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ACTIVE LAYER HYDROLOGY FOR IMNAVAIT CREEK, TOOLIK, ALASKA

from

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INTRODUCTION

In the annual hydrologic cycle, snowmelt is the most significant event at Imnavait Creek located near Toolik Lake, Alaska. Precipitation that has accumulated for more than 6 months on the surface melts in a relatively short period of 7 to 10 days once sustained melting occurs. Because rainfall precipitation is light and the intensity is also low, significant runoff events are few. Convective storms covering relatively small areas on the North Slope of Alaska can produce significant small-scale events in a small watershed scale, but these events are rapidly attenuated outside the basin.

During the ablation period, runoff dominates the hydrologic cycle. Some meltwater goes to rewetting the organic soils in the active layer. The remainder is lost primarily because of evaporation, since transpiration is not a very active process at this time.

Following the snowmelt period, evapotranspiration becomes the dominate process, with base flow contributing the other watershed losses. It is important to note that the water initally lost by evapotranspiration entered the organic layer during melt. This water from the snowpack ensures that each year the various plant communities will have sufficient water to start a new summer of growth.

Light intensity rainstorms during the summer seldom generate any significant runoff. Most of the water goes for satisfying soil moisture deficits in the active layer due to evapotranspiration. In fact, the streamflow for this zero order stream can go to below measurable quantities during long periods of drought. This has happened each of the past two summers at Imnavait Creek. Intense convective storms or prolonged rainfall from frontal systems can satisfy the soil moisture deficit and produce runoff. Frontal storms increases streamflow in all regional streams, while convective storms are locally important.

The classical approach of using a water balance to develop an understanding of the hydrologic cycle of this area has certain limitations. The problem is that the active layer continues to thaw throughout the summer, so one must cope with an expanding subsurface flow system. The subsurface system expands in response to energy input and the resultant phase change of the ice in the active layer. So, one must understand both the thermal regime of the subsurface system and the response of this system to energy inputs.

To understand the hydrology of the active layer in an arctic watershed underlain by continuous permafrost, we designed a number of simple studies. The studies were relatively simple for a number of reasons: the site was quite remote without any ac power source, the climate was quite hostile, equipment was not available that would work continuously under these environmental conditions, and frequently could not visit the site for periods up to two months.

Although the field experiments are relatively simple and have been carried out at many other watershed sites, to integrate all of the results of these experiments into the total picture of the hydrology of this area is quite complicated. The development of mathematical models that incorporate both heat and mass transport to define the physical processes that take place are quite complex.

Conceptually, the system we are working with is quite easy to picture. However, it is the constitution and the processes themselves that make this system difficult to understand. The system has the advantage that we can easily instrument the subsurface system because the active layer is so shallow.

The following sections of this paper will present preliminary data from the first two field seasons. This will be followed by some preliminary analysis that has been performed to date.

DATA COLLECTION

Data collection in the Imnavait watershed began in August 1984. Since then we have continuously monitored the hydrologic, the meteorologic, and the soil's physical conditions. Information for a complete hydrologic and energy balance of the basin was collected through implementation of four snowmelt runoff plots and measurements of essential microclimate parameters. Soil moisture and temperature profiles were measured adjacent to each snowmelt runoff plot, and heat flux is collected adjacent to one of these plots. Meteorological parameters were measured locally to compliment the total data set. The water content of the snowpack prior to snowmelt was measured throughout the watershed and measured daily adjacent to each plot during snowmelt. The stream draining the basin was measured regularly during the spring melt event to provide information on watershed runoff rates and the volume of snowmelt.

Snowpack Water Content and Temperature

To accurately partition the components of the water balance into runoff, evaporation, storage and infiltration, we began with an accurate measurement of the total snowpack water content. To monitor the snowpack accumulation, we periodically measured the water equivalent of the snowpack adjacent to each runoff plot. Prior to spring melt, we intensively measured the snowpack throughout the watershed to insure an accurate estimate of the initial condition for snowmelt. We measured snowpack depth and water content using an Adirondack snow sampling tube manufactured by Weathertronics. Although the accuracy of the snow sampler was within 2.5 mm, the variability of the snowpack greatly exceeds this. On each visit to the site, we checked the Wyoming snow gage recorder to ascertain its continued operation. Daily during the spring melt, we took snow surveys adjacent to each plot to monitor the progress of snowpack ablation. We collected this information in conjunction with Dr. Carl Benson.

Snowpack temperature was measured at the soil/snow interface, and at 10 cm, 20 cm, and 30 cm adjacent to each runoff plot. Temperature profiles were measured hourly and averaged daily by a Campbell Scientific 21X data logger. The thermistors were piezoelectric crystal sensors made by Yellow Springs Instrument. The accuracy of these thermistors was +/- 0.2° C.

Rainfall Volumes and Intensity

We measured the unfrozen precipitation using Aerojet General tipping bucket rain gages. Only one gage (unshielded) was in operation in 1985, and it failed during July. A second gage was installed in the spring of 1986 to prevent another loss of data, and wind shields were also installed on both gages then. The rain gages were accurate to 0.25 mm, but they probably reported low before the wind screens were installed.

Soil Temperature, Heat Flux, and Moisture Content

In addition to the snowpack temperature, we measured the soil profile temperature from the surface to 40 cm depth, in 5 cm increments. These thermistors measured the temperature every hour and averaged them every day almost continuously since March 1985. Two Weathertronics soil heat flux plates were installed at the organic/mineral interface and in the mineral soil next to the 10 cm and 20 cm thermistors bordering plot 3. Weathertronics report an accuracy of +/- 5% in their heat flux plates. Heat flux has been recorded hourly since 5 June 1986. Prior to that time, heat flux was averaged daily. The heat flux plate at the organic/mineral interface failed in October 1986.

The unfrozen soil water content has been measured using a Tektronix time domain reflectometer (TDR). We have used the TDR extensively for this purpose and have found a consistent accuracy of +/- 2%. The soil profile near each plot was instrumented with 30 cm long horizontal TDR probes in the organic and mineral soils at depths of 5 cm, 10 cm, 15 cm, 20 cm, 25 cm, 30 cm, and 40 cm. The soil thermistors and heat flux plates were placed in close proximity to compliment soil moisture data. Soil moisture has been measured periodically throughout the winter and frequently during the spring melt and summer. Soil samples were collected to determine total moisture content in the active layer profile. The extreme spatial variability in total moisture due to ice lens formation has limited the usefulness of these data.

Large samples of the soil profile were collected just outside the watershed from a hillslope with similar aspect, grade, and morphologic characteristics. These samples were used in the laboratory to determine some of the physical properties of the soil. Thusfar, we have measured the hydraulic conductivity (Table 1), the thermal conductivity (Figure 28), the bulk density (Table 1), and the soil moisture characteristic curve (Figures 24-27) for individual layers of the soil profile. The values presented in Table 1 represent the average of several samples. Although the very nature of the active layer is one of great variability, we feel these numbers are reasonable estimates of the mean.

Meteorological Measurements and Instrumentation

Meteorological parameters included air temperature, relative humidity, precipitation, wind velocity, wind run, wind direction, and the radiation components. Measurement of the daily energy balance was necessary for characterization of the hydrologic processes. Individual components of radiation were measured from March through September in 1985 and 1986. Measurements included incoming shortwave, reflected shortwave, net radiation absorbed, total incoming radiation, and total emitted radiation. The radiation instruments were installed in March and removed in September in both 1985 and 1986. The frequent occurrence of hoarfrost on the radiometer surfaces in the winter reduces the value of measurements then.

Incoming and reflected solar radiation was measured using the Weathertronics albedometer. The spectral range of this sensor was 0.3 to 3 microns, which excludes longwave terrestrial radiation. The accuracy of each sensor was reported as +/- 1%. The cosine response was less than 1% when the sun angle is within 0 to 70 degrees of perpendicular of the sensor plane. Incoming shortwave radiation (0.3 to 3.0 microns) was also measured using an Eppley spectral pyranometer. The cosine response of this instrument was +/- 3% between 0 and 70 degrees. The accuracy of this instrument was +/- 1% in the range of values encountered. The net absorbed radiation (0.3 to 60 microns) was measured using a Swissteco net radiometer. This sensor measured the total radiation absorbed. We also measured net radiation with a second sensor, a Weathertronics pyrradiometer. This sensor outputs the total incoming and total emitted radiation, the difference being the net absorbed radiation. The accuracy of the pyrradiometer was within 2%.

Air temperature and relative humidity have been measured continuously since March 1985, with one significant loss of data from 29 May 1985 to 9 November 1985. At that time, two new air temperature/relative humidity sensors were added to prevent another such loss. In October 1986, we lowered one of the sensors from two to one meter height to also measure the temperature/R.H. gradient. We initially used the Weathertronics humidity/temperature probe housed in a self aspirating radiation shield. The accuracy of the temperature sensor was +/- 0.10° C in the range measured. The relative humidity probe was accurate to +/- 2% between 0 and 80%, and +/- 3% between 80 and 100% relative humidity. We presently use the Campbell Scientific model 207 temperature and relative humidity probe. Campbell Scientific report worst-case accuracy of +/- 0.4° C between -33° C and $+48^{\circ}$ C for the temperature sensor, and 3% error between 12 and 100% relative humidity. These probes were also housed in a self aspirating radiation shield.

Wind direction and wind run have been measured continuously since April 1985 with only a few minor losses of data. In the fall of 1986, we changed the method of output of wind data from recording only hourly wind run and average direction to recording mean wind speed, mean windvector magnitude, mean windvector direction, and standard deviation of direction. Wind velocity and wind run was measured using a Weathertronics anemometer. The threshold of wind measurement was 0.22 m/s. The accuracy was +/- 0.07 m/s. Wind direction was measured using a Campbell Scientific wind direction sensor. Direction can be measured within 5 degrees.

Wind run and precipitation are totalized continuously. All other meteorological parameters are measured every minute. Those measurements are recorded and totalized or averaged hourly by the Campbell Scientific 21X dataloggers. Except for air temperature and relative humidity, all meteorological instruments are positioned 1.5 m above the snow or soil surface, and are lowered or raised as the snow depth changes.

Surficial Plot and Basin Runoff

The surficial snowmelt runoff was continuously measured during the thaw events through the use of four runoff plots which were installed in August 1984. The plots were placed along a diagonal to the slope of the watershed in fell-field and tussock tundra zones to enable detection of position and slope effects on runoff. Each plot, measuring 89 square meters, was bounded with heavy (40 mil) plastic to isolate it from the surrounding area. A collection system was constructed at the lower end of each plot and the water flowed via gravity feed through a series of gutters to a holding tank. The rate and volume of runoff were measured using Leupold and Stevens F type water level recorders. The water levels in the tanks were continuously monitored and periodically emptied.

The plots were not monitored during the summer of 1985. An attempt was made in 1986 to determine the runoff from the summer precipitation events, but it was difficult to empty the tanks as frequently as necessary. A partial analysis of the available data is included.

Streamflow from Imnavait Creek was measured frequently during the spring melt events. In the spring of 1985, we used a pygmy current meter to develop a stage discharge relationship. In the spring of 1986 we used a Montedoro-Whitney PVM-2A electromagnetic current meter to again determine the stage discharge relationship. Cooperation with Dr. Kaye Everett has ensured a complete streamflow data set.

Runoff Plot and Stream Water Chemistry

Our runoff plots give us the unique opportunity to evaluate the effects of slope position on many hydrologic and biologic processes. Since they are isolated from the runoff of the above hillslope, these samples will provide information on the magnitude and origin of transported nutrients during the runoff event.

Samples from the runoff of each plot were collected at peak flow daily during snowmelt in 1985 and 1986 and during the major summer runoff events in 1986. Water samples were concurrently collected from the stream for comparison. In 1985, these samples were analyzed for magnesium, calcium, potassium and aluminum by Dr. Kaye Everett. In 1986, the water samples were analyzed for the same 4 elements and silicon, ammonium, nitrate, copper, zinc, iron, sodium and manganese by Dr. Giles Marion.

Energy and Moisture Losses Due to Evaporation

The proportion of the water and energy balance due to evaporation is perhaps the most difficult component to measure. We determined reasonable estimates of evaporation from the snowpack using a water balance approach from each plot and the entire basin. To determine the amount of summer evaporation, an evaporation pan was monitored in 1986. Although we now have a very good estimate of potential evaporation, we must still determine a pan coefficient before we can confidently estimate true evaporation. The amount of evaporation from the soil surface will be between the amount of precipitation and pan evaporation (Figure 10).

PRELIMINARY ANALYSIS

Snowmelt Runoff Analysis

The spring melt on the North Slope represents a very dynamic and energetic process. Snow, which has been accumulating since the previous September, melts in a very brief yet intense runoff event. To characterize these hydrologic processes, we developed a field study to measure the components of the water balance, the components of the energy balance, and their interrelations.

The average total accumulated snowpack in 1985 was 10.2 cm of water equivalent. In 1986, the total was 10.9 cm. The relative closeness of the snowpack water equivalent in the two seasons allows us to evaluate differences in the hydrologic processes of the spring melt. Even though the water equivalents of the two years were nearly equal, the spring melt events and subsequent water balances were quite different.

The winter of 1985 had several significant wind events, so much of the snow was redistributed in drifts, especially in the valley bottom near the stream. The winter of 1986 had no such wind events, and the snowpack was more uniformly distributed across the watershed. This was particularly evident from examination of the maps of snow distribution (Liston, 1986).

In 1985, there was an early warming trend, and a significant amount of the snow melted in early May (Figure 1). The warm conditions did not continue long enough to produce measurable runoff from the snowmelt. Snowmelt did not begin again for two more weeks. On May 19, when sustained melt began, ablation and the resulting runoff were complete within 12 days. In 1986, the spring melt began on May 28, and the total ablation and snowmelt runoff were complete within 14 days (Figure 2). Even though the solar insolation was very near the yearly maximum, sustained snowmelt did not begin in either year until a convective air mass from the south brought warmer air temperatures.

