THE INFLUENCE OF SUMMERTIME PRECIPITATION EVENTS ON MELTWATER PRODUCTION IN THE KARAKORAM, NORTHERN PAKISTAN

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ABSTRACT

The majority of water production in the Upper Indus Basin (UIB) comes from snow and ice melt in the high mountains of the Karakoram. Pakistan depends heavily upon the waters of the UIB for power generation, irrigation and water supply. A fundamental step necessary to improve runoff prediction capabilities is to improve our understanding of the physical processes which govern meltwater production in the UIB. The focus of this paper concerns the influence of summertime precipitation events on meltwater production in the Karakoram. Precipitation data collected in the Biafo Glacier Basin and in the Kaghan Valley suggest that summertime precipitation events in the Karakoram are often derived from monsoonal sources. Water discharge measurements from two gauging stations on the main stem of the Indus River show a dramatic drop in discharge during summertime precipitation events in the Karakoram, even though these storms can be accompanied by heavy rainfall at lower elevations. This indicates that energy inputs are the fundamental control on the temporal variation of runoff from the UIB during the summer melt period.

INTRODUCTION

The majority of water runoff from the Upper Indus Basin (UIB) comes from snow and ice melt in the high mountains of the Karakoram. Pakistan depends heavily upon the waters of the UIB, which flow into the Tarbela Reservoir (Figure 1), for power generation, irrigation and water supply. Seventy to eighty per cent of the total annual runoff entering the Tarbela Reservoir originates from melting of seasonal snowcover and glacier ice at elevations above 3500 m above sea level (asl). Glacier basins are concentrated along the northern edge of the watershed, especially in the Karakoram Himalaya . This mountain range contains over 15,000 km^2 of perennial snow and ice (Mercer, 1975). The overwhelming role the Karakoram plays in the hydrology of the UIB draws attention to the snow and ice conditions in this mountain range.

