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Remote sensing for prediction of floods in the Jhelum River and the significance of the Pir Panjal depression

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ABSTRACT

The Mangla Dam is constructed across the Jhelum River in Pakistan and has a catchment area of about 33,334 sq km. It is also fed by the Neelum, Kunhar, and Punch Rivers. Flooding downstream of the dam is a recurring phenomenon. The Jhelum River originates in the Pir Panjal depression and covers an area of 12,650 sq km. The depression constitutes about 38% of the Mangla Dam's overall catchment area and 65.5% of the Jhelum River's sub-catchment area.

The satellite imageries, meteorological data, vegetation cover, and thermal infrared images indicate that the depression has its own typical characteristics and an equally anomalous response, particularly in terms of water discharge. The floodwater from the Pir Panjal depression constitutes less than 50% of the Mangla Reservoir's summer discharge.

Vigilant remotely sensed information and images from weather satellites, water flow measurements at strategically located ground stations, and close coordination amongst the Irrigation Department, water management authorities, the Meteorological Department, and in particular with the agencies acquiring remotely sensed data may provide a practical remedy for the recurring calamity downstream of the Mangla Dam.

INTRODUCTION

The Jhelum River originates in the Kashmir Valley (the so-called Pir Panjal depression) from a deep spring at Vernag. It meanders northwestwards from the northern slope of the Pir Panjal Range and southwestwards from the Wular Lake. The Jhelum River is 177 km long in the depression. It takes an acute turn towards the south at Muzaffarabad, and the Mangla Dam is constructed across it further downstream near the Jhelum Town in Pakistan (Fig. 1).

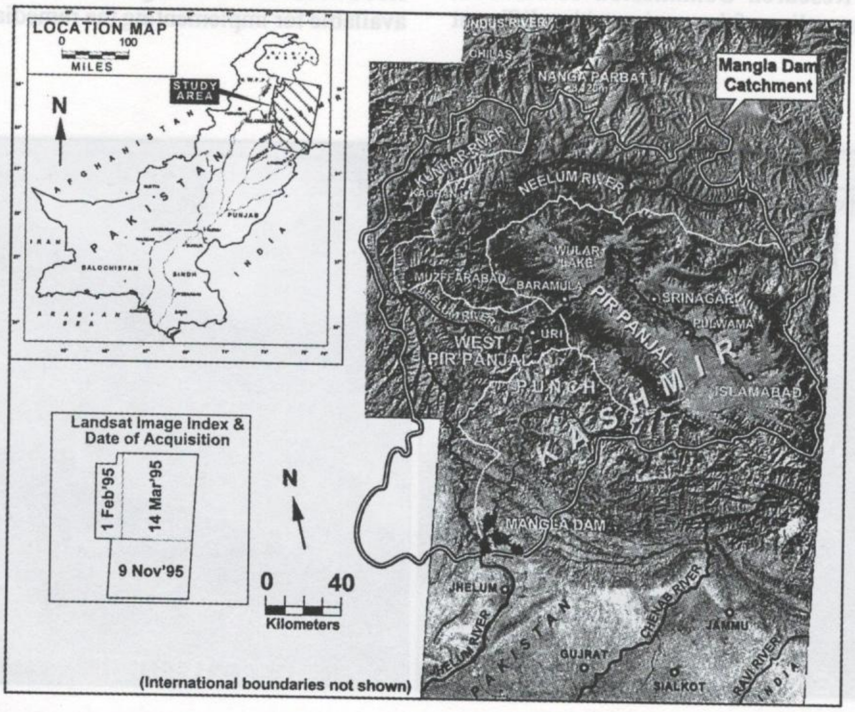

Fig. 1: The Mangla Dam catchment area. Note the relative size of the Pir Panjal watershed as interpreted on a mosaic of Landsat's false colour composite.

The Wular Lake occupies the lowest part of the large NW–SE oriented leaf-shaped Pir Panjal watershed, which is an important feature of the hydrographic system of Kashmir. Normally, the surface area of the lake is 16 km x 10 km, and varies from 30 to 260 sq km depending on the season. The lake controls the outflow of the Upper Jhelum River. The ancient name of the lake was Karewa–the name given to the Karewa Formation of mostly glacial origin of Pleistocene age. At the height of the Ice Age, it had an area of more than 7,800 sq km. The lake existed intermittently during the warm interglacial periods of melting ice and periodically filled the whole valley of Kashmir from end to end to a depth of more than 300 m (Wadia 1979). The depression, surrounded by a ring of high mountains, provides a perfect closed catchment and most of the runoff in the valley eventually reaches the Wular Lake. The watershed has a 2,100 m deep gorge with almost vertical walls in the northwestern part of the Pir Panjal Range, through which the lake water is drained into the Jhelum River.