The snowmelt runoff was measured each spring using our four runoff plots and by frequently measuring the streamflow. Although the sun remained above the horizon for 24 hours each day at that time, there was still a strong diurnal effect in the runoff from the plots (Figures 3 and 4). The diurnal effect was still present in the stream hydrograph, but it was tempered somewhat by the basin (Figure 5 and 6). In both seasons, the snowpack varied on the plots from highest to lowest as plot 1, plot 2, plot 4, and plot 3. With the thinnest snowpack, plot 3 ripened first and began draining first. Plot 1, with the greatest snowpack, took the longest for the snowpack to reach isothermal condition and began draining last. As one would expect, there was a direct relationship between the initial snowpack and the amount of runoff. As Figure 9 shows, this was a nonlinear relationship because the amount of evaporation was also a function of the snowpack. The X intercept of this graph implies that no runoff will occur if the snowpack has less than about 4.5 cm of water equivalent.

Basin and Plot Water Balances

The snowmelt water balance can be described as the sum of the runoff, the evaporation, and the soil storage being equal to the premelt snowpack water content. We were able to complete the water balance by determining the snowpack water equivalent, the volume and rates of snowmelt runoff, and the amount of water in soil storage for 4 individual runoff plots and for the entire watershed.

The organic mat is quite desiccated in the spring. Through a laboratory analysis, the amount of water required to re-wet the organic soil was measured. This amount, 1.5 cm depth of water, was assumed to be the same for all plots. The water content of the mineral soil was very high in the preceding fall of both years. Although there probably was depletion of moisture from the mineral soil over the winter, the total moisture content near the surface was still quite high in the spring. The infiltration rate of water into frozen soils with a high moisture content is very low (Kane and Stein, 1983). Therefore, we assume the total amount of water going into soil storage is 1.5 cm.

Using our measurement of runoff and assuming the soil storage is a constant, we were able to calculate the remaining component of the water balance, the evaporation. The amount of the water balance attributed to evaporation from each plot depends upon the initial water content of the plot. Plots with thinner snowpack lost a greater proportion of that water to evaporation. A summary of the apportionment of the water balance is displayed in Figures 7 and 8. In 1986, the water balance of the plot average compared quite well with that of the basin average. The water balance of 1985 did not correlate nearly as well. As mentioned previously, the snow was redistributed extensively in 1985, with much more being deposited in the valley bottom near the stream. This snow was immediately available for runoff, whereas the snowpack of 1986, being more uniformly distributed across the watershed, lost more water through evaporation.

Soil Temperature and Heat Flux

Soil temperatures were measured adjacent to each runoff plot and soil heat flux was measured adjacent to plot 3. Winter air temperatures frequently dropped below -40^{o} C, but the soil, being insulated by the snow and warmed by heat transfer from below, remained above -15^{o} C (Figure 16 and 17). In the summer, the air temperature actually rose briefly to 30^{o} C, but the soil surface remained below 15^{o} C.

Winter and soil freezing came in September. The active layer cooled to the 0° C isotherm within a few days of freezing air temperatures. The mineral soil remained isothermal at 0° C for several weeks, while the wet soil progressed through the phase change. As the soil warmed in the spring, the entire active layer did not warm to 0° C and remain there as the soil ice melted but instead warmed from the surface down. Each layer warmed through 0° C and completed the phase change before the underlying layer warmed to 0° C. This can be explained in terms of heat transfer theory. In the fall, water can still migrate carrying heat with it. Thus the cooling process is both a conductive and a convective process. In the spring, the ice-rich soil prevents infiltration of water, so the warming process is only conductive.

Soil heat flux was measured at the organic/mineral interface and in the mineral soil (Figure 18-23). The diurnal variation caused by wide fluctuations of air temperature during the summer was evident at both levels. The instantaneous magnitude and daily amplitude of the heat flux plate at the base of the organic layer were always greater than in the mineral soil. The mineral soil has less heat flux because the organic soil has a lower thermal conductivity than the mineral soil. Thus the organic layer functions as a layer of insulation for the underlying soil. The organic soil experiences wider daily fluctuations because it has a lower specific heat than the mineral soil. Even a thin snowpack will greatly dampen the diurnal variation as can be seen in Figures 18 and 19. Snow, falling in late August, greatly reduced the soil heat flux and as the snowpack deepened, the diurnal variation was completely suppressed.

The heat flux was averaged hourly and the soil temperature was averaged daily. Therefore, we could not calculate the thermal conductivity of the soil throughout the year, but only when soil temperatures were stable. The active layer underwent a brief period of fairly steady heat flow in early June 1986. Using Fourier's Law, we determined the thermal conductivity of the mineral soil to be 0.75 W/m °C, with a mean soil temperature of -2° C and saturated conditions. For the same time period, the thermal conductivity of the organic soil was 0.54 W/m °C, with a mean soil temperature of -1° C and approximately 10% (vol) moisture content. These values compare well with curves developed in the laboratory (Figure 28).

Analysis of Summer Precipation Runoff

The amount of runoff from summer precipitation was not measured in 1985. The plots were monitored more closely in the summer of 1986, but a significant portion of the data were lost during the large rainfall events since the runoff collection tanks could not always be emptied as necessary. An analysis of the available data shows that drainage from each plot completely stops after the snowmelt runoff (Figure 11). The ice-rich active layer continues to melt throughout the summer, but the excess water released during this phase change is lost primarily by evapotranspiration. After extended periods of drought, the active layer can absorb a significant amount of precipitation before runoff will occur. In these periods of drought, the flow in Imnavait Creek commonly drops below 0.01 m^3/s (Figure 13).

Stream and Plot Water Chemistry

Water samples were collected daily at peak flow from each plot and the stream during the 1985 and 1986 spring melt events. Analysis of all the samples for 1986 is not yet complete. The concentrations of the samples analyzed for plot 1 are shown in Figures 29-31. The analysis for samples collected in 1986 from all plots and the stream is summarized in Table 2. Results of the chemical analysis from the 1985 event are shown in Table 3. Typically for most chemical species measured during the spring melt, the highest concentration occurred on the first day of runoff, with successive samples decreasing in concentration. Samples collected during runoff from summer rainfall events usually contained higher concentrations of these species after a period of drought.

Hydrologic Role of the Active Layer

Most of the yearly precipitation falls in July and August (Figure 12), ensuring a high soil moisture content in the fall. Although the Arctic Slope receives relatively little yearly precipitation, the active layer remains moist to saturated. Surface and subsurface drainage from the active layer primarily occurs during the spring melt event and following major rain events. The ice-rich permafrost precludes vertical drainage. The hydraulic conductivity of the organic mat is quite high averaging 0.02 cm/s while the mineral soil can be 0.001 cm/s (Table 1). Thus most horizontal drainage will occur above the mineral soil in the organic mat.

We can see from the TDR data (Figures 14 and 15) that the moisture content in the organic soil spiked at the beginning of snowmelt. However, the moisture content just 10 cm lower did not greatly increase until 2 weeks later. It is readily apparent that the snowmelt runoff flows primarily through the organic mat, and any flow into the mineral soil can be neglected.

COMMENTS ON FUTURE WORK

In the next year, we will refine our observations on the hydrologic processes in the Imnavait watershed. We will continue our research project of partitioning the water balance into its components. We hope to improve our estimates of the amount of evaporation by measuring the evaporative loss of moisture from the snowpack. We have designed another simple study using small styrofoam boxes in which we will place blocks of snow. We will periodically weigh these boxes to determine the mass loss or gain prior to and during snowmelt. This will provide information on the energy losses and gains due to condensation, sublimation, and evaporation. It will also enable us to verify the results of our water balance.

We will improve our measurement of total soil moisture through the use of a nuclear moisture/density gage. This instrument has a reported resolution of 1-3 inches. Measurement of the total moisture content and density changes over time complimented with measurements of the surface energy balance and the soil unfrozen moisture content will allow calculation of the coupled heat flow and perhaps more general modeling of this phenomenon.

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Table 2. Chemical concentrations of water samples collected from runoff plots and Imnavait Creek in 1985.

SNOWMELT RUNOFF OVERLAND/THROUGHFLOW
PPM

LOCATION	DATE	Mg	Ca	K	Al	pH
PLOT 1	5/23/85	0.33	0.65	0.58		5.6
	24	0.10	0.20	0.40		5.6
	25	0.15	0.50	0.40		5.2
	26	0.20	0.50	0.60		6.0
	27	0.20	0.50	0.50		5.2
	28	0.20	0.45	0.50	0.00	5.3
	29	0.18	0.60	0.40		5.3
	30	0.13	0.40	0.30		5.4
PLOT 2	5/23/85	0.25	0.90	0.58		5.6
	24	0.00	0.00	0.10*		5.5
	25	0.23	0.75	0.65		5.5
	26	0.18	0.70	0.53		5.9
	27	0.25	0.80	0.70		5.5
	28	0.18	0.70	0.55		5.1
	29	0.25	0.65	0.50		5.6
PLOT 3	5/23/85	0.20	0.55	0.50		5.4
	24	0.10	0.00	0.20	0.00	5.6
	25	0.23	0.55	0.50		5.4
PLOT 4	5/23/85	0.35	0.65	0.55	0.00	5.3
	24	0.00	0.00	0.20*		5.6
	25	0.20	0.70	0.50		5.2
	26	0.20	0.50	0.40		5.8
IMNAVAIT CREEK						
	5/24/85	0.35	0.85	0.75	0.00	5.3
	25	0.15	0.55	0.30	0.00	5.4
	26	0.15	0.55	0.35		5.5
	27	0.15	0.35	0.25		5.6
	28	0.28	0.75	0.40		5.8
	29	0.15	0.55	0.25	0.00	5.8
	30	0.13	0.60	0.30		5.6
	31	0.83	1.80	0.40		5.8
	6/01/85	0.20	0.65	0.30	0.00	5.7
	2	0.23	0.60	0.25	0.00	5.7
	3	0.10	0.70	0.20		5.8
	4	0.23	0.80	0.25		5.7
	5	0.10	0.40	0.00		5.7
	6	0.20	0.70	0.00		5.8
	7	0.25	0.60	0.20		5.8
	8	0.25	0.70	0.10	0.00	5.8

*Rerun with same results

Table 3. Chemical concentrations of water samples collected from runoff plots and Imnavait Creek in 1986.

SNOWMELT RUNOFF OVERLAND/THROUGHFLOW
PPM

LOCATION	DATE	Ca	Mg	Na	K	Si	NH_4-N	NO_3-N
Plot 1	6/02/86	1.16	.34	.46	1.48	.40	<.001	.008
	03	.61	.24	.49	1.20	.25		
	04	.34	.15	.38	.83	.15	<.001	.019
	05	.20	.08	.32	.58	.08	<.001	.019
	7/31/86	1.20	.21	.75	.57	2.9		
	8/01/86	1.0	.16	.65	4.7	3.1		
	02	1.2	.22	.68	.11			
	06	1.1	.19	.45	.053	2.8		
Plot 2	6/02/86	1.12	.40	.45	1.51	.31	<.001	.004
	03	.78	.23	.33	1.20	.12	<.001	.011
	04	.57	.14	.23	.89	.05	<.001	.028
	05	.77	.20	.24	.92	.08	<.001	.022
	7/31/86	1.2	.21	1.4	2.8	2.9		
	8/01/86	1.2	.20	.69	1.4	3.3		
	02					3.4		
	06	1.1	.20	.71	.16	3.0		
Plot 3	6/02/86	.99	.28	.30	1.38	.18	<.001	.001
	03	.54	.18	.39	1.01	.11	<.001	.007
	04	.79	.25	.59	1.35	.22	<.001	.036
	05	.83	.24	.60	1.32	.20	<.001	.031
	7/31/86	.83	.18	.87	15.2	2.9		
	8/01/86	.73	.15	.52	1.8	3.1		
	06	.80	.16	.46	.16	3.1		
Plot 4	6/02/86	.77	.38	.47	1.26	.36	<.001	.027
	03	.44	.22	.28	.98	.16	<.001	.005
	04	.22	.10	.29	.73	.07		
	05	.30	.14	.42	1.01	.14	<.001	.050
	7/31/86	.90	.27	.68	18.9	1.9		
	8/01/86					3.0		
	02	.82	.22	.32	.00	3.2		
	06	.82	.21	.27	.10	2.8		
	08	.78	.18	.27	.15	3.1		
STREAM								
	6/03/86	1.25	.47	.32	1.75	.40	<.001	.146
	04	.98	.42	.42	1.48	.34	<.001	.029
	05	.48	.21	.19	.89	.15	<.001	.020

Table 3, continued.

