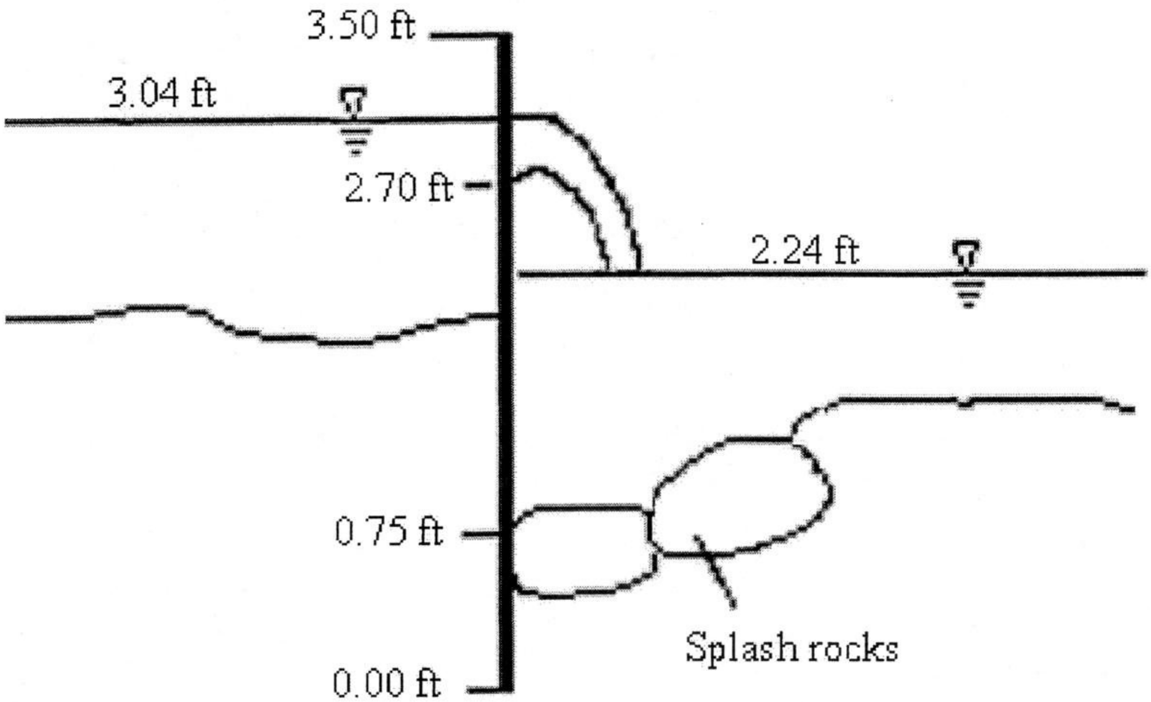
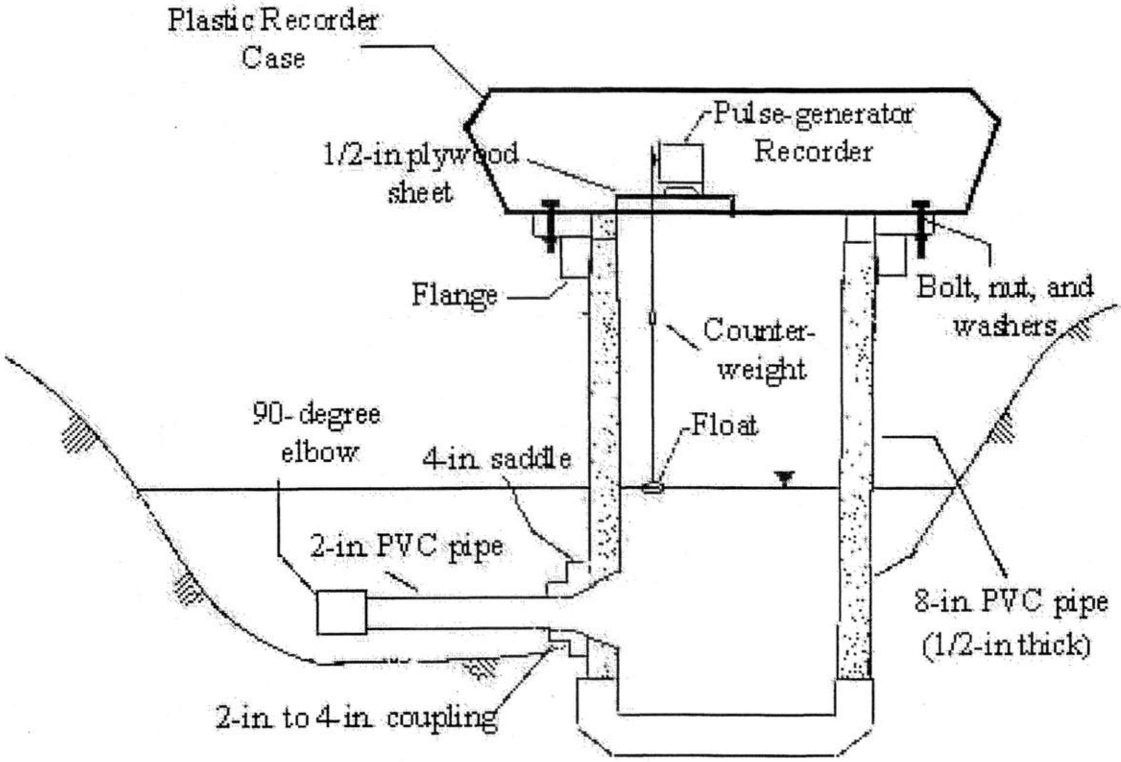
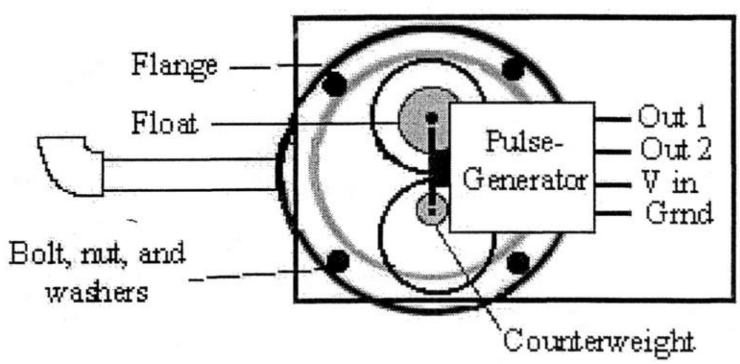


Figure 33. Channel profile at Gunflint Trail weir, average flow conditions



Profile View



Plan View

Figure 34. Diagram of stilling well assembly (modified from Latkovich and Leavesley 1993)

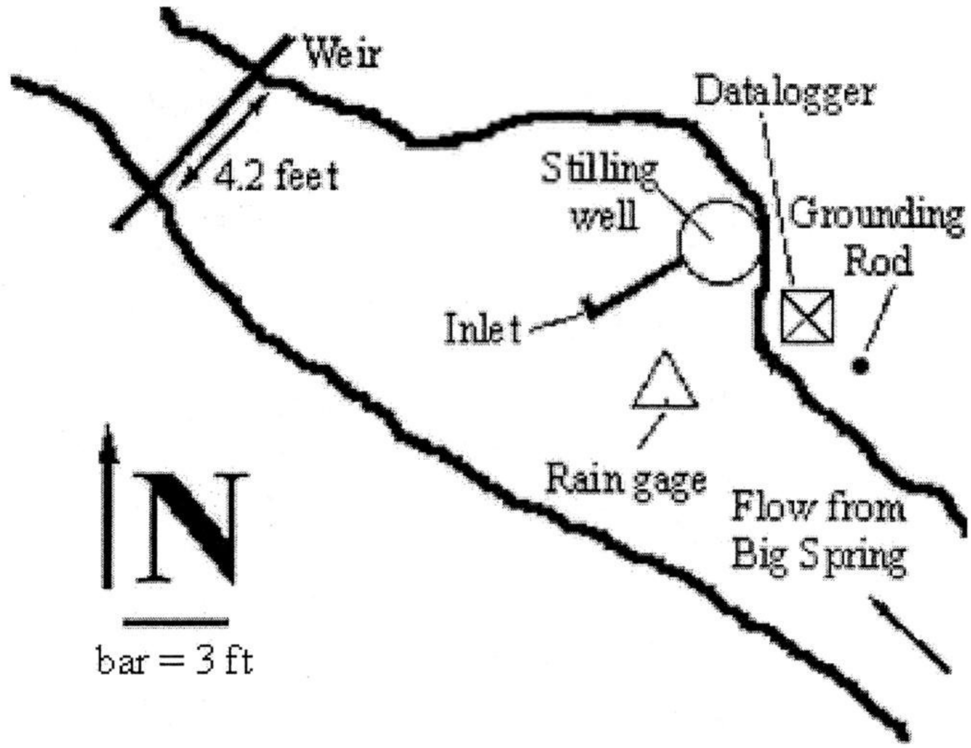


Figure 35. Layout of Gunflint Trail weir monitoring equipment

Figure 36. View of Gunflint Trail weir and equipment from upstream

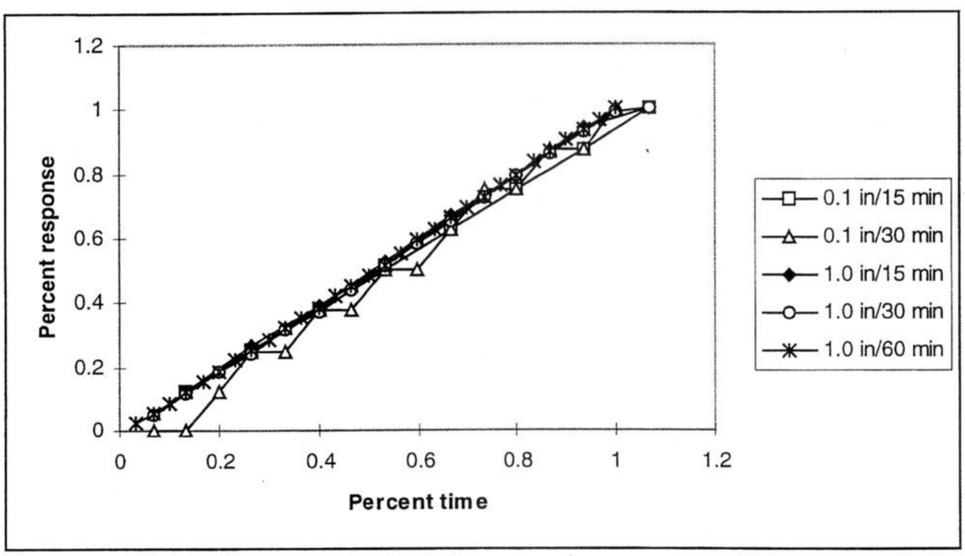


Figure 37. Relative gage response to simulated rainfall (two-minute intervals)