The interpretation of a mosaic of Landsat imagery on 1:1,000,000 scale covering the northeastern part of Pakistan and Kashmir highlighted the typical shape of the Pir Panjal depression (Fig. 2) and its large size relative to the overall catchment area of the Mangla Dam (Fig. 1). The depression is contoured in the FEP Atlas (1993) with the highest mean annual rainfall exceeding 2,000 mm in its central part. The valley has a very cool and sub-humid climate with an average summer monsoon precipitation of 1,000 mm or more, along with an extensive vegetation cover. The NOAA thermal infrared images of the region obtained from the Space and Upper Atmosphere Research Commission of Pakistan (SUPARCO) show the outline of depression with a different temperature response (e.g. NOAA -11, dated 18 February 1989 @ 1325 PST). All these combinations of physiographic and meteorological characteristics indicate that there should be an equally anomalous response, particularly in terms of floodwater contribution of the Pir Panjal depression.

THE PIR PANJAL DEPRESSION

The Pir Panjal depression is a tectonic basin, which also contains old glacial deposits. This depression with a NW–SE oriented larger axis extending for about 180 km, has an average valley-floor width of 30–35 km. However, a maximum width of the catchment is 65–70 km and it covers an area of about 12,650 sq km. The Jhelum River continues westwards from the southwestern corner of the lake where a water regulator is present, and carries with it the remaining runoff through a single gorge in the northwestern part of the Pir Panjal Range located just west of the town of Baramula.

The total discharge of the Pir Panjal catchment area constitutes a major part of the runoff, which contributes to the Wular Lake as well as the Mangla Reservoir, and eventually to the downstream flooding of the Punjab plains in Pakistan.

In this typical physiographic and meteorological setting, monitoring of the cloud pattern and rainfall in the upper reaches of the Jhelum River (particularly, over the Pir Panjal depression) can be of great assistance in estimating the rainfall and expected flood contribution from this sub-basin. This will also help predicting the lag time by which a certain flood reaches the Mangla Reservoir, and hence the time available for implementing the remedial measures.

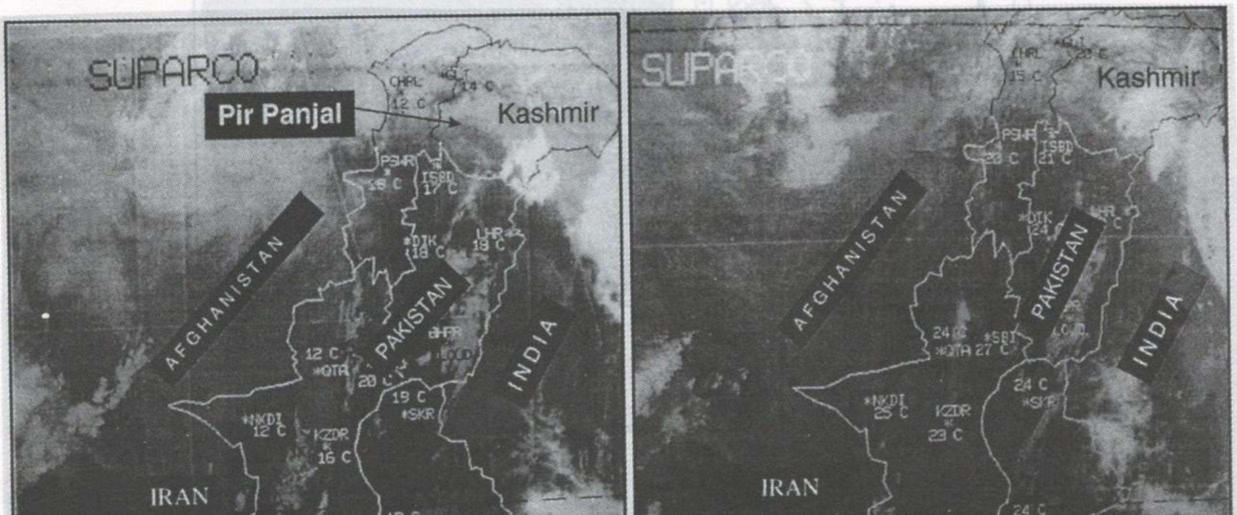

Fig. 2: A comparison of NOAA Weather Satellite images. Pir Panjal depression is fully exposed in the left image (04:10 PST), while the clouds have partly covered the oval shape in the next image (08:37 PST) on the right.