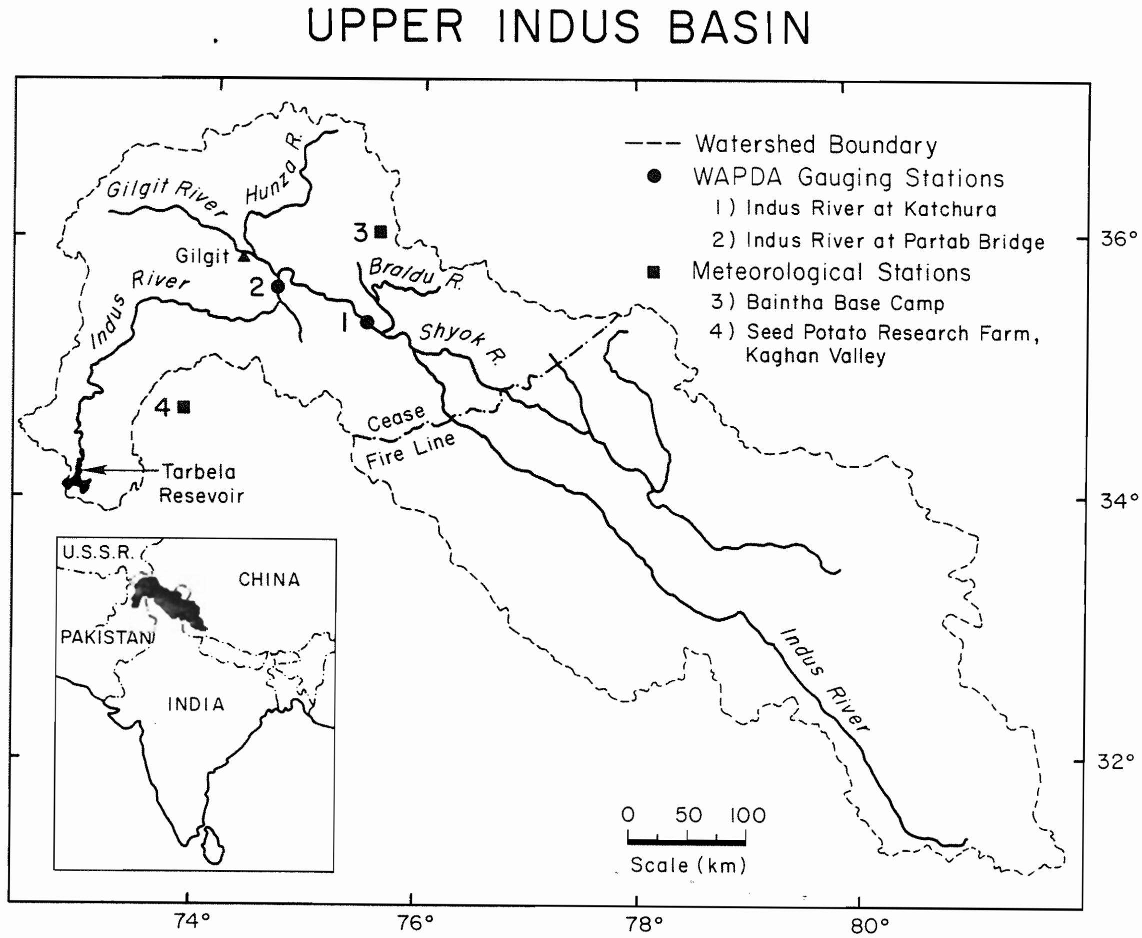

Figure 1. Map of the Upper Indus Basin (UIB) watershed with major rivers. The UIB watershed above Tarbela Dam covers an area of 164, 000 km^2. The data presented in this paper comes from water discharge gauging sites at Katchura and Partab Bridge and meteorological stations at Baintha Base Camp (4080 m) in the Biafo Glacier Basin and the Seed Potato Research Farm (2670 m) in the upper Kaghan Valley.

Within the Karakoram, there exists strong altitudinal gradients in precipitation. Rain shadowing by surrounding high mountains and powerful valley wind systems result in severe desiccation of valley bottoms. This is most apparent below 3000 m asl. For example, annual precipitation at 5000 m asl in the central Karakoram during 1985-1986 was about 1.9 m water equivalent (Wake, 1989), while the mean annual precipitation at Gilgit (1490 m) from 1952-1982 was 0.13 m (Whiteman, 1985). It is precipitation falling at elevations above 3500 m asl, generally in the form of snow, that creates the only large moisture surplus for the region. However, precipitation records for the UIB come from weather stations which lie well below 3500 m asl, mostly in semi-arid and arid valley locations (Butz and Hewitt, 1986). Precipitation records from these valley stations provide little indication of precipitation events at higher elevations. Therefore, in order to confidently determine the influence of summertime precipitation on meltwater production in the Karakoram, we must look at meteorological records from elevations above 3500 m asl.

Summertime precipitation events can exert a negative influence on the production of meltwater from glacierized basins for two reasons: incoming solar radiation is reduced during precipitation events and, when precipitation occurs as snowfall surface albedo increases, thereby altering the energy balance at the snow surface and reducing the amount of energy available to melt snow and ice (Young 1977; Rothlisberger and Lang, 1988) This paper provides a review of some unique meteorological and snow accumulation data collected in the central Karakoram and upper Kaghan Valley during the summer melt period in 1985 and 1986, and compares it to water discharge records for the UIB. The results hold important implications for the development of any forecasting model which attempts to predict runoff from the UIB.

REGIONAL PRECIPITATION PATTERNS

The climate of the Karakoram is dominated by the influx of westerly air masses (Barry and Chorley, 1982). Throughout the winter, the subtropical westerly jet stream steers depressions toward the Karakoram and Northern India. These lows appear to penetrate across the Middle East from the Mediterranean Sea and the Atlantic Ocean. During the winter the jet stream is split into two distinct branches; one passing to the north and the other to the south of the Tibetan Plateau. In May and June the jet stream slowly weakens, and by mid-June is altogether diverted to the north of the plateau. While the regional air stream continues to be influenced by the westerlies, temporary destruction of the Tibetan anticyclone can result in the incursion of monsoonal air masses into the Karakoram, resulting in heavy precipitation. We know from our own experiences during late summer in 1985 and 1986 that significant amounts of snowfall can occur in the northern portions of the basin during the summer.