Figure 38. Photograph of Syene Road spring

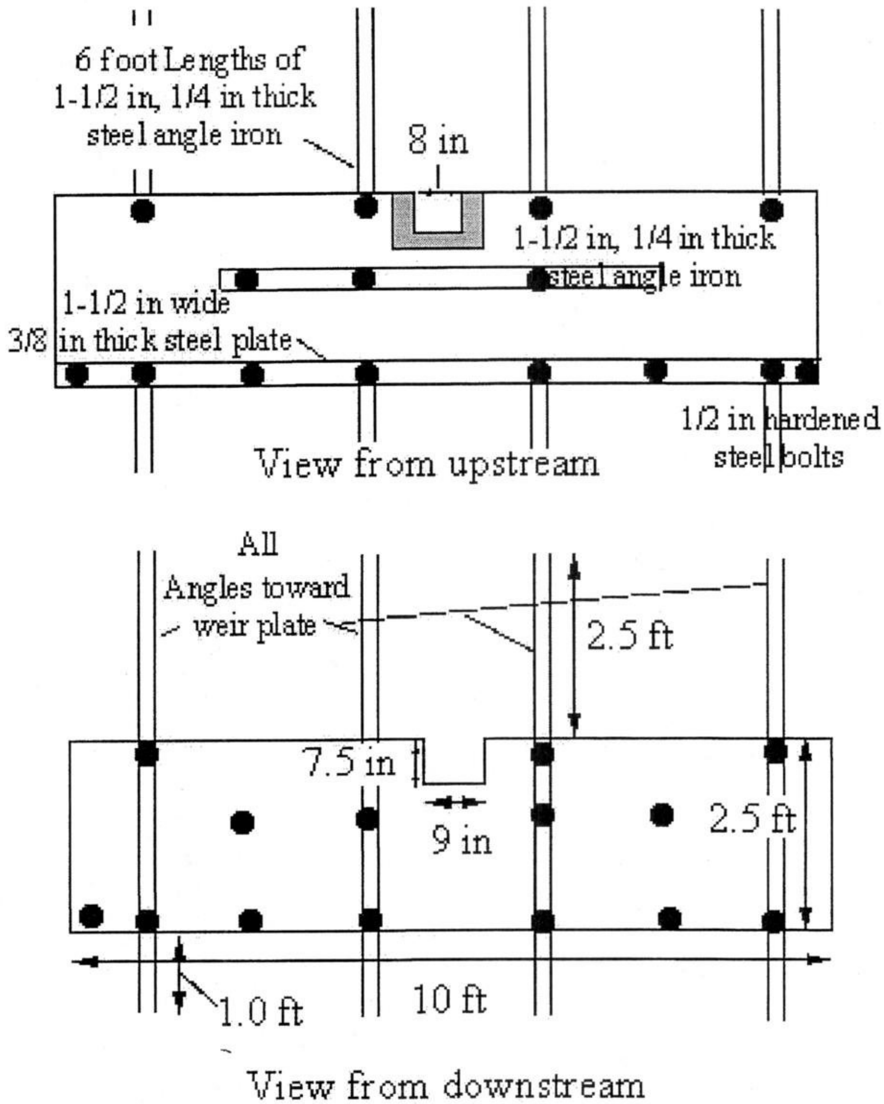


Figure 39. Diagram of Syene Road weir

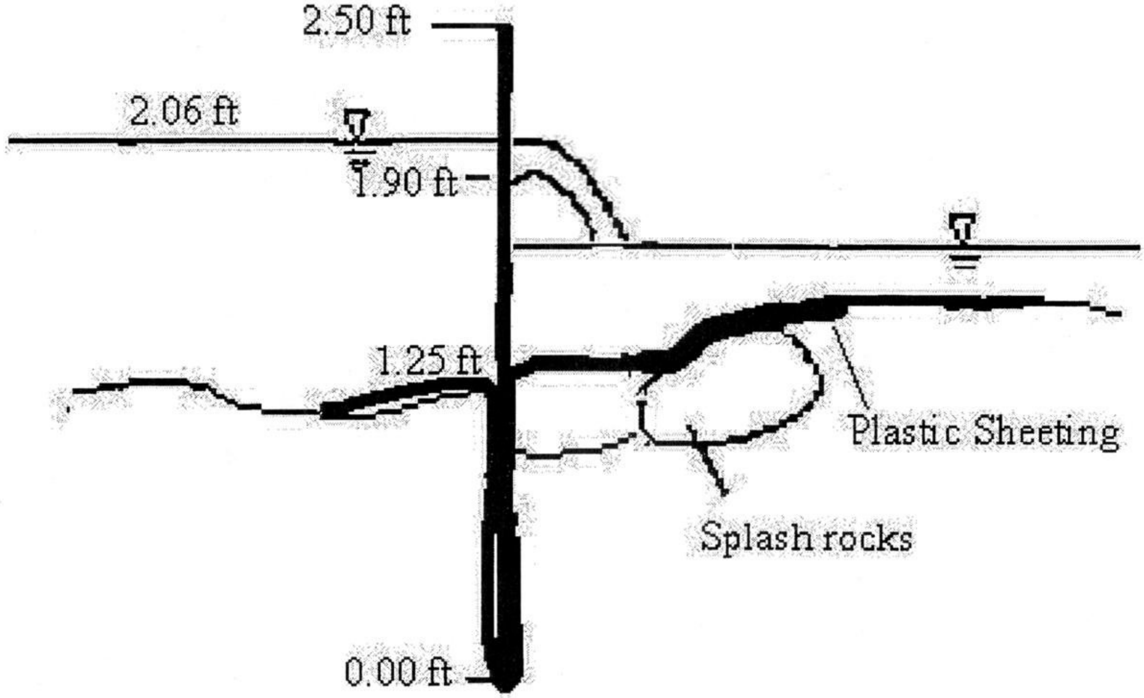


Figure 40. Channel profile at Syene Road weir, average flow conditions

Figure 41. Photograph of Syene Road weir and equipment

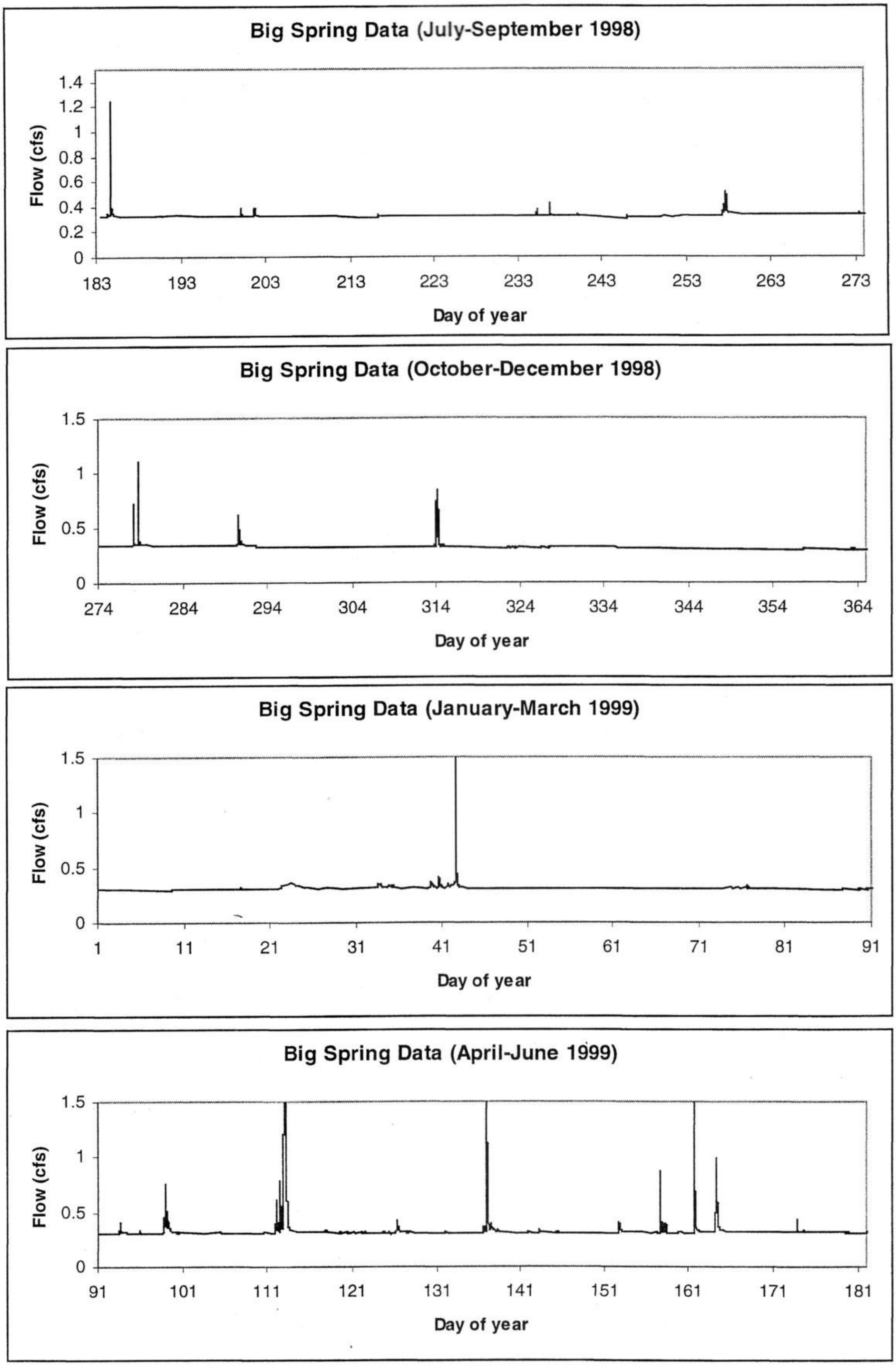


Figure 42a-d. Flows observed at Gunflint Trail weir

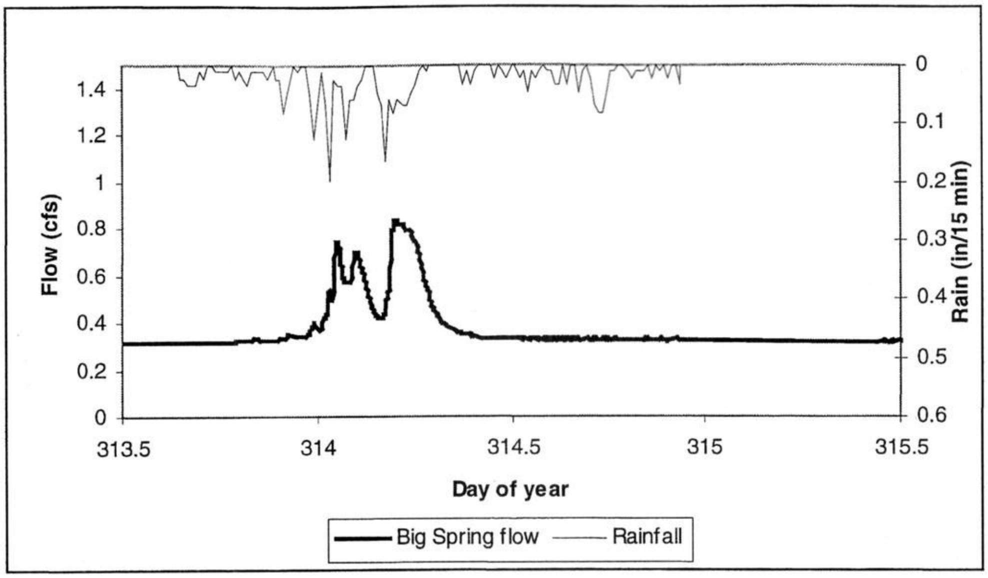


Figure 43. Big Spring flow response to November 9-10, 1998, storm event

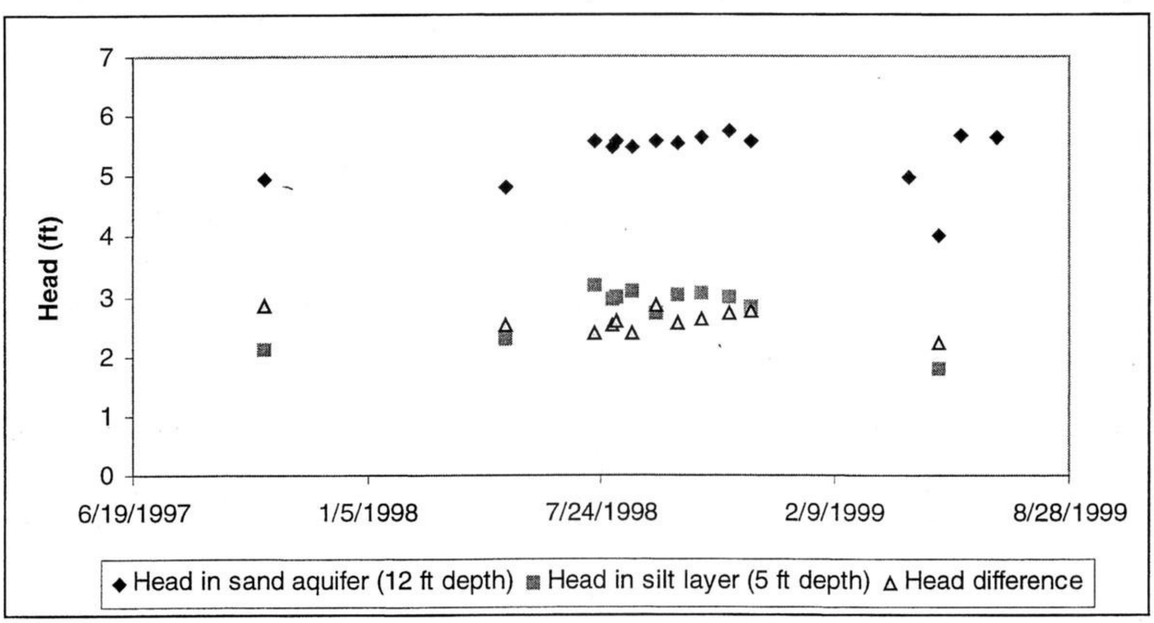


Figure 44. Hydraulic head measurements beneath Big Spring

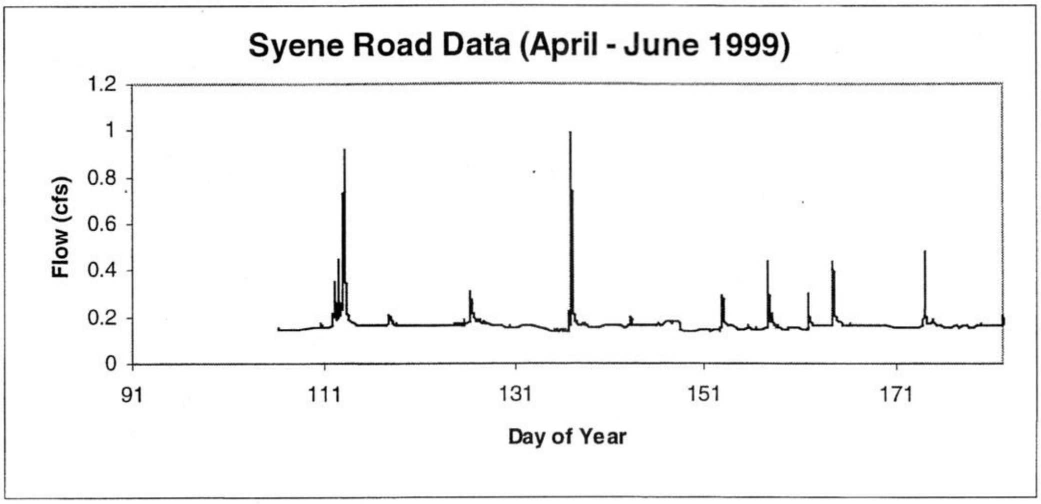


Figure 45. Flows observed at Syene Road weir

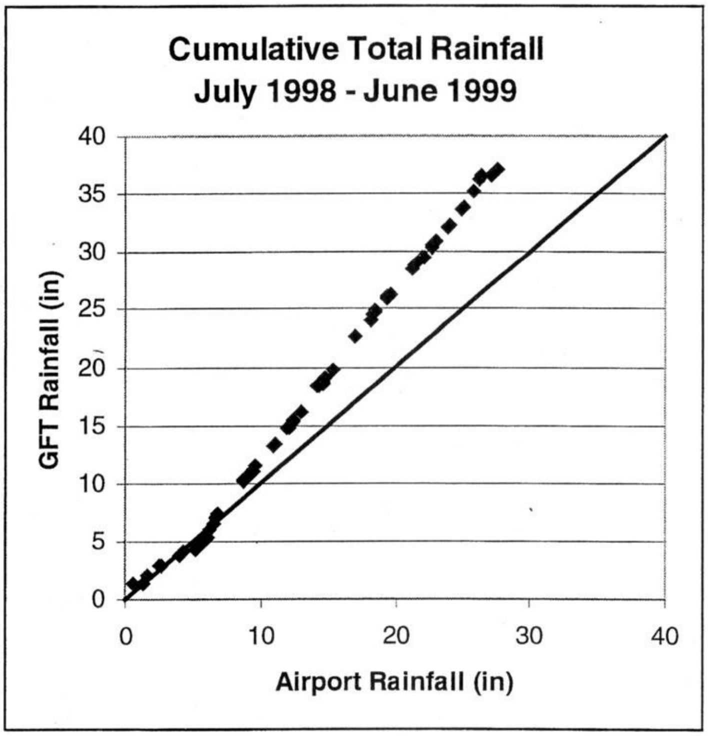
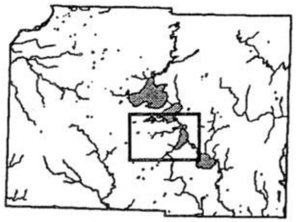


Figure 46. Comparison of precipitation records



Dane County

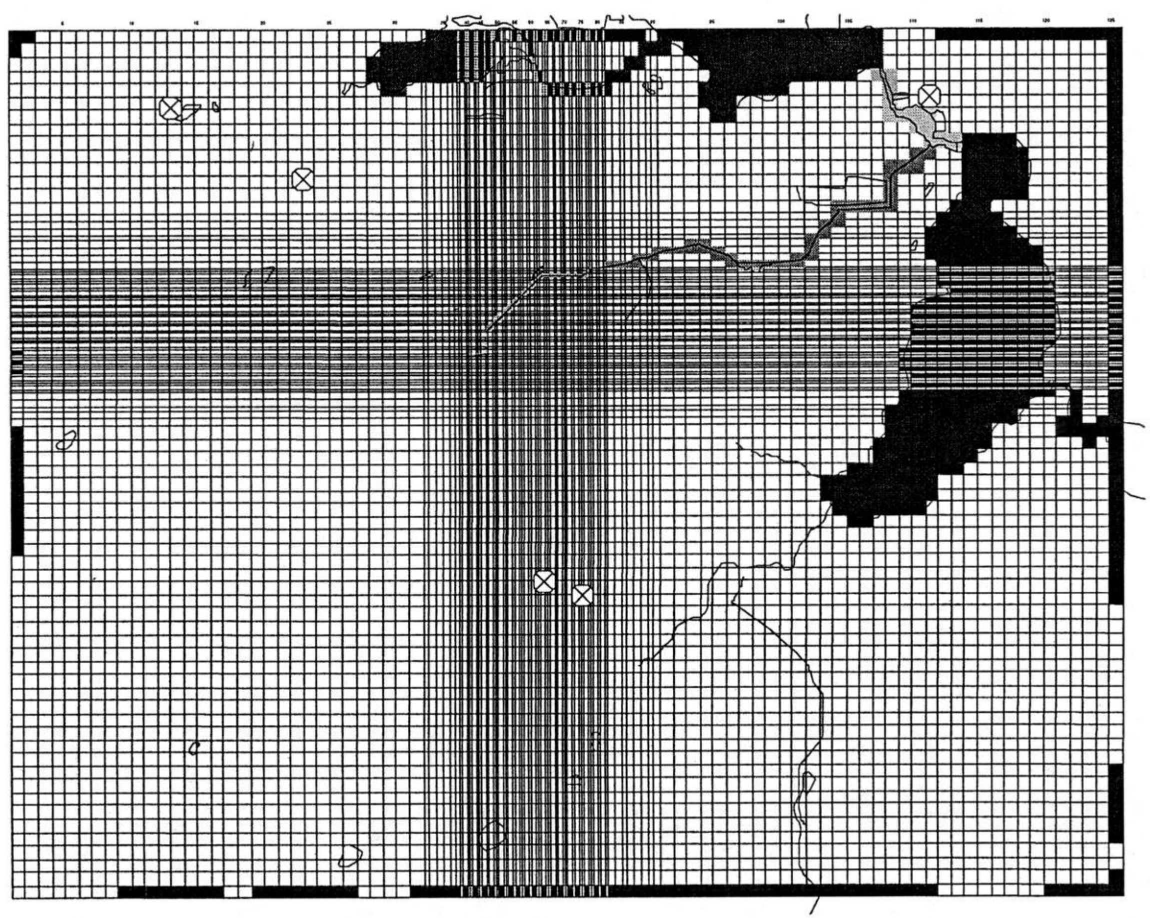
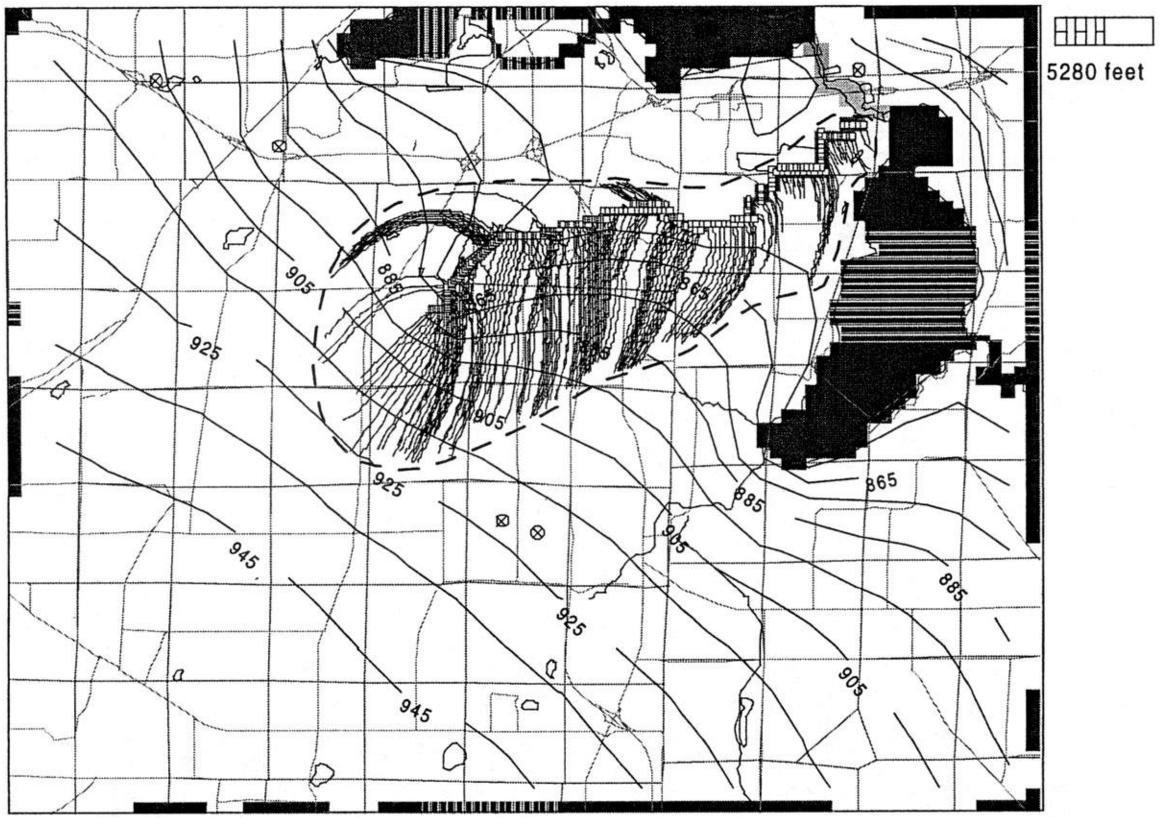


Figure 47. Nine Springs model grid

Figure 48. Approximate ground-watershed boundary under current (1995) pumping conditions

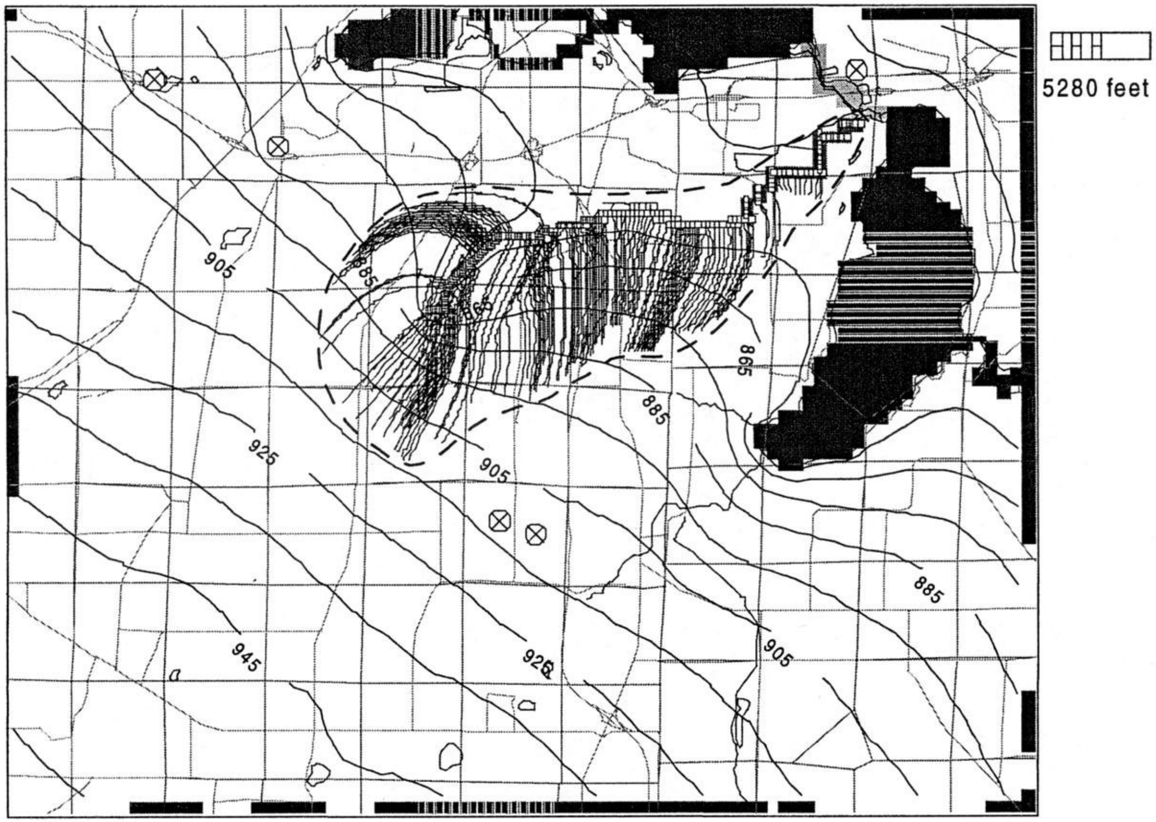


— — — — Approximate Ground-watershed Boundary

———— Particle Pathlines

—— 865 —— Watertable Contour, feet a.m.s.l.

Figure 49. Approximate ground-watershed boundary under proposed (2020) pumping conditions



– – – – Approximate Ground-watershed Boundary

——— Particle Pathlines

— 865 — Watertable Contour, feet a.m.s.l.