The Pir Panjal depression constitutes about 38% of the overall Mangla Dam catchment area but, because of the highest mean annual rainfall in this watershed, its cumulative water contribution is estimated at 50% of the total annual inflow into the Mangla Reservoir (Tables 1 and 2). However, a considerable portion of this water is retained in the Wular Lake and released through a regulator at Sopore. Close monitoring of cloud concentration and rainfall through weather satellites like those of NOAA series, supplemented by ground information of rainfall measurements by weather radar (for real-time flood forecasting), and water measurements on monitoring stations, particularly in summer, could help estimating the floodwater inflow and lag time for a certain discharge into the Mangla Reservoir. An advance notice to the extent of even a couple of hours could be crucial for emergency remedial measures, both at the Mangla Dam and for the civil authorities downstream. Synchronised opening of the Mangla Dam gates would not only empty the reservoir to accommodate any peak floodwater approaching the lake but also allow flowing a calculated amount of discharge downstream of the Mangla Dam.

MANGLA DAM CATCHMENT AREA

The total catchment of the Mangla Dam is spread over an area of about 33,334 sq km. The Jhelum, Neelum, Punch, Kunhar, and their tributaries feed the Mangla Reservoir. A mosaic of Landsat imagery (Fig. 3) shows the shapes and highlights the relative sizes of different sub-catchments of the above four rivers. The catchment area of above rivers, their relative percentage with reference to the total Mangla Dam catchment, and potential annual water contribution from each are shown in Table 1.

Table 1: Comparison of catchment area and the potential water contribution by different rivers to the Mangla Reservoir

Dam catchment [area, sq km] (% of the Mangla catchment)	Sub-catchment [area, sq km] (% of the Jhelum River catchment)	Annual potential water contribution	
		Million acre-feet	%
Jhelum River [19,321], (58 %)	Pir Panjal [12,650], (65.5 %)	14.940	48
	West Pir Panjal [6,671], (34.5 %)	4.995	16
Neelum River [7,356], (22 %)	-	5.110	16
Punch River [4,222], (13 %)	-	3.632	12
Kunhar River [2,435], (7 %)	-	2.470	8
Mangla Dam [33,334], (100 %)	-	31.147	100

Note: An average annual outflow of the Mangla Dam as intimated by DSO (WAPDA) is 22 MAF. The above estimates of 31.147 MAF show the potential water contribution due to rain for a certain year based on regional rainfall contours as provided in the FEP Atlas-1993 and are on the higher side as the interception, evapo-transpiration, soil water storage, groundwater recharge, irrigation, snow melting effect, and the like are not considered. Similarly, the water is also retained in the Wular Lake resulting in a lower figure of 22 MAF.

Table 2: Arial extent and computations of potential annual rainfall in the catchment areas of the four rivers

Catchment (% of the Mangla Dam catchment) [area, sq km]	Sub-catchment (% of the Jhelum River catchment) [area, sq km]	Related area and mean annual rainfall	Cumulative (mean) annual rainfall / runoff **				
			Rainfall, m (mean)	Million m^3	Million acre-feet (MAF)		Contribution to flooding, %
Jhelum River *(58)* [19,321]	Pir Panjal **(65.5)* [12,650]	2,600 sq km receives over 2000 mm (Say 2,250 mm)	2.25	5,850	4.74	14.94	48
		10,050 sq km receives 1000–2000 mm (Say 1,250 mm)	1.25	12,563	10.2		
	West Pir Panjal *(34.5)* [6,671]	3,202 sq km receives 1000–2000 mm (Say 1,250 mm)	1.25	4,002.5	3.245	4.995	16
		3,469 sq. km. receives 500–000 mm (Say 625 mm)	0.625	2,168	1.75		
Kishan Ganga River *(22)* [7,356]	-	2,722 sq km receives 1000–000 mm (Say 1,250 mm)	1.25	3,402.5	2.76	5.11	16
		4,634 sq km receives 500–000 mm (Say 625 mm)	0.625	2,897	2.35		
Punch River *(13)* [4,222]	-	2,955 sq km receives 1000–000 mm (Say 1,250 mm)	1.25	3,694	2.99	3.632	12
		1,267 sq km receives 500–000 mm (Say 625 mm)	0.625	792	0.642		
Kunhar River *(7)* [2,435]	-	2,435 sq km receives 1000–000 mm (Say 1,250 mm)	1.25	3,044	2.47	2.47	8
Mangla Dam *(100)* [33,334]				38,413	31.147	31.147	100

* 38% of the Mangla Dam's total catchment area, and 65% of the Jhelum River sub-catchment area.

