

ABSTRACT

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Worldwide, increasing human activity continues to impact the environment. The response and resilience of an ecosystem to such disturbances can range between subtle and striking. Usually on a macro-scale (Arctic Haze and Climate Change) such impacts are subtle and decades are required before significant responses are observed. On the micro-scale (oil spills, local destruction of surface vegetation) the impact is immediate and readily apparent within one or two years. Mesoscale disturbances can be wide ranging with some impacts immediately apparent (construction of roads and pipelines), while others are not as obvious (dust from roads). The recovery of an arctic ecosystem to micro scale disturbances such as the removal of vegetation can take many decades through natural processes.

To be able to evaluate anthropogenic impacts on an ecosystem, it is necessary first to understand all facets of how the ecosystem works: what the main processes (physical, biological, chemical) are, at what rates they proceed, and how they can be manipulated. Arctic ecosystems are dominated by physical processes of energy exchange. Snow, ice and permafrost are dominant characteristics of high latitude ecosystems. Considerable quantities of energy go into latent heat of fusion and vaporization. Snow melt is the most significant hydrologic event each year and following ablation, substantial changes occur in the surface energy balance as the albedo changes from approximately 0.75 to 0.2 during the summer months.

This project has continued to maintain its strong program of data collection, both hydrologic and meteorologic, to better understand dominant physical processes. However, our main focus has shifted into model oriented research. Using the hydrologic and meteorologic data base and results of the process oriented research, we have used various models to better define the physical processes and their interrelationships at Imnavait Creek in Arctic Alaska. Currently, the HBV hydrologic model, the TDHC two-dimensional heat conduction model, a snowmelt and several evapotranspiration models are being used.

Work in the next year will include: continuation of field measurement of hydrologic and meteorologic processes with the intent of quantifying certain stochastic processes, continuing to improve our understanding of physical processes and further development of our hydrologic, thermal, snowmelt and evapotranspiration models. New modeling efforts will be coupling the geochemical and hydrologic processes (with Dr. Everett) and providing hydrologic input into the general ecosystem model (Dr. Reynolds).

INTRODUCTION

Anthropogenic impacts on the terrestrial ecology of Arctic Alaska are a direct consequence of oil development:

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- i) Enhanced surface drainage by newly constructed roads and pipelines
- ii) Deposition of roadway dust on the tundra
- iii) Deposition of atmospheric pollutants that are originally discharged to the atmosphere as a waste product of oil development
- iv) Alteration of soil thermal regime due to changing the surface condition such as albedo
- v) The generation and release of greenhouse gases into the atmosphere that result in warming and degradation of permafrost.

While production at the well known Prudhoe Bay field has peaked, the Middle-east political situation has brought about increased activity in the area. Renewed exploration efforts and improved oil recovery technology have quickened the pace of activity in the Arctic Alaska, and future development of the Arctic National Wildlife Refuge seems even more certain. All of this human activity guarantees that ecological disturbances will be ongoing for some time.

In order to evaluate ecosystem sensitivity in the Arctic to energy related activities, the Department of Energy initiated an ecosystem study of Arctic Tussock Tundra. This study differed from previous studies in that a strong physical component was integrated into the study that included hydrology and meteorology.

The central hypothesis of this study is:

Ecosystem sensitivity to energy-related disturbances in arctic landscapes is constrained by a distinct set of parameters at each level in a spatial hierarchy. Alteration of climate, a macroscale disturbance, is likely to affect primary productivity, plant community composition, and wildlife habitat along latitudinal/temperature/precipitation gradients, but is constrained by nutrient availability in most habitats. The cumulative effect of expanding road and pipeline networks, a mesoscale influence, is constrained by resource availability and social influences, such as legislation and land-use planning. At the microscale, the thermal characteristics of the site and the role of water in altering the thermal regime are the primary constraining variables, which can be measured as the cumulative shift in the depth of the active layer, balance between nutrient availability, nutrient uptake by the vegetation, nutrient export from the system, and the effects on higher organisms.

Many biological processes have been studied for numerous years, so a strong scientific base existed in some areas.

In the disciplines of hydrology and meteorology, few scientific

studies have been performed in the Arctic. Many earlier studies had limited goals and short duration; also, the quality of field data is questionable.

When this project was initiated in 1984, it was assumed by many that a basic understanding of arctic hydrology and meteorology already existed and that future work could assess the impact of disturbance on the system. There are many reasons why we have not yet built a basic understanding of the physical processes in the Arctic:

1. There have been very few studies.
2. Many studies concentrated on summer processes and ignored or missed snow accumulation and ablation events.
3. Numerous studies had limited goals such as measuring runoff for a watershed but no other measurements.
4. Because of adverse weather, the quality of many field measurements are questionable.
5. Until the recent availability of solid state electronics, instruments for recording performed poorly in this environment and therefore often large gaps exist in the data time series.

OBJECTIVE

The hypothesis specific to this proposal is:

We do not presently understand thoroughly the interactions between the physical and biological systems in the Arctic and if we are ever going to be capable of predicting long term ecosystem response to anthropogenic impacts of energy development, a sound understanding of heat and mass transfer processes is critical.

Prior to this study, there have been no studies in Arctic Alaska that examined all the components of the hydrologic cycle at the same time. Most earlier studies concentrated on examining runoff and precipitation. Lacking is a clear understanding of the processes associated with the active layer. The active layer is important physically and biologically: It is the source of water and nutrients for plants, conveys water downslope to surface drainages, provides water for evaporation and transpiration, acts as a temporary storage reservoir and dictates the quantity of near-surface runoff during major rainfall and snowmelt events. Hydrologic processes in the Arctic will be altered as the active layer increases in thickness in response to climatic warming. So, climatic change in the Arctic has a two-fold impact; process such as precipitation runoff and evapotranspiration will change, but also the structure of the watershed will change in the form of increased active layer thickness and this could cause additional changes to the above mentioned processes.

Local disturbances, such as surface albedo alterations or vegetation removal, result in rapid thawing of the permafrost and in certain conditions, considerable erosion by surface runoff. These disturbances are highly visible and persist until the slopes reach a table stage and revegetation occurs. There are a large number of these disturbances but the areal extent is much lower. As we look at disturbances on a larger spatial scale, we see that the disturbances to the ecological system are much more subtle. On a micro scale (dust from roadways), disturbances need to be studied for many decades. In summary, the larger the area impacted, the more subtle will be the impact and therefore, the longer we will have to study the response of the ecosystem and the greater the amount of time to develop adequate models for prediction purposes.

There is also a large stochastic component involved in ecosystem processes. The greatest variability occurs in atmospheric processes, followed by surface and then subsurface processes. Buffering by surface vegetation and soils are primarily responsible for the pattern of variability.

Our objectives that are specific to physical processes in an arctic environment for the integrated R4D program are:

- i) Monitor in the field, meteorologic and hydrologic processes to quantify both the absolute values and the year to year variation. This includes runoff on plot and watershed scales, precipitation (both as snow and rain), soil moisture levels, and numerous meteorological measurements (air, snow and soil temperatures, long and solar radiation incoming and outgoing, wind speed and direction at several levels, and relative humidity at several levels). The availability of such data in the Arctic is very limited.
- ii) Couple our present hydrologic model with the watershed geochemistry processes being monitored by Dr. K. Everett of Ohio State University.
- iii) Continue to develop both our watershed hydrologic model and our active layer thermal model to incorporate processes unique to the Arctic that are presently not handled by the models
- iv) Assist Dr. James Reynolds at San Diego State University in the development of the hydrologic component of the ecosystem model.
- v) Apply both our hydrologic and thermal models to evaluate the hydrologic consequences of climatic warming in the Arctic.
- vi) Continue to cooperate in the area of snow hydrology

with Dr. Carl Benson, areas of watershed hydrology and geochemistry with Dr. Kaye Everett and with other project Principal Investigators in providing them with both meteorologic and hydrologic data.

vii) Refine snowmelt model.

PROGRESS SUMMARY

We have continued our meteorological and hydrologic data collection in support of our process-oriented research. The six years of data collected to date is unique in its scope and continuity in a North Hemisphere Arctic setting. This valuable data base has allowed us to further our understanding of the interconnections and interactions between the atmosphere/hydrosphere/biosphere/lithosphere. The increased understanding of the heat and mass transfer processes has allowed us to increase our model-oriented research efforts.