LOCATION	DATE	Cu	Zn	AL	Fe	Mn	P
Plot 1	6/02/86						
	03						
	04						
	05						
	7/31/86	.0015	.291	1.49	0.41	0.02	.0000
	8/01/86	.0030	.748	1.52	0.45	0.030	.0002
	02	.0028	.676	.90	.27	.016	
	06	.0029	.182	1.52	0.38	0.040	.0117
Plot 2	6/02/86						
	03						
	04						
	05						
	7/31/86	.0000	.215	.81	0.28	.007	.0035
	8/01/86	.0016	.390	.92	0.26	0.012	.0031
	02						
	06	.0026	.208	.83	0.30	.018	.0024
Plot 3	6/02/86						
	03						
	04						
	05						
	7/31/86	.0020	.277	1.69	0.39	0.020	.0083
	8/01/86	.0026	.664	1.39	0.40	0.016	.0050
	06	.0029	.242	1.41	0.34	0.011	.0009
Plot 4	6/02/86						
	03						
	04						
	05						
	7/31/86	.0016	.202	1.17	0.58	0.039	.0072
	8/01/86						.0005
	02	.0027	.646	1.21	.68	0.032	.0031
	06	.0033	.138	1.11	0.59	0.037	.0005
	08	.0022	.465	1.03	0.63	0.035	.0057
STREAM							
	6/03/86						
	04						
	05						

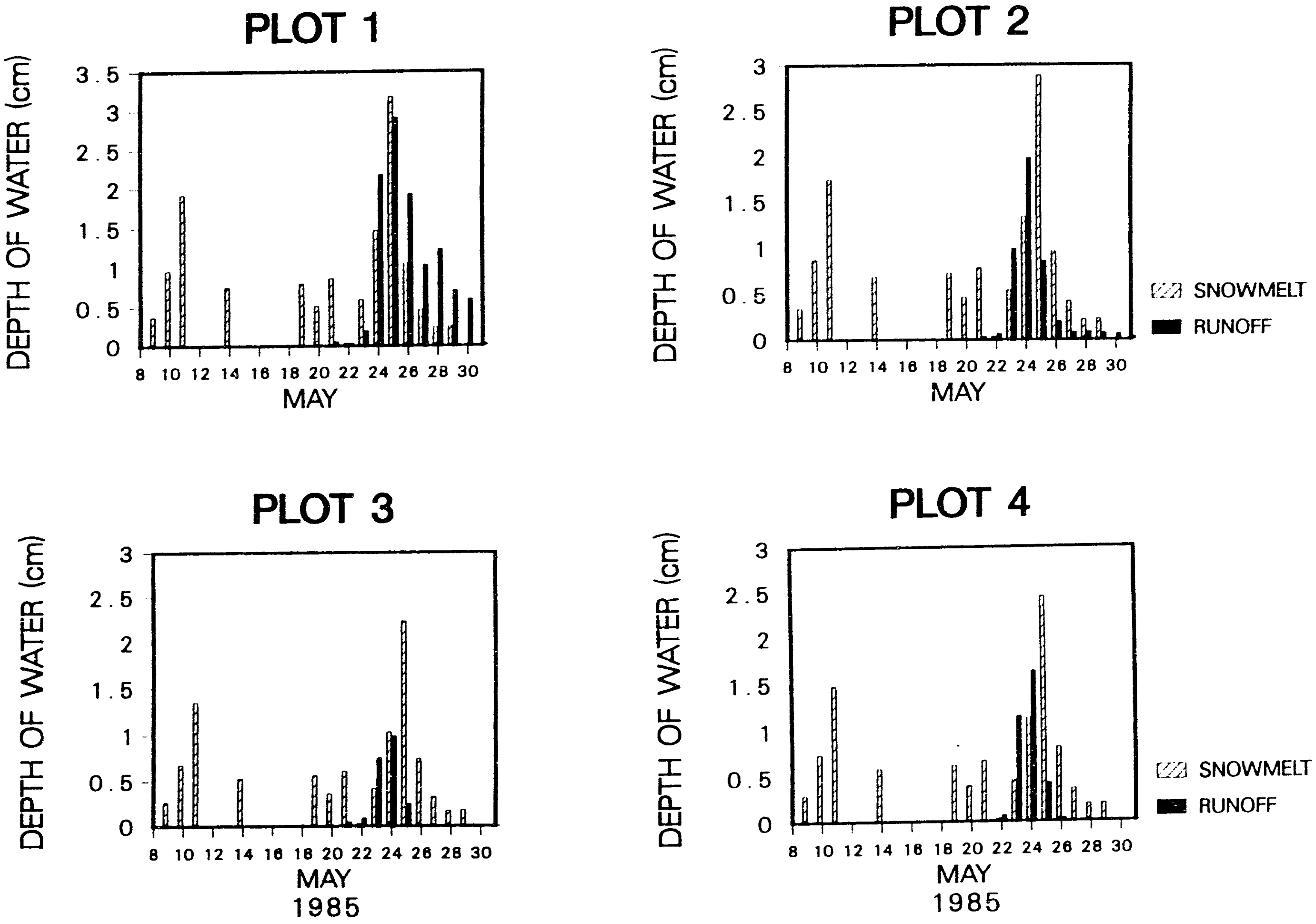


Figure 1. Comparison of total daily plot runoff and average daily snowmelt normalized for plot initial snowpack water content for 1985.

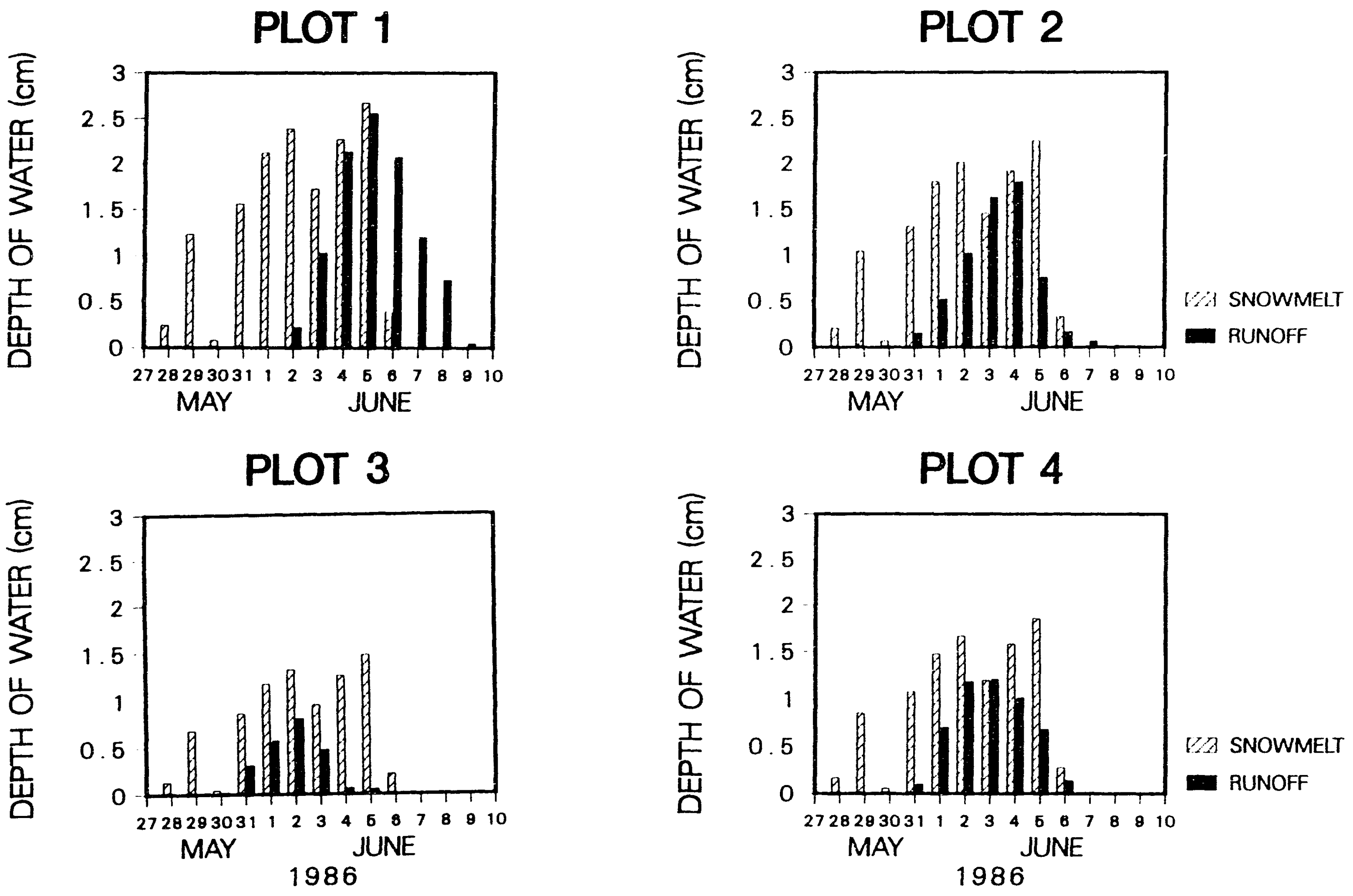


Figure 2. Comparison of total daily plot runoff and average daily snowmelt normalized for plot initial snowpack water content for 1986.

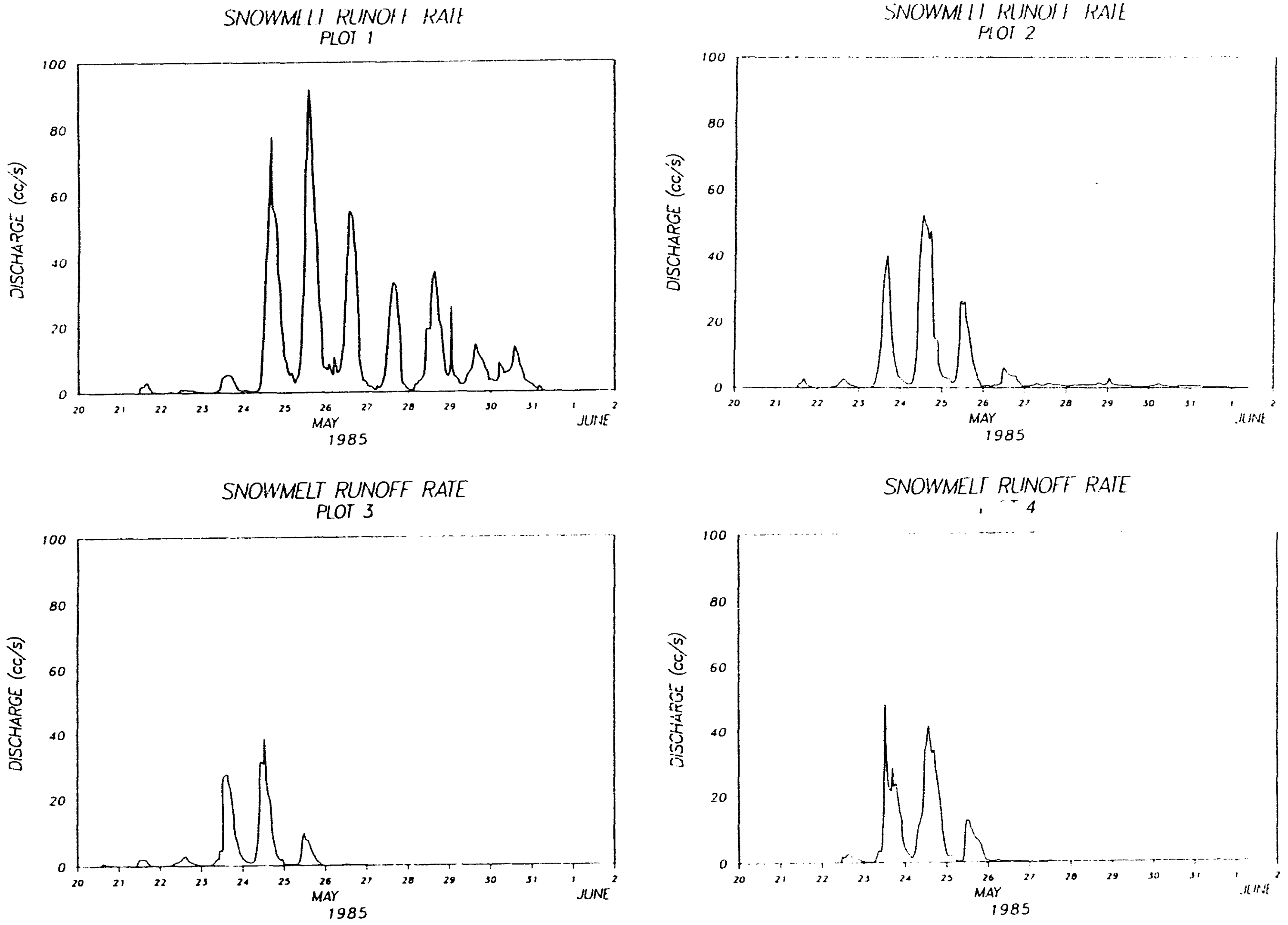


Figure 3. Comparison of snowmelt hydrographs from runoff plots for 1985.

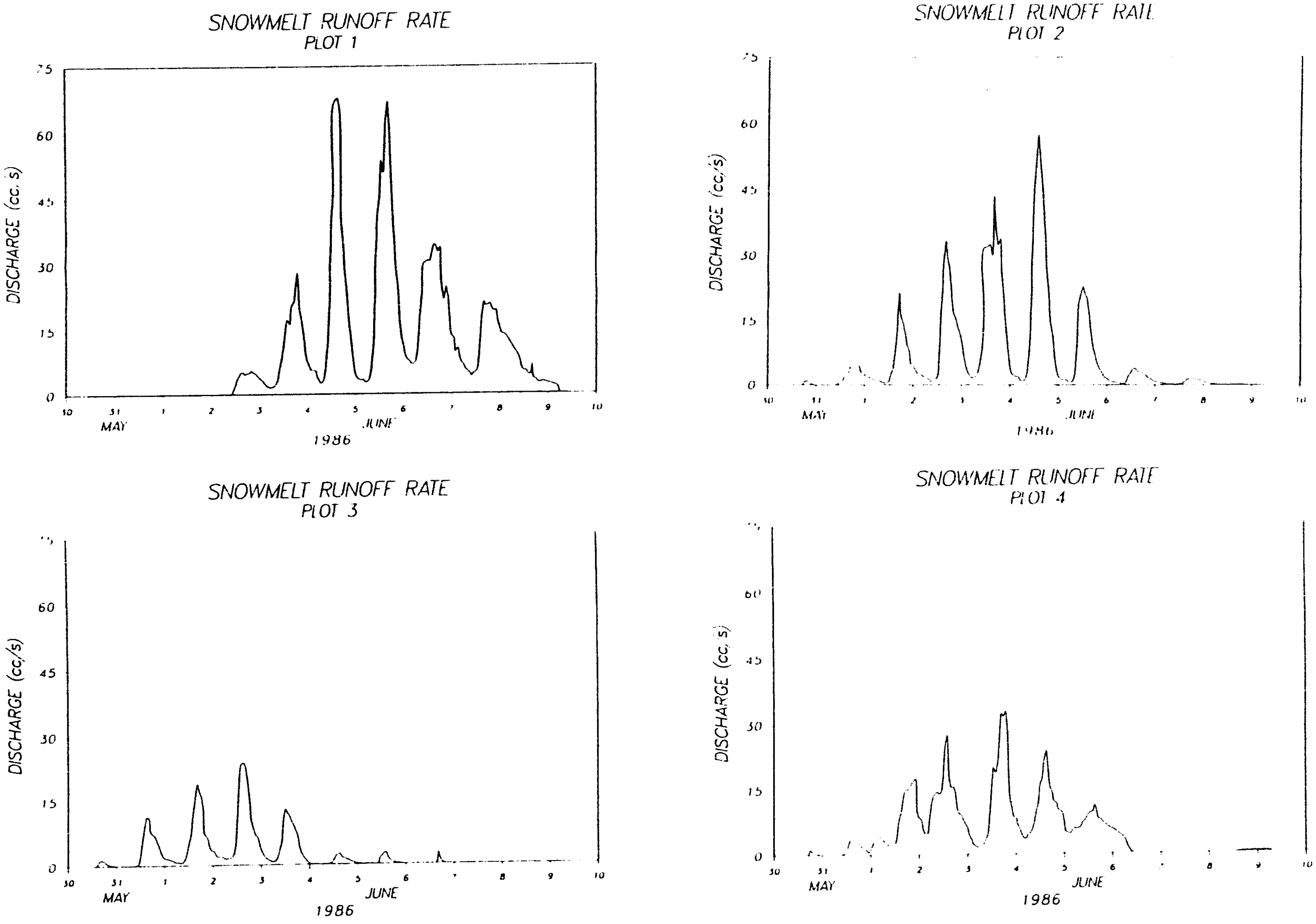


Figure 4. Comparison of snowmelt hydrographs from runoff plots for 1986.