** Evapo-transpiration, groundwater recharge, irrigation, and snow melting effects are not considered.

Fig. 3: The shapes and relative sizes of the Jhelum, Neelum, Kunhar, and Punch River catchments, which contribute to the Mangla Dam Lake (the interpretation of the satellite imagery mosaic)

RAINFALL AND VEGETATION

The regional isohyetal maps of the FEP Atlas (1993) were superimposed on the Mangla Dam's catchment map to estimate the mean annual rainfall and resulting runoff for the sub-catchments (Fig. 4). These annual means were added to obtain the total contribution of each river. A range of 1,000–2,000 mm rain was averaged out to 1,250 mm for a period of a year; similarly 500–1,000 mm to 625 mm, and that mentioned to be receiving rain above 2,000 mm in the FEP Atlas was taken as 2,250 mm for the sake of computation of the potential annual volume of water flowing into the Mangla Reservoir (Table 2). The computed potential water contribution and relative catchment areas of different rivers are shown in Fig. 5.

The forest in the depression is also unique and the largest temperate coniferous forest in the region falls within the Pir Panjal depression. It is a lush green heartland of thick pine and fir forests, with fields of rare saffron crocuses and terraces of rice bordering mulberry groves and orchards heavy with apples, pears, plums, and walnuts (Simons 1999).

REMOTE SENSING

A mosaic of Landsat images and its interpretation highlighted the significance of the Pir Panjal depression; similarly, data from National Oceanic and Atmospheric Administration (NOAA) series of weather satellites can be obtained in real time for any timely estimation of rainfall and prediction of expected flood intensity.

NOAA weather satellites

The NOAA series of weather satellites not only provide the time-lapsed pictures for monitoring the cloud movement but also the following meteorological parameters up to an altitude of 35 km:

- Temperature (potential and virtual temperature of clouds);
- Moisture parameters (precipitable water in mm, dew point / temperature);
- Height (dry and moist hydrostatic height of clouds);
- Pressure and altimeter;
- Winds (wind speed or intensity and direction);
- Lifted condensation level (temperature and pressure details);
- Stability indices;
- Layer quantities;
- Station variables (details about location of the ground receiving station); and
- Miscellaneous (density of dry air, cloud pressure, ground temperature, etc).

The data are received in real time and their interpretation can be made available in about 45 minutes (Ziker-ur-Rehman, personal communication 1998). The above applications of NOAA data, particularly for the Pir Panjal depression, in close coordination with conventional ground-based meteorological observations at different stations would greatly help predicting the potential flood intensity and its expected time of arrival in the downstream reaches.

Historical floods

Three major floods (Table 3; Fig. 6) each with a volume of more than 2 million acre-feet (MAF) occurred in 1929, 1958, and 1992. The Mangla Dam was commissioned in 1968, and therefore it received only the 1992 flood. Similarly, the weather satellite (NOAA series) data are available since late 1980s and hence only the 1992 flood can be compared with the so-called *'change pictures'* obtained through NOAA - 9 and 11, which were functional in those days.

Flood of 1992

The flood passed the dam between 9 and 10 September 1992. The peak flows of 0.987 million cubic feet per second (cfs) and 1.09 million cfs were recorded at 17:00 on 9 September and at 04:00 on 10 September, respectively. The total volume of this flood was estimated at 2.70 MAF.

The 1992 flood was characteristically different from the two previous ones, as it depicted two peaks of inflow close to a million cubic feet per second each, separated by only 11 hours. A very sharp peak on the evening of 9 September was followed by another still larger but relatively broader peak in the early hours of 10 September. During this period, the water inflow and outflow of more than 0.30 million cfs (an exceptionally high flood) lasted continuously for about 34 hours.

Table 3: Comparison of the three historical floods of 1929, 1958, and 1992

Year	1929	1958	1992
Month	August	July	September
Dates	28th and 29th	4th and 5th	9th and 10th
Category	Exceptionally high	Exceptionally high	Exceptionally high
Duration of flow exceeding 300,000 cfs (hours)	23	40	34
Cumulative flood volume (MAF)	2.24	3.0	2.7
Number of peaks	One	One	Two
Maximum peak flow (million cfs)	1.05	0.83	i. 0.987, ii. 1.090
Beginning of flood to peak flow (hours)	52	42	i. 17, ii. 28
Characteristics of peak(s)	Slow rise, medium volume, sharp decline. One peak	Medium rise, high volume, gradual decline. One peak	Sharp rise, high volume, sharp decline. Two peaks
NOAA Images	Not available	Not available	Available
Remarks	Natural causes	Natural causes	Human factor cannot be ruled out, which may have caused two peaks.

