PAPER NO.576

DECISION SUPPORT SYSTEM FOR RESERVOIR OPERATION TO MANAGE SEVERE FLOODS IN PAKISTAN

BY

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ABSTRACT

Large storage volume is available in Mangla Reservoir which can be used for mitigation of severe floods. However this could not be utilised efficiently in the past because of absence of a proper decision support system consisting of a set of computer models. Using the rainfall forecast and measurements, rainfall-runoff models, reservoir routing models and the hydrodynamic river flow models, it is possible to test different flood mitigation scenarios in advance and to decide upon the optimum one.

In this paper the potentiality of flood mitigation by Mangla Reservoir on river Jhelum using a proper decision support system has been investigated. The decision support system should include storm tracking, rainfall forecast and measurement, rainfall-runoff models, a reservoir routing module and a hydrodynamic model [1]of Jhelum and Chenab rivers. In case of severe floods like 1992 flood there is a possibility of reducing the Mangla Reservoir outflow discharge from 8500 to 11500 cumecs (3 or 4 lac cusecs) by pre-releasing storage or delaying the release by storing the inflow hydrograph. However such decisions can not be made without considering the flood hydrograph at Marala Barrage on river Chenab since there is a possibility of synchronisation of flood waves from downstream Mangla Reservoir and Marala Barrage near Trimmu Barrage where rivers Jhelum and Chenab meet. Any decision support system to determine the releases from Mangla Reservoir must include combined model of Jhelum and Chenab rivers.

INTRODUCTION

Tarbela Reservoir across river Indus and Mangla Reservoir across river Jhelum are two large reservoirs which can be adequately used for management of severe floods. Tarbela reservoir is about 850 km upstream of Mithan Kot where four major tributary rivers join river Indus as a combined river below Panjnad Barrage. A flood wave from downstream Tarbela is likely to take 9 days to reach Mithan Kot. Mangla Reservoir is about 315 km upstream of the confluence of river Jhelum with river Chenab above Trimmu Barrage. A flood wave from downstream Mangla Reservoir is likely to reach Trimmu within 3.5 days. Vulnerable population and structures exist a few kilometers downstream Mangla which may be hit by flood in a short time. Therefore, flood management through Mangla Reservoir is a very sensitive issue in view of short lead time and enormous possible damage. For these reasons flood management through Mangla Reservoir has been discussed here using the rainfall-runoff, reservoir routing and river flow models.

Large damages were reported along the Jhelum river downstream Mangla during the 1992 flood. Such damages could have been avoided by utilising the flood storage capacity of

[1] National Engineering Services of Pakistan [NESPAK] (Pvt.) Limited
Note: The thoughts expressed are those of the author and not of the NESPAK.

Mangla Reservoir and releasing such flows downstream Mangla which could avoid damage to life and property located in downstream Mangla reach of river Jhelum. In case of severe floods like 1992 flood there is a possibility of reducing the Mangla Reservoir outflow from 8500 to 11500 cumecs (3 or 4 lac cusecs) by pre-releasing the stored volume or delaying the release by storing the inflow hydrograph. However such decisions can not be made without considering the flood hydrograph at Marala Barrage since there is a possibility of synchronisation of flood waves from downstream Mangla Reservoir and Marala Barrage near Trimmu Barrage where rivers Jhelum and Chenab meet. Any decision support system to decide on the releases from Mangla Reservoir must include combined model of Jhelum and Chenab rivers.

MANGLA RESERVOIR

The Mangla Reservoir drains the Jhelum basin (33000 Km^2, 12870 sq. miles). It has been built primarily for irrigation and hydropower generation is a second priority, while flood mitigation is only incidental if the reservoir level is below the conservation level of 366.4 m (1202 ft). The main characteristics of Mangla Reservoir (WAPDA, 1961) are:

Design live storage capacity	= 6600 MCM (5.34 MAF)
Reservoir crest level	= 376.2 m (1234 ft)
Maximum conservation level (MCL)	= 366.4 m (1202 ft)
Minimum operation level	= 317.0 m (1040 ft)
Emergency spillway level	= 368.3 m (1208 ft)
Design flood discharge	= 31200 cumecs (11 lac cusecs)
Main spillway capacity	= 24600 cumecs (8.7 lac cusecs)
Emergency spillway capacity	= 6500 cumecs (2.3 lac cusecs)
PMF discharge	= 66300 cumecs (23.4 lac cusecs)
PMF volume	= 9500 MCM (7.69 MAF)
Hydropower capacity	= 1000 MW

The other details can be found in WAPDA (1961) and Izhar-ul-Haq (1990).