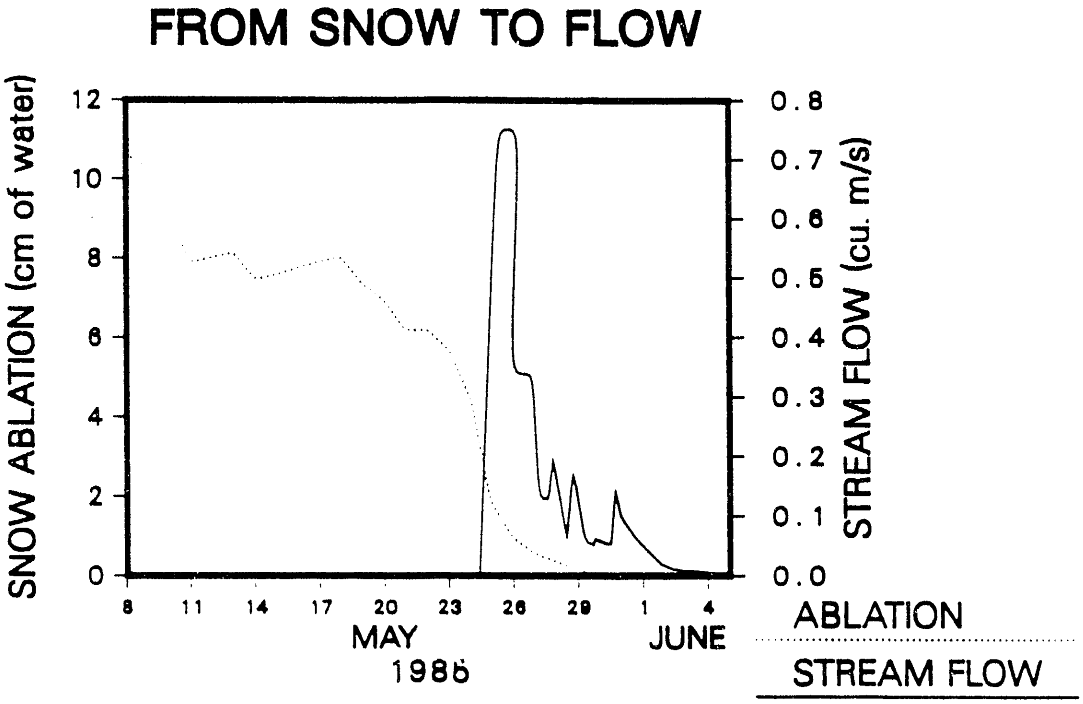


Figure 5. Snowpack ablation and consequent stream flow hydrograph of Imnavait Creek in 1985.

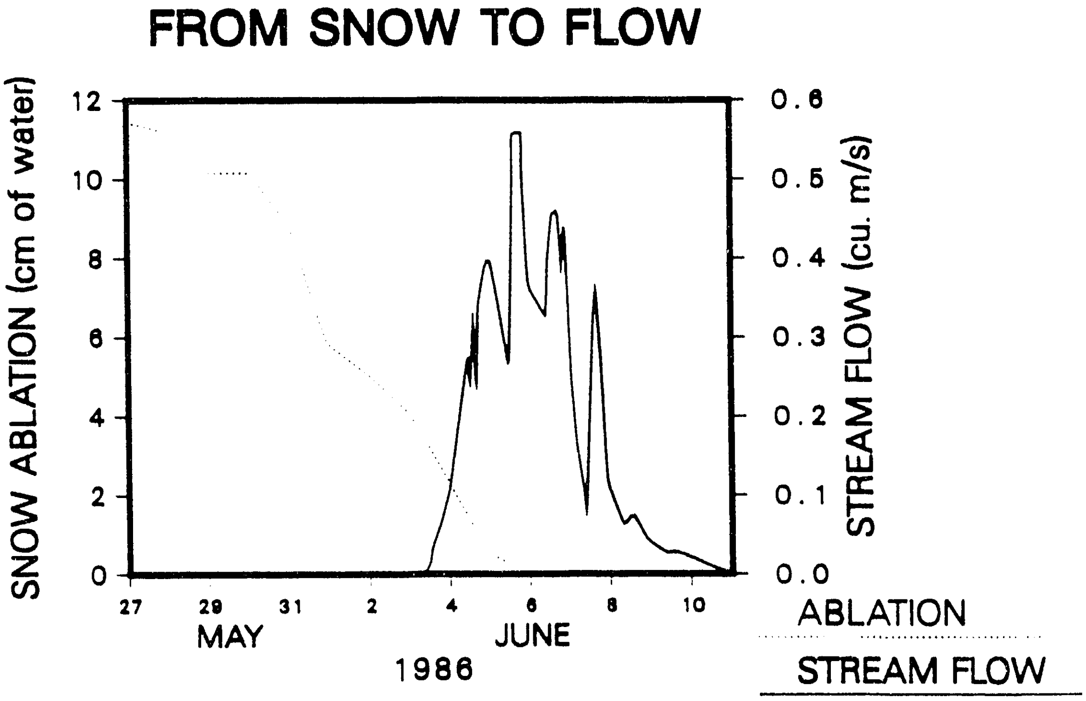
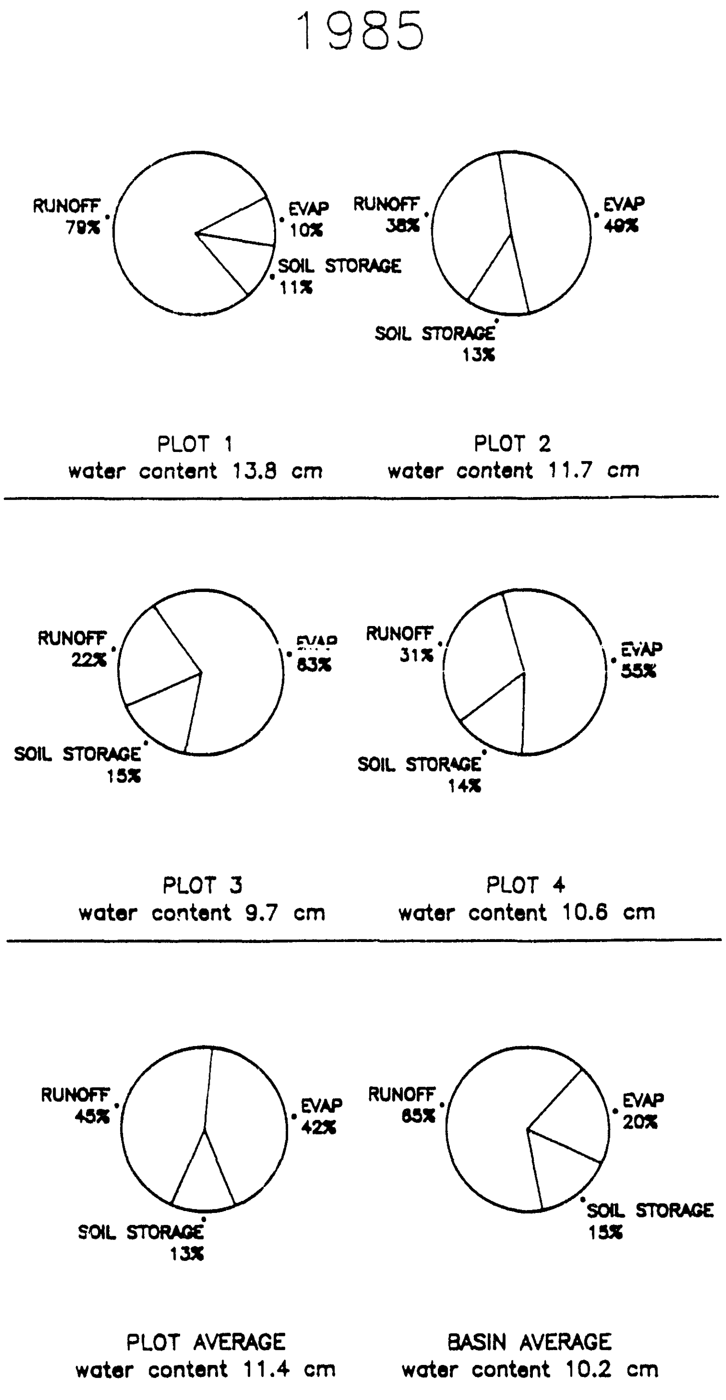


Figure 6. Snowpack ablation and consequent stream flow hydrograph of Imnavait Creek in 1986.



PLOT 1
water content 13.8 cm

PLOT 2
water content 11.7 cm

PLOT 3
water content 9.7 cm

PLOT 4
water content 10.6 cm

PLOT AVERAGE
water content 11.4 cm

BASIN AVERAGE
water content 10.2 cm

Figure 7. Partition of the water balance of 1985 spring melt for runoff plots and Imnavait watershed.

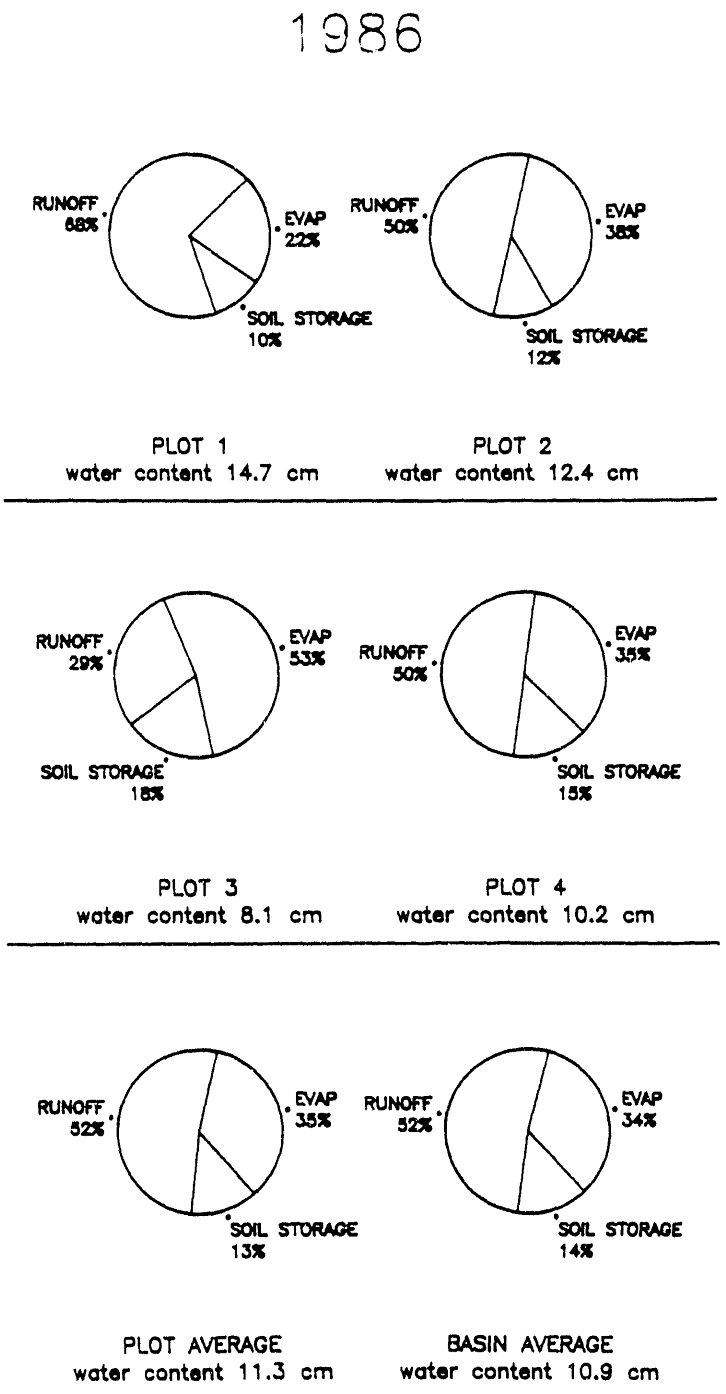


Figure 8. Partition of the water balance of 1986 spring melt for runoff plots and Imnavait watershed.