During the summer of 1985 and 1986, as part of the field research undertaken by the Snow and Ice Hydrology Project, meteorological data was collected at an on ice station at 4080 m asl, adjacent to Baintha Base Camp (Figure 1) in the Biafo Glacier basin. Precipitation was measured daily using a standard five inch rain gauge. In addition, incoming shortwave radiation was measured hourly from 08:00 to 17:00 hours using a Kipp and Zonen Pyranometer. Detailed descriptions of site characteristics and meteorological data collected appears in Wake (1985; 1986). Reliable precipitation measurements are also available for 1985 and 1986 from the Seed Potato Research Farm at Battakundi (2670 m asl; 34° 39' N, 73° 32'W; unpublished data). This station lies in the upper Kaghan Valley, approximately 240 km south-west of Baintha Base Camp, in the foothills of the western Himalaya (Figure 1). During the summer (July through September) this region is dominated by precipitation derived from the south-west Indian monsoon (WMO, 1977; de Scally, 1989).

Precipitation in the Karakoram is almost always preceded or accompanied by precipitation in the upper Kaghan Valley (Figure 2), indicating that summertime precipitation events in the Karakoram are often derived from monsoonal sources. This data supports conclusions derived from an analysis of the physical and chemical stratigraphy of the snowpack in the central Karakoram (Wake 1989), which suggest that thirty to fifty percent of net annual accumulation above 4500 m asl in the central Karakoram occurs during the summer and that much of this moisture is derived from the Arabian Sea and then transported to the Karakoram by monsoonal circulation

KARAKORAM GLACIERS AND WATER DISCHARGE RECORDS

The Water and Power Development Authority (WAPDA) in Pakistan routinely measures water discharge at many locations in the UIB. The discharge data presented in this paper comes from two gauging stations on the main stem of the Indus - the Katchura and Partab Bridge gauging sites (Figure 1). Both watersheds are characterized by a large percentage of glacierization. The drainage basin area and mean annual discharge for these gauging stations appears in Table I.

Table I.

Gauging Station	Area (km2)	Mean Annual Discharge* (km3)	Period of Record*
Indus River at Katchura	112,700	34.8	1970-1986
Indus River at Partab Bridge	142,700	59.5	1966-1986

*Data from Pipes and Quick (1986)

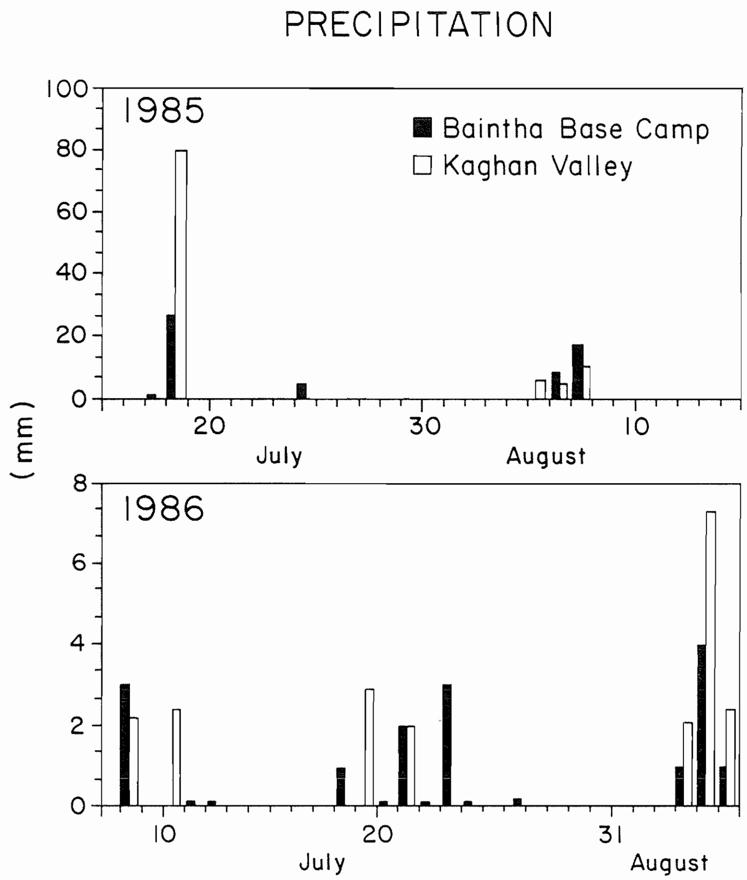

Figure 2. Comparison of summertime precipitation records from Baintha Base Camp (4080 m) in the Biafo Glacier Basin and the Seed Potato Research Farm (2670 m) in the upper Kaghan Valley. Note that precipitation in the Karakoram is almost always accompanied or preceded by precipitation in the Kaghan Valley. As the majority of summertime precipitation in the Kaghan valley is supplied by the Indian monsoon, the data suggests that summertime precipitation in the Karakoram is often derived from monsoonal sources.