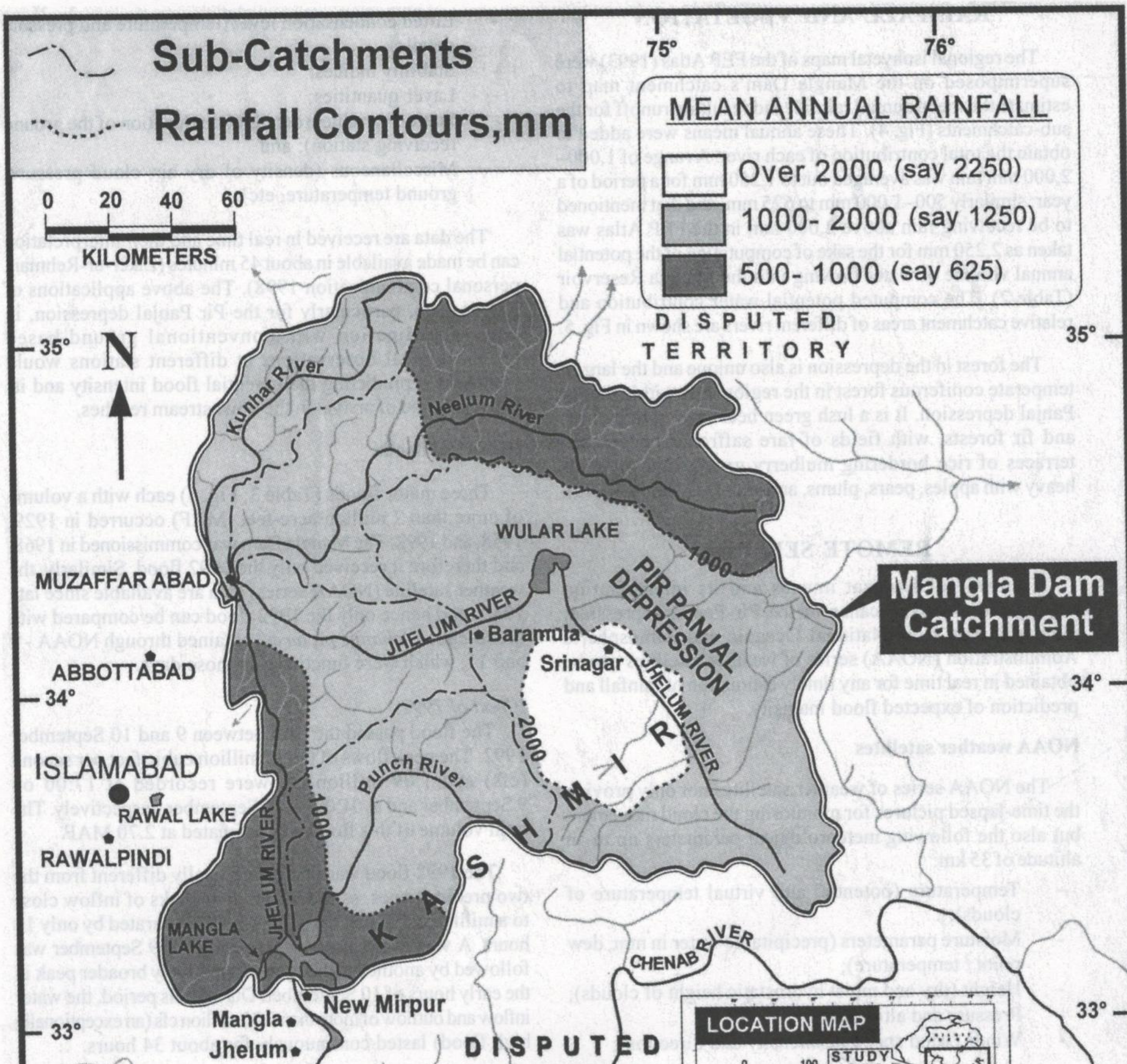

Fig. 4: The Mangla Dam catchment. The mean annual rainfall over the Jhelum, Neelum, Kunhar, and Punch watersheds (the interpretation of the satellite imagery mosaic superimposed on rainfall contours from FEP Atlas 1993)