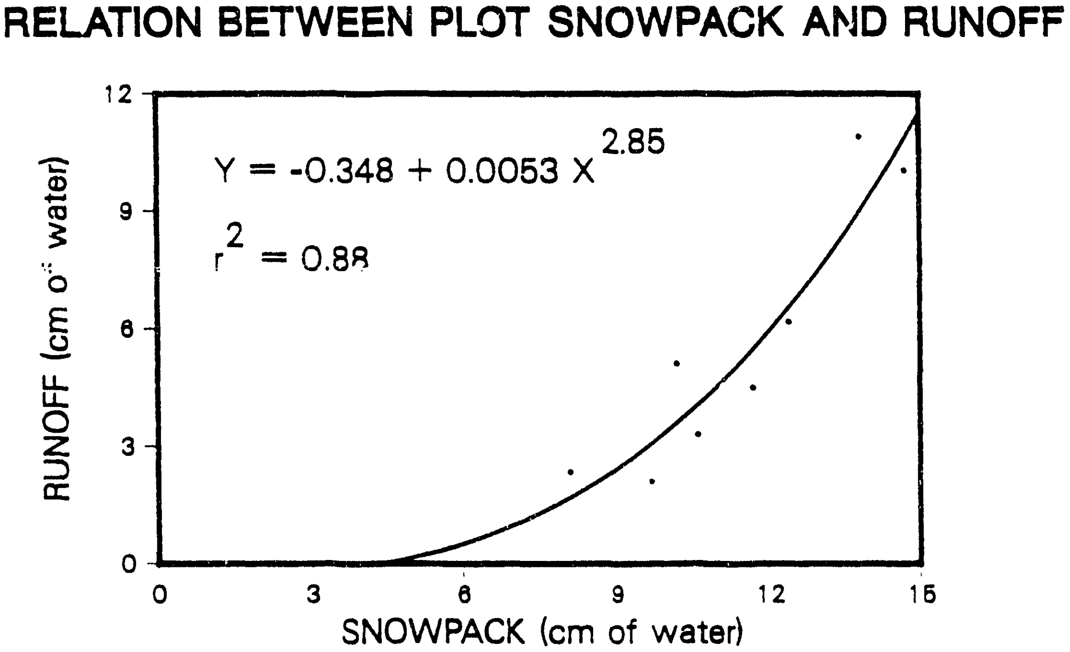


Figure 9. The relationship of initial snowpack water content and subsequent snowmelt runoff from 1985 and 1986 data.

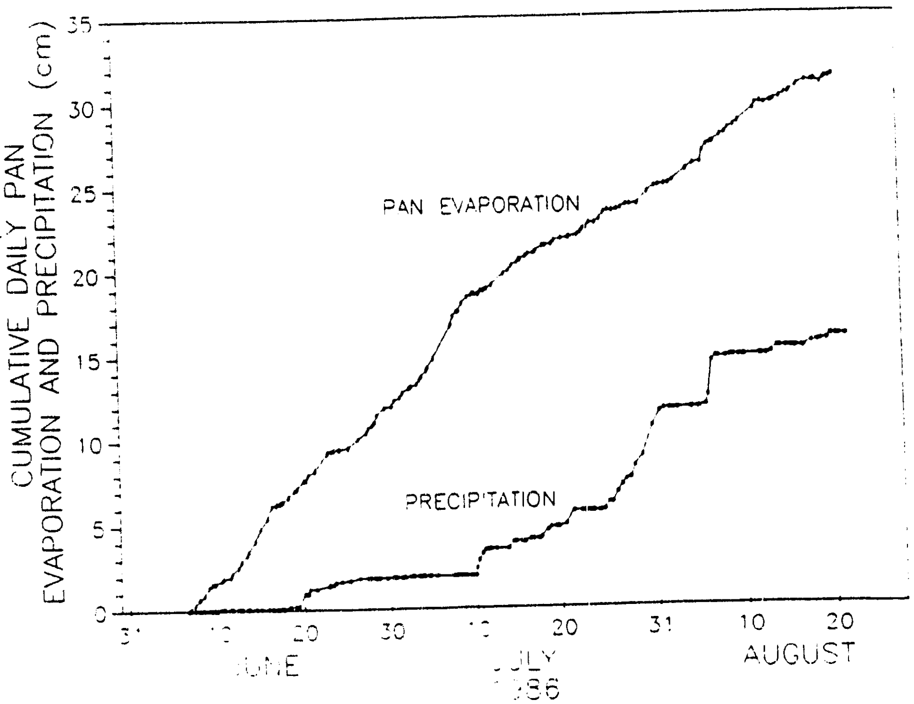


Figure 10. Comparison of the cumulated daily total precipitation and cumulated daily total pan evaporation.

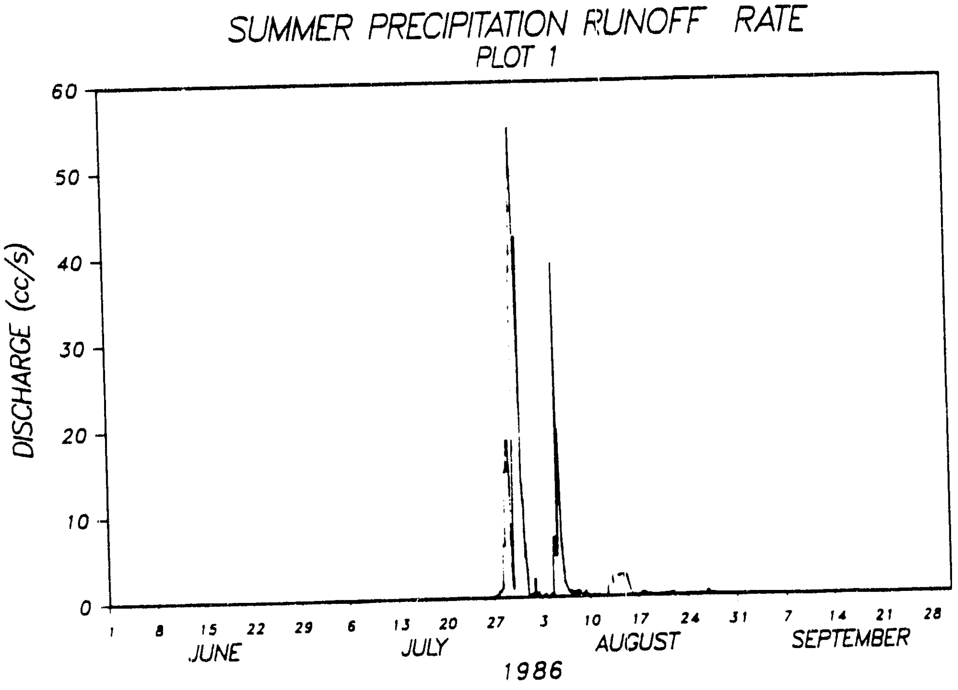


Figure 11. Hydrograph of 1986 summer precipitation runoff from plot 1.

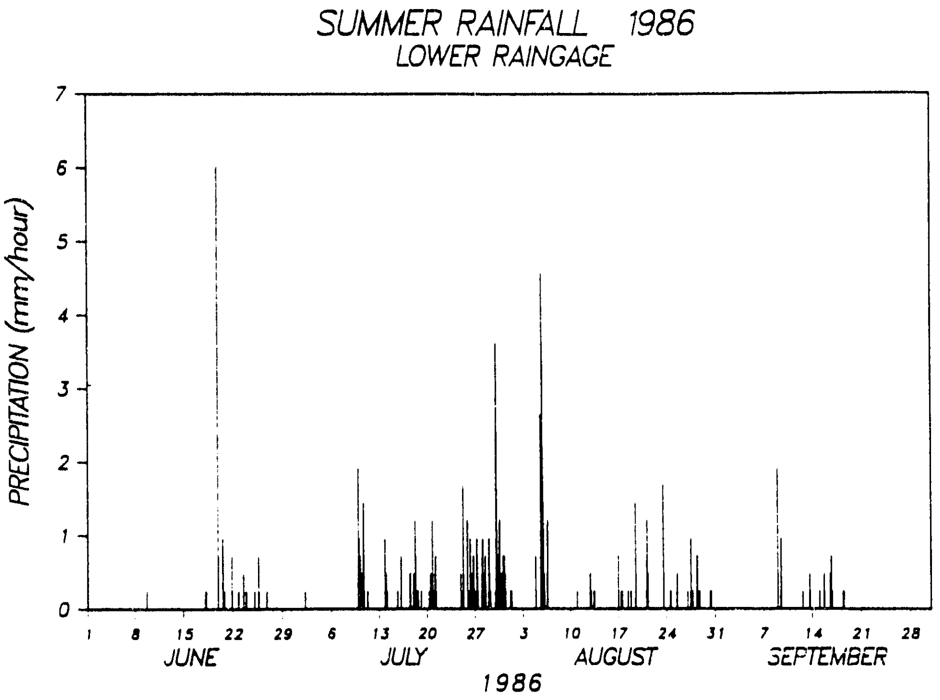


Figure 12. Rainfall intensity and distribution in 1986.

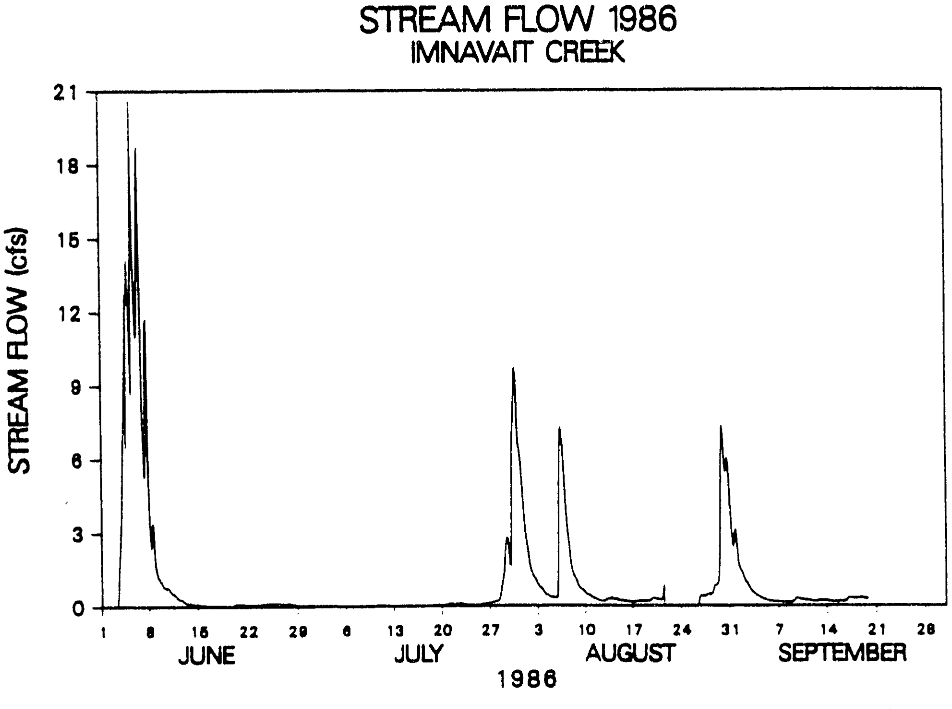
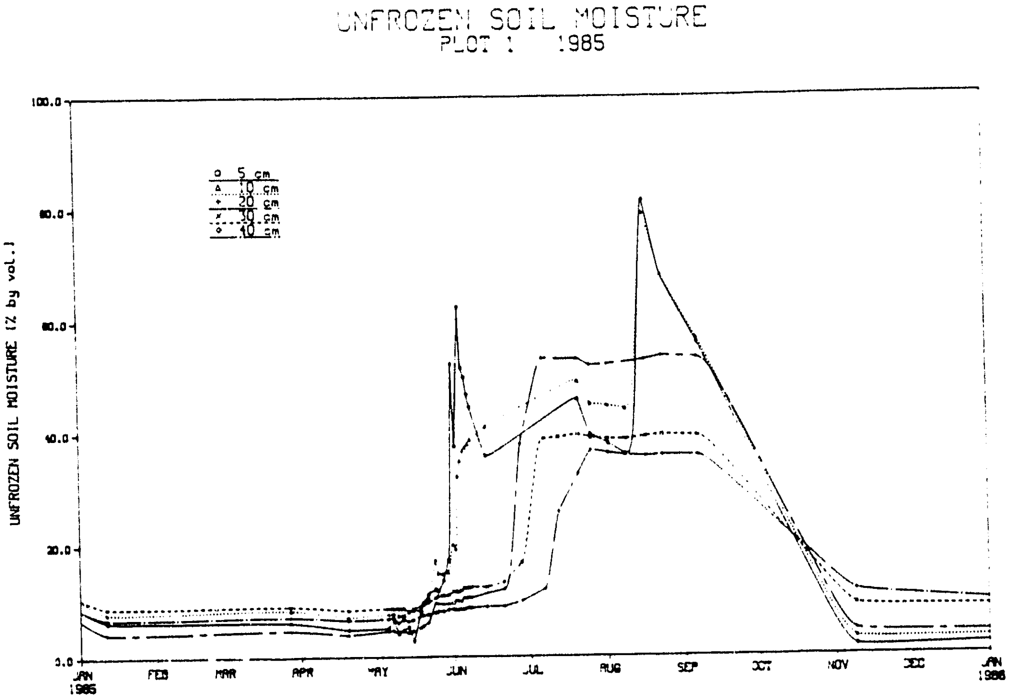
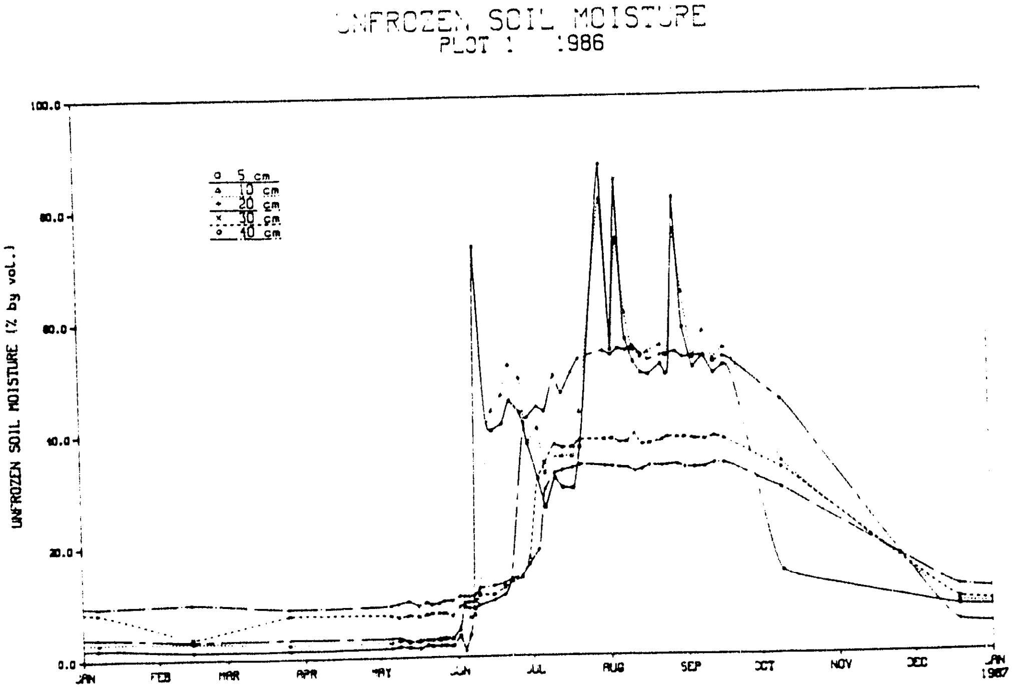


Figure 13. Streamflow hydrograph of Imnavait Creek in 1986.