FLOOD MITIGATION BY MANGLA RESERVOIR

In this paper flood mitigation through reservoir operation of Mangla Reservoir is divided in three aspects i.e. meteorological, hydrological and hydraulic. The meteorological and hydrological aspects have been discussed in detail by a number of researchers including Bell et al (1994), Majid (1996), Ahmed et al (1997) and Bhatti and Ahmed (1997) therefore, these are only briefly reviewed in this paper. The hydraulic aspects and a overall decision support system have not been considered in the past therefore a detailed account of these aspects is given in this paper.

METEOROLOGICAL ASPECTS

Floods in Mangla catchment of river Jhelum and catchment of river Chenab occur due to monsoon depressions emerging from Bay of Bengal which travel to Rajisthan in India before moving to these catchments. For Mangla catchment it is possible to make one day rainfall

forecast when the weather system starts moving from Rajisthan in India. However an alert can be given 2 to 3 days earlier when the weather system starts travelling from the Bay of Bengal to Rajisthan. More accurate forecast is issued subsequently after pursuing the weather system track up to Mangla catchment. (Majid, 1996)

Usually the monsoon rainfall in Mangla catchment occurs with a similar rainfall in the catchment areas of river Chenab (Majid, 1996). The time of concentration of flood peaks at Mangla Reservoir and Marala Barrage are similar. The flood waves from these rim stations travel in almost same time (60 to 80 hours) to the point of confluence of two rivers i.e. Trimmu Barrage which may cause synchronisation of flood waves and therefore, damage at Trimmu and downstream in river Chenab.

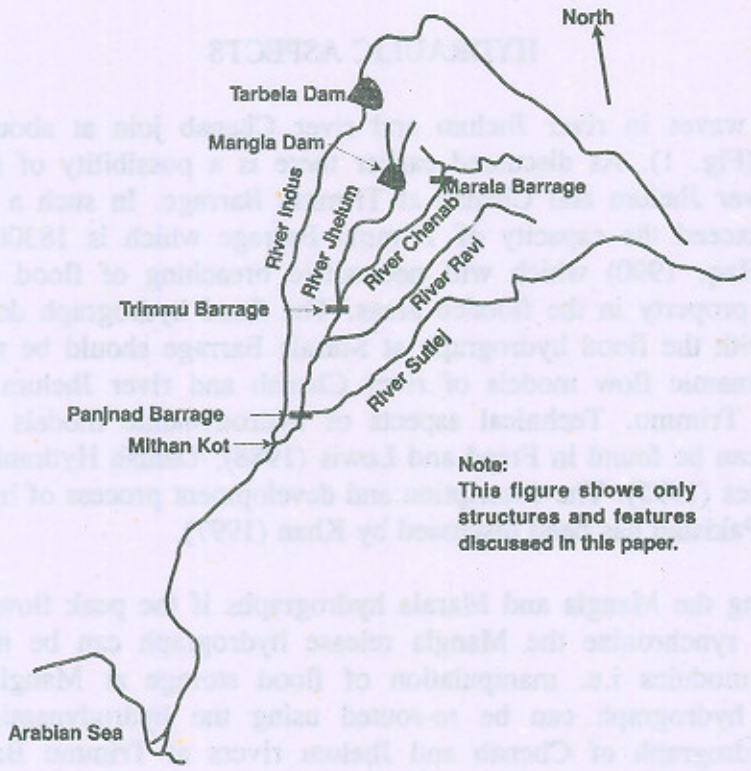


Figure 1 Indus River System

HYDROLOGICAL ASPECTS

The lead time between rainfall and runoff to Mangla for the different sub catchments ranges between 8 to 12 hours (Majid, 1996). A qualitative forecast of rainfall on Mangla catchment can be issued 36 hours in advance. However a fairly accurate quantitative rainfall forecast can be made 12 hours in advance using the measured rainfall. The inflow to Mangla Reservior can be simulated with calibrated rainfall-runoff models. Details of forecasting inflow hydrographs to major reserviors of Pakistan using remote sensing equipment, signal transmission and hydrological modelling can be found in Bell et al. (1994). Based on these elements, different flood mitigation scenarios can be formulated and Mangla Reservoir can be

effectively used for mitigating high floods. The objective is to shave the flood peak to a safe discharge downstream Mangla Reservoir even if the reservoir level is at MCL of 366.4m (1202 ft). Different scenarios can be formulated depending upon the volume of the forecasted flood. One scenario which can hold for floods like 1992, would be to pre-release some volume before the arrival of the flood. Khan and Saleem-ud-Din (1996) have discussed Mangla Reservoir release scenarios for different inflow hydrograph conditions and their impact on reservoir level.