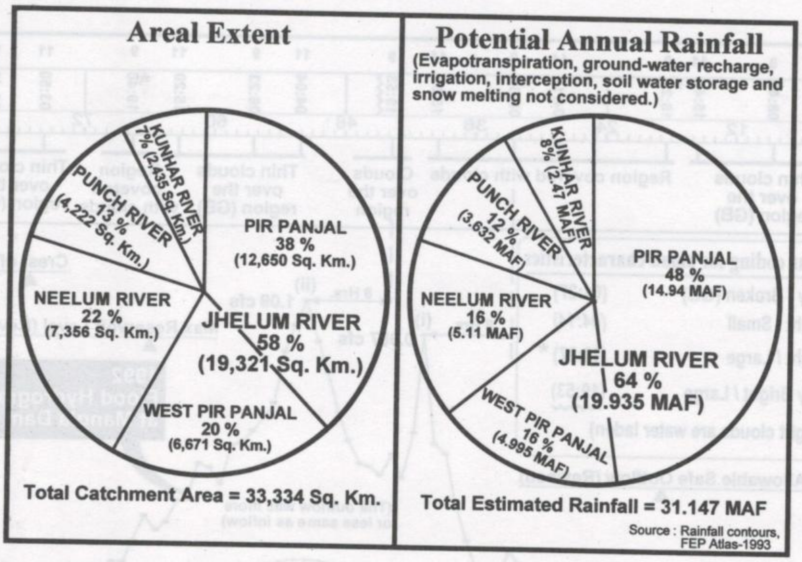

Fig. 5: The Mangla Dam catchment. Relative share of the rivers contributing to the Mangla Lake

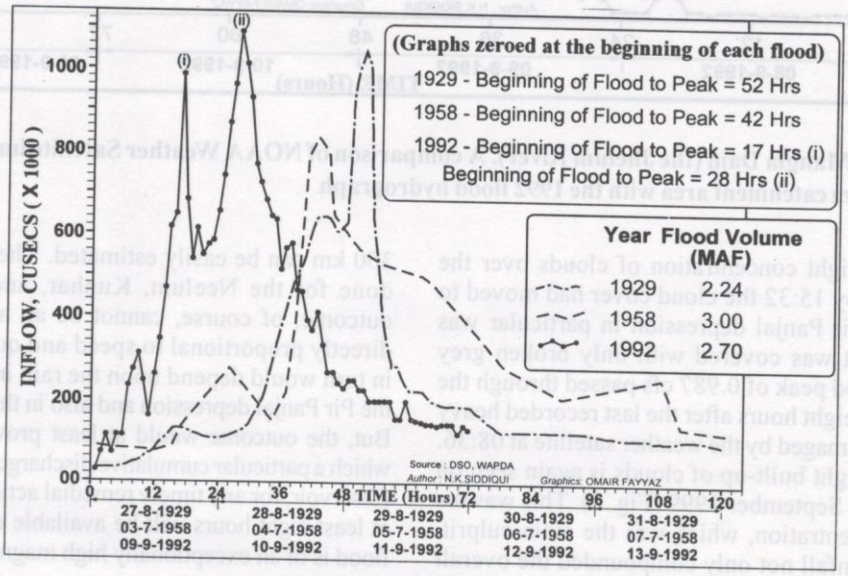

Fig. 6: A comparison of the three historical floods in the Jhelum River

Flood of 1958

The flood passed the Mangla flood monitoring station between 4 and 5 July 1958. The peak flow of 0.830 million cfs was recorded at 18:00 on 4 July. During this period, the flow of more than 0.3 million cfs lasted continuously for about 40 hours. The overall volume of this flood is estimated at 3.0 MAF. Though the flood volume was highest of the recorded three floods, but as the peak inflow was relatively smaller, and the overall inflow and the subsequent outflow were more evenly distributed, it might not have been as damaging as the floods of 1929 and 1992.

Flood of 1929

The flood passed the Mangla flood monitoring station between 28 and 29 August 1929. The peak flow of 1.05 million cfs was recorded around 04:00 on the morning of 29 August. During this period, the flow of more than 0.3 million cfs lasted continuously for about 23 hours. The overall volume of this flood was estimated at 2.24 MAF.

COMPARISON OF THE 1992 FLOOD WITH THE NOAA DATA

The 1992 flood is compared with the NOAA images of the same period (Fig. 7). The match seems to be perfect. It may be noted that the bright white clouds as seen on the NOAA images are interpreted to be laden with water that caused heavy rains. As seen on the successive NOAA images recorded during the flood, there were bright clouds at 18:27 on 8 September. Again, at 08:36 on 9 September