UNFROZEN SOIL MOISTURE
PLOT 1 1985

Figure 14. Variation in soil unfrozen water content for several depths for 1985.



UNFROZEN SOIL MOISTURE
PLOT 1 1986

Figure 15. Variation in soil unfrozen water content for several depths for 1986.

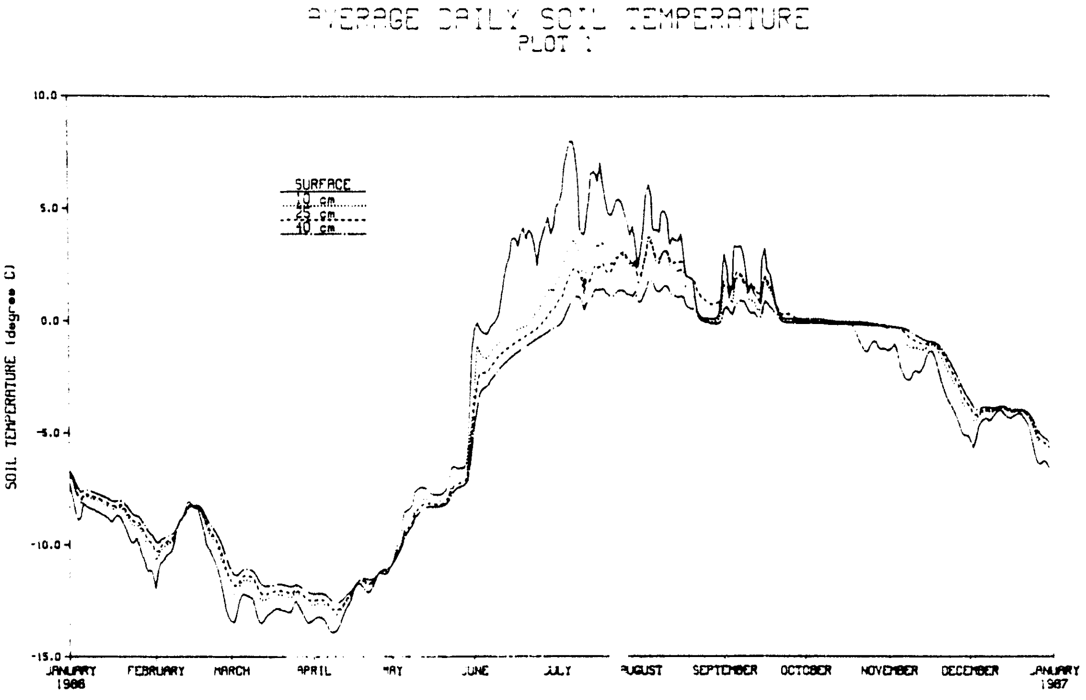


Figure 16. Variation in soil temperature for several depths in 1985.

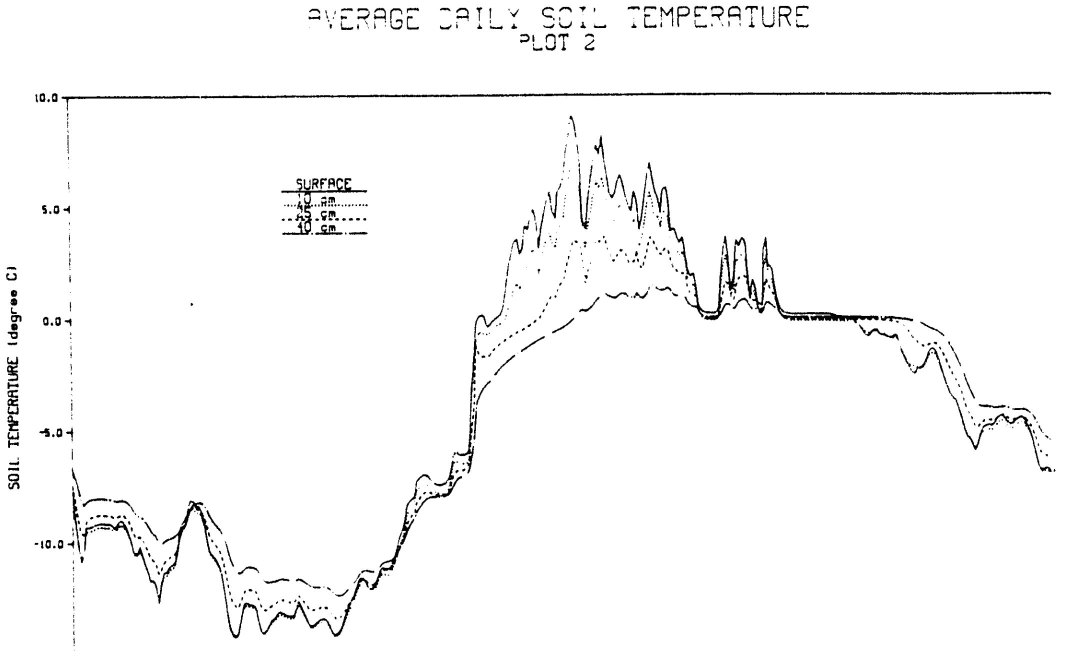


Figure 17. Variation in soil temperature for several depths in 1986.

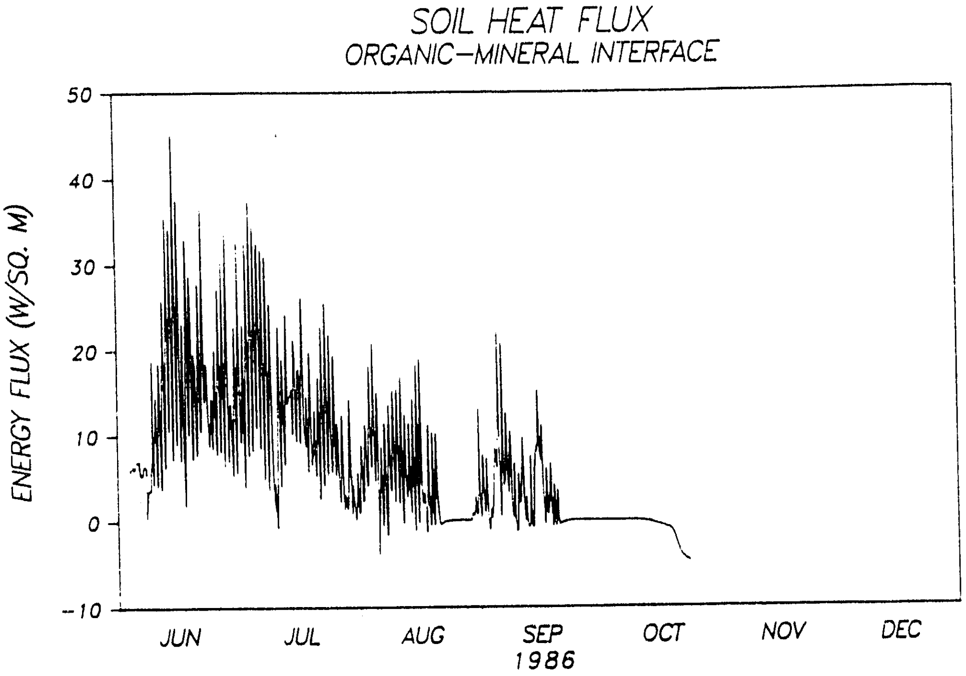


Figure 18. Fluctuations in soil heat flux at the bottom of the organic mat for June through December 1986.

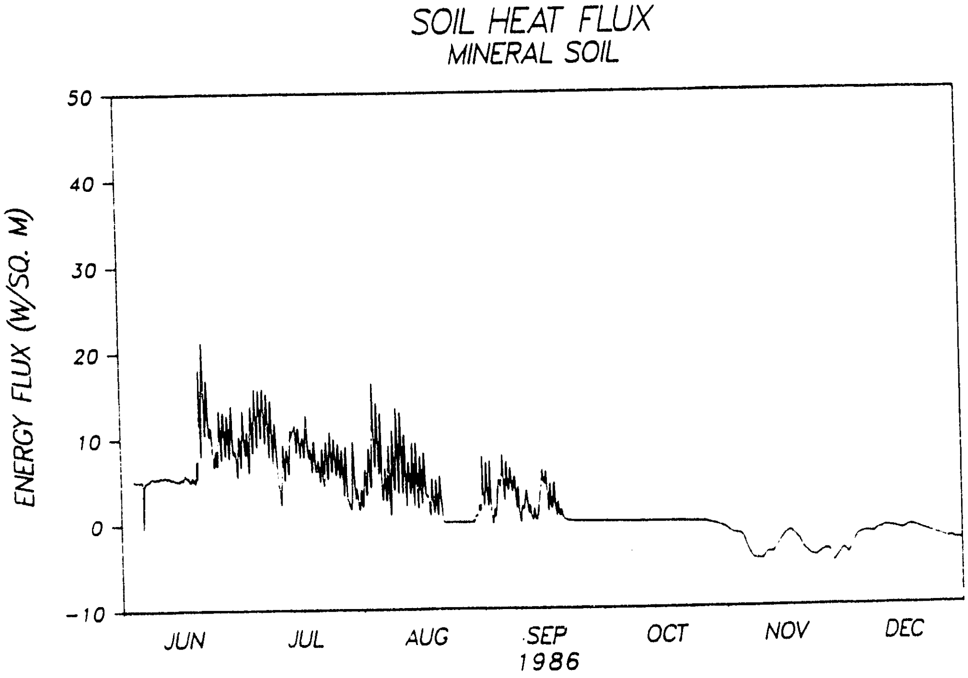


Figure 19. Fluctuations in soil heat flux in the mineral soil for June through December 1986.

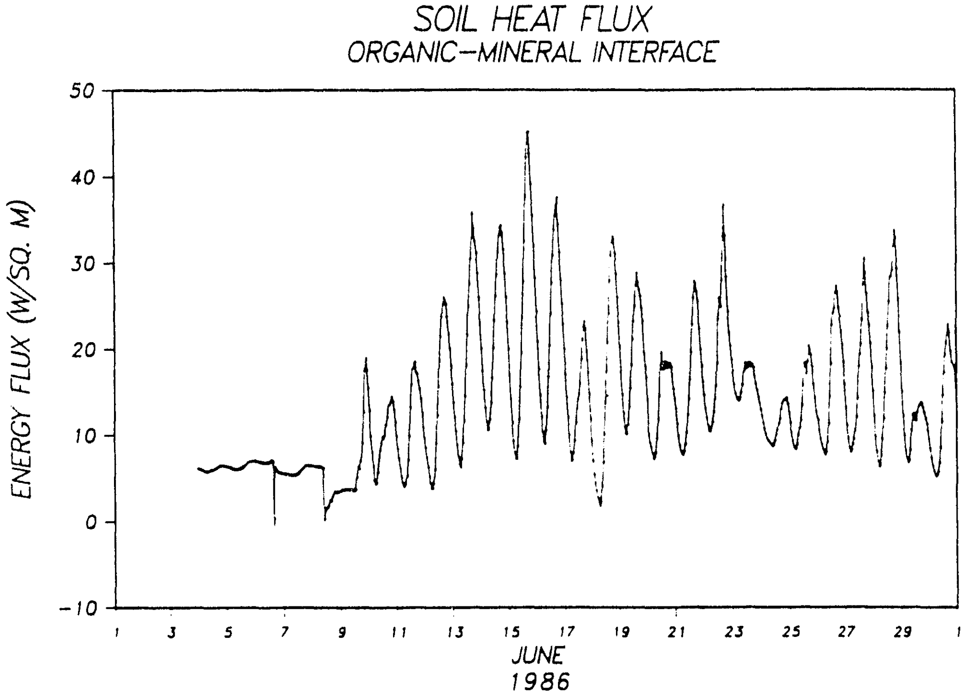


Figure 20. Diurnal variation in heat flux at the bottom of the organic mat for June 1986.

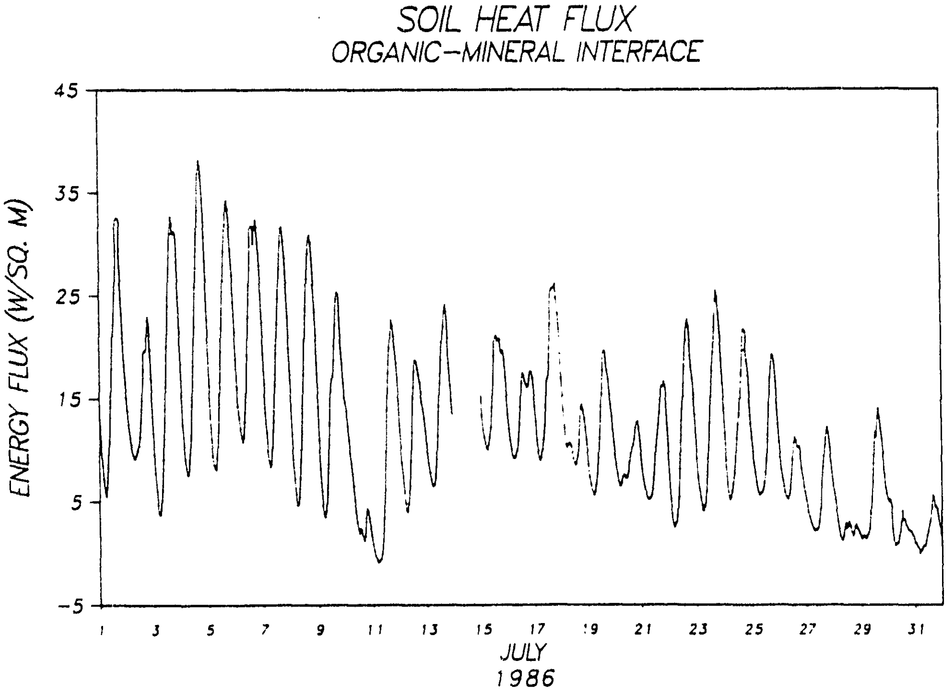


Figure 21. Diurnal variation in heat flux at the bottom of the organic mat for July 1986.