Spring snowmelt on the North Slope of Alaska is the dominant hydrologic event of the year. (Kane et al., 1990a). This event provides most of the moisture for use by vegetation in the spring and early summer period. The mechanisms and timing of snowmelt are important factors in predicting runoff, the migrations of birds and large mammals and the diversity of plant communities. It is important globally due to the radical and abrupt change in the surface energy balance over vast areas.

We were able to explore the trends and differences in the snowmelt process along a transect from the Brooks Range to the Arctic Coastal plain. Snowpack ablation was monitored at three sites. These data were analyzed along with meteorologic data at each site. The initiation of ablation was site specific being largely controlled by the complementary addition of energy from radiation and sensible heat flux. Although the research sites were only 115 km apart, the rates and mechanisms of snowmelt varied greatly (Figure 1.). Usually, snowmelt begins at the mid-elevations in the foothills and progresses northerly toward the coast and southerly to the mountains. In the more southerly areas snowmelt progressed much faster and was more influenced by sensible heat advected from areas south of the Brooks Range (Table 1.). In contrast, snowmelt in the more northerly areas was slower and the controlled by net radiation. (Hinzman et al., 1990b)

The hydrologic cycle of an arctic watershed is dominated by such physical elements as snow, ice, permafrost, seasonally frozen soils, wide fluctuations in surface energy balance and phase change of snow and ice to water. At Imnavait basin, snow accumulation begins in September or early October and maximum snowpack water equivalent is reached just prior to the onset of ablation in mid May. No significant mid winter melt occurs in this basin. Considerable snowfall redistribution by wind to depressions and valley bottoms is evident (Figure 2). This is hydrologically important as it places the snow close to runoff

SNOWPACK ABLATION

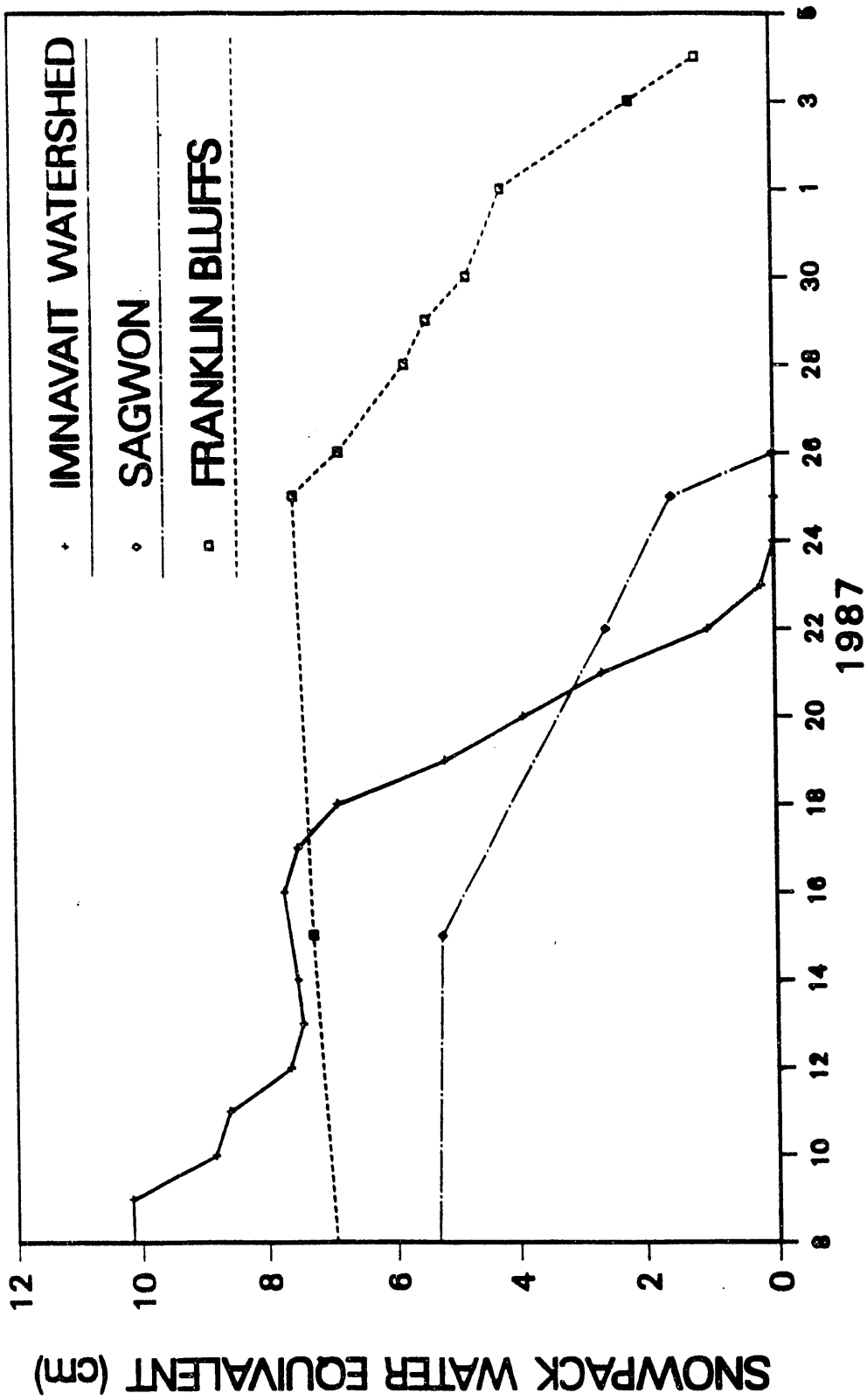


Figure 1. Snowpack ablation at Imnavait Creek, Sagwon and Franklin Bluffs in 1987.