A reservoir routing program based on Pul's method (Bedient and Huber, 1988) or reservoir operation model based on system analysis and optimisation techniques such as MNGFOP (Bhatti and Ahmed 1997) or MDDDP (Ahmed et al, 1997) can be used to route inflow flood hydrographs through Mangla Reservoir. Different Mangla release scenarios can be formulated using any of these modules.

HYDRAULIC ASPECTS

The flood waves in river Jhelum and river Chenab join at about 5 km upstream Trimmu Barrage (Fig. 1). As discussed earlier there is a possibility of synchronization of flood waves in river Jhelum and Chenab at Trimmu Barrage. In such a case the resulting flood peak may exceed the capacity of Trimmu Barrage which is 18300 cumecs (645000 cusecs) (Izhar-ul-Haq, 1990) which will necessitate breaching of flood embankments and endanger life and property in the flooded areas. The flood hydrograph downstream Mangla Reservoir along with the flood hydrograph at Marala Barrage should be routed through the combined hydrodynamic flow models of river Chenab and river Jhelum to pre-assess the flood situation at Trimmu. Technical aspects of hydrodynamic models based on the St. Venant equations can be found in Fread and Lewis (1988), Danish Hydraulic Institute (1992) and Delft Hydraulics (1995). The description and development process of hydrodynamic river models related to Pakistan has been discussed by Khan (1997).

After routing the Mangla and Marala hydrographs if the peak flows of river Jhelum and river Chenab synchronize the Mangla release hydrograph can be modified by using reservoir routing modules i.e. manipulation of flood storage at Mangla Reservoir. The modified Mangla hydrograph can be re-routed using the hydrodynamic model and the resulting flood hydrograph of Chenab and Jhelum rivers at Trimmu Barrage can be re-determined.

During real time operation a number of hypothetical scenarios can be formulated from rainfall forecast/measurement, rainfall-runoff models and reservoir routing module. The release from Mangla forms the input for the combined hydrodynamic model of the river Jhelum downstream Mangla and river Chenab downstream Marala.

EXAMPLE OF FLOOD MITIGATION OF 1992 FLOOD

The 1992 flood in the catchments of river Jhelum and river Chenab were caused by two rainfall storms (FFWC, 1992):

- Rainfall storm at midnight between 8th and 9th September which produced a peak inflow of 27910 cumecs (987000 cusecs) at Mangla at 1700 hr on the 9th of September. The peak flow at Marala Barrage was 9000 cumecs (318000 cusecs) at 1900 hr on the 9th of September.
- Rainfall storm at midnight between 9th and 10th September which, produced a peak inflow of 30900 cumecs (1090000 cusecs) at Mangla at 0400 hr on the 10th of September. The peak flow at Marala was (24000 cumecs) 845000 cusecs at 1100 hr on the 10th of September.

The 1992 flood mitigation was a failure since storage at Mangla was not properly utilised and large scale damages occurred down stream Mangla.

Hypothetically assuming that all components of decision support system were available during the mitigation of 1992 flood a qualitative forecast could have been issued on the morning of September 8, 1992 at 0800 hrs, followed by a quantitative forecast on the morning of September 9, 1992 at 0800 hrs. Since the inflow hydrograph for 1992 flood is known it is possible to formulate hypothetical reservoir release scenarios for flood mitigation using the hydrological reservoir routing module. Three such hypothetical scenarios are tested here in order to highlight the significance of hydrodynamic flow routing models in deciding a suitable release scenario for Mangla Reservoir.

A) Start pre-releasing 8500 cumecs (3 lac cusecs) at 1000 hr on the 8th of September 1992 and 11500 cumecs (4 lac cusecs) after 24 hours.

B) Start releasing 11500 cumecs (4 lac cusecs) when inflow >= 11500 cumecs (4 lac cusecs).

C) The actual operation made in 1992.