Figure 50. Comparison of ground-watershed boundaries

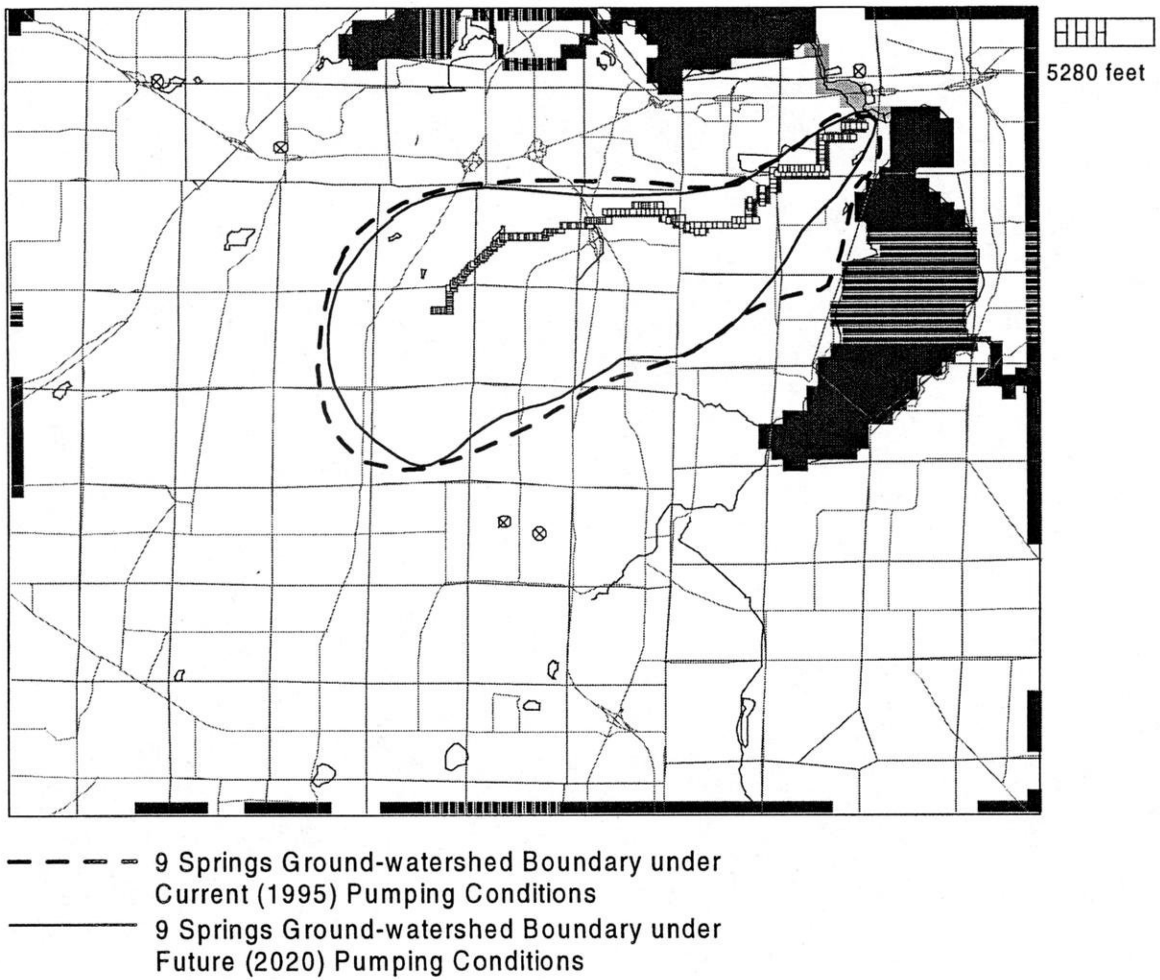
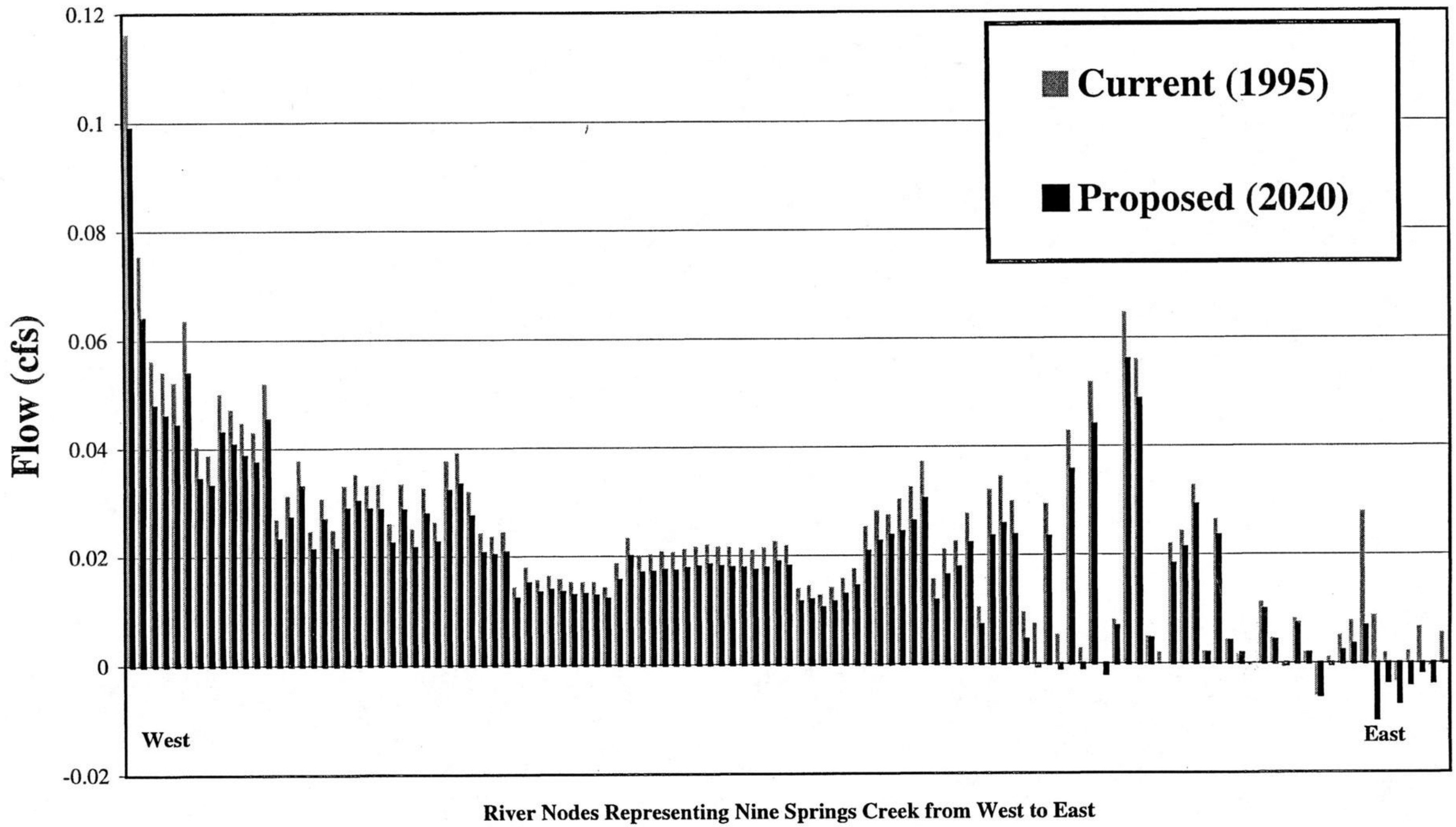


Figure 51. Groundwater discharge to Nine Springs Creek under current and proposed pumping schemes



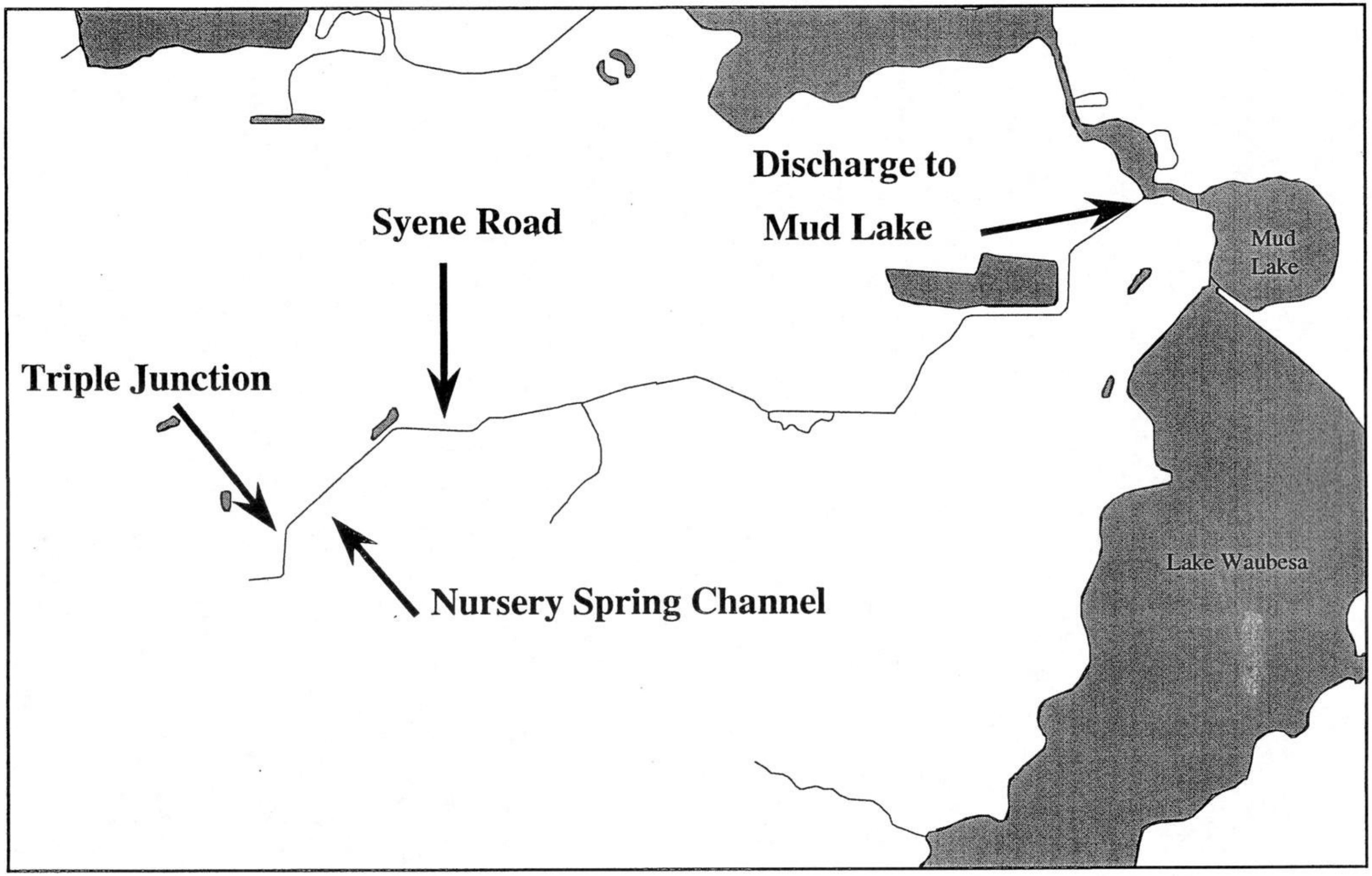
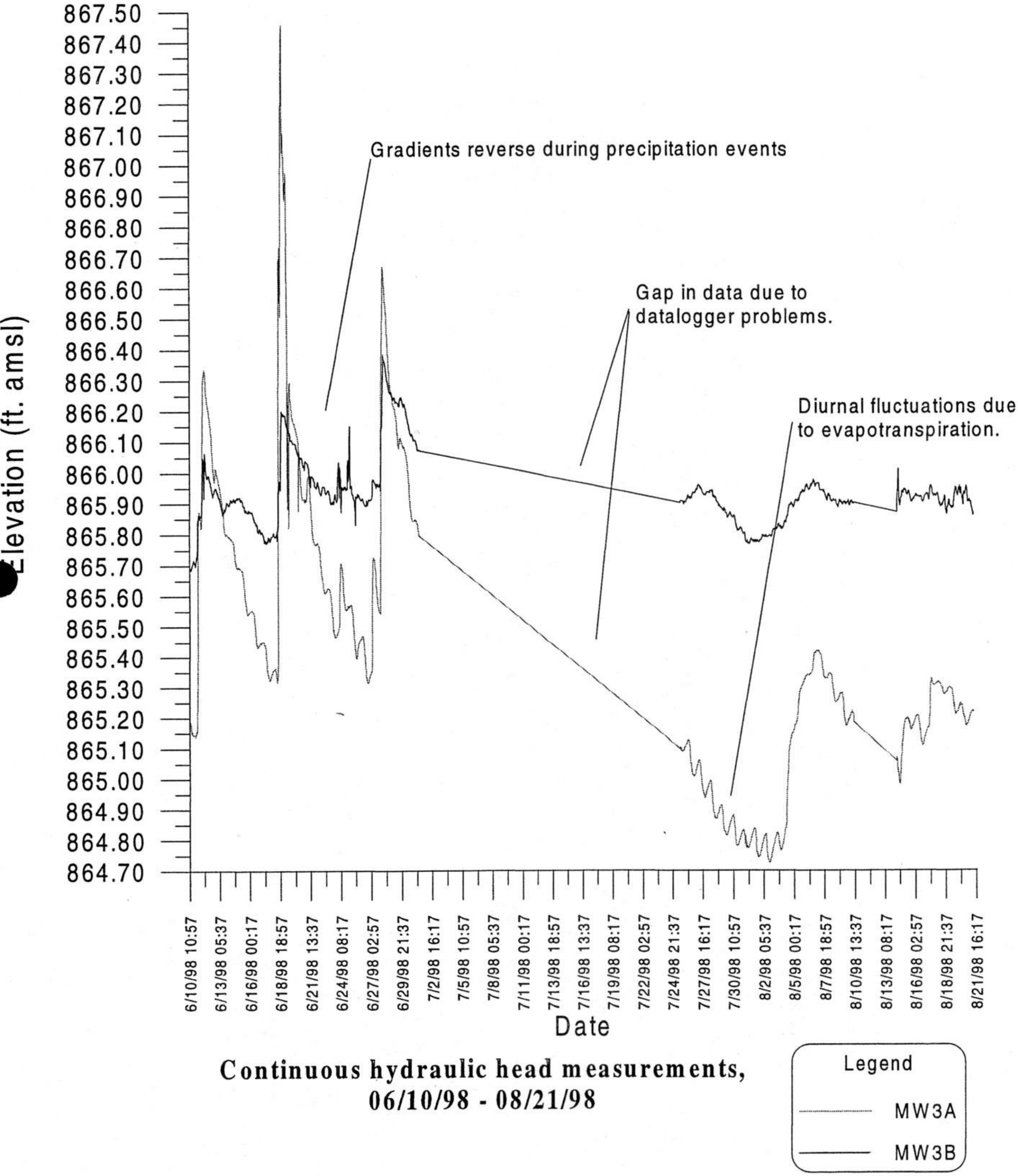
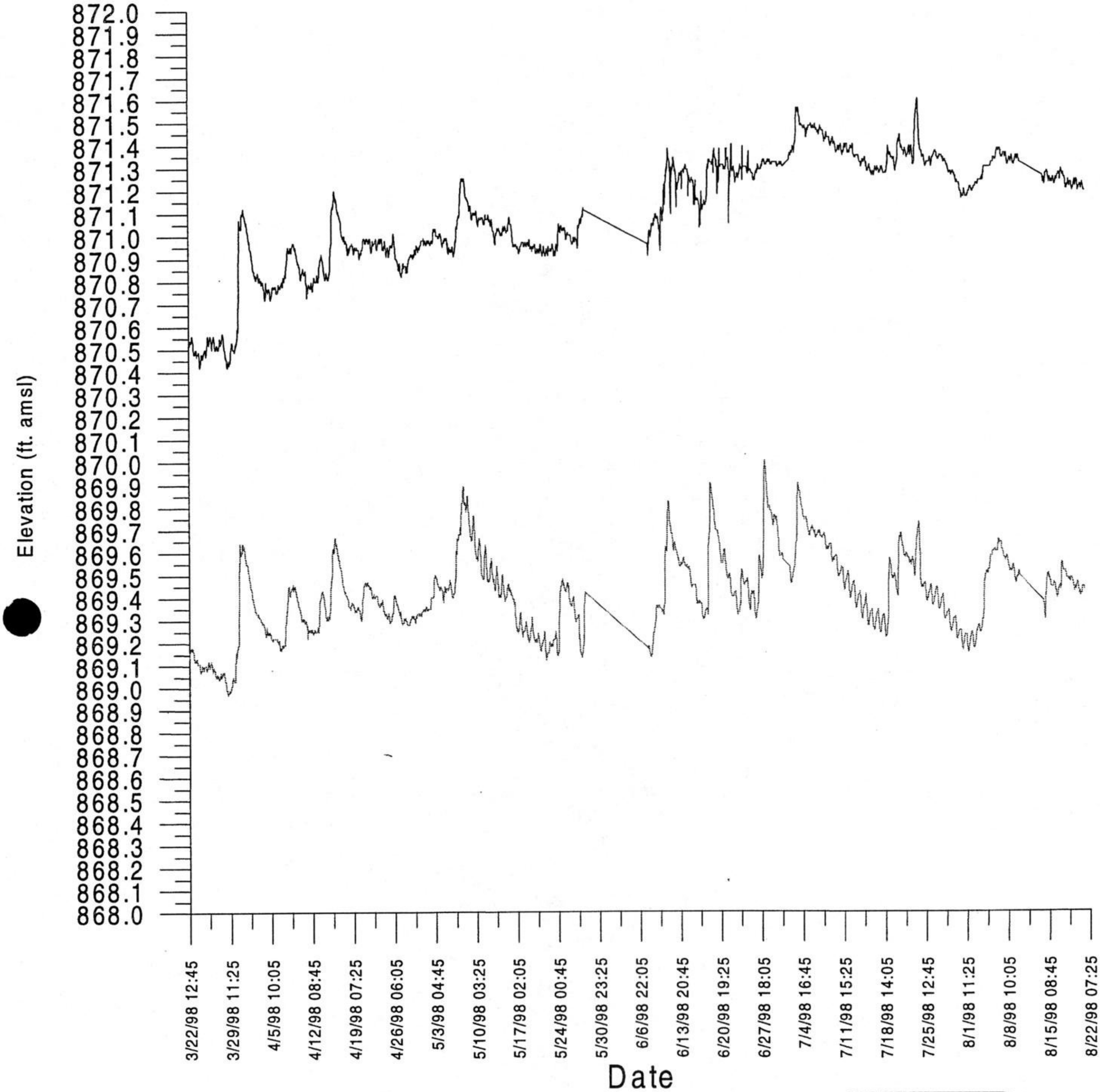