IMNAVAIT WATERSHED BASIN TRANSECT

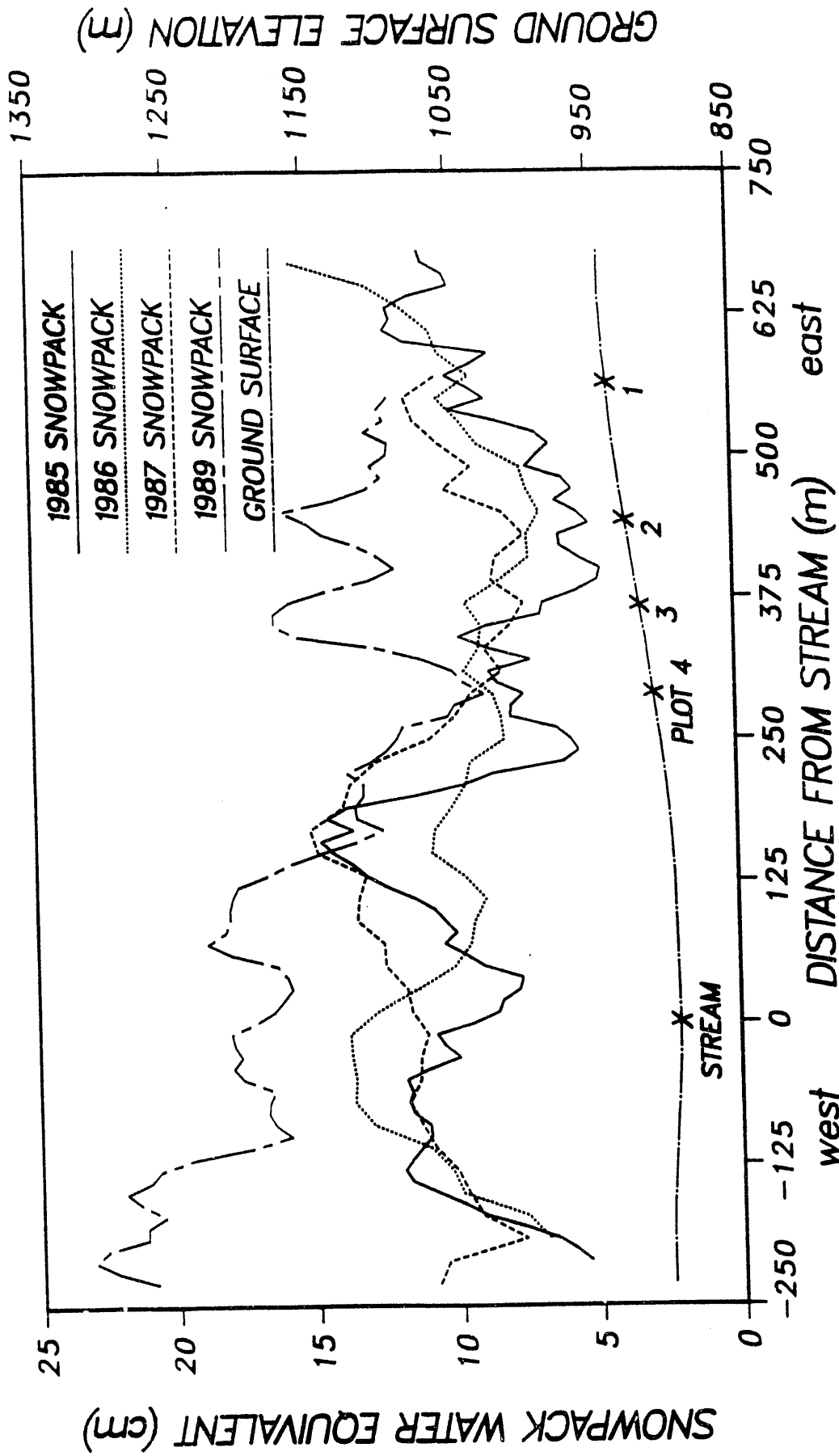


Figure 2. Snow distribution and ground surface elevations on a transect of valley.

Table 1. Comparison of the relative magnitudes (percentage) of components of the surface energy balance at Imnavait Creek, Sagwon and Franklin Bluffs in 1987, 1988, 1989 and 1990.

Location	Year	Net Radiation (%)		Sensible Heat (%)		Evaporation Condensation (%)		Heat Flux Into Soil (%)		Snow Melt (%)		Snow Melt Period
		+	-	+	-	+	-	+	-	+	-	
Imnavait Creek	1987	47.9	6.4	47.5	0.8	0.1	16.1	4.5	41.5	0.0	35.2	May 8-25
Imnavait Creek	1988	65.0	7.9	31.4	9.0	0.1	21.0	3.4	23.7	0.0	38.4	May 10-14
Imnavait Creek	1989	59.1	4.4	39.9	0.0	0.0	14.3	1.0	25.0	0.0	56.4	May 18-30
Imnavait Creek	1990	65.3	3.5	34.4	0.0	0.0	15.4	0.3	44.3	0.0	36.8	May 7-20
Sagwon	1987	63.3	0.0	19.4	25.6	0.2	27.0	17.0	30.2	0.0	17.1	May 9-28
Sagwon	1988	*	*	*	*	*	*	*	*	*	*	May 20-June 7
Sagwon	1989	76.9	0.0	18.5	4.4	2.3	8.9	2.2	30.1	0.0	56.6	May 20-June 1
Sagwon	1990	36.9	0.0	61.3	0.4	0.8	22.9	1.0	15.5	0.0	61.2	May 5-15
Franklin Bluffs	1987	88.8	0.0	9.7	4.6	0.8	10.1	0.8	52.7	0.0	32.6	May 25-June 8
Franklin Bluffs	1988	71.5	0.0	21.3	4.6	1.6	16.4	5.6	43.6	0.0	35.4	May 22-June 3
Franklin Bluffs	1989	76.8	0.0	15.2	0.8	7.7	1.3	0.2	26.0	0.0	71.9	May 27-June 11
Franklin Bluffs	1990	82.9	0.0	14.3	0.2	1.9	5.6	1.0	35.0	0.0	59.2	May 9-14

* - instrument failure prevented analysis

channels, raising soil moisture in these areas and increasing the proportion of runoff. The wind also greatly impacts the properties of the snowpack (Figure 3) by producing high density slabs within the snowpack (Kane et al. 1990a).

Snowmelt ranges from early May to late June. Runoff dominates this portion of the annual hydrologic cycle. The pattern of ablation was strongly influenced by the direction of the predominant winds. Southerly winds generally enhanced ablation and northerly winds retarded ablation. The initial melt infiltrates the snowpack and upper soils and then refreezes warming the the snowpack and upper soils. Around 15 mm of the early melt is stored in the organic soils that are desiccated during the long arctic winter. Little if any melt water enters the relatively impermeable ice rich mineral soils. Evaporation

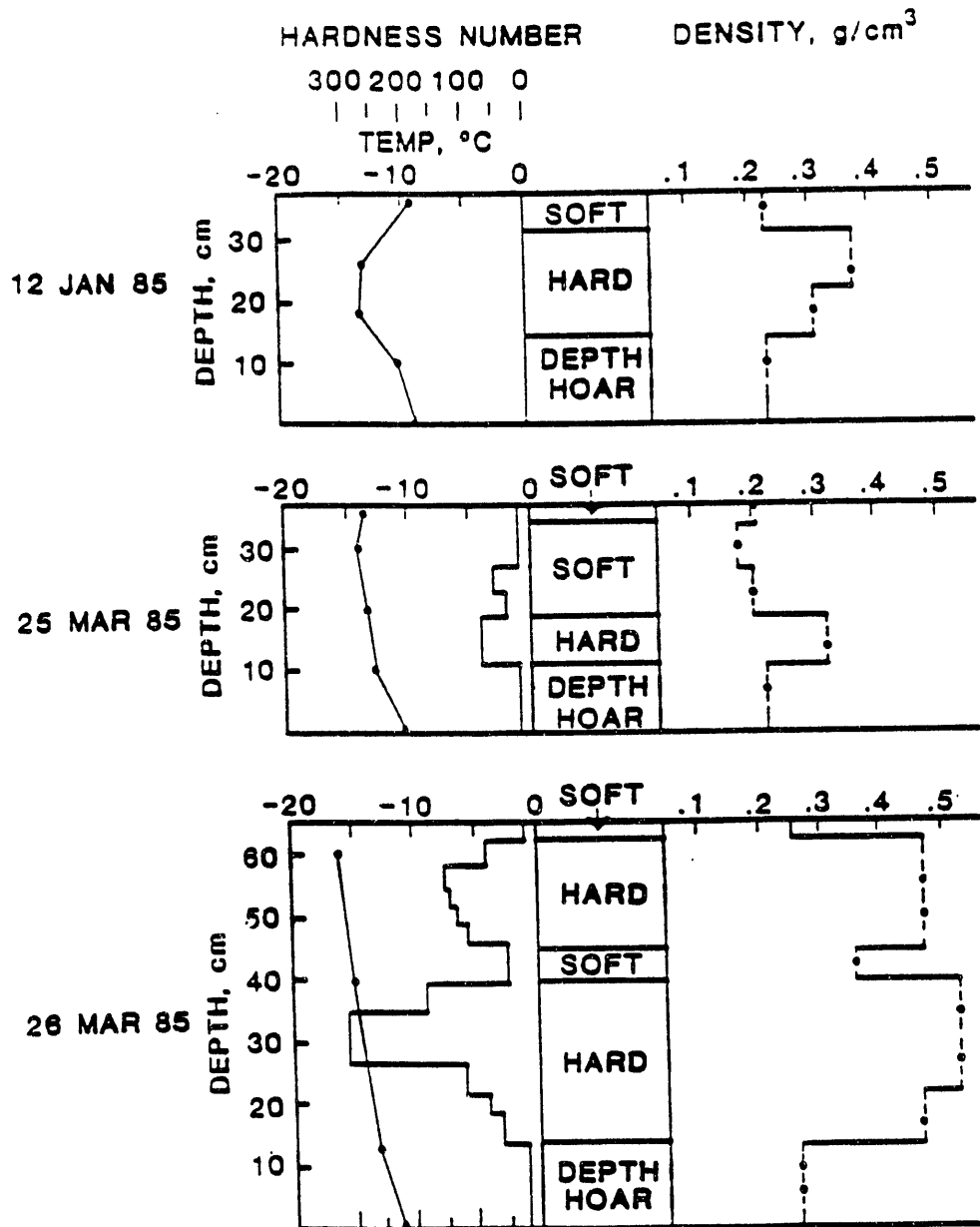


Figure 3. Snowpack properties on three dates during the winter of 1985.

from the melting snowpack is proportionally a significant part of the total snowpack water equivalent. Basin runoff begins 1 to 3 days after melt begins on the west facing slopes. The state and condition of the snowpack greatly affects the pattern of runoff in both timing and rate. A water balance was done for four small plots and the entire basin the partitioning of the snowmelt is summarized in Table 2.