These 1992 release scenarios at Mangla Reservoir are routed along with actual flood hydrograph at Marala reservoir using a combined hydrodynamic model of river Chenab and river Jhelum. The resulting flood hydrograph at Trimmu is compared with the capacity of Trimmu Barrage. The results of routing of different flood hydrograph scenarios downstream Mangla Reservoir are discussed below:

Scenario A

Flow downstream Marala Barrage = 1992 flood wave
Flow downstream Mangla Reservoir = 8500 to 11500 cumecs (3 to 4 lac cusecs)

Fig. 2 shows the flood hydrographs at downstream Mangla Reservoir, downstream Marala Barrage, river Jhelum at confluence, river Chenab at confluence and resultant flood hydrograph at Trimmu Barrage. The downstream Mangla hydrograph consists of a pre-release of 8500 m^3/s (3 lac cusecs) from 1000 hrs on 8th of September till 0900 hrs on 9th of September 1992 followed by a release of 11500 m^3/s (4 lac cusecs) from 1000 hrs on 9th of September 1992 till 0800 hrs on 11th of September 1992.

The flood peak of river Jhelum at confluence reaches later than the flood peak of river Chenab at confluence. The comparison of Trimmu Barrage capacity with the resultant flood hydrograph at Trimmu Barrage shows that the breaching section upstream Trimmu Barrage needs to be operated with a peak flow of 5000 m^3/s (1.75 lac cusecs) passing through the breach.

Scenario B

Flow downstream Marala Barrage = 1992 flood wave
Flow downstream Mangla Reservoir = 11500 cumces (4 lac cusecs)

Fig. 3 shows the results of scenario B. The downstream Mangla hydrograph consists of a delayed release of 11500 m^3/s (4 lac cusecs) from 1500 hrs on 9th of September 1992 till 1000 hrs on 12th of September 1992 i.e. delayed release from Mangla Reservoir.

The flood hydrograph of river Jhelum at confluence is delayed as compared to other scenarios and it does not overlap the flood hydrograph of river Chenab at confluence in the peak region resulting in lower flood peak at Trimmu than the previous scenarios. The comparison of Trimmu Barrage capacity with the resultant flood hydrograph at Trimmu Barrage shows that the flow required to be passed through Trimmu breach has decreased to a peak flow of <4000 m^3/s (1.4 lac cusecs).

Scenario C

Flow downstream Marala Barrage = 1992 flood wave
Flow downstream Mangla Reservoir = 1992 flood wave

Fig. 4 shows the real time scenario of 1992 flood with the actual flood hydrograph downstream Mangla Reservoir. The high flows in river Jhelum resulted in wide spread damage to the downstream areas. The flood peak of river Jhelum reached Trimmu about 6 hrs later than that of river Chenab resulting in overlap of flood hydrographs of two rivers in peak regions. The breaching section upstream Trimmu Barrage was operated with high flows (peak >7000 m^3/s, 2.5 lac cusecs) passing through the breach which caused wide spread damage in the flooded areas.

The scenarios given above are presented here only to highlight the importance of hydrodynamic routing models and a number of other scenarios can be considered.