The Katchura and Partab Bridge gauging sites are characterized by discharge hydrographs which show the majority of runoff occurring during the warm summer melting period from mid June to early September (Figure 3), indicating that their flow is dominated by melt water from glacier basins. About eighty to ninety percent of water discharge occurs after snow cover has disappeared from areas below 4500 m asl and at a time when rapid melting takes place between 3000 and 4500 m asl, on the middle and lower zones of the glaciers. During July and August melt rates in relatively clean ice range from 80-100 $mm \cdot d^{-1}$; this accounts for the major contribution to water discharge from the glacier basins during this time period (Hewitt and others, 1989).

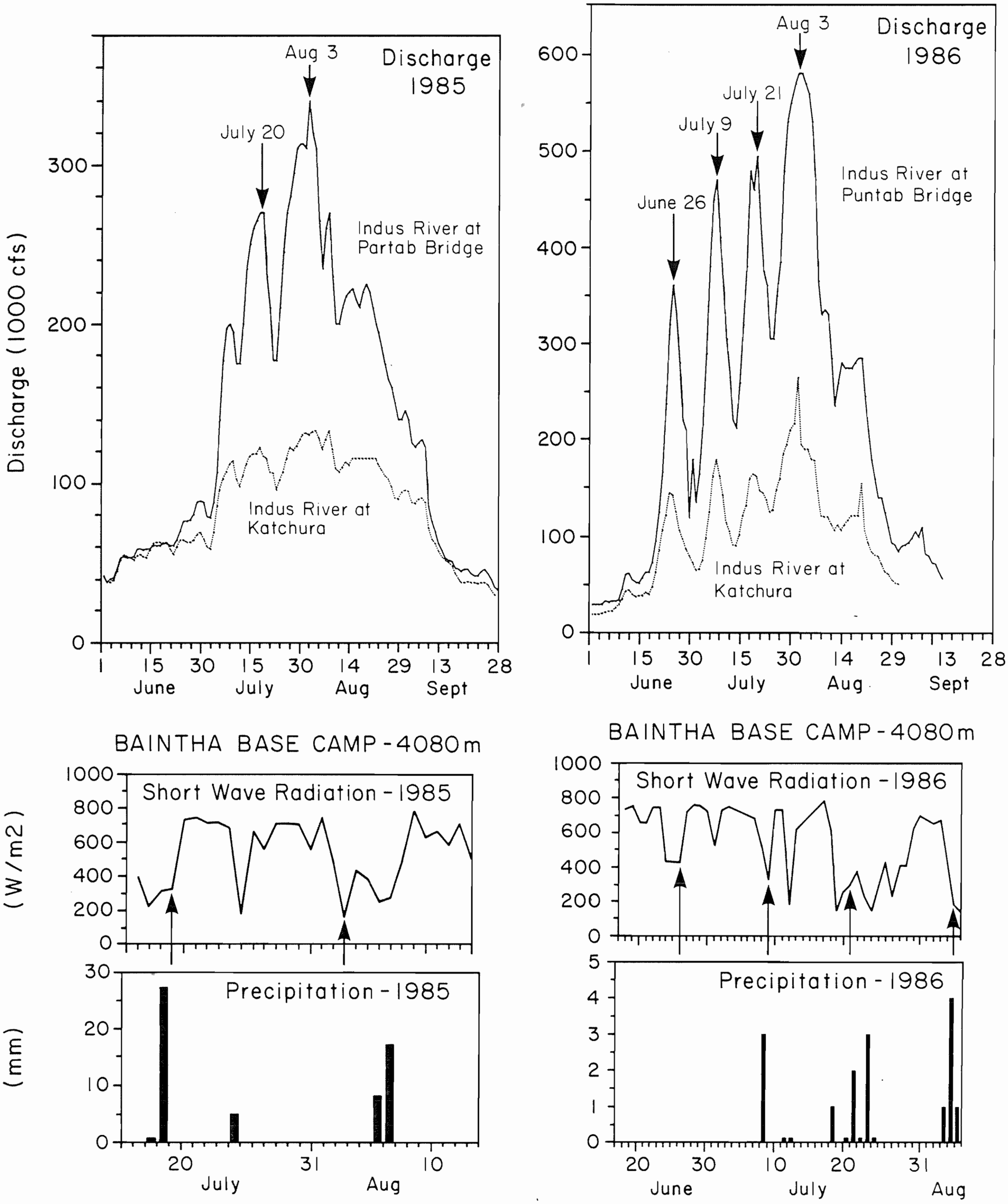

Figure 3. Water discharge records and meteorological data from the Upper Indus Basin for summers (A) 1985 and (B) 1986. The solid arrows identify rapid decreases in water runoff accompanied by a precipitation event and/or a decrease in incoming shortwave radiation. Note the scale change for water discharge and precipitation between the records from 1985 and 1986.

DISCUSSION

Over the course of two summers in the Karakoram (1985 and 1986) there were six rapid decreases in water discharge from the Upper Indus Basin, five of which are associated with summertime precipitation events (Figure 3). Each of these six events is discussed below.

1. July 20-23, 1985:

Incoming shortwave radiation decreased sharply on July 17. Rain at Baintha Base Camp (BBC) began on July 18 and was very heavy on the July 19. Total precipitation for two days was 28 mm. From July 20-23 water discharge in the Indus River decreased by 21% and 23 % at Katchura and Partab Bridge gauging stations, respectively.

2. August 3-5, 1985:

Incoming shortwave radiation decreased sharply on Aug 3 and remained low until August 8. It rained at BBC from August 6 to 7 with total precipitation of 25 mm. On August 3, approximately 80 mm of snow fell at 5000 m asl in the accumulation zone of the Biafo Glacier. It then snowed heavily from August 5 to 7 with total accumulation of 280 mm of snow. From August 3-6 water discharge in the Indus River decreased by 9% and 27% at the Katchura and Partab Bridge gauging stations, respectively. From August 8-10 discharge at the gauging sites decreased by 19% and 26%.

3. June 26-30, 1986:

Incoming short wave radiation decreased sharply on June 25. No precipitation was recorded at BBC, however discharge measured at the Katchura and Partab Bridge gauging stations decreased by 35% and 65%, respectively.