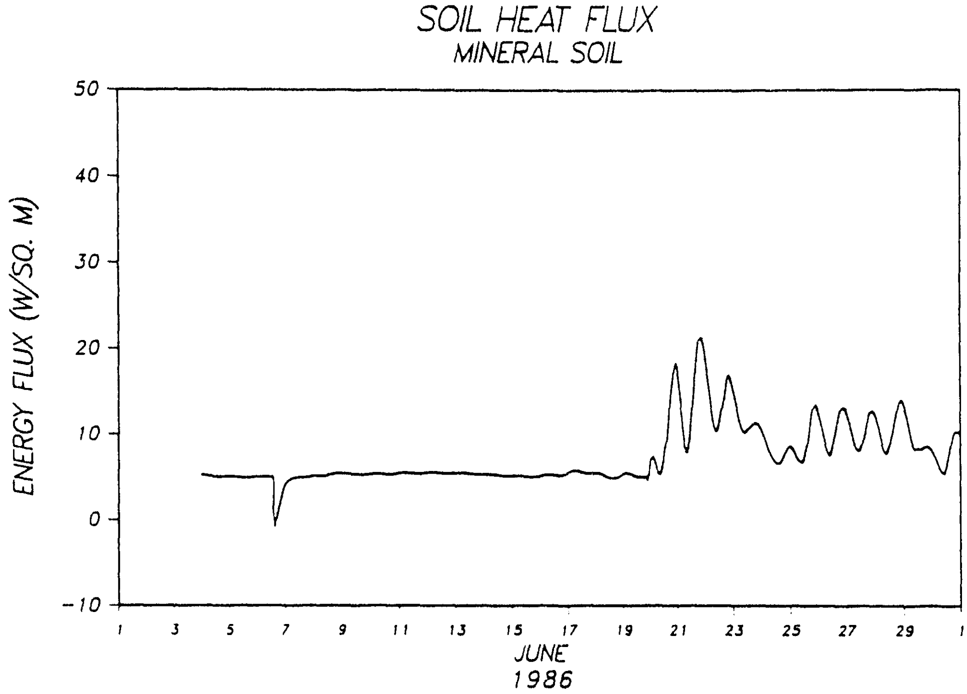


Figure 22. Diurnal variation in soil heat flux in the mineral soil in June 1986.

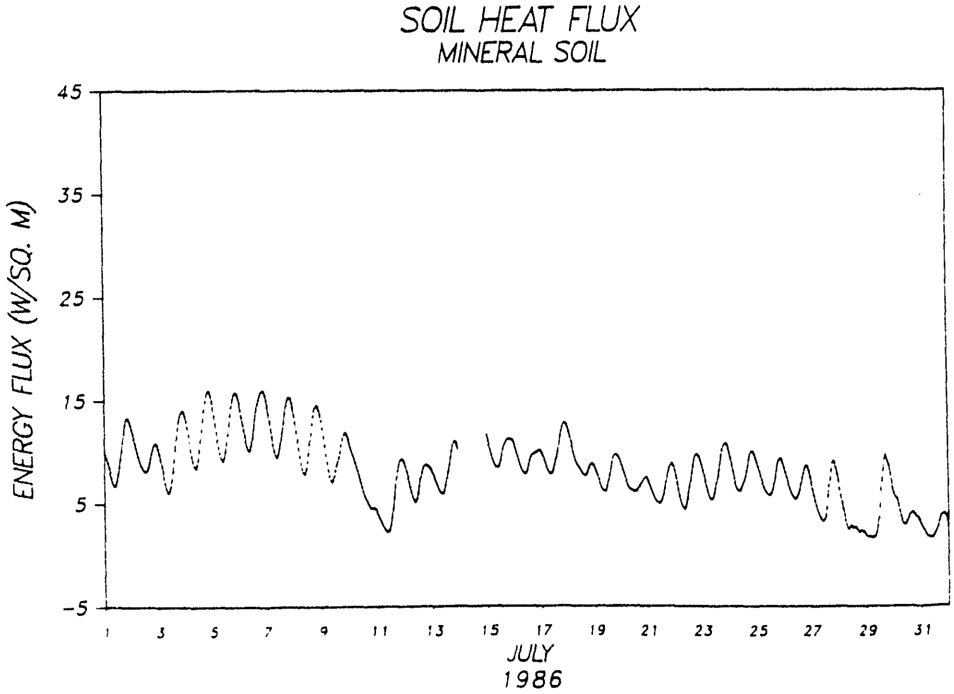


Figure 23. Diurnal variation in soil heat flux in the mineral soil in July 1986.

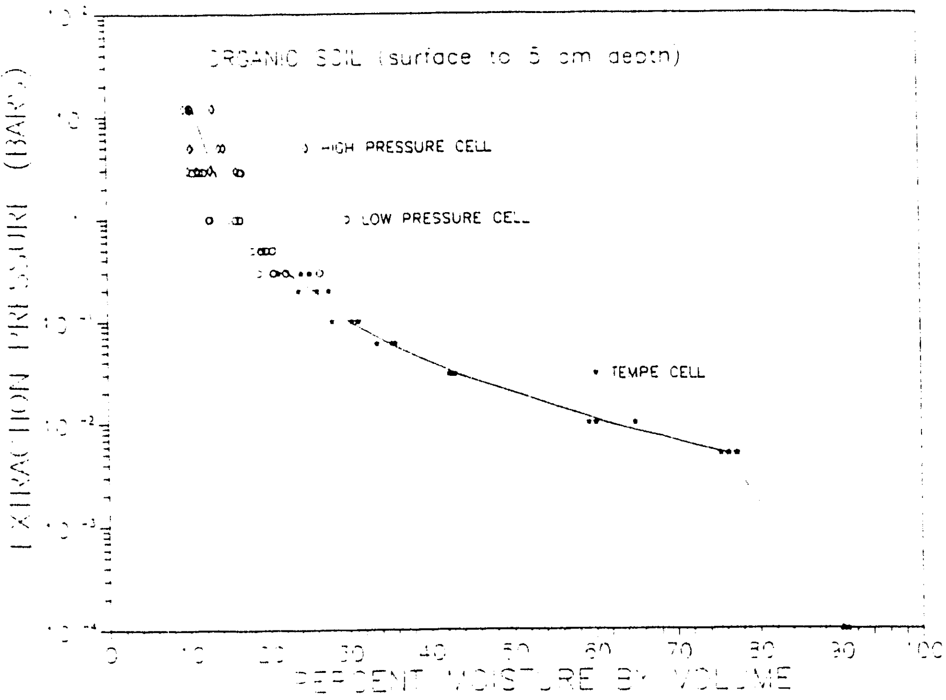


Figure 24. Characteristic curve for organic soil (0-5 cm) from Imnavait watershed.

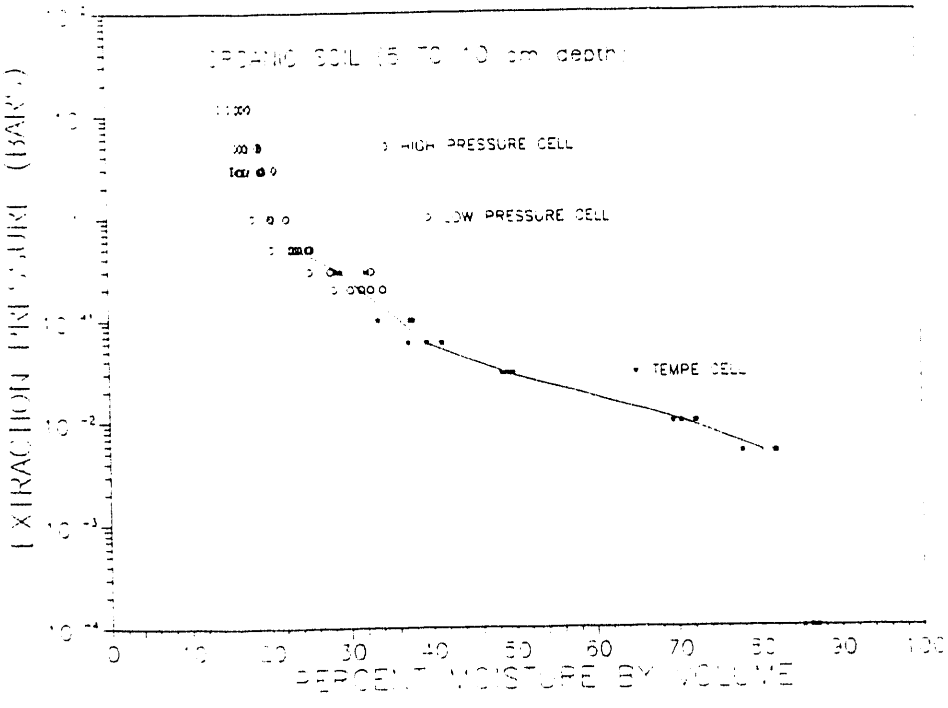


Figure 25. Characteristic curve for organic soil (5-10 cm) from Imnavait watershed.

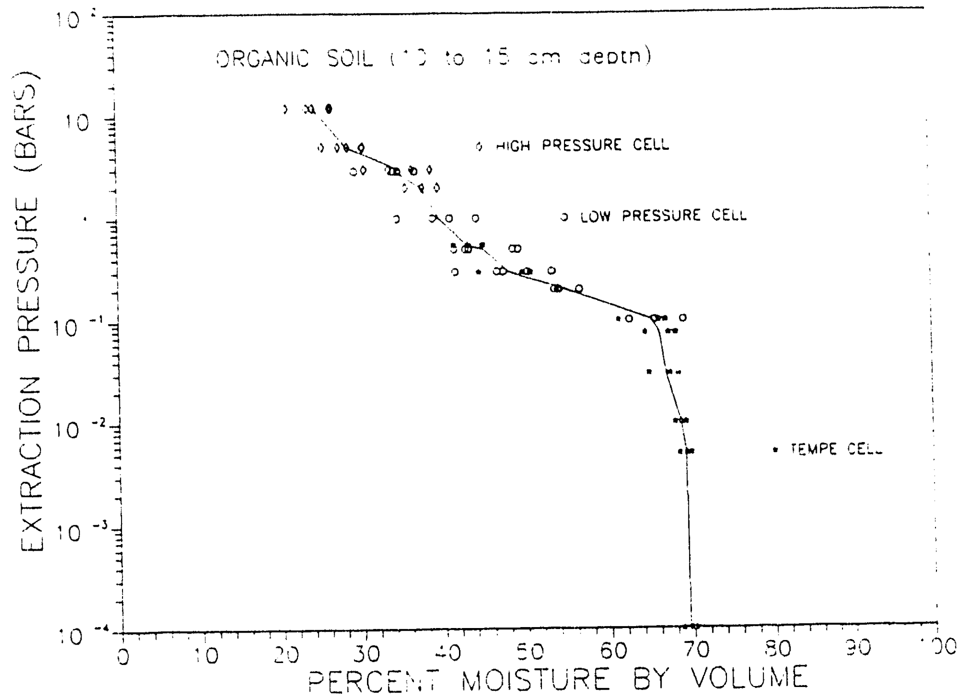


Figure 26. Characteristic curve for organic soil (10-15 cm) from Imnavait watershed.

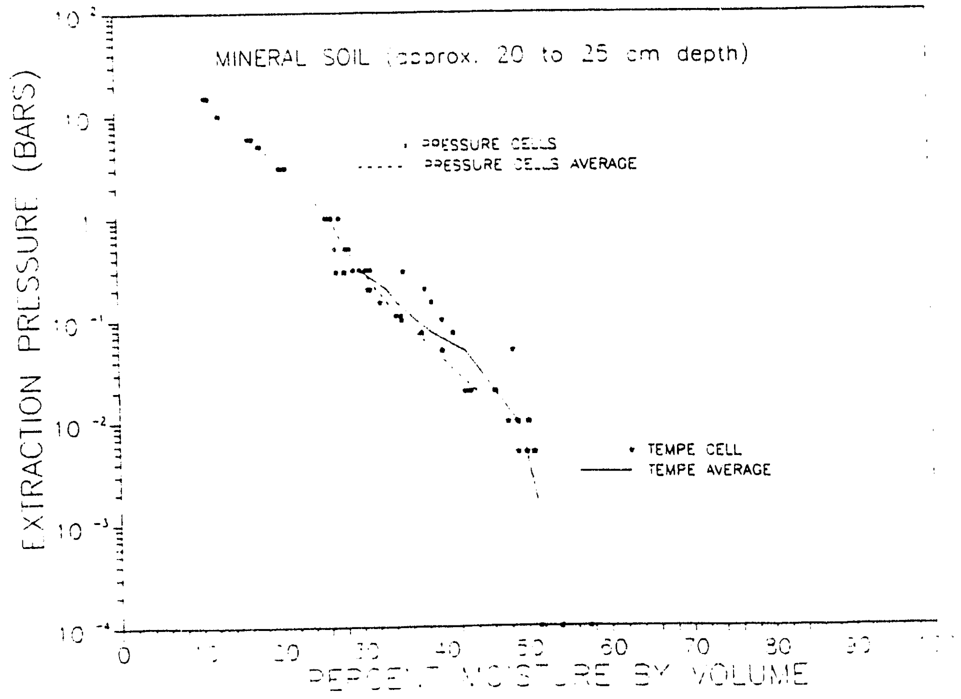


Figure 27. Characteristic curve for mineral soil (20-25 cm) from Imnavait watershed.