Modeling the snowmelt and runoff processes in the Arctic is limited by both the lack of hydrologic data and the quality of meteorological data available. There are many factors that characterize the snowmelt and runoff that must be considered when modeling these processes in the Alaskan Arctic. Spring snowmelt in the Arctic is a brief event, usually lasting about 10 days. Peak flows normally occur within 36 hours of the beginning of streamflow. All downslope movement of water occurs within the top 10 cm of the highly organic soil material or on the surface. Snow damming of the initial snowmelt runoff is a process that greatly affects the timing and rate of streamflow (Hinzman and Kane, 1990).

Snowmelt was modeled at the three North Slope sites using meteorological and hydrologic data collected at the sites. Energy balance and degree-day modeling methods were both explored. Each method produced reasonably good results. However, the energy balance method requires a very extensive data base and these data are not usually available for other areas in the Arctic. The degree-day method, although simple and not data intensive, does not account for warming and cooling of the snowpack. Because of this flaw, the degree-day method predicts melt beginning too early in each time period, both in the initiation of melt and daily melt when evening temperatures drop below freezing.

The HBV model was used in an investigation of the hydrologic regime of Imnavait Basin during the spring snowmelt period (Hinzman and Kane, 1990). From the analysis of five spring melt events we found that HBV can adequately predict soil moisture, evaporation, snow ablation and accumulation and runoff. It models the volumes of snowmelt runoff well (Table 3), but more data are needed to improve the determination of snowmelt initiation.

The summer hydrology can vary significantly from year to year, depending on the pattern and magnitude of summer precipitation. Annual water balance calculations, including both snowmelt and summer data, are presented in Table 4. The surface organic soils seem to play a much more dominant hydrologic role than the deeper mineral soils. The mineral soils remain near saturation much of the year with phase change being the dominant activity. During dry periods, runoff is minimal or ceases in the headwater stream and water tracks, indicating that subsurface flow contributions from the thawing of the active layer are minimal, if not insignificant (Table 5) (Kane et al., 1989).

Table 2. Partitioning of the melting snowpack.

	Initial Water Content, cm	Runoff %	Evaporation %	Soil Storage %
----- 1985 -----				
Plot 1	13.8	79	10	11
Plot 2	11.7	38	49	13
Plot 3	9.7	22	63	15
Plot 4	10.6	31	55	14
Plot Average	11.4	45	42	13
Basin Average	10.2	65	20	15
----- 1986 -----				
Plot 1	14.7	68	22	10
Plot 2	12.4	50	38	12
Plot 3	8.1	29	53	18
Plot 4	10.2	50	35	15
Plot Average	11.3	52	35	13
Basin Average	10.9	52	34	14
----- 1987 -----				
Plot 1	9.8	69	16	15
Plot 2	10.7	33	53	14
Plot 3	10.2	*	*	*
Plot 4	10.0	20	65	15
Plot Average	10.2	41	44	15
Basin Average	10.8	66	20	14
----- 1988 -----				
Plot 1	7.2	+	+	+
Plot 2	7.3	16	63	21
Plot 3	8.4	43	39	18
Plot 4	6.9	33	45	22
Plot Average	7.4	31	49	20
Basin Average	7.8	50	31	19
----- 1989 -----				
Plot 1	13.5	*	*	*
Plot 2	11.6	34	53	13
Plot 3	11.7	34	53	13
Plot 4	13.7	*	*	*
Plot Average	12.6	34	53	13
Basin Average	15.5	61	30	10

* No measurements made for this plot because of leakage.

+ No measurements collected

Table 3. Observed and simulated water balances.

Year	Measured				Modeled Hourly				Modeled Daily			
	Snowpack Water	Snowmelt Runoff	Soil Storage	Evapo- trans	Snowmelt Runoff	r ²	Soil Storage	Evapo- trans	Snowmelt Runoff	r ²	Soil Storage	Evapo- trans
	(cm)	(cm)	(cm)	(cm)	(cm)		(cm)	(cm)	(cm)		(cm)	(cm)
1985	10.2	6.6	1.5	2.1	6.1	0.84	1.8	3.2	6.2	0.87	3.6	3.6
1986	10.9	5.7	1.5	3.7	6.8	0.78	1.3	3.2	7.1	0.90	1.5	4.9
1987	10.8	7.1	1.5	2.2	6.2	0.83	2.7	3.4	8.0	0.87	1.3	4.2
1988	7.8	3.9	1.5	2.4	3.8	0.82	1.4	3.1	3.6	0.77	1.0	4.2
1989	15.5	9.4	1.5	4.6	11.4	0.78	1.0	3.3	12.1	0.69	1.1	4.2

Summer runoff events are controlled by the antecedent moisture conditions of the organic soils in the active layer because the saturated mineral soils are relatively impermeable. Downslope movement of water is initiated when saturated conditions develop following rainfall or summer snowmelt in the near-surface inorganic soils. Water released from the thawing of the mineral soils is probably used by plants or lost through evaporation during dry periods. Summer precipitation events, although never near the volume of snowmelt, can produce peaks in the streamflow hydrograph if the intensity is high (Kane and Hinzman, 1988).

Evapotranspiration (ET) vies with runoff as the primary mechanism for annual water loss from a watershed such as Imnavait Creek that is underlain by permafrost. ET on a watershed scale was calculated from water balance studies and compared to point measurements of pan evaporation and estimates of ET by energy balance and Priestley-Taylor methods (Figure 4.) (Kane et al., 1990b). Since it is difficult to determine the daily change in soil moisture, the energy balance appears to be the best method to determine daily ET. The water balance approach is the best method to determine total ET over the course of the summer because it is possible to delete the soil moisture term due to and insignificant change annually in this watershed. Priestley-Taylor gave adequate estimates of ET with only limited data. ET is greatest in the early summer, immediately following the spring snowmelt, during the period of maximum incoming radiation, but not necessarily maximum air or soil temperatures. The cumulative potential evaporation is greater than the cumulative summer precipitation. The source for ET in early summer is from snowmelt or moisture stored in the active layer (Kane et al., 1990b).

The snow melt flood at Imnavait Creek takes place sometime between 12 May and 2 June and constitutes the single most important hydrologic and geochemical event. Five years of study indicate this event spans 7 to 10 days and that peak discharge can be expected to be between 0.6 and 0.9 cu. m/s. Ion concentrations peak during the first 15% of the event while pH is at a minimum. In all cases, ion concentrations in the spring runoff are 4 to 9 times those of the snowpack. Precipitation, including dryfall, contributes significant amounts of Ca, Mg, K, Na, Cl and SO₄. Potassium is in surface waters only during melt-

SPRING AND ANNUAL WATER BALANCES

YEAR	SNOWPACK WATER (cm)	SUMMER PRECIP (cm)	TOTAL PRECIP (cm)	SNOWMELT RUNOFF (cm)	SUMMER RUNOFF (cm)	TOTAL RUNOFF (cm)	EVAPO-TRANS (cm)	PAN EVAP (cm)
1985	10.2	25.1	35.3	6.6	*	*	*	*
1986	10.9	16.3	27.2	5.7	6.2	11.9	15.3	31.0
1987	10.8	27.2	38.0	7.1	17.9	25.0	13.0	32.0
1988	7.8	25.2	33.0	3.9	7.2	11.1	18.0	21.9
1989	15.5	25.7	41.2	9.4	7.8	17.2	24.0	42.0
1990	10.6	11.9**	22.5	6.4	2.8	9.2	13.3**	35.0**

* - data unavailable

** - preliminary data

Table 4. Imnavait Watershed spring and annual water balances for the water years 1985 through 1990.