Figure 52. Nine Springs Creek reaches

Appendix A. Water level records

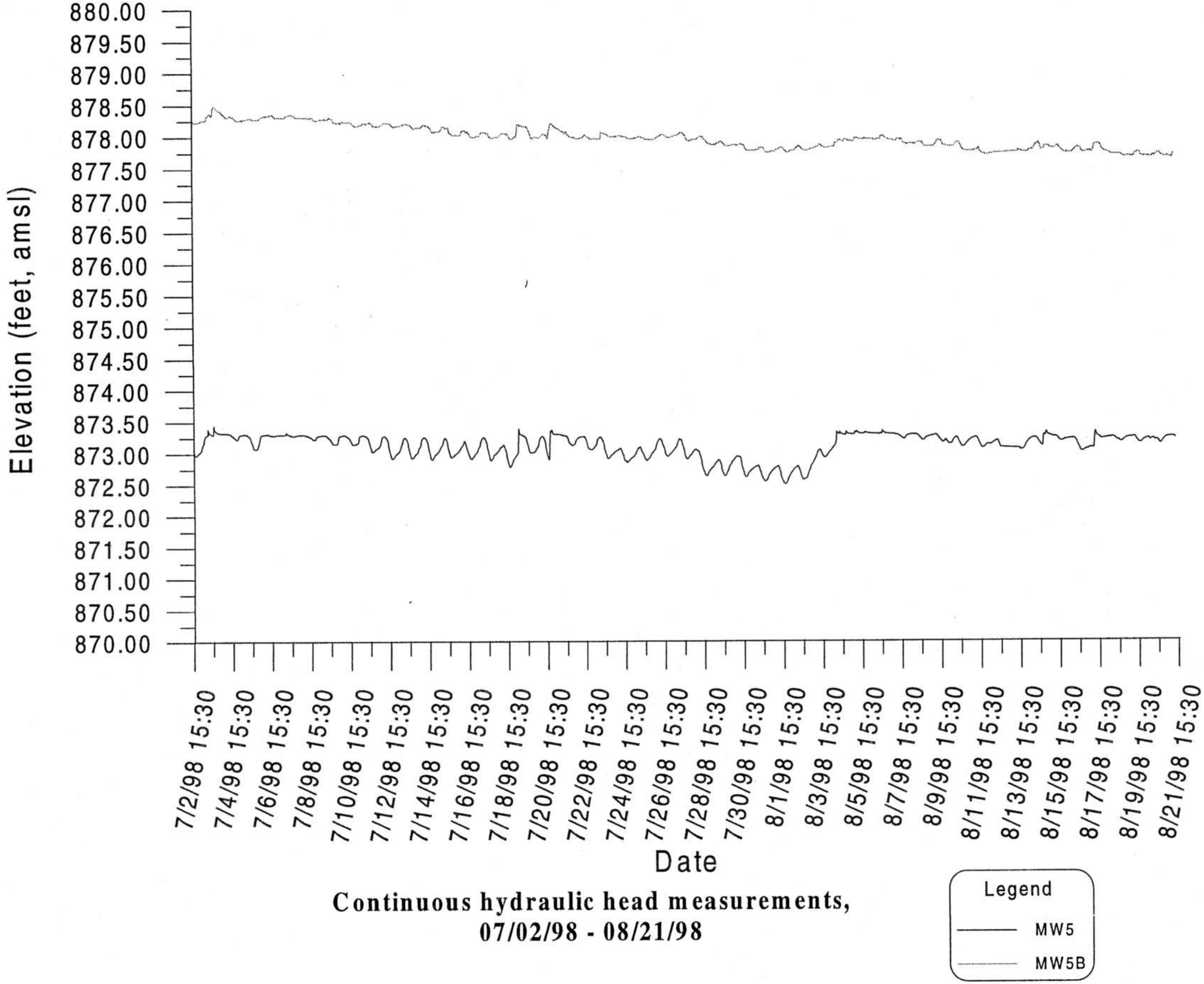


Continuous hydraulic head measurements, 06/10/98 - 08/21/98

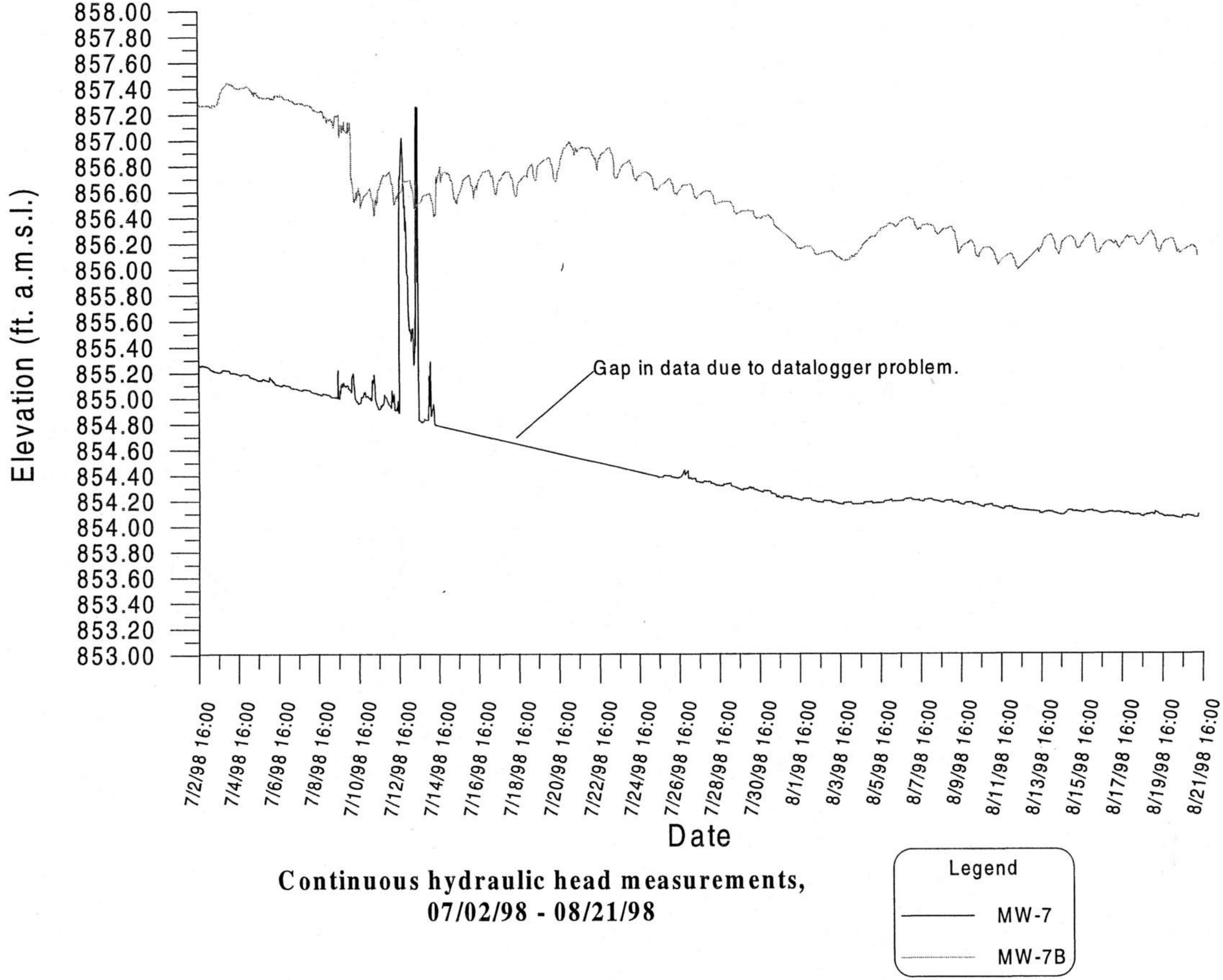


Continuous hydraulic head measurements, 03/22/98 - 08/21/98

Legend
MW1A
MW1C



**Continuous hydraulic head measurements,
07/02/98 - 08/21/98**



Continuous hydraulic head measurements, 07/02/98 - 08/21/98

Appendix B. Groundwater sampling results

LOCATION	date	Na,ppm	mol/kg	K,ppm	mol/kg	Ca,ppm	mol/kg	Activity coeff.	Mg,ppm	mol/kg	Activity coeff.
PEAT SPRING											
	3/11/99	6	2.610E-04	1	2.558E-05	80	1.996E-03	6.750E-01	39	1.604E-03	6.893E-01
	12/16/98	6.6	2.871E-04	<0.3	0.00E+00	84	2.096E-03	6.670E-01	44	1.810E-03	6.819E-01
	8/11/98	5.9	2.566E-04	0.9	2.302E-05	74	1.846E-03	6.774E-01	39	1.604E-03	6.915E-01
	5/29/98	5.8	2.523E-04	0.9	2.302E-05	75	1.871E-03	6.794E-01	39	1.604E-03	6.932E-01
	2/27/98	4.8	2.088E-04	0.4	1.023E-05	69	1.722E-03	6.995E-01	29	1.193E-03	7.118E-01
	11/25/97	6.2	2.697E-04	0.9	2.302E-05	77	1.921E-03	6.726E-01	42	1.728E-03	6.870E-01
BIG SPRING											
	3/11/99	8	3.480E-04	0.9	2.302E-05	83	2.071E-03	6.642E-01	43	1.769E-03	6.794E-01
	12/16/98	7.9	3.436E-04	0.9	2.302E-05	83	2.071E-03	6.661E-01	43	1.769E-03	6.811E-01
	8/11/98	8	3.480E-04	1	2.558E-05	84	2.096E-03	6.620E-01	45	1.851E-03	6.774E-01
	5/29/98	7.6	3.306E-04	1	2.558E-05	81	2.021E-03	6.660E-01	43	1.769E-03	6.810E-01
	2/27/98	7.5	3.262E-04	0.9	2.302E-05	80	1.996E-03	6.660E-01	44	1.810E-03	6.810E-01
	11/25/97	7.7	3.349E-04	0.9	2.302E-05	79	1.971E-03	6.677E-01	43	1.769E-03	6.825E-01
POOL											
	5/29/98	7.6	3.306E-04	0.9	2.302E-05	81	2.021E-03	6.652E-01	44	1.810E-03	6.803E-01
	2/27/98	6.9	3.001E-04	0.8	2.046E-05	76	1.896E-03	6.714E-01	42	1.728E-03	6.859E-01
	11/25/97	8	3.480E-04	1	2.558E-05	80	1.996E-03	6.663E-01	44	1.810E-03	6.813E-01
MW1C											
	3/11/99	11	4.785E-04	1.9	4.859E-05	82	2.046E-03	6.625E-01	44	1.810E-03	6.778E-01
	12/16/98	11	4.785E-04	1.7	4.348E-05	85	2.121E-03	6.630E-01	46	1.892E-03	6.783E-01
	8/11/98	9.9	4.306E-04	1.9	4.859E-05	84	2.096E-03	6.599E-01	46	1.892E-03	6.755E-01
	5/29/98	9.2	4.002E-04	2.2	5.627E-05	79	1.971E-03	6.663E-01	47	1.933E-03	6.813E-01
	2/27/98	9.5	4.132E-04	3.1	7.928E-05	75	1.871E-03	6.620E-01	49	2.016E-03	6.774E-01
MW3B											
	3/11/99	9.2	4.002E-04	1.4	3.581E-05	92	2.295E-03	6.542E-01	47	1.933E-03	6.702E-01
	12/16/98	9	3.915E-04	1.4	3.581E-05	96	2.395E-03	6.525E-01	46	1.892E-03	6.686E-01
	8/11/98	8.8	3.828E-04	1.9	4.859E-05	93	2.320E-03	6.527E-01	47	1.933E-03	6.688E-01
	5/29/98	8.4	3.654E-04	1.3	3.325E-05	90	2.246E-03	6.543E-01	48	1.974E-03	6.703E-01
	2/27/98	8.3	3.610E-04	3	7.673E-05	87	2.171E-03	6.579E-01	50	2.057E-03	6.736E-01
	11/25/97	8.9	3.871E-04	8.4	2.148E-04	72	1.796E-03	6.580E-01	54	2.221E-03	6.737E-01
MW3A											
	3/11/99	3.8	1.653E-04	0.6	1.535E-05	83	2.071E-03	6.722E-01	40	1.645E-03	6.866E-01
	12/16/98	4.4	1.914E-04	0.9	2.302E-05	83	2.071E-03	6.736E-01	40	1.645E-03	6.879E-01
	8/11/98	4.3	1.870E-04	1.2	3.069E-05	85	2.121E-03	6.695E-01	42	1.728E-03	6.842E-01
	5/29/98	4.4	1.914E-04	0.6	1.535E-05	84	2.096E-03	6.707E-01	42	1.728E-03	6.853E-01
	2/27/98	6.1	2.653E-04	0.7	1.790E-05	89	2.221E-03	6.575E-01	46	1.892E-03	6.733E-01
	11/25/97	5.3	2.305E-04	0.9	2.302E-05	85	2.121E-03	6.630E-01	43	1.769E-03	6.782E-01
MW4B											
	3/11/99	8	3.480E-04	1.1	2.813E-05	87	2.171E-03	6.594E-01	46	1.892E-03	6.750E-01
	12/16/98	7.5	3.262E-04	1.3	3.325E-05	86	2.146E-03	6.646E-01	45	1.851E-03	6.797E-01
	8/11/98	7.2	3.132E-04	1.3	3.325E-05	84	2.096E-03	6.604E-01	46	1.892E-03	6.759E-01
	5/29/98	7.5	3.262E-04	1.3	3.325E-05	84	2.096E-03	6.608E-01	46	1.892E-03	6.763E-01
	2/27/98	7.7	3.349E-04	1.2	3.069E-05	83	2.071E-03	6.611E-01	46	1.892E-03	6.765E-01
	11/25/97	7.2	3.132E-04	1.4	3.581E-05	82	2.046E-03	6.633E-01	45	1.851E-03	6.785E-01
MW2B											
	3/11/99	5.8	2.523E-04	14	3.581E-04	96	2.395E-03	6.450E-01	52	2.139E-03	6.618E-01
	12/16/98	5.4	2.349E-04	12	3.069E-04	98	2.445E-03	6.446E-01	51	2.098E-03	6.615E-01
	8/11/98	5	2.175E-04	14	3.581E-04	91	2.270E-03	6.507E-01	49	2.016E-03	6.670E-01
	5/29/98	5.6	2.436E-04	16	4.092E-04	88	2.196E-03	6.515E-01	49	2.016E-03	6.678E-01
	2/27/98	5.6	2.436E-04	9.9	2.532E-04	92	2.295E-03	6.508E-01	55	2.262E-03	6.672E-01
	11/25/97	6.2	2.697E-04	8.8	2.251E-04	84	2.096E-03	6.493E-01	55	2.262E-03	6.658E-01
MW2A											
	3/11/99	3.2	1.392E-04	78	1.995E-03	110	2.745E-03	6.274E-01	52	2.139E-03	6.459E-01
	12/16/98	6.5	2.827E-04	46	1.176E-03	100	2.495E-03	6.344E-01	53	2.180E-03	6.523E-01
	8/11/98	4.6	2.001E-04	54	1.381E-03	88	2.196E-03	6.495E-01	46	1.892E-03	6.660E-01
	5/29/98	1.7	7.395E-05	78	1.995E-03	75	1.871E-03	6.657E-01	37	1.522E-03	6.808E-01
	2/27/98	4.1	1.783E-04	20	5.115E-04	93	2.320E-03	6.462E-01	52	2.139E-03	6.630E-01
	11/25/97	5.6	2.436E-04	19	4.859E-04	90	2.246E-03	6.467E-01	50	2.057E-03	6.634E-01
MW5A											
	3/10/99	12	5.220E-04	1.1	2.813E-05	96	2.395E-03	6.480E-01	47	1.933E-03	6.646E-01
	12/17/98	12	5.220E-04	1.2	3.069E-05	93	2.320E-03	6.502E-01	46	1.892E-03	6.666E-01
	8/12/98	12	5.220E-04	1.3	3.325E-05	92	2.295E-03	6.503E-01	48	1.974E-03	6.667E-01
	6/3/98	12	5.220E-04	1.7	4.348E-05	93	2.320E-03	6.499E-01	48	1.974E-03	6.663E-01
MW5B											
	12/17/98	13	5.655E-04	1.4	3.581E-05	85	2.121E-03	6.624E-01	43	1.769E-03	6.777E-01
	8/12/98	13	5.655E-04	1.3	3.325E-05	85	2.121E-03	6.603E-01	44	1.810E-03	6.758E-01
	6/3/98	13	5.655E-04	1.6	4.092E-05	84	2.096E-03	6.597E-01	45	1.851E-03	6.752E-01
MW6A											
	3/10/99	13	5.655E-04	0.9	2.302E-05	87	2.171E-03	6.636E-01	43	1.769E-03	6.789E-01