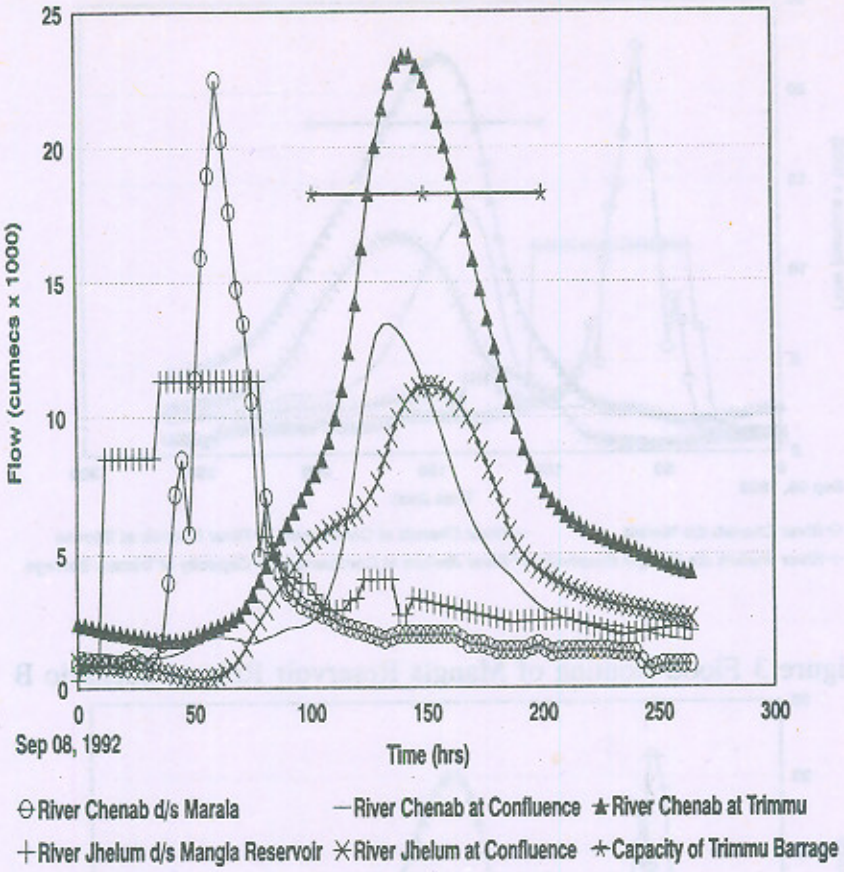


Figure 2 Flood Routing of Mangla Reservoir Release Scenario A

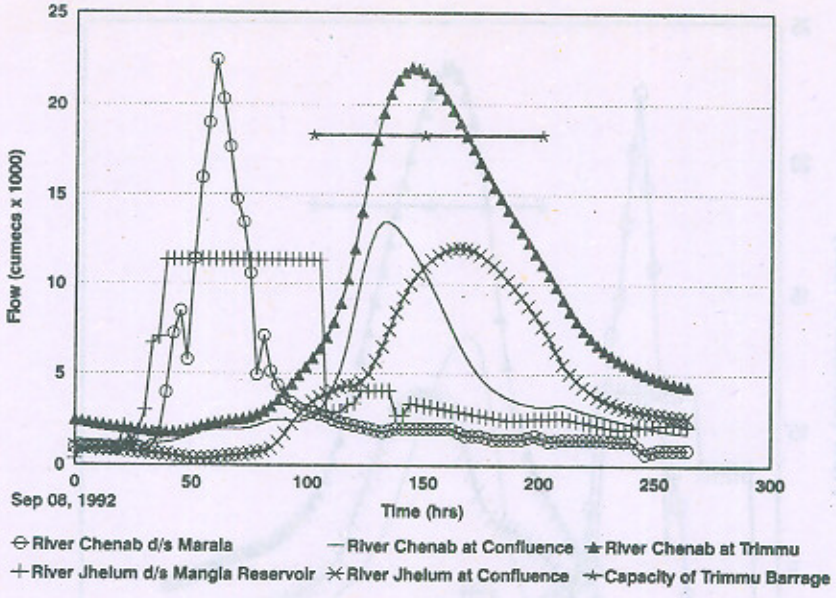


Figure 3 Flood Routing of Mangla Reservoir Release Scenario B

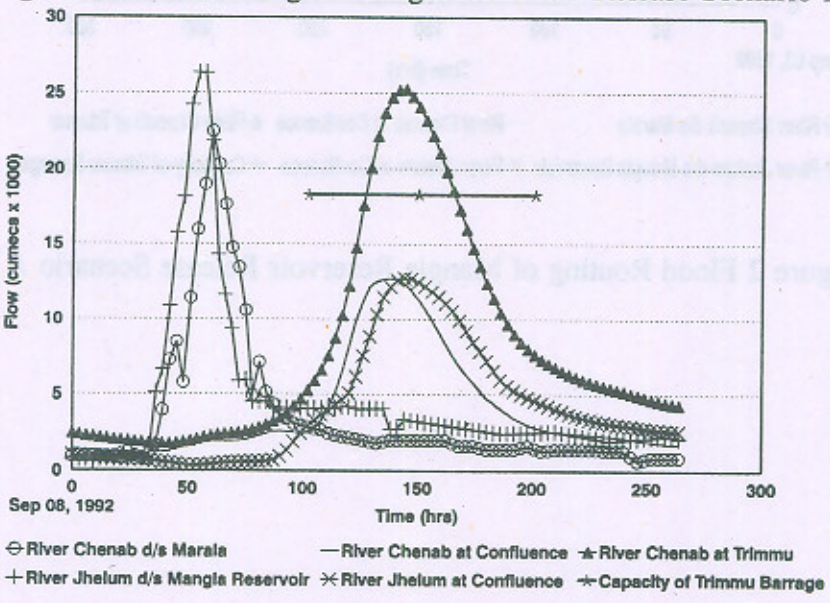


Figure 4 Flood Routing of Mangla Reservoir Release Scenario C

PROCEDURE DURING REAL TIME OPERATION

During the real time operation the following procedure illustrated in Fig. 5 should be used to ensure proper reservoir operation at Mangla Reservoir to avoid synchronization of flood at Trimmu Barrage.