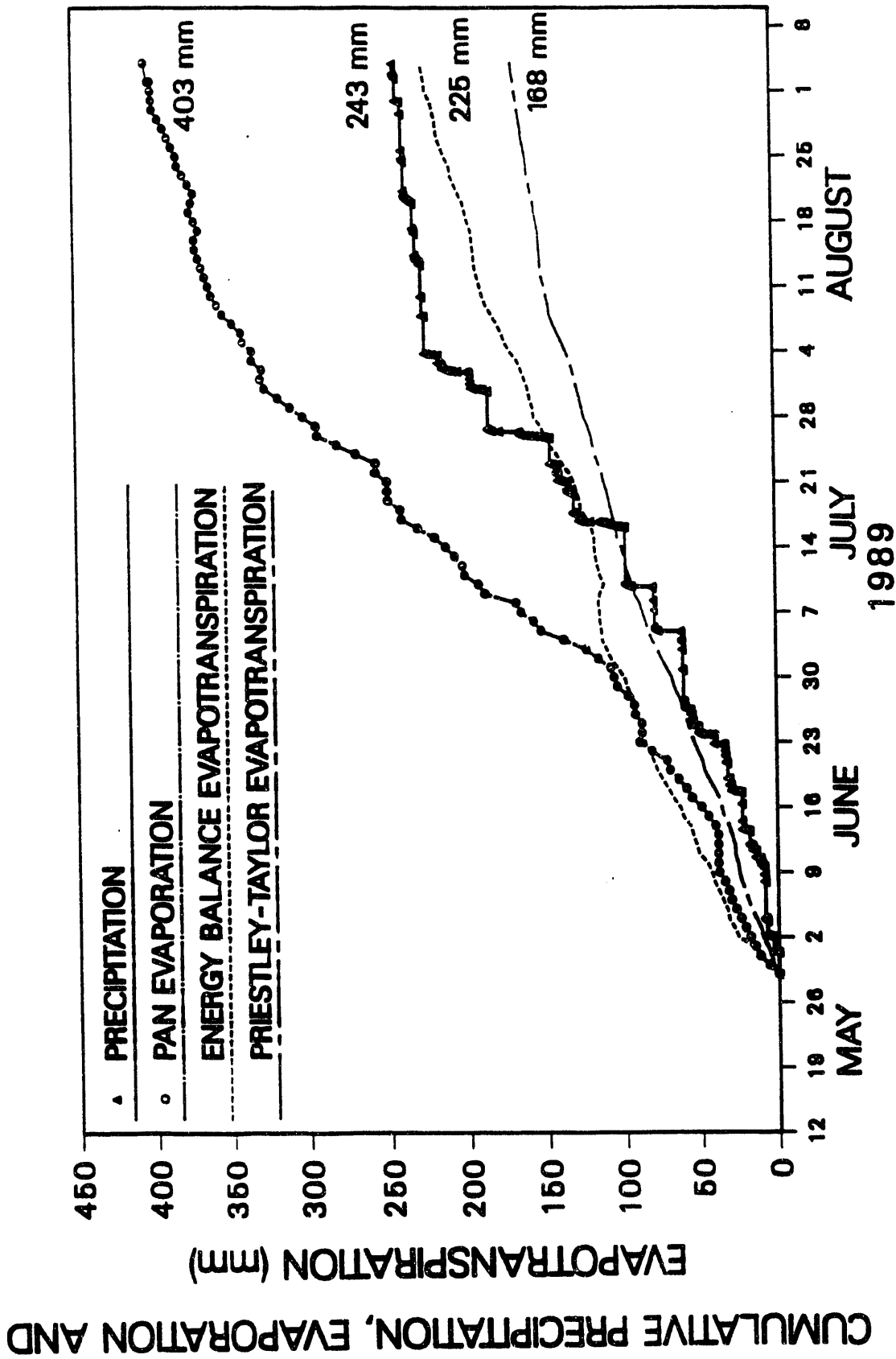


Figure 4. Comparison of precipitation, pan evaporation and calculations of evapotranspiration during the summer of 1989.

TABLE 5. Rainfall events that produced minimal runoff.

Date	Precip (mm)	Runoff (mm)	5 Day Antecedent (mm)	10 Day Antecedent (mm)
<u>1986</u>				
Jun 18-Jun 26	12.75	0.8	0.0	0.24
Jul 9-Jul 11	12.75	0.04	0.0	0.24
Jul 13-Jul 21	15.14	0.3	12.75	12.75
<u>1987</u>				
Jun 26-Jun 27	13.7	0.0	0.0	2.2
Jul 10-Jul 11	12.6	0.0	0.0	7.5

off and for a short time after. Calcium, Mg, suspended solids and electrical conductivity all reach broad peaks in mid-summer. Only pH shows a relationship to discharge. On a seasonal basis a substantial charge imbalance favoring cations occurs. It seems probable that the, as yet, unmeasured negative charge is associated with organic anions. No seasonal trends were recorded for Mg, K or Mn in subsurface flow in the surrounding slopes. Calcium, Fe, and Al showed a late season peak, and the concentration of Na and Si decreased as the melt season progressed (Everett et al., 1989).

Almost all biological activity in the far north regions takes place within a shallow zone above the permafrost called the active layer. In Imnavait watershed the active layer is an extremely variable multilayered system consisting of a mat of mosses and sedges on about 10 cm of organic soil over a silt. The layer of organic soil tends to mollify thermal and hydrologic fluctuations below it. We found the temporal pattern of soil moisture and temperatures in the active layer were consistent year to year, but ranged greatly from season to season. The volumetric moisture content of the organic soil varied by up to 60%, but the mineral soil remained near saturation throughout the year. The hydraulic conductivity of the organic soils is 10 to 1000 times greater than the silts below it, and most downslope drainage occurred in the organic soils (Table 6.) (Hinzman et al., 1990).

The thermal conductivity of the soils depend upon the phase and amount of the moisture present. The thermal conductivity of a saturated organic soil decreased by 50% upon thawing. the saturated mineral soil decreased by about 30% after thawing (Figure 5.). Regardless of the temperature of moisture content, the organic soil has a lower thermal conductivity than the mineral soil and will serve as a layer of insulation to the permafrost.