LOCATION	date	Na,ppm	mol/kg	K,ppm	mol/kg	Ca,ppm	mol/kg	Activity coeff.	Mg,ppm	mol/kg	Activity coeff.
	12/17/98	13	5.655E-04	0.9	2.302E-05	86	2.146E-03	6.611E-01	44	1.810E-03	6.766E-01
	8/12/98	13	5.655E-04	1.2	3.069E-05	85	2.121E-03	6.598E-01	44	1.810E-03	6.753E-01
•	6/3/98	13	5.655E-04	1.1	2.813E-05	84	2.096E-03	6.584E-01	46	1.892E-03	6.741E-01
MW6B											
	3/10/99	13	5.655E-04	1	2.558E-05	87	2.171E-03	6.638E-01	43	1.769E-03	6.790E-01
	12/17/98	13	5.655E-04	1	2.558E-05	86	2.146E-03	6.613E-01	44	1.810E-03	6.767E-01
	8/12/98	13	5.655E-04	1.2	3.069E-05	86	2.146E-03	6.596E-01	44	1.810E-03	6.751E-01
	6/3/98	13	5.655E-04	1.1	2.813E-05	84	2.096E-03	6.597E-01	45	1.851E-03	6.753E-01
MW7A											
	3/10/99	2.8	1.218E-04	1	2.558E-05	66	1.647E-03	6.946E-01	33	1.357E-03	7.073E-01
	12/17/98	2.7	1.174E-04	0.9	2.302E-05	64	1.597E-03	6.960E-01	34	1.399E-03	7.085E-01
	8/12/98	2.9	1.261E-04	1.4	3.581E-05	66	1.647E-03	6.951E-01	34	1.399E-03	7.077E-01
	6/3/98	3.1	1.348E-04	1.2	3.069E-05	65	1.622E-03	6.957E-01	34	1.399E-03	7.083E-01
MW7B											
	3/10/99	3.3	1.435E-04	1.1	2.813E-05	69	1.722E-03	6.908E-01	35	1.440E-03	7.037E-01
	12/17/98	3.3	1.435E-04	1.2	3.069E-05	70	1.747E-03	6.889E-01	36	1.481E-03	7.019E-01
	8/12/98	3.3	1.435E-04	1.3	3.325E-05	71	1.771E-03	6.870E-01	37	1.522E-03	7.003E-01
	6/3/98	3.3	1.435E-04	1.2	3.069E-05	69	1.722E-03	6.882E-01	37	1.522E-03	7.014E-01
JONES											
	3/12/99	13	5.655E-04	1	2.558E-05	88	2.196E-03	6.588E-01	44	1.810E-03	6.744E-01
	12/18/98	14	6.090E-04	0.9	2.302E-05	86	2.146E-03	6.621E-01	44	1.810E-03	6.774E-01
	8/13/98	13	5.655E-04	0.7	1.790E-05	86	2.146E-03	6.601E-01	44	1.810E-03	6.756E-01
WDNR#9											
	3/12/99	5.5	2.392E-04	1.5	3.836E-05	72	1.796E-03	6.835E-01	38	1.563E-03	6.970E-01
	12/18/98	5.4	2.349E-04	1.3	3.325E-05	70	1.747E-03	6.850E-01	37	1.522E-03	6.984E-01
	8/13/98	5.3	2.305E-04	1.6	4.092E-05	72	1.796E-03	6.812E-01	38	1.563E-03	6.949E-01
EISELE											
	3/12/99	4.8	2.088E-04	1.2	3.069E-05	88	2.196E-03	6.617E-01	44	1.810E-03	6.771E-01
	12/18/98	4.7	2.044E-04	0.6	1.535E-05	86	2.146E-03	6.617E-01	45	1.851E-03	6.771E-01
	8/13/98	4.8	2.088E-04	0.7	1.790E-05	86	2.146E-03	6.627E-01	44	1.810E-03	6.780E-01
CHURCH											
	3/12/99	2.7	1.174E-04	0.9	2.302E-05	64	1.597E-03	6.993E-01	33	1.357E-03	7.115E-01
	12/22/98	2.6	1.131E-04	1	2.558E-05	63	1.572E-03	6.999E-01	33	1.357E-03	7.121E-01
	8/13/98	2.6	1.131E-04	0.9	2.302E-05	63	1.572E-03	6.998E-01	33	1.357E-03	7.120E-01
FINCH											
	3/12/99	5.7	2.479E-04	1.2	3.069E-05	84	2.096E-03	6.687E-01	41	1.687E-03	6.835E-01
	12/18/98	5.4	2.349E-04	0.9	2.302E-05	79	1.971E-03	6.737E-01	41	1.687E-03	6.880E-01
	8/13/98	5.6	2.436E-04	0.9	2.302E-05	80	1.996E-03	6.711E-01	41	1.687E-03	6.856E-01
H&M											
	3/12/99	9.3	4.045E-04	1.2	3.069E-05	92	2.295E-03	6.578E-01	44	1.810E-03	6.735E-01
	12/18/98	9.2	4.002E-04	1.1	2.813E-05	87	2.171E-03	6.597E-01	44	1.810E-03	6.752E-01
	8/13/98	9.2	4.002E-04	1.1	2.813E-05	88	2.196E-03	6.593E-01	45	1.851E-03	6.749E-01
KARLS NIEHAUS											
	8/13/98	3.7	1.609E-04	0.8	2.046E-05	72	1.796E-03	6.863E-01	37	1.522E-03	6.996E-01
SYENE SPRING											
	3/10/99	13	5.655E-04	1.1	2.813E-05	87	2.171E-03	6.637E-01	43	1.769E-03	6.789E-01
	12/18/98	13	5.655E-04	1	2.558E-05	86	2.146E-03	6.612E-01	44	1.810E-03	6.766E-01
	8/12/98	14	6.090E-04	1	2.558E-05	86	2.146E-03	6.585E-01	45	1.851E-03	6.742E-01
NURSERY SPRING											
	3/11/99	7.7	3.349E-04	1.2	3.069E-05	81	2.021E-03	6.703E-01	42	1.728E-03	6.850E-01
	12/16/98	7.8	3.393E-04	0.8	2.046E-05	80	1.996E-03	6.704E-01	42	1.728E-03	6.850E-01
	8/11/98	7.7	3.349E-04	1	2.558E-05	84	2.096E-03	6.626E-01	44	1.810E-03	6.779E-01
CREEK											
	3/10/99	16	6.960E-04	1.3	3.325E-05	80	1.996E-03	6.680E-01	40	1.645E-03	6.828E-01
	12/16/98	11	4.785E-04	1.1	2.813E-05	80	1.996E-03	6.694E-01	41	1.687E-03	6.841E-01
NORTH SPRING											
	3/10/99	53	2.305E-03	1.2	3.069E-05	110	2.745E-03	6.243E-01	50	2.057E-03	6.431E-01

LOCATION	date	Cl,ppm	mol/kg	field Alkalinity, ppm	mol/kg	Activity coeff.	HCO3,ppm	mol/kg
PEAT SPRING								
	3/11/99	23.6	6.657E-04	250	4.097E-03	9.019E-01	295	4.834E-03
	12/16/98	17.7	4.993E-04	220	3.605E-03	8.988E-01	362	5.932E-03
	8/11/98	23.5	6.629E-04	---	---	---	279	4.572E-03
	5/29/98	20.3	5.726E-04	---	---	---	286	4.687E-03
	2/27/98	14.3	4.034E-04	---	---	---	271	4.441E-03
	11/25/97	23.2	6.544E-04	---	---	---	307	5.031E-03
BIG SPRING								
	3/11/99	31.8	8.970E-04	250	4.097E-03	8.978E-01	305	4.998E-03
	12/16/98	30.7	8.660E-04	190	3.114E-03	8.985E-01	306	5.015E-03
	8/11/98	30.8	8.688E-04	---	---	---	305	4.998E-03
	5/29/98	28.9	8.152E-04	---	---	---	301	4.933E-03
	2/27/98	30.1	8.491E-04	---	---	---	298	4.884E-03
	11/25/97	29.5	8.322E-04	---	---	---	296	4.851E-03
POOL								
	5/29/98	28.6	8.068E-04	---	---	---	302	4.949E-03
	2/27/98	23.9	6.742E-04	---	---	---	294	4.818E-03
	11/25/97	29.7	8.378E-04	---	---	---	295	4.834E-03
MW1C								
	3/11/99	40.5	1.142E-03	250	4.097E-03	8.971E-01	306	5.015E-03
	12/16/98	39.9	1.126E-03	225	3.687E-03	8.973E-01	311	5.097E-03
	8/11/98	39.1	1.103E-03	---	---	---	311	5.097E-03
	5/29/98	34.8	9.817E-04	---	---	---	307	5.031E-03
	2/27/98	36.5	1.030E-03	---	---	---	317	5.195E-03
MW3B								
	3/11/99	25.3	7.137E-04	250	4.097E-03	8.940E-01	325	5.326E-03
	12/16/98	25.7	7.250E-04	225	3.687E-03	8.933E-01	330	5.408E-03
	8/11/98	25.9	7.306E-04	---	---	---	334	5.474E-03
	5/29/98	24	6.770E-04	---	---	---	328	5.375E-03
	2/27/98	25.7	7.250E-04	---	---	---	336	5.506E-03
	11/25/97	25.9	7.306E-04	---	---	---	332	5.441E-03
MW3A								
	3/11/99	7.1	2.003E-04	350	5.736E-03	9.008E-01	320	5.244E-03
	12/16/98	7.3	2.059E-04	260	4.261E-03	9.013E-01	300	4.916E-03
	8/11/98	7.5	2.116E-04	---	---	---	312	5.113E-03
	5/29/98	9.3	2.623E-04	---	---	---	327	5.359E-03
	2/27/98	10.1	2.849E-04	---	---	---	370	6.064E-03
	11/25/97	10.7	3.018E-04	---	---	---	354	5.801E-03
MW4B								
	3/11/99	33.3	9.394E-04	350	5.736E-03	8.960E-01	309	5.064E-03
	12/16/98	33.2	9.365E-04	200	3.278E-03	8.979E-01	311	5.097E-03
	8/11/98	31.6	8.914E-04	---	---	---	313	5.129E-03
	5/29/98	30.2	8.519E-04	---	---	---	313	5.129E-03
	2/27/98	31.4	8.858E-04	---	---	---	313	5.129E-03
	11/25/97	30.6	8.632E-04	---	---	---	307	5.031E-03
MW2B								
	3/11/99	12.9	3.639E-04	375	6.146E-03	8.904E-01	377	6.178E-03
	12/16/98	14	3.949E-04	230	3.769E-03	8.895E-01	382	6.260E-03
	8/11/98	12.7	3.583E-04	---	---	---	376	6.162E-03
	5/29/98	10	2.821E-04	---	---	---	382	6.260E-03
	2/27/98	13.5	3.808E-04	---	---	---	397	6.506E-03
	11/25/97	16.6	4.683E-04	---	---	---	381	6.244E-03
MW2A								
	3/11/99	9.2	2.595E-04	500	8.194E-03	8.835E-01	526	8.620E-03
	12/16/98	7.1	2.003E-04	250	4.097E-03	8.855E-01	363	5.949E-03
	8/11/98	3.5	9.873E-05	---	---	---	347	5.687E-03
	5/29/98	5.6	1.580E-04	---	---	---	372	6.096E-03
	2/27/98	3.7	1.044E-04	---	---	---	372	6.096E-03
	11/25/97	4.2	1.185E-04	---	---	---	425	6.965E-03
MW5A								
	3/10/99	40.1	1.131E-03	325	5.326E-03	8.916E-01	325	5.326E-03
	12/17/98	39.9	1.126E-03	260	4.261E-03	8.917E-01	320	5.244E-03
	8/12/98	40.8	1.151E-03	---	---	---	316	5.179E-03
	6/3/98	40.9	1.154E-03	---	---	---	312	5.113E-03
MW5B								
	12/17/98	36.8	1.038E-03	230	3.769E-03	8.971E-01	318	5.211E-03
	8/12/98	37.4	1.055E-03	---	---	---	320	5.244E-03
	6/3/98	36.5	1.030E-03	---	---	---	321	5.261E-03
MW6A								
	3/10/99	37.4	1.055E-03	350	5.736E-03	8.976E-01	320	5.244E-03

LOCATION	date	Cl,ppm	mol/kg	field Alkalinity, ppm	mol/kg	Activity coeff.	HCO3,ppm	mol/kg
	12/17/98	36.5	1.030E-03	260	4.261E-03	8.959E-01	320	5.244E-03
	8/12/98	36.8	1.038E-03	---	---	---	320	5.244E-03
	6/3/98	36.4	1.027E-03	---	---	---	326	5.343E-03
MW6B								
	3/10/99	36.5	1.030E-03	350	5.736E-03	8.976E-01	320	5.244E-03
	12/17/98	36.1	1.018E-03	260	4.261E-03	8.959E-01	320	5.244E-03
	8/12/98	37.1	1.047E-03	---	---	---	320	5.244E-03
	6/3/98	36.5	1.030E-03	---	---	---	319	5.228E-03
MW7A								
	3/10/99	2.7	7.616E-05	380	6.227E-03	9.091E-01	320	5.244E-03
	12/17/98	2.4	6.770E-05	260	4.261E-03	9.089E-01	303	4.966E-03
	8/12/98	3.1	8.745E-05	---	---	---	301	4.933E-03
	6/3/98	2.7	7.616E-05	---	---	---	301	4.933E-03
MW7B								
	3/10/99	1.3	3.667E-05	350	5.736E-03	9.076E-01	327	5.359E-03
	12/17/98	0.9	2.539E-05	250	4.097E-03	9.063E-01	330	5.408E-03
	8/12/98	2	5.642E-05	---	---	---	331	5.424E-03
	6/3/98	1.4	3.949E-05	---	---	---	337	5.523E-03
JONES								
	3/12/99	35.8	1.010E-03	250	4.097E-03	8.957E-01	321	5.261E-03
	12/18/98	35.7	1.007E-03	230	3.769E-03	8.962E-01	323	5.293E-03
	8/13/98	35.6	1.004E-03	---	---	---	323	5.293E-03
WDNR#9								
	3/12/99	17.6	4.965E-04	250	4.097E-03	9.050E-01	285	4.671E-03
	12/18/98	18	5.078E-04	325	5.326E-03	9.049E-01	286	4.687E-03
	8/13/98	18.8	5.303E-04	---	---	---	285	4.671E-03
EISELE								
	3/12/99	22.1	6.234E-04	300	4.916E-03	8.968E-01	284	4.654E-03
	12/18/98	21.4	6.037E-04	350	5.736E-03	8.961E-01	286	4.687E-03
	8/13/98	21.2	5.980E-04	---	---	---	291	4.769E-03
CHURCH								
	3/12/99	1.7	4.795E-05	250	4.097E-03	9.107E-01	288	4.720E-03
	12/22/98	2	5.642E-05	350	5.736E-03	9.103E-01	287	4.703E-03
	8/13/98	1.8	5.078E-05	---	---	---	289	4.736E-03
FINCH								
	3/12/99	23	6.488E-04	300	4.916E-03	8.995E-01	295	4.834E-03
	12/18/98	20.9	5.896E-04	260	4.261E-03	9.006E-01	298	4.884E-03
	8/13/98	22.8	6.432E-04	---	---	---	298	4.884E-03
H&M								
	3/12/99	34	9.591E-04	300	4.916E-03	8.953E-01	302	4.949E-03
	12/18/98	33.1	9.337E-04	250	4.097E-03	8.945E-01	304	4.982E-03
	8/13/98	32.1	9.055E-04	---	---	---	303	4.966E-03
KARLS NIEHAUS								
	8/13/98	9.3	2.623E-04	---	---	---	300	4.916E-03
SYENE SPRING								
	3/10/99	38.4	1.083E-03	350	5.736E-03	8.976E-01	319	5.228E-03
	12/18/98	37.8	1.066E-03	260	4.261E-03	8.966E-01	321	5.261E-03
	8/12/98	36.9	1.041E-03	---	---	---	324	5.310E-03
NURSERY SPRING								
	3/11/99	26.3	7.419E-04	350	5.736E-03	9.001E-01	294	4.818E-03
	12/16/98	25.7	7.250E-04	210	3.441E-03	8.994E-01	299	4.900E-03
	8/11/98	21.2	5.980E-04	---	---	---	310	5.080E-03
CREEK								
	3/10/99	42.9	1.210E-03	550	9.013E-03	8.992E-01	307	5.031E-03
	12/16/98	34.2	9.647E-04	260	4.261E-03	8.997E-01	310	5.080E-03
NORTH SPRING								
	3/10/99	132	3.724E-03	350	5.736E-03	8.822E-01	383	6.277E-03

LOCATION	date	Activity coeff.	CO3,ppm	(calculated CO3) mol/kg	Activity Coef.	SO4,ppm	mol/kg	NO3 + NO2 as N, ppm
PEAT SPRING								
	3/11/99	9.012E-01	0	2.23E-06	6.635E-01	15	1.562E-04	8.07
	12/16/98	8.981E-01	0	2.17E-06	6.549E-01	13	1.353E-04	1.6
	8/11/98	9.020E-01	0	2.12E-06	6.661E-01	23	2.394E-04	9.16
	5/29/98	9.028E-01	0	3.44E-06	6.681E-01	14	1.457E-04	7.6
	2/27/98	9.102E-01	0	3.29E-06	6.897E-01	7	7.287E-05	0.55
	11/25/97	9.002E-01	0	---	---	20	2.082E-04	6.55
BIG SPRING								
	3/11/99	8.971E-01	0	1.15E-06	6.519E-01	28	2.915E-04	10.9
	12/16/98	8.978E-01	0	1.16E-06	6.539E-01	19	1.978E-04	11.1
	8/11/98	8.962E-01	0	1.82E-06	6.495E-01	28	2.915E-04	11.9
	5/29/98	8.977E-01	0	2.86E-06	6.538E-01	27.9	2.904E-04	11
	2/27/98	8.978E-01	0	1.42E-06	6.538E-01	27	2.811E-04	10.7
	11/25/97	8.984E-01	0	---	---	26	2.707E-04	10.9
POOL								
	5/29/98	8.974E-01	0	2.87E-06	6.530E-01	27.5	2.863E-04	11
	2/27/98	8.998E-01	0	2.22E-06	6.596E-01	29	3.019E-04	8.2
	11/25/97	8.979E-01	0	---	---	26	2.707E-04	10.9
MW1C								
	3/11/99	8.964E-01	0	9.18E-07	6.500E-01	27	2.811E-04	10
	12/16/98	8.966E-01	0	7.41E-07	6.506E-01	7	7.287E-05	10.4
	8/11/98	8.954E-01	0	1.48E-06	6.473E-01	26	2.707E-04	10.9
	5/29/98	8.979E-01	0	3.67E-06	6.541E-01	8.2	8.536E-05	10
	2/27/98	8.962E-01	0	6.00E-07	6.495E-01	26	2.707E-04	9.7
MW3B								
	3/11/99	8.932E-01	0	9.71E-07	6.411E-01	33	3.435E-04	14.1
	12/16/98	8.925E-01	0	7.83E-07	6.393E-01	34	3.539E-04	14.5
	8/11/98	8.926E-01	0	1.58E-06	6.395E-01	33	3.435E-04	15.2
	5/29/98	8.933E-01	0	1.96E-06	6.413E-01	32.9	3.425E-04	14.5
	2/27/98	8.946E-01	0	2.53E-06	6.451E-01	8.3	8.640E-05	14.2
	11/25/97	8.947E-01	0	---	---	31	3.227E-04	10.8
MW3A								
	3/11/99	9.001E-01	0	1.92E-06	6.604E-01	16	1.666E-04	11.1
	12/16/98	9.006E-01	0	1.34E-06	6.619E-01	13	1.353E-04	13.1
	8/11/98	8.991E-01	0	1.18E-06	6.575E-01	12	1.249E-04	14.8
	5/29/98	8.995E-01	0	2.47E-06	6.589E-01	8.1	8.432E-05	10.9
	2/27/98	8.945E-01	0	1.11E-06	6.447E-01	41	4.268E-04	3.21
	11/25/97	8.966E-01	0	---	---	31	3.227E-04	8.8
MW4B								
	3/11/99	8.952E-01	0	9.26E-07	6.468E-01	29	3.019E-04	10.6
	12/16/98	8.972E-01	0	1.35E-06	6.523E-01	8	8.328E-05	10.9
	8/11/98	8.956E-01	0	1.87E-06	6.478E-01	30	3.123E-04	11.5
	5/29/98	8.958E-01	0	3.73E-06	6.482E-01	29.7	3.092E-04	10.8
	2/27/98	8.959E-01	0	1.87E-07	6.485E-01	30	3.123E-04	10.7
	11/25/97	8.967E-01	0	---	---	28	2.915E-04	10.8
MW2B								
	3/11/99	8.896E-01	0	1.12E-06	6.312E-01	42	4.372E-04	12.5
	12/16/98	8.895E-01	0	1.80E-06	6.308E-01	43	4.476E-04	12
	8/11/98	8.919E-01	0	1.78E-06	6.373E-01	37	3.852E-04	11.1
	5/29/98	8.922E-01	0	1.81E-06	6.383E-01	37.2	3.873E-04	11
	2/27/98	8.919E-01	0	2.98E-07	6.375E-01	5.6	5.830E-05	9.67
	11/25/97	8.913E-01	0	---	---	39	4.060E-04	8.76
MW2A								
	3/11/99	8.826E-01	0	1.23E-06	6.123E-01	36	3.748E-04	6.25
	12/16/98	8.855E-01	0	8.54E-07	6.198E-01	55	5.726E-04	28
	8/11/98	8.914E-01	0	1.03E-06	6.361E-01	37	3.852E-04	22.1
	5/29/98	8.976E-01	0	1.12E-06	6.535E-01	12.1	1.260E-04	12
	2/27/98	8.901E-01	0	8.80E-07	6.326E-01	35	3.644E-04	20.1
	11/25/97	8.903E-01	0	---	---	35	3.644E-04	14.6
MW5A								
	3/10/99	8.908E-01	0	9.69E-07	6.345E-01	41	4.268E-04	16.3
	12/17/98	8.917E-01	0	2.40E-06	6.368E-01	42	4.372E-04	16.3
	8/12/98	8.917E-01	0	1.49E-06	6.369E-01	38	3.956E-04	15.6
	6/3/98	8.916E-01	0	2.34E-06	6.365E-01	38.6	4.018E-04	15.8
MW5B								
	12/17/98	8.964E-01	0	2.40E-06	6.499E-01	18.7	1.947E-04	10.8
	8/12/98	8.956E-01	0	2.41E-06	6.477E-01	26	2.707E-04	9.9
	6/3/98	8.953E-01	0	3.04E-06	6.470E-01	28.1	2.925E-04	9.68
MW6A								
	3/10/99	8.968E-01	0	6.06E-07	6.513E-01	7	7.287E-05	10.6