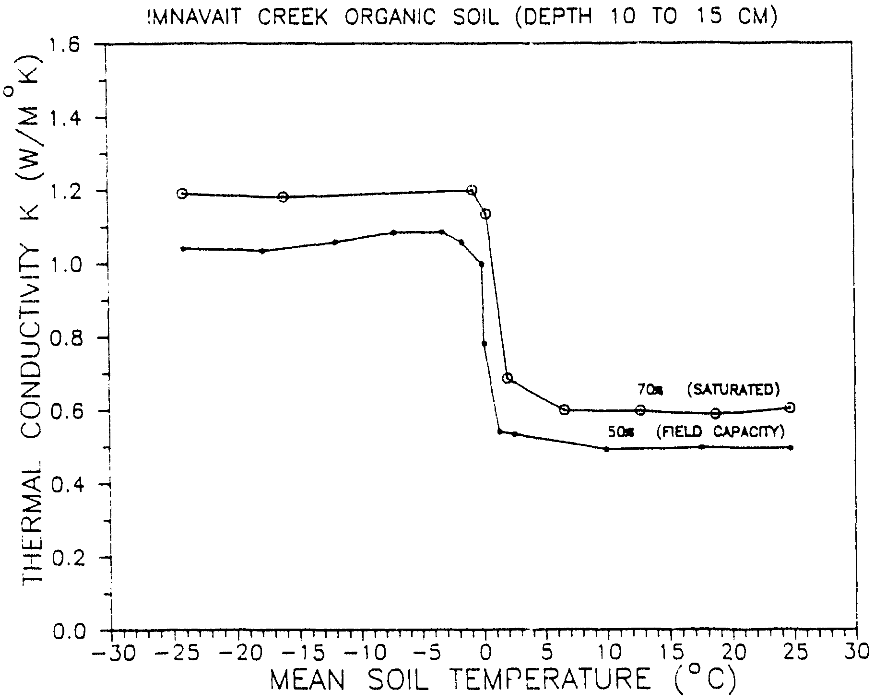


Figure 28. Variation of thermal conductivity with temperature for organic soil.

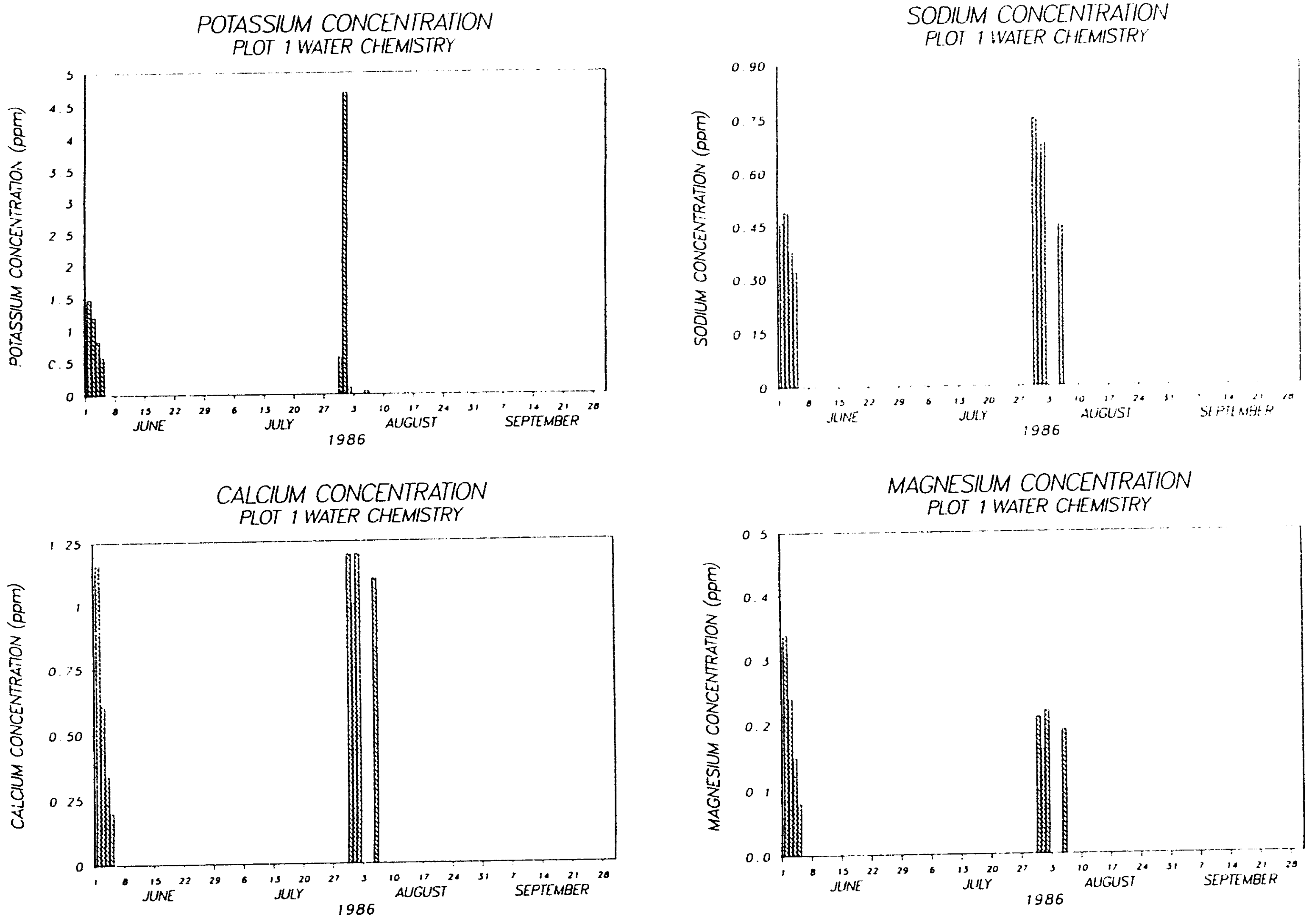


Figure 29. Chemical concentration of potassium, sodium, calcium, and magnesium in water samples collected from runoff from plot 1.

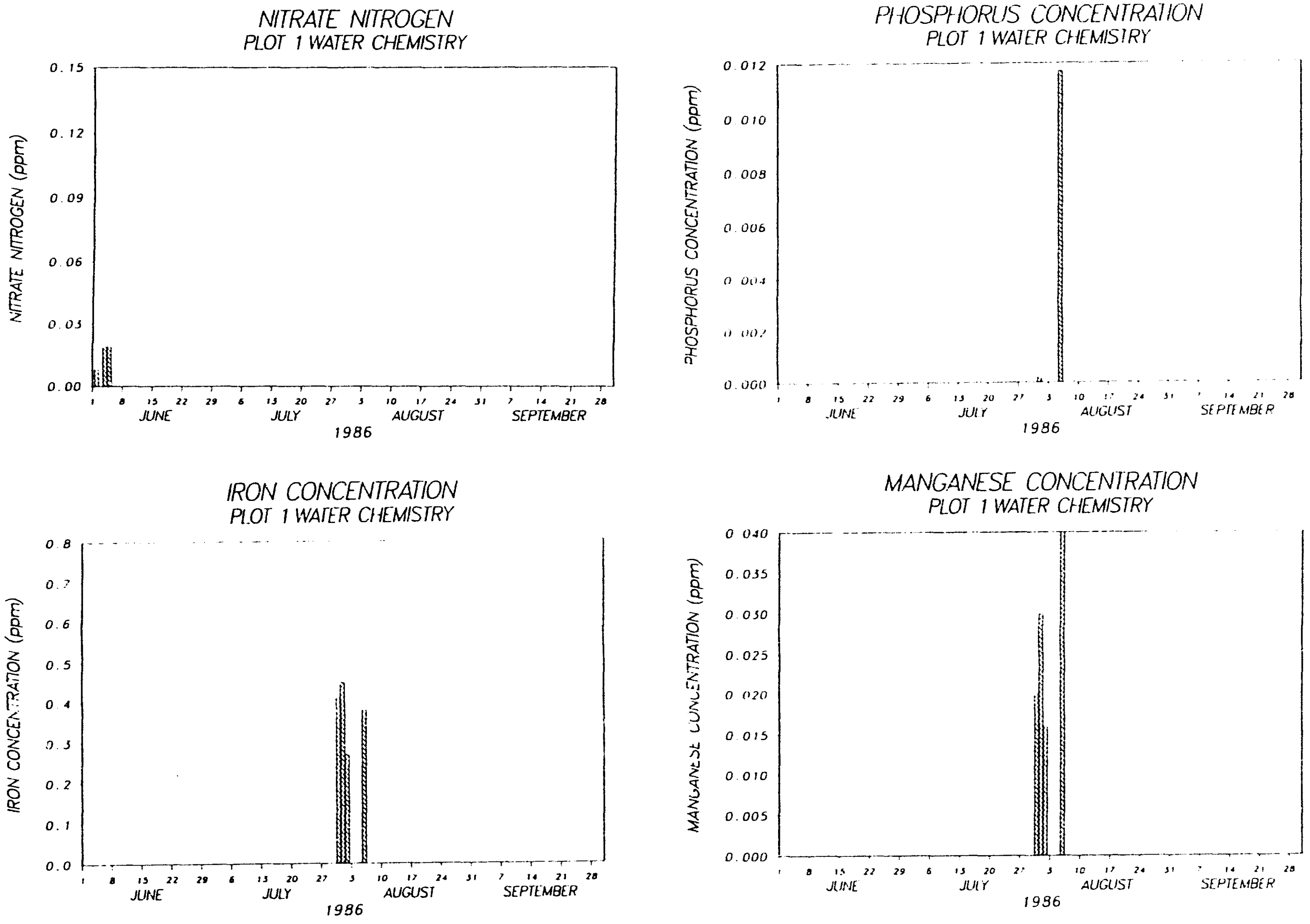
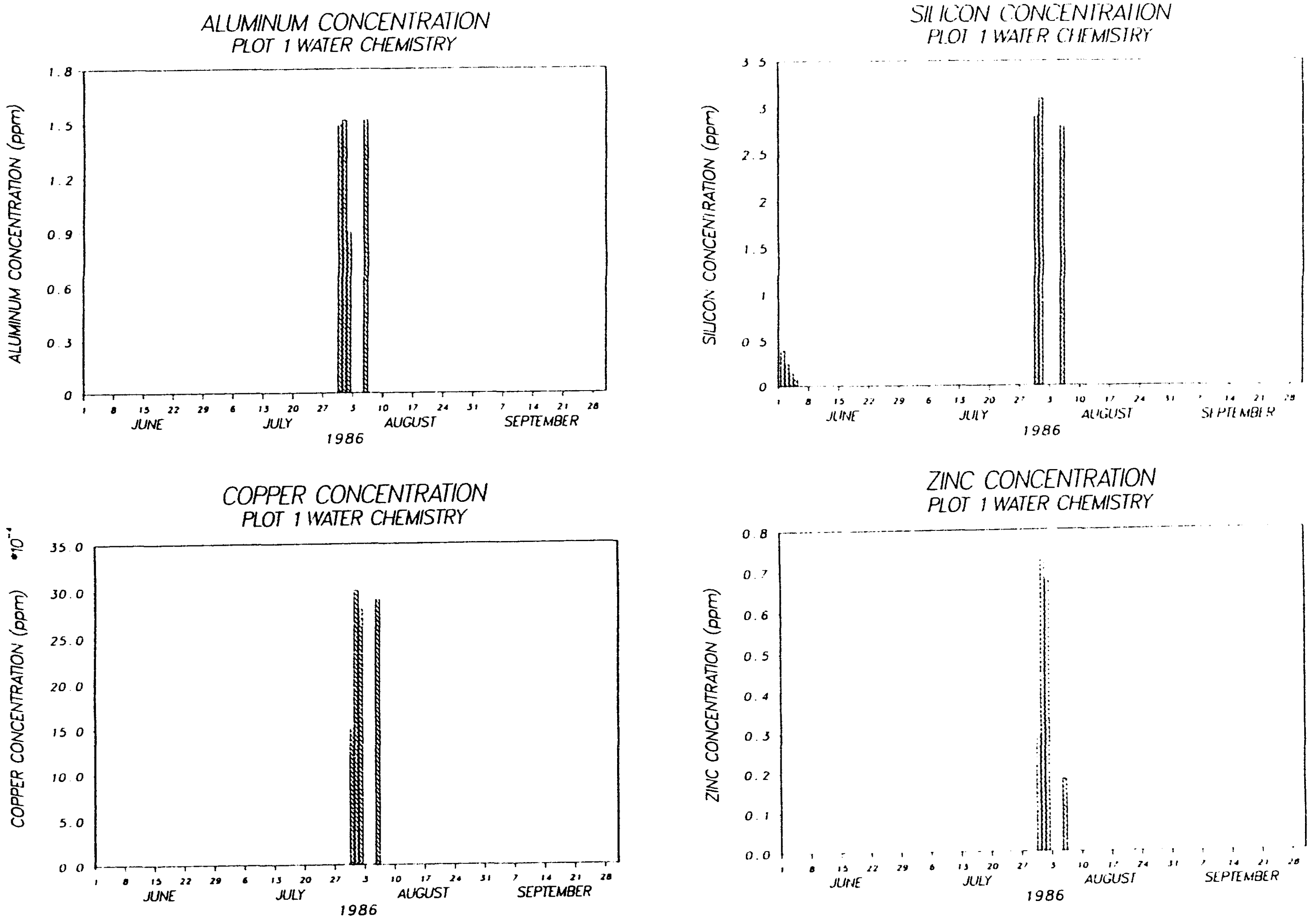


Figure 30. Chemical concentration of nitrate, phosphorus, iron, and manganese in water samples collected from runoff from plot 1.


ALUMINUM CONCENTRATION
PLOT 1 WATER CHEMISTRY

SILICON CONCENTRATION
PLOT 1 WATER CHEMISTRY

COPPER CONCENTRATION
PLOT 1 WATER CHEMISTRY

ZINC CONCENTRATION
PLOT 1 WATER CHEMISTRY

Figure 31. Chemical concentration of aluminum, silicon, copper, and zinc in water samples collected from runoff from plot 1.

END

DATE
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12/2/92