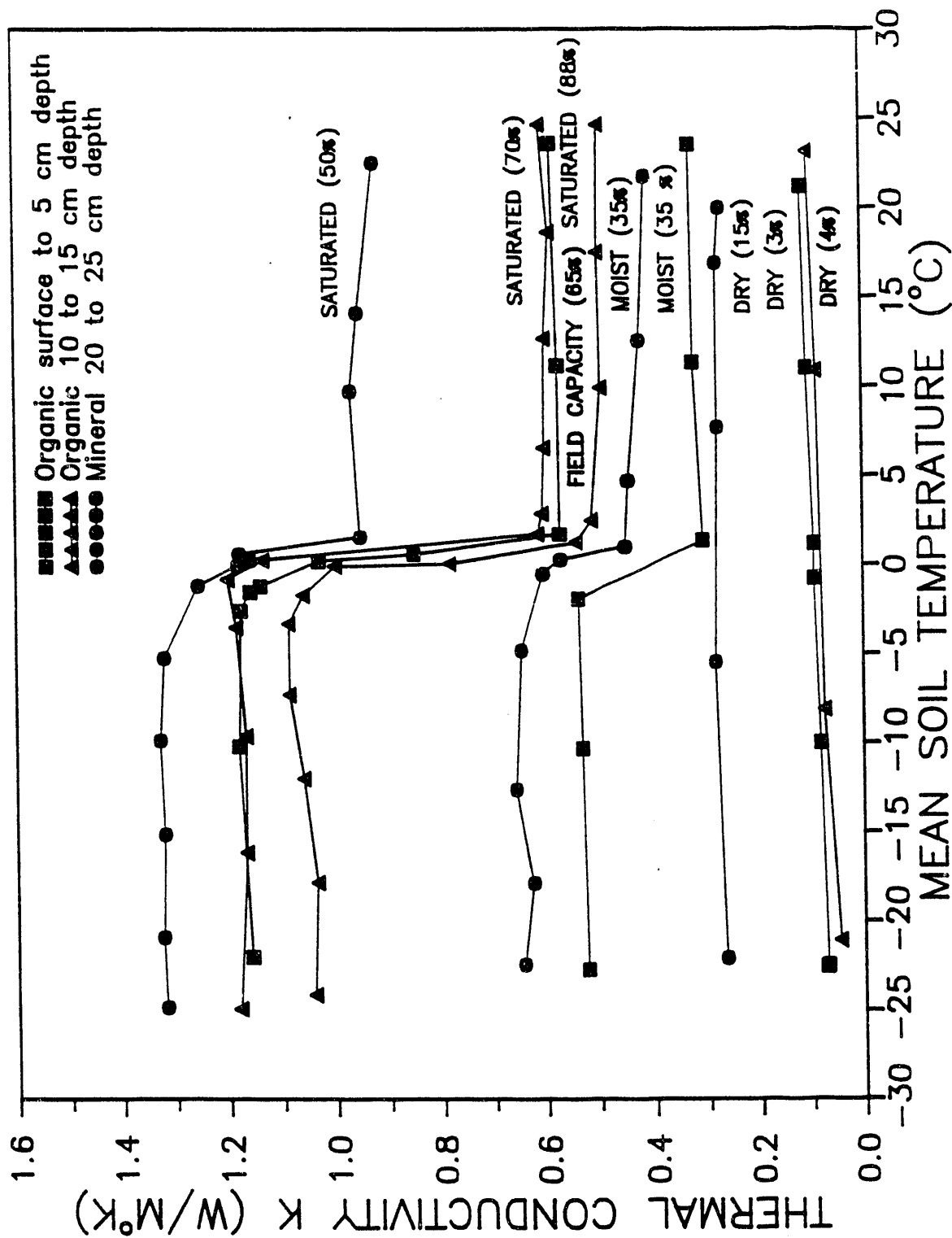


Figure 5. Laboratory measurements of effective thermal conductivity of active layer soils as a function of temperature, soil type and moisture content.

Table 6. Summary of the physical properties of soil samples taken from Imnavait watershed.

Horizon Type	Depth (cm)	Hydraulic Conduct. (cm/s) (10 ⁻³)	Range (cm/s) (10 ⁻³)	Bulk Density (g/cm ³)	Range (g/cm ³)	Porosity	No. of Samples
organic	0-5	19.4	16-22	0.15	0.13-0.16	0.90	4
organic	5-10	10.4	1.1-12	0.18	0.16-0.18	0.86	3
org/min	10-15	3.76	0.4-3.4	1.39	1.38-1.40	0.70*	3
mineral	15-20	0.87	0.08-2.6	1.53	1.43-1.57	0.55*	6
mineral	20-25	1.42	0.6-3.7	1.33	1.30-1.42	0.54*	3
mineral	25-40	0.94	0.13-3.3	1.40	1.36-1.43	0.46*	3

* Values determined from TDR when soils were saturated.

The topic of global warming is currently being explored by many researchers world wide. We have used our data base and knowledge of the physical systems at Imnavait basin gleaned from our process-oriented research to formulate potential response of an arctic watershed during a period of global climatic change.

Existing climate models predict that the greatest change from present climatic conditions will happen in the polar regions. In the Arctic, continuous permafrost exists and climatic warming could have severe consequences. We examined the consequence of global warming on the active layer using a finite element, two dimensional, heat conduction model with phase change to predict the soil temperatures. After verification that the model could be used to with confidence to predict the soil thermal regime, various climatic warming scenarios were used as input to estimate the thermal response for the next 50 years. Results show that an increase in the average annual soil surface temperature of 2°C increases the active layer thickness at Imnavait Creek by about 20 cm after 50 years. A 4°C change increases the active layer thickness by about 40 cm and increases of 6 and 8°C greatly increase the active layer thickness and eventually produce a talik (Figure 6). These simulations indicate that an increase in surface temperature of approximately 4.5°C will be enough to ultimately thaw the permafrost in this area (Kane et al. 1990c).

The formation of a talik would allow subsurface water flow to persist throughout the winter, which would have substantial impact upon soil moisture levels and streamflows. Hydrologically, in a scenario of climatic warming, snow ablation would be earlier (Figure 7), snow deposition would be less frequent in the summer and later in the fall, evapotranspiration would increase and cumulative runoff would decrease. Superimposing precipitation increases on the warming scenarios would increase soil moisture, cumulative evapotranspiration and cumulative runoff (Figures 8, 9 and 10). Decreasing precipitation would have the opposite effect (Kane and Hinzman 1990).

PREDICTED THAW DEPTH

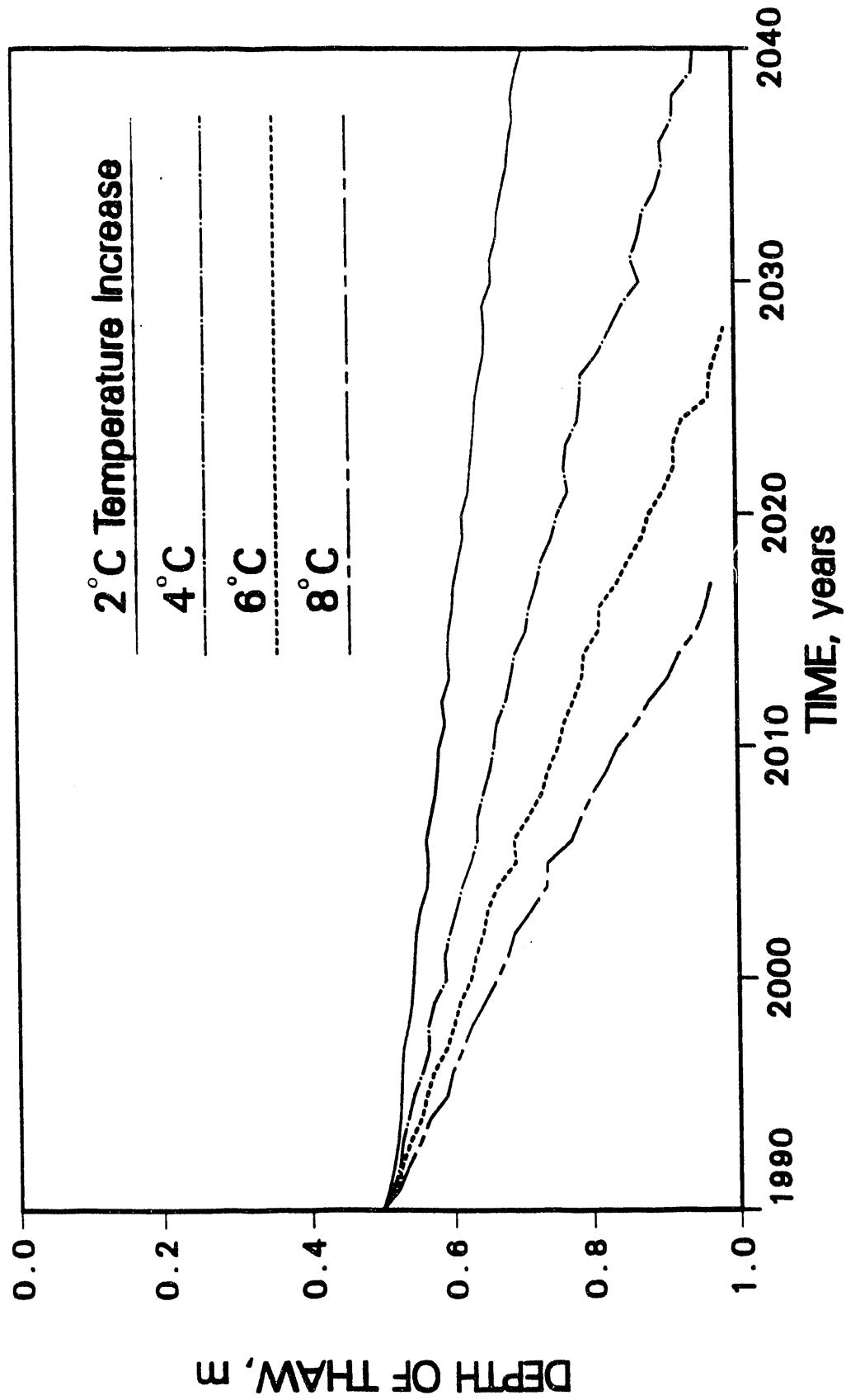


Figure 6. Increased depth of thaw of the active layer in response to each climatic warming scenario over 50 years.