LOCATION	date	Activity coeff.	CO3,ppm	(calculated CO3) mol/kg	Activity Coef.	SO4,ppm	mol/kg	NO3 + NO2 as N, ppm
	12/17/98	8.959E-01	0	1.91E-06	6.486E-01	18.7	1.947E-04	10.7
	8/12/98	8.954E-01	0	9.59E-07	6.471E-01	28	2.915E-04	10.6
	6/3/98	8.949E-01	0	1.23E-06	6.457E-01	27.9	2.904E-04	10.4
MW6B								
	3/10/99	8.969E-01	0	9.60E-07	6.514E-01	7	7.287E-05	10.6
	12/17/98	8.959E-01	0	1.21E-06	6.487E-01	18	1.874E-04	10.9
	8/12/98	8.953E-01	0	1.52E-06	6.469E-01	27	2.811E-04	10.3
	6/3/98	8.953E-01	0	1.91E-06	6.470E-01	28	2.915E-04	10.3
MW7A								
	3/10/99	9.084E-01	0	7.73E-07	6.845E-01	5	5.205E-05	2.28
	12/17/98	9.089E-01	0	2.31E-06	6.859E-01	7.4	7.704E-05	2.37
	8/12/98	9.086E-01	0	1.15E-06	6.850E-01	6	6.246E-05	2.22
	6/3/98	9.088E-01	0	1.83E-06	6.856E-01	6.2	6.454E-05	2.28
MW7B								
	3/10/99	9.070E-01	0	1.25E-06	6.803E-01	7	7.287E-05	0.16
	12/17/98	9.063E-01	0	3.16E-06	6.783E-01	7.9	8.224E-05	<0.069
	8/12/98	9.056E-01	0	1.59E-06	6.763E-01	8	8.328E-05	<0.01
	6/3/98	9.060E-01	0	3.23E-06	6.776E-01	5.9	6.142E-05	ND
JONES								
	3/12/99	8.950E-01	0	1.52E-06	6.460E-01	27	2.811E-04	10.3
	12/18/98	8.962E-01	0	1.93E-06	6.496E-01	12.8	1.333E-04	10.4
	8/13/98	8.955E-01	0	7.69E-07	6.474E-01	26	2.707E-04	9.48
WDNR#9								
	3/12/99	9.043E-01	0	1.72E-06	6.725E-01	14	1.457E-04	4.76
	12/18/98	9.049E-01	0	2.18E-06	6.742E-01	14.8	1.541E-04	5.25
	8/13/98	9.034E-01	0	1.72E-06	6.701E-01	23	2.394E-04	5.04
EISELE								
	3/12/99	8.961E-01	0	6.76E-07	6.492E-01	30	3.123E-04	18.5
	12/18/98	8.961E-01	0	1.36E-06	6.492E-01	30.8	3.206E-04	18.5
	8/13/98	8.965E-01	0	8.73E-07	6.503E-01	29.6	3.081E-04	17.4
CHURCH								
	3/12/99	9.101E-01	0	1.10E-06	6.894E-01	7	7.287E-05	1.13
	12/22/98	9.103E-01	0	8.74E-07	6.900E-01	7	7.287E-05	1.25
	8/13/98	9.103E-01	0	1.11E-06	6.899E-01	7	7.287E-05	1.12
FINCH								
	3/12/99	8.988E-01	0	1.12E-06	6.567E-01	25	2.603E-04	9.89
	12/18/98	9.006E-01	0	8.98E-07	6.620E-01	14.6	1.520E-04	9.65
	8/13/98	8.997E-01	0	8.97E-07	6.593E-01	22.6	2.353E-04	9.84
H&M								
	3/12/99	8.946E-01	0	7.18E-07	6.450E-01	31	3.227E-04	12.7
	12/18/98	8.953E-01	0	1.82E-06	6.470E-01	32.8	3.415E-04	12.8
	8/13/98	8.952E-01	0	1.44E-06	6.466E-01	30.4	3.165E-04	12.2
KARLS NIEHAUS								
	8/13/98	9.053E-01	0	1.14E-06	6.755E-01	6.3	6.558E-05	5.6
SYENE SPRING								
	3/10/99	8.969E-01	0	1.91E-06	6.513E-01	7	7.287E-05	10.3
	12/18/98	8.959E-01	0	2.65E-06	6.486E-01	18.2	1.895E-04	10.1
	8/12/98	8.949E-01	0	3.07E-06	6.458E-01	27	2.811E-04	9.83
NURSERY SPRING								
	3/11/99	8.994E-01	0	7.03E-07	6.585E-01	16	1.666E-04	10.2
	12/16/98	8.994E-01	0	2.26E-06	6.585E-01	16	1.666E-04	10.7
	8/11/98	8.964E-01	0	1.86E-06	6.501E-01	32	3.331E-04	13
CREEK								
	3/10/99	8.985E-01	0	1.16E-06	6.559E-01	18	1.874E-04	7.16
	12/16/98	8.990E-01	0	7.41E-06	6.574E-01	17.3	1.801E-04	7.15
NORTH SPRING								
	3/10/99	8.814E-01	0	4.50E-07	6.089E-01	37	3.852E-04	4.06

LOCATION	date	mol/kg	pH	Field Cond (umhos or uS)	Temp.	Corr. Cond. (umhos or uS)	TDS, ppm	DO, ppm	Charge Balance, %
PEAT SPRING									
	3/11/99	5.764E-04	7.2	465	10	652	467	7	7.88
	12/16/98	1.143E-04	7.1	450	5	728	529	11	8.56
	8/11/98	6.543E-04	7.2	750	19	847	454	8	5.96
	5/29/98	5.429E-04	7.4	650	24	662	449	---	8.45
	2/27/98	3.929E-05	7.4	350	2.5	614	396	---	9.13
	11/25/97	4.679E-04	---	500	10.2	697	483	---	7.21
BIG SPRING									
	3/11/99	7.786E-04	6.9	600	11	819	510	7	5.17
	12/16/98	7.929E-04	6.9	550	7	838	502	9	6.45
	8/11/98	8.500E-04	7.1	700	20	774	514	8	6.19
	5/29/98	7.857E-04	7.3	650	17	767	501	---	5.42
	2/27/98	7.643E-04	7.0	500	7	762	498	---	5.99
	11/25/97	7.786E-04	---	500	10.2	697	493	---	5.62
POOL									
	5/29/98	7.857E-04	7.3	700	21	758	503	---	5.92
	2/27/98	5.857E-04	7.2	500	4.5	822	481	---	6.19
	11/25/97	7.786E-04	---	490	9.8	690	495	---	6.63
MW1C									
	3/11/99	7.143E-04	6.8	440	4.5	723	521	7	5.13
	12/16/98	7.429E-04	6.7	500	6	785	512	7	9.17
	8/11/98	7.786E-04	7.0	750	13	973	529	7	5.84
	5/29/98	7.143E-04	7.4	650	15	803	497	---	8.97
	2/27/98	6.929E-04	6.6	500	4	835	526	---	5.13
MW3B									
	3/11/99	1.007E-03	6.8	485	7	739	546	7	6.96
	12/16/98	1.036E-03	6.7	550	7	838	557	7	6.66
	8/11/98	1.086E-03	7.0	720	13	934	559	7	5.67
	5/29/98	1.036E-03	7.1	700	7	1067	547	---	6.39
	2/27/98	1.014E-03	7.2	700	4	1169	533	---	9.00
	11/25/97	7.714E-04	---	510	9.8	719	543	---	6.47
MW3A									
	3/11/99	7.929E-04	7.1	430	6	675	481	3.5	7.32
	12/16/98	9.357E-04	7.0	500	7	762	462	6	9.41
	8/11/98	1.057E-03	6.9	680	13	882	479	5	8.80
	5/29/98	7.786E-04	7.2	650	14	823	486	---	8.87
	2/27/98	2.293E-04	6.8	500	3	863	566	---	6.74
	11/25/97	6.286E-04	---	485	9.8	683	539	---	4.25
MW4B									
	3/11/99	7.571E-04	6.8	430	3	742	523	7	7.16
	12/16/98	7.786E-04	7.0	500	7	762	503	7	8.95
	8/11/98	8.214E-04	7.1	750	12.5	986	525	6	5.39
	5/29/98	7.714E-04	7.4	700	15	865	523	---	6.09
	2/27/98	7.643E-04	6.1	700	3.5	1188	523	---	5.65
	11/25/97	7.714E-04	---	470	10	659	512	---	5.81
MW2B									
	3/11/99	8.929E-04	6.8	600	6.5	928	598	6	7.60
	12/16/98	8.571E-04	7.0	600	8	889	617	7	6.74
	8/11/98	7.929E-04	7.0	700	11.5	943	596	6	6.15
	5/29/98	7.857E-04	7.0	650	13.5	833	599	---	5.64
	2/27/98	6.907E-04	6.2	600	5	971	588	---	11.08
	11/25/97	6.257E-04	---	600	11	819	599	---	6.11
MW2A									
	3/11/99	4.464E-04	6.7	700	7	1067	743	7	8.29
	12/16/98	2.000E-03	6.7	700	8	1037	659	7	7.53
	8/11/98	1.579E-03	6.8	800	12.5	1051	602	6	9.06
	5/29/98	8.571E-04	6.8	650	15	803	593	---	9.18
	2/27/98	1.436E-03	6.7	600	5	971	600	---	6.91
	11/25/97	1.043E-03	---	550	11	751	643	---	2.63
MW5A									
	3/10/99	1.164E-03	6.8	600	10	841	577	5	4.13
	12/17/98	1.164E-03	7.2	550	8	815	570	7	3.25
	8/12/98	1.114E-03	7.0	650	12	865	564	7	4.94
	6/3/98	1.129E-03	7.2	700	11.5	943	562	---	5.48
MW5B									
	12/17/98	7.714E-04	7.2	460	6	722	527	7	6.11
	8/12/98	7.071E-04	7.2	650	15	803	537	7	5.67
	6/3/98	6.914E-04	7.3	700	15	865	539	---	5.77
MW6A									
	3/10/99	7.571E-04	6.6	550	8	815	518	5	8.07

LOCATION	date	mol/kg	pH	Field Cond	Temp.	Corr. Cond.	TDS, ppm	DO, ppm	Charge Balance, %
	12/17/98	7.643E-04	7.1	550	8	815	530	8	6.71
	8/12/98	7.571E-04	6.8	800	22	849	539	7	5.18
	6/3/98	7.429E-04	6.9	650	12	865	545	---	5.37
MW6B									
	3/10/99	7.571E-04	6.8	550	8	815	517	5	8.25
	12/17/98	7.786E-04	6.9	550	8	815	529	5.5	6.81
	8/12/98	7.357E-04	7.0	750	19	847	539	7	5.69
	6/3/98	7.357E-04	7.1	650	12	865	537	---	5.65
MW7A									
	3/10/99	1.629E-04	6.7	380	9	547	432	5	4.83
	12/17/98	1.693E-04	7.2	300	8	444	417	6	6.70
	8/12/98	1.586E-04	6.9	500	14	633	417	7	8.19
	6/3/98	1.629E-04	7.1	510	15.8	619	415	---	7.83
MW7B									
	3/10/99	1.143E-05	6.9	390	8	578	443	4	7.79
	12/17/98	0.000E+00	7.3	340	8	504	449	2	8.38
	8/12/98	0.000E+00	7.0	450	14	570	454	3.5	8.97
	6/3/98	0.000E+00	7.3	560	14.8	696	455	---	7.85
JONES									
	3/12/99	7.357E-04	7.0	600	8.5	876	539	---	6.37
	12/18/98	7.429E-04	7.1	480	9	691	527	---	7.75
	8/13/98	6.771E-04	6.7	600	14	760	538	---	6.10
WDNR#9									
	3/12/99	3.400E-04	7.1	435	9	626	437	---	9.33
	12/18/98	3.750E-04	7.2	420	9.5	597	438	---	7.27
	8/13/98	3.600E-04	7.1	500	11.5	674	449	---	7.27
EISELE									
	3/12/99	1.321E-03	6.7	600	10	841	491	---	6.63
	12/18/98	1.321E-03	7.0	455	12	605	493	---	6.19
	8/13/98	1.243E-03	6.8	600	12	798	495	---	5.92
CHURCH									
	3/12/99	8.071E-05	6.9	390	11	532	398	---	9.53
	12/22/98	8.929E-05	6.8	370	10.5	512	397	---	9.10
	8/13/98	8.000E-05	6.9	450	13	584	398	---	8.90
FINCH									
	3/12/99	7.064E-04	6.9	550	11	751	484	---	7.77
	12/18/98	6.893E-04	6.8	500	11	683	469	---	7.87
	8/13/98	7.029E-04	6.8	600	15	742	481	---	6.49
H&M									
	3/12/99	9.071E-04	6.7	650	14	823	525	---	7.35
	12/18/98	9.143E-04	7.1	550	15	680	524	---	5.49
	8/13/98	8.714E-04	7.0	750	18	866	521	---	7.19
KARLS NIEHAUS									
	8/13/98	4.000E-04	6.9	500	12.5	657	435	---	8.83
SYENE SPRING									
	3/10/99	7.357E-04	7.1	550	8	815	518	7	8.15
	12/18/98	7.214E-04	7.2	550	7	838	531	7	6.71
	8/12/98	7.021E-04	7.3	700	15	855	544	8	6.20
NURSERY SPRING									
	3/11/99	7.286E-04	6.7	455	6	714	477	8	8.56
	12/16/98	7.643E-04	7.2	500	8	741	482	7	7.43
	8/11/98	9.286E-04	7.1	650	13	843	513	8	5.79
CREEK									
	3/10/99	5.114E-04	6.9	550	11	751	511	7	5.83
	12/16/98	5.107E-04	7.7	400	5	647	502	7	6.36
NORTH SPRING									
	3/10/99	2.900E-04	6.4	800	12	1064	769	4.5	3.81

LOCATION	date	Charge Balance, %	Total Hardness, mg/L	Ionic Strength
PEAT SPRING		Field Alk.		
	3/11/99	13.93	359.9	1.07E-02
	12/16/98	28.63	390.4	1.15E-02
	8/11/98	---	344.9	1.05E-02
	5/29/98	---	347.4	1.03E-02
	2/27/98	---	291.4	8.53E-03
	11/25/97	---	364.7	1.09E-02
BIG SPRING				
	3/11/99	11.75	383.8	1.18E-02
	12/16/98	21.76	383.8	1.16E-02
	8/11/98	---	394.5	1.20E-02
	5/29/98	---	378.8	1.16E-02
	2/27/98	---	380.4	1.16E-02
	11/25/97	---	373.8	1.14E-02
POOL				
	5/29/98	---	382.9	1.17E-02
	2/27/98	---	362.2	1.11E-02
	11/25/97	---	380.4	1.16E-02
MW1C				
	3/11/99	11.66	385.4	1.20E-02
	12/16/98	19.96	401.1	1.19E-02
	8/11/98	---	398.6	1.22E-02
	5/29/98	---	390.2	1.16E-02
	2/27/98	---	388.4	1.20E-02
MW3B				
	3/11/99	15.50	422.7	1.29E-02
	12/16/98	18.76	428.6	1.31E-02
	8/11/98	---	425.2	1.31E-02
	5/29/98	---	421.8	1.29E-02
	2/27/98	---	422.5	1.25E-02
	11/25/97	---	401.4	1.25E-02
MW3A				
	3/11/99	3.73	371.5	1.10E-02
	12/16/98	14.79	371.5	1.08E-02
	8/11/98	---	384.7	1.12E-02
	5/29/98	---	382.2	1.11E-02
	2/27/98	---	411.1	1.25E-02
	11/25/97	---	388.8	1.19E-02
MW4B				
	3/11/99	2.80	406.1	1.23E-02
	12/16/98	23.61	399.5	1.17E-02
	8/11/98	---	398.6	1.22E-02
	5/29/98	---	398.6	1.22E-02
	2/27/98	---	396.1	1.21E-02
	11/25/97	---	389.5	1.19E-02
MW2B				
	3/11/99	7.80	453.2	1.40E-02
	12/16/98	23.85	454.1	1.40E-02
	8/11/98	---	428.4	1.33E-02
	5/29/98	---	420.9	1.32E-02
	2/27/98	---	455.5	1.33E-02
	11/25/97	---	435.5	1.34E-02
MW2A				
	3/11/99	10.44	488.2	1.62E-02
	12/16/98	18.44	467.3	1.53E-02
	8/11/98	---	408.6	1.34E-02
	5/29/98	---	339.2	1.16E-02
	2/27/98	---	445.7	1.38E-02
	11/25/97	---	430	1.38E-02
MW5A				
	3/10/99	4.13	432.7	1.36E-02
	12/17/98	9.43	421.1	1.33E-02
	8/12/98	---	426.8	1.33E-02
	6/3/98	---	429.3	1.34E-02
MW5B				
	12/17/98	16.77	388.8	1.20E-02
	8/12/98	---	392.9	1.22E-02
	6/3/98	---	394.5	1.23E-02
MW6A				
	3/10/99	4.78	393.8	1.18E-02

LOCATION	date	Charge Balance, %	Total Hardness, mg/L	Ionic Strength
	12/17/98	13.73	395.4	1.21E-02
	8/12/98	---	392.9	1.23E-02
	6/3/98	---	398.6	1.24E-02
MW6B				
	3/10/99	4.95	393.8	1.18E-02
	12/17/98	13.84	395.4	1.21E-02
	8/12/98	---	395.4	1.23E-02
	6/3/98	---	394.5	1.23E-02
MW7A				
	3/10/99	-3.27	300.3	8.93E-03
	12/17/98	13.67	299.4	8.82E-03
	8/12/98	---	304.4	8.89E-03
	6/3/98	---	301.9	8.84E-03
MW7B				
	3/10/99	4.52	316	9.26E-03
	12/17/98	21.39	322.6	9.42E-03
	8/12/98	---	329.2	9.58E-03
	6/3/98	---	324.2	9.48E-03
JONES				
	3/12/99	14.62	400.4	1.24E-02
	12/18/98	19.21	395.4	1.20E-02
	8/13/98	---	395.4	1.22E-02
WDNR#9				
	3/12/99	14.46	335.8	9.90E-03
	12/18/98	2.13	326.7	9.76E-03
	8/13/98	---	335.8	1.01E-02
EISELE				
	3/12/99	4.85	400.4	1.21E-02
	12/18/98	-0.55	399.5	1.21E-02
	8/13/98	---	395.4	1.19E-02
CHURCH				
	3/12/99	16.07	295.3	8.55E-03
	12/22/98	-0.26	292.8	8.50E-03
	8/13/98	---	292.8	8.51E-03
FINCH				
	3/12/99	7.17	378.1	1.13E-02
	12/18/98	12.87	365.6	1.08E-02
	8/13/98	---	368.1	1.11E-02
H&M				
	3/12/99	7.57	410.4	1.25E-02
	12/18/98	11.70	397.9	1.23E-02
	8/13/98	---	404.5	1.23E-02
KARLS NIEHAUS				
	8/13/98	---	331.7	9.65E-03
SYENE SPRING				
	3/10/99	4.75	393.8	1.18E-02
	12/18/98	13.86	395.4	1.21E-02
	8/12/98	---	399.5	1.24E-02
NURSERY SPRING				
	3/11/99	2.09	374.7	1.12E-02
	12/16/98	19.42	372.2	1.12E-02
	8/11/98	---	390.4	1.20E-02
CREEK				
	3/10/99		364	1.14E-02
	12/16/98	12.59	368.1	1.13E-02
NORTH SPRING				
	3/10/99	6.31	480	1.67E-02

Appendix C. Gunflint Trail 15-minute rain totals

Appendix C

Table C1. Gunflint Trail 15-minute Rain Totals - WY 1998 (in.)