4. July 9-14, 1986:

Incoming shortwave radiation decreased on July 9 and again on July 12. Precipitation on July 9 totaled 3 mm. There was trace precipitation on July 12 and 13. Discharge in the Indus River decreased by 50% and 55% at the Katchura and Partab Bridge gauging stations, respectively.

5. July 21-25, 1986:

Incoming shortwave radiation was low from July 14-24. Precipitation from July 19-24 totaled 6 mm at BBC. Discharge in the Indus River decreased by 22% and 39% at the Katchura and Partab Bridge gauging stations, respectively.

6. August 3-8, 1986:

Incoming shortwave radiation decreased sharply on August 3 and 4. Precipitation from August 4-6 totaled 6 mm. This was accompanied by heavy snowfall at higher elevations (Hewitt, pers. comm., 1986). Discharge in the Indus River decreased by 55% and 44% at the Katchura and Partab Bridge gauging stations, respectively.

The relationship between summertime precipitation events and rapid decreases in discharge for rivers draining the UIB indicates that energy inputs, necessary to melt snow and glacier ice, are the primary control on meltwater production in the headwaters of the Indus River. The actual precipitation that falls during these events is insignificant in moderating the sharp decrease in water production resulting from a decrease in the amount of energy available to melt snow and ice.

CONCLUSIONS AND PERSPECTIVES

Comparison of meteorological and discharge data for the summer melting period during 1985 and 1986 clearly illustrates that summertime precipitation events above 3500 m asl in the Karakoram result in a substantial decrease in water discharge from rivers draining the Upper Indus Basin, even though these events can be accompanied by heavy rainfall at lower elevations. The reaction of the UIB to these summertime precipitation events indicates that during the summer melt period energy inputs are the fundamental control on temporal variation of runoff from the UIB.

In order to confidently predict runoff from the UIB, it is therefore important to measure precipitation inputs at elevations above 3500 m asl. For any model that attempts to predict runoff from the UIB, it would also be advantageous to incorporate short term weather forecasts for northern Pakistan and north-western India in order to forecast summertime precipitation events in the Karakoram. This would allow for prediction of water runoff from the Upper Indus Basin on a proactive rather than a reactive basis.

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