EFFECT OF CLIMATIC WARMING ON SNOW ABLATION

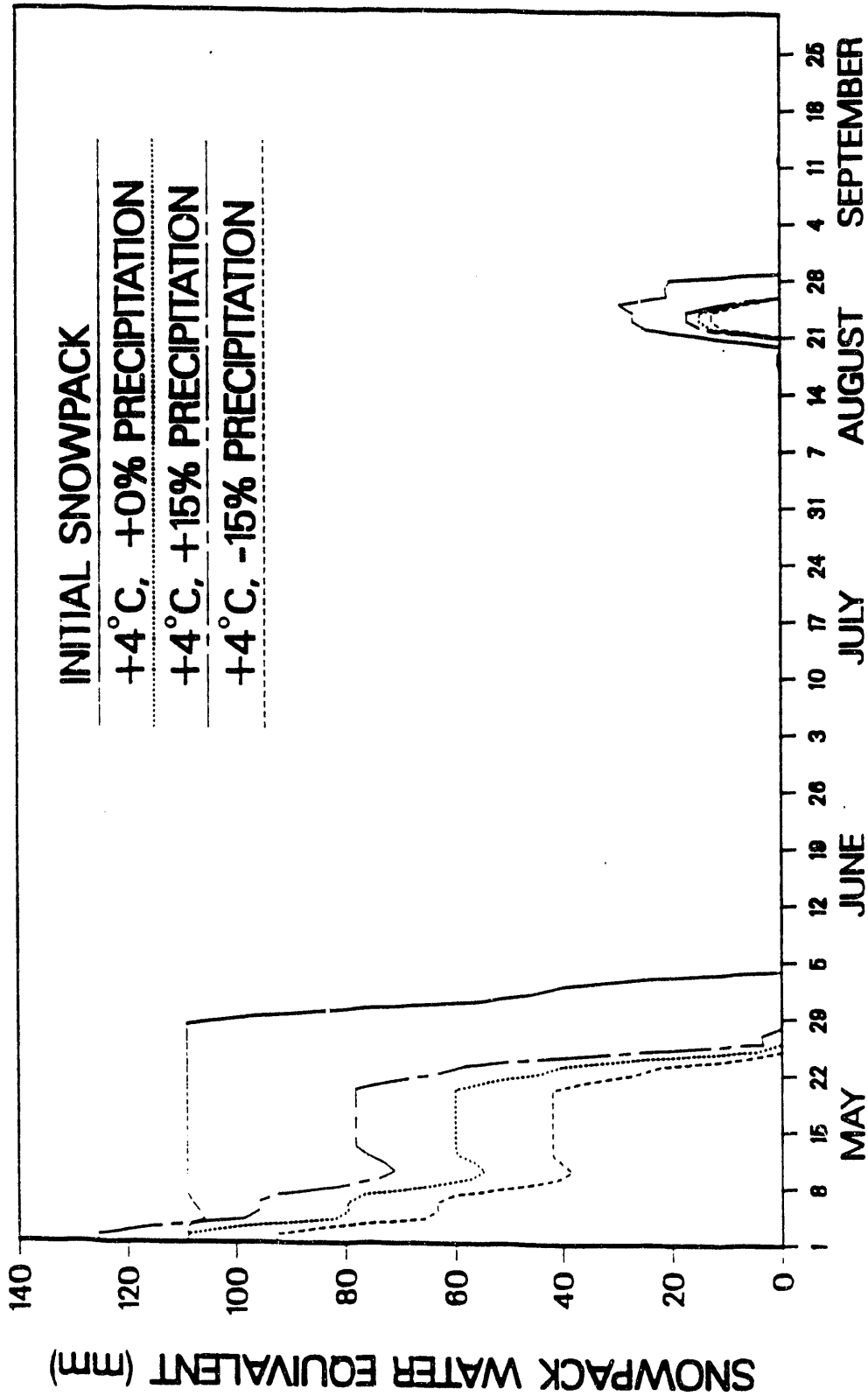


Figure 7. Effect of climatic warming on snow ablation.

EFFECT OF CLIMATIC WARMING ON SOIL MOISTURE

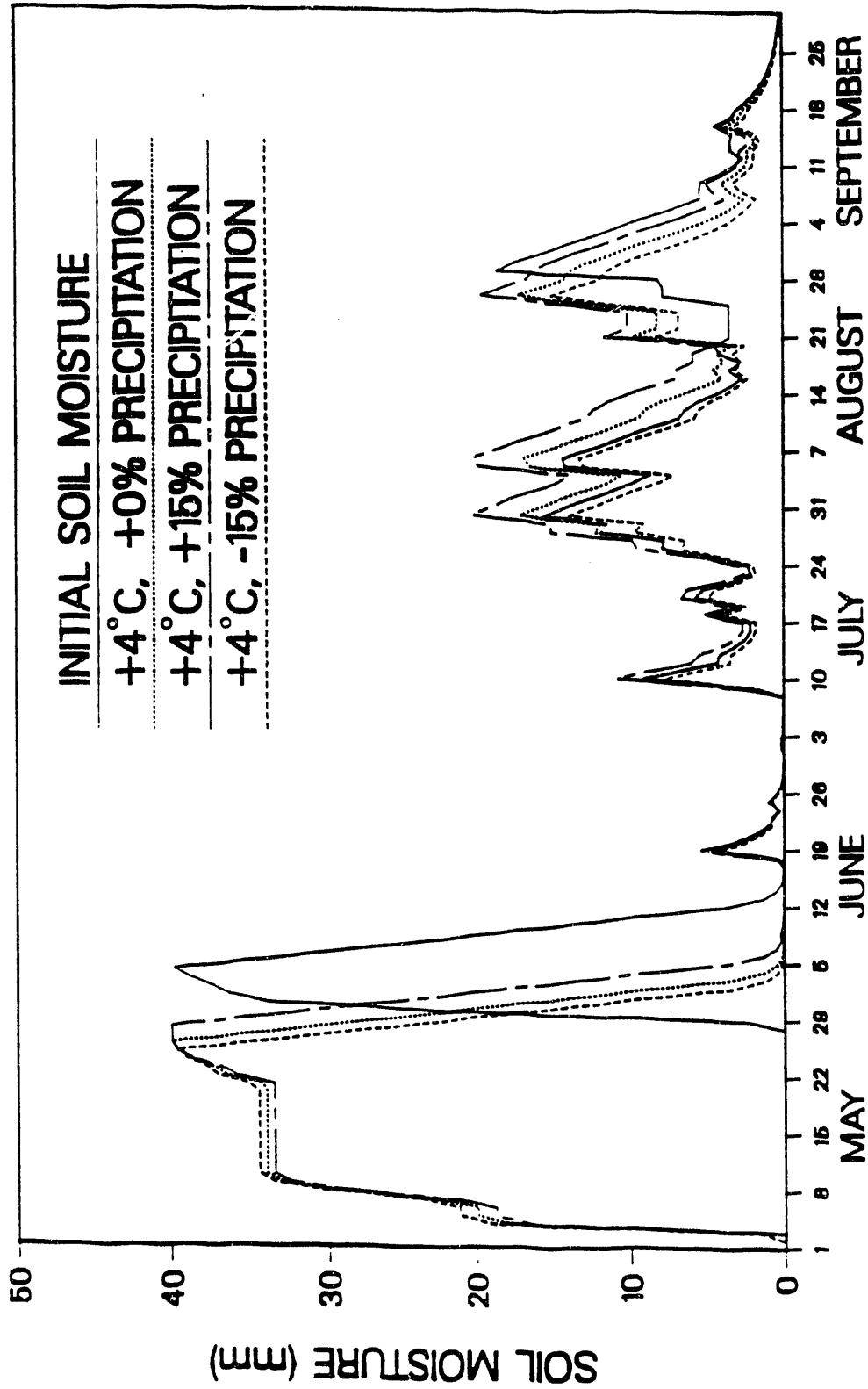


Figure 8. Effect of climatic warming on soil moisture.