Time (CST)	Rain (in.)	Time (CST)	Rain (in.)	Time (CST)	Rain (in.)
7/3/98 9:00	0.0116	8/3/98 21:00	0.0116	8/14/98 20:45	0.0232
7/3/98 9:15	0.0928	8/3/98 21:30	0.0116	8/14/98 21:00	0.0348
7/3/98 9:30	0.1972	8/4/98 5:45	0.0116	8/14/98 21:15	0.0464
7/3/98 9:45	0.0116	8/4/98 6:15	0.0348	8/14/98 21:30	0.0232
7/3/98 15:30	0.0116	8/4/98 6:30	0.058	8/14/98 21:45	0.0116
7/3/98 15:45	0.0348	8/4/98 6:45	0.348	8/17/98 7:00	0.0116
7/3/98 16:00	0.058	8/4/98 7:00	0.0464	8/17/98 7:15	0.0116
7/3/98 16:15	0.4176	8/4/98 7:15	0.0116	8/17/98 7:45	0.0116
7/3/98 16:30	0.1856	8/4/98 8:15	0.0232	8/17/98 8:00	0.0116
7/3/98 16:45	0.0348	8/4/98 8:30	0.0116	8/17/98 8:15	0.0348
7/3/98 17:00	0.0348	8/4/98 8:45	0.0116	8/17/98 8:30	0.058
7/3/98 17:15	0.0116	8/4/98 9:00	0.0116	8/17/98 8:45	0.0696
7/3/98 17:45	0.0696	8/4/98 10:30	0.0464	8/17/98 9:00	0.0812
7/3/98 18:00	0.0348	8/4/98 10:45	0.0928	8/17/98 9:15	0.0812
7/3/98 18:15	0.0232	8/4/98 11:00	0.0116	8/17/98 9:30	0.0348
7/3/98 18:30	0.0116	8/4/98 18:30	0.0116	8/17/98 9:45	0.0116
7/3/98 20:00	0.0348	8/5/98 5:00	0.0116	8/17/98 10:00	0.0116
7/3/98 21:15	0.0116	8/5/98 5:15	0.058	8/20/98 21:00	0.0116
7/7/98 7:15	0.0116	8/5/98 5:45	0.0116	8/20/98 21:15	0.0116
7/7/98 7:30	0.0116	8/5/98 6:30	0.0232	8/21/98 13:30	0.0116
7/7/98 8:45	0.0232	8/5/98 6:45	0.0464	8/21/98 18:15	0.116
7/7/98 9:00	0.0116	8/5/98 7:00	0.0348	8/21/98 18:30	0.0348
7/19/98 2:00	0.0116	8/5/98 7:15	0.0232	8/21/98 18:45	0.0116
7/19/98 2:30	0.0696	8/5/98 7:30	0.0232	8/21/98 19:00	0.0116
7/19/98 2:45	0.4988	8/5/98 7:45	0.0116	8/22/98 5:45	0.0116
7/19/98 3:00	0.1392	8/5/98 8:15	0.0116	8/23/98 4:00	0.0116
7/19/98 3:15	0.0232	8/5/98 16:45	0.0116	8/23/98 4:15	0.0464
7/19/98 3:30	0.0348	8/5/98 17:15	0.0232	8/23/98 4:30	0.0116
7/19/98 3:45	0.0116	8/5/98 17:30	0.0116	8/23/98 4:45	0.0232
7/20/98 17:15	0.0116	8/5/98 18:00	0.0116	8/23/98 5:00	0.0116
7/20/98 17:30	0.4292	8/6/98 7:15	0.0116	8/23/98 5:15	0.0232
7/20/98 17:45	0.0464	8/6/98 11:30	0.0116	8/23/98 5:30	0.0464
7/20/98 18:00	0.058	8/6/98 11:45	0.0116	8/23/98 5:45	0.0812
7/20/98 18:30	0.0116	8/6/98 14:30	0.0116	8/23/98 6:00	0.116
7/20/98 18:45	0.058	8/6/98 14:45	0.0232	8/23/98 6:15	0.0812
7/20/98 19:00	0.0116	8/6/98 15:00	0.058	8/23/98 6:30	0.1508
7/20/98 19:15	0.0696	8/6/98 15:15	0.0116	8/23/98 6:45	0.0116
7/20/98 19:30	0.0232	8/6/98 15:45	0.0116	8/24/98 4:30	0.0116
7/20/98 20:00	0.0348	8/6/98 16:30	0.0232	8/24/98 11:45	0.0116
7/20/98 20:15	0.0116	8/6/98 22:15	0.0116	8/24/98 12:00	0.0232
7/22/98 9:45	0.0116	8/9/98 23:30	0.0116	8/24/98 12:15	0.0464
7/30/98 8:00	0.0116	8/14/98 17:30	0.2204	8/24/98 13:15	0.0116
8/3/98 4:30	0.0116	8/14/98 17:45	0.0696	8/24/98 16:00	0.0116
8/3/98 4:45	0.0116	8/14/98 18:00	0.0232	8/24/98 20:15	0.0116
8/3/98 5:15	0.0116	8/14/98 18:15	0.0232	8/24/98 21:00	0.058
8/3/98 20:30	0.0116	8/14/98 18:30	0.0116	8/24/98 21:15	0.406

Table C1. Gunflint Trail 15-minute Rain Totals - WY 1998 (in.) (continued)

Time (CST)	Rain (in.)	Time (CST)	Rain (in.)	Time (CST)	Rain (in.)
8/24/98 23:15	0.0116	9/14/98 7:00	0.0812	9/14/98 19:00	0.0116
8/27/98 14:15	0.0116	9/14/98 7:15	0.0232	9/14/98 19:30	0.0116
8/27/98 14:30	0.0464	9/14/98 7:30	0.0232	9/14/98 20:45	0.0116
8/27/98 14:45	0.0812	9/14/98 7:45	0.0812	9/15/98 10:45	0.0116
8/27/98 15:00	0.0928	9/14/98 8:00	0.058	9/23/98 23:00	0.0116
8/27/98 15:15	0.0464	9/14/98 8:15	0.0232	9/23/98 23:30	0.0116
8/27/98 16:15	0.0116	9/14/98 8:30	0.0464	9/23/98 23:45	0.0348
8/27/98 22:15	0.0348	9/14/98 8:45	0.0116	9/24/98 0:00	0.0464
8/27/98 22:30	0.0232	9/14/98 9:00	0.0232	9/24/98 0:15	0.0348
8/27/98 22:45	0.058	9/14/98 9:15	0.0464	9/24/98 0:30	0.058
8/27/98 23:00	0.0348	9/14/98 9:30	0.0464	9/24/98 0:45	0.0812
8/27/98 23:15	0.0116	9/14/98 9:45	0.0464	9/24/98 1:00	0.0232
8/28/98 0:45	0.0116	9/14/98 10:00	0.0232	9/24/98 1:30	0.0116
8/28/98 1:15	0.0348	9/14/98 10:15	0.0232	9/25/98 19:00	0.0116
8/28/98 1:30	0.0464	9/14/98 10:30	0.0232	9/25/98 21:00	0.0116
8/28/98 1:45	0.0348	9/14/98 10:45	0.058	9/25/98 21:15	0.0116
8/28/98 2:00	0.058	9/14/98 11:00	0.0812	9/26/98 1:45	0.0116
8/28/98 2:15	0.0116	9/14/98 11:15	0.0348	9/30/98 11:15	0.1856
8/28/98 2:45	0.0232	9/14/98 11:30	0.0348	9/30/98 11:30	0.0696
8/28/98 3:00	0.0232	9/14/98 11:45	0.058	9/30/98 11:45	0.0232
8/28/98 3:15	0.0116	9/14/98 12:00	0.1044	9/30/98 12:00	0.0232
8/28/98 3:30	0.0116	9/14/98 12:15	0.0464	9/30/98 12:15	0.0232
8/28/98 4:30	0.0116	9/14/98 12:30	0.0348	9/30/98 15:30	0.0116
9/6/98 23:15	0.0116	9/14/98 12:45	0.0116		
9/14/98 0:15	0.0116	9/14/98 13:15	0.0116		
9/14/98 0:30	0.0116	9/14/98 13:30	0.0232		
9/14/98 0:45	0.0116	9/14/98 13:45	0.0116		
9/14/98 1:00	0.0116	9/14/98 14:00	0.0116		
9/14/98 2:15	0.0116	9/14/98 14:15	0.0116		
9/14/98 2:30	0.0116	9/14/98 14:30	0.0232		
9/14/98 2:45	0.0116	9/14/98 14:45	0.0348		
9/14/98 3:00	0.0348	9/14/98 15:00	0.0232		
9/14/98 3:15	0.0116	9/14/98 15:15	0.0464		
9/14/98 3:30	0.0116	9/14/98 15:30	0.116		
9/14/98 3:45	0.0116	9/14/98 15:45	0.0696		
9/14/98 4:00	0.0464	9/14/98 16:00	0.0696		
9/14/98 4:15	0.0348	9/14/98 16:15	0.0232		
9/14/98 4:30	0.0464	9/14/98 16:30	0.058		
9/14/98 4:45	0.0812	9/14/98 16:45	0.0464		
9/14/98 5:00	0.0812	9/14/98 17:00	0.0696		
9/14/98 5:15	0.058	9/14/98 17:15	0.0348		
9/14/98 5:30	0.0464	9/14/98 17:30	0.058		
9/14/98 5:45	0.058	9/14/98 17:45	0.0464		
9/14/98 6:00	0.058	9/14/98 18:00	0.0232		
9/14/98 6:15	0.0464	9/14/98 18:15	0.0348		
9/14/98 6:30	0.0232	9/14/98 18:30	0.058		
9/14/98 6:45	0.0348	9/14/98 18:45	0.0348		

Table C2. Gunflint Trail 15-minute Rain Totals - WY 1999 (in.)

Time (CST)	Rain (in.)	Time (CST)	Rain (in.)	Time (CST)	Rain (in.)
10/2/98 17:15	0.0116	10/5/98 4:15	0.0464	10/17/98 16:30	0.058
10/2/98 18:00	0.0116	10/5/98 4:30	0.0232	10/17/98 16:45	0.0812
10/2/98 19:15	0.0116	10/5/98 4:45	0.0116	10/17/98 17:00	0.0464
10/2/98 19:45	0.0116	10/5/98 5:00	0.0116	10/17/98 17:15	0.0232
10/2/98 20:00	0.0116	10/5/98 5:15	0.0348	10/17/98 17:30	0.0116
10/2/98 20:30	0.0116	10/5/98 5:30	0.0116	10/17/98 17:45	0.0232
10/2/98 20:45	0.0116	10/5/98 12:30	0.0116	10/17/98 18:00	0.0696
10/2/98 21:00	0.0116	10/5/98 15:30	0.0348	10/17/98 18:15	0.0696
10/2/98 21:15	0.0116	10/5/98 15:45	0.0348	10/17/98 18:30	0.0116
10/2/98 22:45	0.0116	10/5/98 16:00	0.0116	10/17/98 19:00	0.0116
10/2/98 23:00	0.0116	10/5/98 16:45	0.0464	10/17/98 19:15	0.0116
10/2/98 23:15	0.0116	10/5/98 17:00	0.3364	10/17/98 19:30	0.0116
10/2/98 23:30	0.0116	10/5/98 17:15	0.1392	10/17/98 19:45	0.0116
10/3/98 0:15	0.0116	10/5/98 17:30	0.058	10/17/98 20:45	0.0116
10/3/98 0:30	0.0348	10/5/98 18:00	0.0696	10/17/98 23:30	0.0116
10/3/98 1:00	0.0116	10/5/98 18:15	0.1392	10/18/98 0:30	0.0696
10/3/98 1:45	0.0116	10/5/98 18:30	0.0232	10/18/98 1:15	0.0116
10/3/98 3:45	0.0116	10/6/98 7:30	0.0116	10/27/98 3:00	0.0232
10/3/98 6:45	0.0116	10/6/98 7:45	0.0116	10/27/98 3:15	0.0116
10/3/98 7:00	0.0464	10/6/98 8:15	0.0116	10/27/98 3:30	0.0116
10/3/98 7:15	0.0348	10/6/98 11:45	0.0116	10/27/98 3:45	0.0232
10/3/98 7:30	0.0348	10/6/98 12:00	0.0116	10/27/98 4:00	0.0348
10/3/98 7:45	0.0232	10/6/98 12:30	0.0116	10/27/98 4:15	0.0348
10/3/98 8:00	0.0116	10/6/98 12:45	0.0232	10/27/98 4:30	0.0232
10/3/98 8:15	0.0116	10/6/98 13:00	0.0116	10/27/98 4:45	0.0116
10/3/98 16:00	0.0116	10/6/98 13:15	0.0116	10/27/98 5:00	0.0116
10/3/98 18:00	0.0116	10/6/98 13:45	0.0116	10/27/98 9:15	0.0116
10/3/98 19:00	0.0116	10/6/98 14:45	0.0116	10/27/98 9:45	0.0232
10/3/98 19:15	0.0464	10/6/98 15:00	0.0116	10/27/98 11:15	0.0116
10/3/98 19:30	0.058	10/6/98 16:00	0.0116	10/27/98 12:30	0.0232
10/3/98 19:45	0.0232	10/6/98 16:15	0.0116	10/27/98 12:45	0.0116
10/3/98 20:00	0.0232	10/17/98 3:15	0.0116	10/27/98 13:00	0.0464
10/3/98 20:15	0.0116	10/17/98 3:30	0.0812	10/27/98 13:15	0.0232
10/3/98 20:30	0.0116	10/17/98 3:45	0.058	10/27/98 14:15	0.0116
10/4/98 10:45	0.0116	10/17/98 4:00	0.0348	10/27/98 18:00	0.0232
10/5/98 1:45	0.0812	10/17/98 10:30	0.0348	10/27/98 18:15	0.0232
10/5/98 2:00	0.0232	10/17/98 10:45	0.1856	10/27/98 18:45	0.0348
10/5/98 2:15	0.1972	10/17/98 11:00	0.0116	10/27/98 22:00	0.0116
10/5/98 2:30	0.174	10/17/98 12:00	0.2436	10/29/98 9:45	0.0232
10/5/98 2:45	0.0928	10/17/98 12:15	0.0696	10/29/98 13:45	0.0116
10/5/98 3:00	0.058	10/17/98 12:30	0.0464	10/30/98 3:45	0.0116
10/5/98 3:15	0.058	10/17/98 12:45	0.0232	11/8/98 10:15	0.0348
10/5/98 3:30	0.058	10/17/98 13:30	0.0116	11/8/98 10:30	0.0232
10/5/98 3:45	0.0232	10/17/98 13:45	0.0116	11/9/98 15:30	0.0232
10/5/98 4:00	0.0116	10/17/98 16:15	0.0232	11/9/98 15:45	0.0232

Table C2. Gunflint Trail 15-minute Rain Totals - WY 1999 (in.) (continued)

Time (CST)	Rain (in.)	Time (CST)	Rain (in.)	Time (CST)	Rain (in.)
11/9/98 16:00	0.0348	11/10/98 9:15	0.0116	12/6/98 14:45	0.0116
11/9/98 16:30	0.0348	11/10/98 9:30	0.0348	12/7/98 14:30	0.0232
11/9/98 16:45	0.0116	11/10/98 9:45	0.0116	12/7/98 14:45	0.0232
11/9/98 17:00	0.0232	11/10/98 11:00	0.0232	4/15/99 23:45	0.0116
11/9/98 17:45	0.0116	11/10/98 11:30	0.0116	4/16/99 1:45	0.0116
11/9/98 18:30	0.0116	11/10/98 11:45	0.0232	4/18/99 2:45	0.0116
11/9/98 19:00	0.0232	11/10/98 12:30	0.0232	4/18/99 4:30	0.0116
11/9/98 19:15	0.0116	11/10/98 12:45	0.0116	4/18/99 6:30	0.0116
11/9/98 19:30	0.0232	11/10/98 13:00	0.0464	4/18/99 16:15	0.0116
11/9/98 19:45	0.0348	11/10/98 13:15	0.0116	4/18/99 17:30	0.0116
11/9/98 20:00	0.0116	11/10/98 13:30	0.0232	4/20/99 12:30	0.0116
11/9/98 20:15	0.0116	11/10/98 13:45	0.0116	4/20/99 13:00	0.0116
11/9/98 20:30	0.0116	11/10/98 14:15	0.0116	4/20/99 13:15	0.0116
11/9/98 20:45	0.0116	11/10/98 14:30	0.0116	4/20/99 13:30	0.0116
11/9/98 21:00	0.0232	11/10/98 14:45	0.0348	4/20/99 13:45	0.0116
11/9/98 21:30	0.0232	11/10/98 15:00	0.0348	4/20/99 14:00	0.0232
11/9/98 21:45	0.0232	11/10/98 15:30	0.0348	4/20/99 14:15	0.0232
11/9/98 22:00	0.0812	11/10/98 16:15	0.0464	4/20/99 14:30	0.0348
11/9/98 22:15	0.0464	11/10/98 16:30	0.0116	4/20/99 14:45	0.0348
11/9/98 22:45	0.0116	11/10/98 17:00	0.0232	4/20/99 15:00	0.0696
11/9/98 23:30	0.0464	11/10/98 17:15	0.0696	4/20/99 15:15	0.058
11/9/98 23:45	0.1276	11/10/98 17:30	0.0812	4/20/99 15:30	0.0348
11/10/98 0:15	0.0116	11/10/98 17:45	0.0812	4/20/99 15:45	0.0348
11/10/98 0:30	0.0696	11/10/98 18:00	0.0464	4/20/99 16:00	0.0232
11/10/98 0:45	0.1972	11/10/98 18:15	0.0116	4/20/99 16:15	0.0116
11/10/98 1:00	0.0232	11/10/98 18:30	0.0116	4/21/99 19:45	0.0232
11/10/98 1:15	0.0348	11/10/98 19:15	0.0116	4/21/99 20:00	0.0928
11/10/98 1:30	0.0348	11/10/98 19:30	0.0232	4/21/99 20:15	0.0696
11/10/98 1:45	0.1276	11/10/98 19:45	0.0116	4/21/99 20:30	0.0116
11/10/98 2:00	0.058	11/10/98 20:00	0.0116	4/21/99 20:45	0.0116
11/10/98 2:15	0.058	11/10/98 20:15	0.0116	4/21/99 21:15	0.0116
11/10/98 2:30	0.0348	11/10/98 20:45	0.0232	4/21/99 21:45	0.0116
11/10/98 2:45	0.0232	11/10/98 21:15	0.0116	4/21/99 22:00	0.0464
11/10/98 3:45	0.0464	11/10/98 21:45	0.0232	4/21/99 22:15	0.0232
11/10/98 4:00	0.0696	11/10/98 22:30	0.0348	4/21/99 22:30	0.0464
11/10/98 4:15	0.1624	11/18/98 17:15	0.0116	4/21/99 22:45	0.0812
11/10/98 4:30	0.058	11/18/98 17:30	0.0116	4/21/99 23:00	0.058
11/10/98 4:45	0.0812	11/18/98 17:45	0.0116	4/21/99 23:15	0.0464
11/10/98 5:00	0.058	11/18/98 18:00	0.0116	4/21/99 23:30	0.0116
11/10/98 5:15	0.0696	11/29/98 13:30	0.0116	4/22/99 0:45	0.0232
11/10/98 5:30	0.0696	11/30/98 6:00	0.0116	4/22/99 1:00	0.058
11/10/98 5:45	0.0464	11/30/98 6:15	0.0116	4/22/99 1:15	0.0928
11/10/98 6:00	0.0348	11/30/98 6:30	0.0348	4/22/99 1:30	0.0812
11/10/98 6:15	0.0116	11/30/98 6:45	0.0232	4/22/99 1:45	0.0696
11/10/98 6:45	0.0116	12/1/98 8:30	0.0116	4/22/99 2:00	0.0812
11/10/98 9:00	0.0348	12/6/98 14:00	0.0116	4/22/99 2:15	0.058