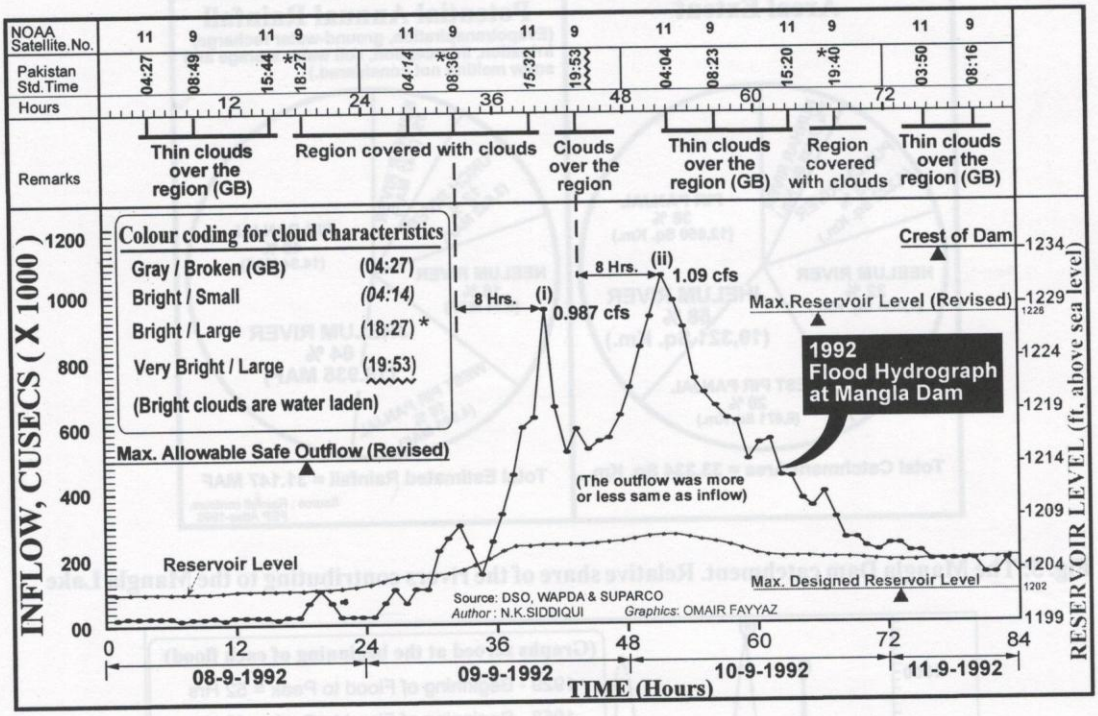

Fig. 7: The Mangla Dam (the Jhelum River). A comparison of NOAA Weather Satellite images of the Mangla Dam catchment area with the 1992 flood hydrograph

there was a large bright concentration of clouds over the catchment whereas by 15:32 the cloud cover had moved to the north, and the Pir Panjal depression in particular was partly exposed, as it was covered with only broken grey clouds. The first flood peak of 0.987 cfs passed through the dam at 17:00, about eight hours after the last recorded heavy cloud concentration imaged by the weather satellite at 08:36. Similarly, a large bright built-up of clouds is again seen on the 19:53 image of 9 September 1999 (Fig. 8). This was the heaviest cloud concentration, which was the main culprit, and the resulting rainfall not only compounded the overall rainfall since the evening of 8 September (the 18:27 image) but also the already devastating flood situation. It resulted in the second and a larger flood peak of 1.09 million cfs, which passed the dam at 04:00 on 10 September 1999, just eight hours after the event of 19:53. The NOAA image of 04:04 (Fig. 8) shows that the Mangla Dam catchment area was generally clear of clouds and the bright cloud cover had shifted further east. From these facts, it can be safely assumed that eight hours is the minimum lag time for a heaviest flood, which originates in the Pir Panjal depression and other contributing rivers in the north. Hence, for the floods of lesser magnitude the lag time could be more than eight hours – a time sufficient for implementing remedial measure at the Mangla Dam.

LAG TIME

The lag time for a certain discharge to reach the Mangla Reservoir from the Wular Lake situated at a distance of about 300 km can be easily estimated. The same exercise can be done for the Neelum, Kunhar, and Punch Rivers. The outcome, of course, cannot be an absolute figure as it is directly proportional to speed and quantity of water, which in turn would depend upon the rain intensity, particularly in the Pir Panjal depression and also in the other sub-catchments. But, the outcome would at least provide a range of time in which a particular cumulative discharge could reach the Mangla Reservoir, for any timely remedial action. As discussed above, at least eight hours will be available even if the approaching flood is of an exceptionally high magnitude.

Any ominous movement of clouds towards the Pir Panjal watershed and the adjoining watersheds of the Neelum and Kunhar Rivers should immediately be intimated to alert the concerned authorities. The discharge in the upper accessible reaches of the Jhelum River, with a ground station located west of 74° longitude, should be carefully monitored with at least hourly intimation at the Mangla Dam. This would provide the crucial time required for planning the remedial measures.

A planned opening or closing of the Mangla Dam gates would allow an optimum discharge, which could be synchronised with the expected increase or reduction in water flowing from the upstream reaches.