HYDROLOGIC RESPONSE TO CLIMATIC WARMING

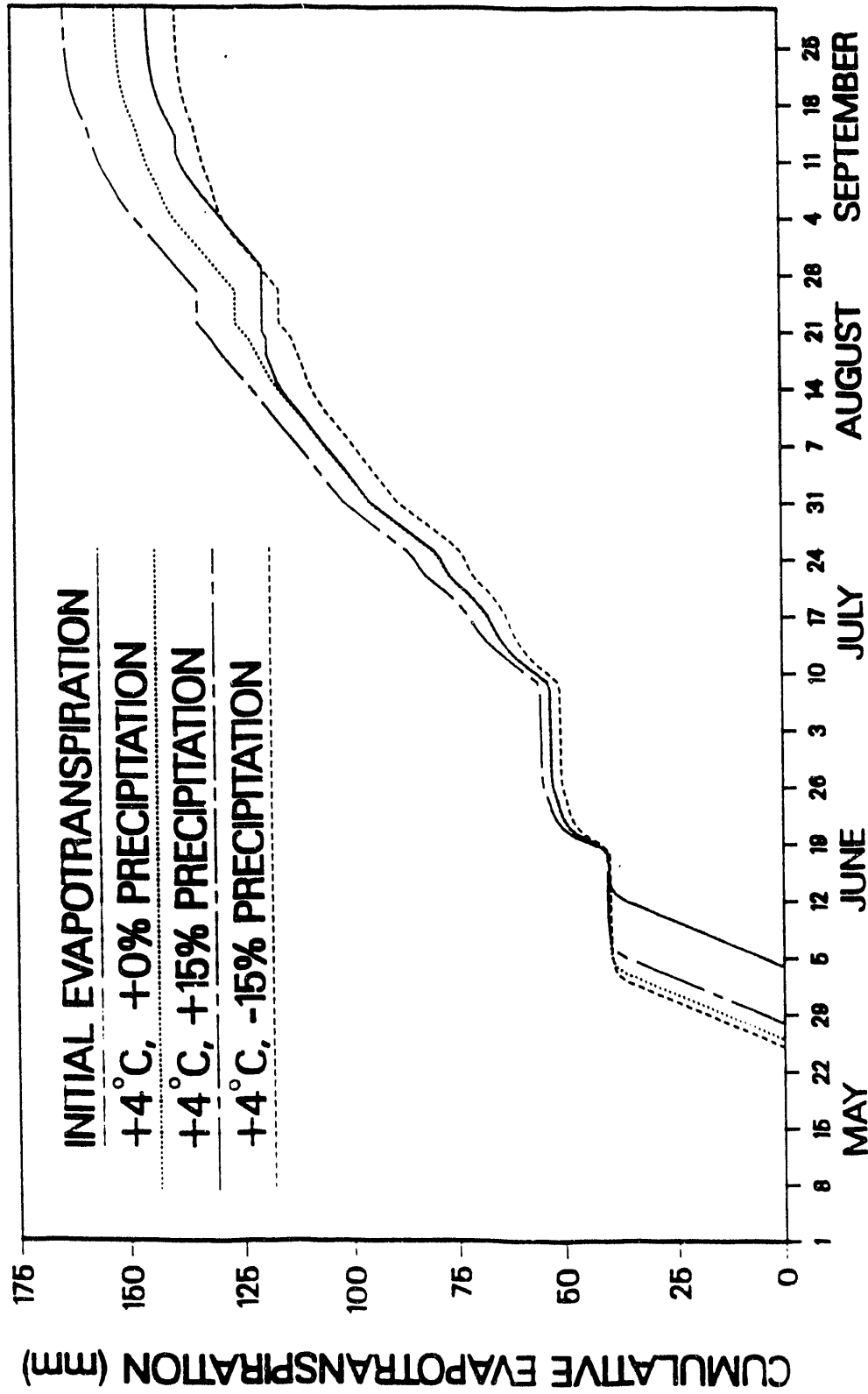


Figure 9. Effect of climatic warming on evapotranspiration.

EFFECT OF CLIMATIC WARMING ON TOTAL RUNOFF

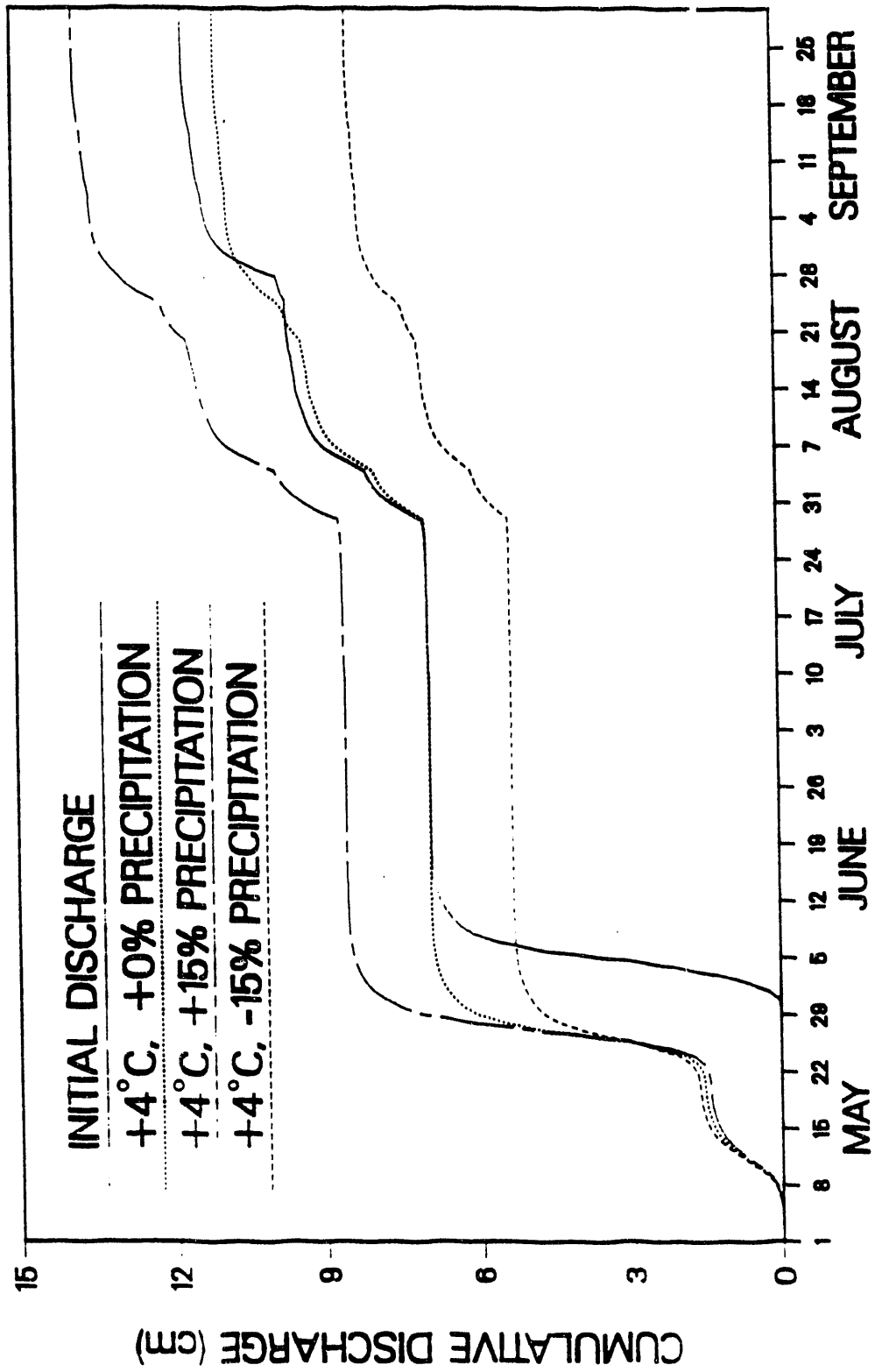


Figure 10. Effect of climatic warming on total runoff.

Two issues that could dramatically alter these results are the response of the vegetation and cloud cover. Although the snow free period will increase, it does not appear that it will be beneficial to the plants. Most of the change will occur in the fall when the plants are responsive to light conditions. Clouds could significantly alter the surface energy balance by reducing shortwave radiation; possibly offsetting atmospheric warming (Kane et al., 1990d). In response to climatic warming, thickening of the active layer will increase the soil-water storage capacity. If massive ice in the soils melt, there would be additional runoff associated with this and there could be additional surface storage in depressions created by the subsiding surface.

A doctoral dissertation was completed by Larry D. Hinzman based primarily on the research at Imnavait Basin. In this work Dr. Hinzman discussed the hydrologic and thermal regimes of Imnavait Creek (Hinzman, 1990).

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