Table C2. Gunflint Trail 15-minute Rain Totals - WY 1999 (in.) (continued)

Time (CST)	Rain (in.)	Time (CST)	Rain (in.)	Time (CST)	Rain (in.)
4/22/99 2:30	0.058	4/22/99 23:45	0.0696	4/27/99 18:15	0.0232
4/22/99 2:45	0.0116	4/23/99 0:00	0.116	4/27/99 18:30	0.0232
4/22/99 3:15	0.0116	4/23/99 0:15	0.116	4/27/99 18:45	0.0232
4/22/99 3:30	0.058	4/23/99 0:30	0.0928	4/27/99 19:00	0.0348
4/22/99 3:45	0.0116	4/23/99 0:45	0.116	4/27/99 19:15	0.0232
4/22/99 4:15	0.0232	4/23/99 1:00	0.1044	4/27/99 19:30	0.0232
4/22/99 4:45	0.0232	4/23/99 1:15	0.116	4/27/99 19:45	0.0348
4/22/99 5:45	0.0116	4/23/99 1:30	0.1392	4/27/99 20:00	0.0116
4/22/99 6:30	0.0232	4/23/99 1:45	0.0812	4/27/99 20:15	0.0232
4/22/99 8:00	0.0116	4/23/99 2:00	0.0928	4/27/99 20:45	0.0116
4/22/99 9:30	0.0928	4/23/99 2:15	0.0812	4/27/99 21:15	0.0116
4/22/99 9:45	0.0928	4/23/99 2:30	0.0464	5/4/99 17:15	0.0116
4/22/99 10:15	0.0116	4/23/99 2:45	0.0348	5/4/99 17:30	0.1044
4/22/99 10:30	0.1276	4/23/99 3:00	0.0232	5/4/99 22:30	0.0116
4/22/99 10:45	0.0464	4/23/99 3:15	0.0232	5/5/99 5:45	0.0116
4/22/99 11:00	0.0116	4/23/99 3:30	0.0116	5/5/99 6:30	0.0116
4/22/99 11:30	0.0232	4/23/99 3:45	0.0232	5/5/99 6:45	0.0116
4/22/99 11:45	0.1044	4/23/99 4:00	0.0348	5/5/99 7:00	0.0232
4/22/99 12:00	0.0464	4/23/99 4:15	0.0116	5/5/99 7:15	0.0116
4/22/99 12:15	0.0696	4/23/99 4:30	0.0348	5/5/99 9:00	0.0116
4/22/99 12:30	0.058	4/23/99 4:45	0.0348	5/6/99 5:15	0.116
4/22/99 12:45	0.0116	4/23/99 5:00	0.0348	5/6/99 5:30	0.0812
4/22/99 13:00	0.0116	4/23/99 5:15	0.0348	5/6/99 5:45	0.058
4/22/99 15:15	0.0116	4/23/99 5:30	0.0232	5/6/99 6:00	0.0232
4/22/99 16:00	0.0116	4/23/99 5:45	0.0232	5/6/99 6:15	0.0232
4/22/99 17:15	0.0116	4/23/99 6:00	0.0116	5/6/99 6:30	0.0116
4/22/99 17:45	0.0232	4/27/99 12:45	0.0232	5/6/99 6:45	0.0116
4/22/99 18:00	0.0116	4/27/99 13:00	0.0348	5/6/99 7:00	0.0928
4/22/99 19:00	0.0116	4/27/99 13:15	0.0116	5/6/99 7:15	0.2204
4/22/99 19:15	0.116	4/27/99 13:30	0.0116	5/6/99 7:30	0.0464
4/22/99 19:30	0.1044	4/27/99 13:45	0.0116	5/6/99 7:45	0.0116
4/22/99 19:45	0.0464	4/27/99 14:00	0.0116	5/6/99 8:00	0.0348
4/22/99 20:00	0.058	4/27/99 14:15	0.0232	5/6/99 9:00	0.0232
4/22/99 20:15	0.0812	4/27/99 14:30	0.0116	5/6/99 9:15	0.0464
4/22/99 20:30	0.1044	4/27/99 15:00	0.0116	5/6/99 9:30	0.058
4/22/99 20:45	0.058	4/27/99 15:15	0.0116	5/6/99 9:45	0.0232
4/22/99 21:15	0.0464	4/27/99 15:30	0.0116	5/6/99 10:00	0.0116
4/22/99 21:30	0.0348	4/27/99 15:45	0.0116	5/6/99 10:15	0.0116
4/22/99 21:45	0.058	4/27/99 16:00	0.0232	5/6/99 10:30	0.0232
4/22/99 22:00	0.116	4/27/99 16:15	0.0232	5/6/99 10:45	0.0232
4/22/99 22:15	0.058	4/27/99 16:30	0.0116	5/6/99 11:15	0.0116
4/22/99 22:30	0.0812	4/27/99 17:00	0.0232	5/6/99 11:45	0.0116
4/22/99 22:45	0.1044	4/27/99 17:15	0.0116	5/6/99 12:00	0.0232
4/22/99 23:00	0.1276	4/27/99 17:30	0.0116	5/6/99 12:15	0.0116
4/22/99 23:15	0.0696	4/27/99 17:45	0.0232	5/6/99 12:30	0.0116
4/22/99 23:30	0.058	4/27/99 18:00	0.0232	5/6/99 15:00	0.0232

Table C2. Gunflint Trail 15-minute Rain Totals - WY 1999 (in.) (continued)

Time (CST)	Rain (in.)	Time (CST)	Rain (in.)	Time (CST)	Rain (in.)
5/6/99 18:45	0.0116	5/17/99 10:15	0.0116	6/1/99 21:00	0.0116
5/7/99 3:15	0.0116	5/17/99 10:30	0.0116	6/1/99 21:15	0.0232
5/7/99 3:45	0.0232	5/17/99 13:15	0.0116	6/2/99 1:15	0.0116
5/7/99 6:45	0.0116	5/17/99 21:30	0.0116	6/2/99 1:30	0.0116
5/7/99 9:00	0.0116	5/18/99 4:15	0.0348	6/2/99 1:45	0.0348
5/7/99 9:15	0.0116	5/18/99 4:30	0.0232	6/2/99 2:00	0.0232
5/7/99 10:00	0.0116	5/18/99 4:45	0.0232	6/2/99 2:15	0.0116
5/7/99 18:45	0.0116	5/18/99 7:45	0.0232	6/2/99 4:45	0.0116
5/11/99 21:45	0.0116	5/18/99 8:00	0.0348	6/2/99 5:00	0.0232
5/11/99 22:00	0.0116	5/18/99 8:15	0.0116	6/2/99 5:15	0.0116
5/11/99 22:30	0.0116	5/18/99 8:30	0.0232	6/2/99 5:30	0.0116
5/11/99 23:00	0.0116	5/18/99 8:45	0.0232	6/2/99 7:00	0.0116
5/11/99 23:15	0.0116	5/21/99 14:00	0.0116	6/4/99 10:30	0.1392
5/11/99 23:45	0.0116	5/21/99 14:15	0.0232	6/4/99 10:45	0.0232
5/12/99 0:00	0.0116	5/21/99 14:30	0.0232	6/4/99 11:00	0.0348
5/12/99 0:30	0.0232	5/21/99 14:45	0.0116	6/4/99 11:15	0.0232
5/12/99 0:45	0.0232	5/21/99 18:15	0.0116	6/4/99 11:30	0.0348
5/12/99 1:00	0.0464	5/21/99 18:30	0.0232	6/6/99 14:15	0.0348
5/12/99 1:15	0.0348	5/21/99 18:45	0.0116	6/6/99 14:30	0.0464
5/12/99 1:30	0.0116	5/21/99 19:00	0.0116	6/6/99 15:00	0.0232
5/12/99 1:45	0.0116	5/21/99 19:15	0.0116	6/6/99 15:15	0.6612
5/12/99 2:15	0.0116	5/21/99 19:30	0.0232	6/6/99 15:30	0.0348
5/12/99 3:00	0.0116	5/21/99 19:45	0.0116	6/6/99 16:00	0.0116
5/13/99 1:15	0.0116	5/21/99 20:00	0.0116	6/6/99 17:45	0.0232
5/15/99 16:30	0.0116	5/21/99 20:15	0.0116	6/6/99 21:45	0.0116
5/15/99 16:45	0.0116	5/22/99 0:15	0.0116	6/6/99 22:00	0.0232
5/15/99 17:15	0.0116	5/23/99 4:00	0.0116	6/6/99 22:15	0.0812
5/15/99 17:30	0.0116	5/23/99 4:45	0.0116	6/6/99 22:30	0.174
5/15/99 18:30	0.0116	5/23/99 5:00	0.0232	6/6/99 22:45	0.0232
5/16/99 16:00	0.1392	5/23/99 5:15	0.0232	6/7/99 1:15	0.0116
5/16/99 16:15	0.2668	5/23/99 5:30	0.0348	6/8/99 18:30	0.0232
5/16/99 16:30	0.0464	5/23/99 5:45	0.0812	6/8/99 18:45	0.0232
5/16/99 22:15	0.5684	5/23/99 6:00	0.0464	6/8/99 19:00	0.0116
5/16/99 22:30	0.4756	5/23/99 6:15	0.0116	6/8/99 19:15	0.0464
5/16/99 22:45	0.174	5/23/99 6:30	0.1276	6/8/99 19:30	0.0232
5/16/99 23:00	0.0348	5/23/99 6:45	0.0116	6/8/99 20:00	0.0116
5/16/99 23:15	0.0232	5/23/99 7:00	0.0116	6/9/99 1:45	0.0116
5/16/99 23:30	0.0464	6/1/99 18:45	0.0464	6/10/99 16:30	0.9396
5/16/99 23:45	0.2668	6/1/99 19:00	0.0232	6/10/99 16:45	0.2784
5/17/99 0:00	0.174	6/1/99 19:15	0.1276	6/10/99 17:00	0.0464
5/17/99 0:15	0.0696	6/1/99 19:30	0.0696	6/10/99 17:15	0.058
5/17/99 0:30	0.058	6/1/99 19:45	0.3132	6/10/99 17:30	0.0116
5/17/99 0:45	0.0348	6/1/99 20:00	0.0928	6/10/99 17:45	0.058
5/17/99 1:15	0.0116	6/1/99 20:15	0.0928	6/10/99 18:00	0.0232
5/17/99 9:45	0.0116	6/1/99 20:30	0.058	6/11/99 7:30	0.0116
5/17/99 10:00	0.0348	6/1/99 20:45	0.0348	6/11/99 20:45	0.1392

Table C2. Gunflint Trail 15-minute Rain Totals - WY 1999 (in.) (continued)

Time (CST)	Rain (in.)
6/11/99 21:00	0.0232
6/11/99 22:00	0.0232
6/11/99 22:15	0.0464
6/11/99 22:30	0.0232
6/12/99 2:00	0.0116
6/13/99 0:15	0.0116
6/13/99 0:45	0.0464
6/13/99 1:00	0.058
6/13/99 1:15	0.0696
6/13/99 1:30	0.0232
6/13/99 1:45	0.0116
6/13/99 2:15	0.0116
6/13/99 3:00	0.0116
6/13/99 3:15	0.0116
6/13/99 3:30	0.0116
6/13/99 3:45	0.0116
6/13/99 4:00	0.0232
6/13/99 4:15	0.0464
6/13/99 4:30	0.0348
6/13/99 4:45	0.0812
6/13/99 5:00	0.058
6/13/99 5:15	0.058
6/13/99 5:30	0.0696
6/13/99 5:45	0.058
6/13/99 6:00	0.0812
6/13/99 6:15	0.0928
6/13/99 6:30	0.0464
6/13/99 6:45	0.058
6/13/99 7:00	0.0464
6/13/99 7:15	0.0696
6/13/99 7:30	0.0696
6/13/99 7:45	0.058
6/13/99 8:00	0.0464
6/13/99 8:15	0.0464
6/13/99 8:30	0.0116
6/13/99 8:45	0.0232
6/13/99 9:15	0.0116
6/13/99 9:45	0.0116
6/13/99 23:45	0.0116
6/22/99 16:00	0.174
6/22/99 16:15	0.0696
6/22/99 18:15	0.464
6/22/99 18:30	0.058
6/22/99 18:45	0.0232
6/22/99 19:00	0.0232
6/22/99 19:15	0.0232
6/22/99 19:30	0.058
6/22/99 19:45	0.0348
6/22/99 20:00	0.0116
6/22/99 20:30	0.0116
6/23/99 10:15	0.0116
6/23/99 10:30	0.0116
6/23/99 10:45	0.0116
6/23/99 11:00	0.0116
6/23/99 11:45	0.0116
6/23/99 12:00	0.0232
6/23/99 12:15	0.0116
6/23/99 12:30	0.0116
6/23/99 15:00	0.0116
6/23/99 15:15	0.1392
6/28/99 13:30	0.0116
6/28/99 16:15	0.1392
6/30/99 22:30	0.0232
6/30/99 22:45	0.0696
6/30/99 23:00	0.0464
6/30/99 23:15	0.0348
6/30/99 23:30	0.1624
6/30/99 23:45	0.0696

Appendix D. CR10 Data Logger Program

Appendix D - CR10 Datalogger Program

```
Program:Gunflint Trail Weir and Rain Gage

*      1        Table 1 Programs
  01: 60        Sec. Execution Interval

01:  P3         Pulse
  01: 2         Reps
  02: 1         Pulse Input Chan
  03: 0         High frequency
  04: 7         Loc : Water level down
  05: 1         Mult
  06: 0         Offset

02:  P10        Battery Voltage
  01: 6         Loc : Battery voltage

03:  P35        Z=X-Y
  01: 8         X Loc Water level up
  02: 7         Y Loc Water level down
  03: 11        Z Loc : Change in water level

04:  P89        If X<=>F
  01: 11        X Loc
  02: 2         <>
  03: 0         F
  04: 30        Then Do

05:  P86        Do
  01: 10        Set high Flag 0 (output)

06:  P77        Real Time
  01: 1220      Year,Day,Hour-Minute

07:  P70        Sample
  01: 2         Reps
  02: 11        Loc

08:  P94        Else

09:  P89        If X<=>F
  01: 12        X Loc
  02: 2         <>
  03: 0         F
  04: 30        Then Do

10:  P86        Do
  01: 10        Set high Flag 0 (output)

11:  P77        Real Time
  01: 1220      Year,Day,Hour-Minute

12:  P70        Sample
  01: 2         Reps
  02: 11        Loc
```

```
13:  P95       End

14:  P95       End

15:  P92       If time is
  01: 0        minutes into a
  02: 1440     minute interval
  03: 10       Set high Flag 0 (output)

16:  P70       Sample
  01: 1        Reps
  02: 6        Loc

17:  P30       Z=F
  01: 0        F
  02: 0        Exponent of 10
  03: 12       Z Loc : Rainfall count

18:  P33       Z=X+Y
  01: 13       X Loc Alt rainfall
  02: 12       Y Loc
  03: 12       Z Loc :

19:  P30       Z=F
  01: 0        F
  02: 0        Exponent of 10
  03: 13       Z Loc :

20:  P         End Table 1


*      2       Table 2 Programs
  01: 0.0000   Sec. Execution Interval

01:  P         End Table 2


*      3       Table 3 Subroutines

01:  P85       Beginning of Subroutine
  01: 98       Subroutine Number

02:  P91       If Flag/Port
  01: 10       Do if flag 0 (output) is high
  02: 30       Then Do

03:  P34       Z=X+F
  01: 13       X Loc
  02: 1        F
  03: 13       Z Loc : Alt rainfall

04:  P94       Else

05:  P34       Z=X+F
  01: 12       X Loc
  02: 1        F
  03: 12       Z Loc : Rainfall count

06:  P95       End
```

```
07:  P22       Excitation with Delay
  01: 1        EX Chan
  02: 0        Delay w/EX (units=.01sec)
  03: 20       Delay after EX (units=.01sec)
  04: 0        mV Excitation

08:  P95       End

09:  P         End Table 3


*      A       Mode 10 Memory Allocation
  01: 28       Input Locations
  02: 64       Intermediate Locations
  03: 0.0000   Final Storage Area 2


*      C       Mode 12 Security
  01: 0000     LOCK 1
  02: 0000     LOCK 2
  03: 0000     LOCK 3
```

Input Location Assignments (with comments):

Key:
T=Table Number
E=Entry Number
L=Location Number

```
T:  E:  L:
1:  2:  6:  Loc : Battery voltage
1:  1:  7:  Loc : Water level down
1:  3: 11:  Z Loc : Change in water level
1: 17: 12:  Z Loc : Rainfall count
1: 18: 12:  Z Loc :
3:  5: 12:  Z Loc : Rainfall count
1: 19: 13:  Z Loc :
3:  3: 13:  Z Loc : Alt rainfall
```

CR10 Wiring Connections

CR10 Terminal	Wire Color	Peripheral Terminal
12V	Red	Battery +12
G	Black	Battery ground
5V	Red	Pulse recorder 1
G	Black	Pulse recorder 2
P1	Green	Pulse recorder 3*
P2	White	Pulse recorder 4*
5V	Red	Rain gage red port
C8**	Black	Rain gage black port
G	Black	Grounding rod
Charge	Red	Solar panel
Charge	Black	Solar panel

* Resistors (22 kΩ) connect Pulse recorder port 3 with Pulse recorder port 1 and Pulse recorder port 4 with Pulse recorder port 1.

** Resistor (100 kΩ) connects C8 and G ports