The reservoir can be gradually emptied in anticipation, prior to the rapid arrival of excessive incoming floodwater or vice versa, to provide sufficient time to the authorities for evacuating the population downstream of the dam.

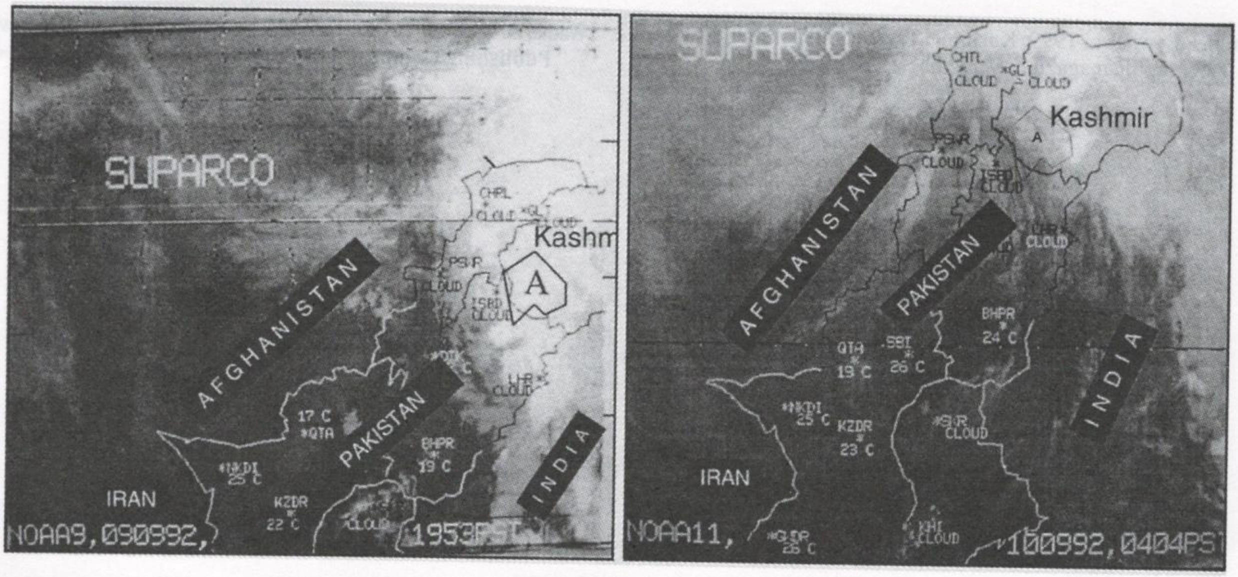

Fig. 8: A comparison of NOAA Weather Satellite images. Note the extensive bright cloud cover over Kashmir in general and the entire Mangla Dam's catchment (A) in particular, at 19:53 PST on 9 September 1992. Within eight hours, i.e. by 04:04 PST, on 10 September the clouds had shed most of their water as indicated by the grey (i.e. thin) cloud cover in the right image in which major part of the catchment and the depression is partly visible. It may be noted that the second peak of 1.09 million cfs, during the 1992 flood (Fig. 7), was encountered at 04:00 PST on 10 September 1992.

GROUND STATIONS

There are three river gauges upstream of the Mangla Dam: at Pattan, Kohala, and Domel on the Jhelum River at a distance of about 90 km, 140 km, and 170 km, respectively from the dam. A fourth river gauge on the river at Chakothi, west of 74° longitude, is recommended. It will be located about 230 km upstream of the dam, and will provide the longest lag time for the water approaching from the Pir Panjal depression into the Mangla Lake. Similarly, the Domel River gauge located downstream of the confluence of the Neelum and Jhelum Rivers is most important for monitoring the approaching floodwater.

CONCLUSIONS

The Pir Panjal depression constitutes about 38% of the total Mangla Dam's catchment area. But, because of its highest mean annual rainfall, the floodwater contribution could be up to 50% or even more, particularly during the summer season. The remote sensing through weather satellites like NOAA can provide the information about cloud movement and rainfall. The flood intensity and the lag time can be estimated for timely warning at the dam. However, it seems that there will be at least eight hours of time available as highlighted by the comparison of the NOAA images with the 1992 flood records.

The whole exercise will be successful only if planned meticulously with close coordination amongst the concerned authorities, as an hour or even a few minutes could be crucial in averting a disaster. A well-planned implementation and effective coordination within different agencies such as the Irrigation Department, Water and Power Development Authority, civil authorities, and in particular the SUPARCO and Meteorological Department may provide a practical remedy for the recurring calamity.

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