1. Meteorological tracking of weather system as it originates from bay of Bengal. Qualitative forecast of rainfall conditions on river Jhelum and Chenab catchments.

2. Quantitative rainfall forecast/measurement on Mangla Reservoir catchment.

3. The forecasted/measured rainfall will be used to compute the inflow hydrograph at Mangla Reservoir using the rainfall-runoff models.

4. The computed inflow hydrograph at Mangla Reservoir should be routed using the reservoir routing module. If the outflow from the reservoir exceeds the 14000 cumecs (5 lac cusecs) than different operational scenarios of Mangla Reservoir may be formulated and reservoir routing can be carried out.

5. The outflow hydrograph at Mangla Reservoir (boundary condition of river Jhelum branch of hydrodynamic model) should be routed along with the real time flood hydrograph at Marala Barrage (boundary condition of river Chenab branch of hydrodynamic model).

6. Verify the flood hydrographs at intermediate stations to ascertain the peak discharges will not endanger their safety and there will be no risk of flooding of populated areas. Compare the peak discharge at Trimmu Barrage with the capacity of Trimmu Barrage.

7. If flood hydrograph at Trimmu Barrage exceeds its capacity go back to step (iv) to formulate a new scenario at downstream Mangla Reservoir by reservoir operation and repeat steps (v) and (vi). Repeat until acceptable situation at Trimmu is achieved.

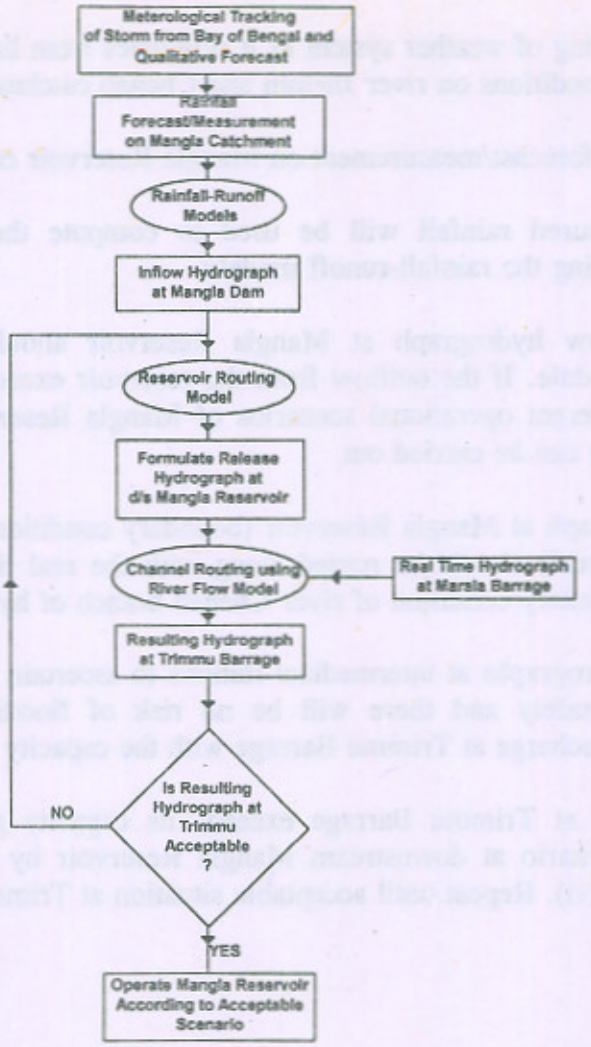


Figure 5
Flow Chart of Decision Support System for Operation of
Mangla Reservior during Floods

CONCLUSIONS

Large storage volume is available in Mangla Reservoir for flood mitigation. It can be utilised efficiently only if a proper decision support system is available. With proper storm tracking and rainfall forecast, outflow scenarios should be formulated using the reservoir routing modules in which the maximum Mangla release is limited to avoid damage downstream of dam. Usually the monsoon rainfall in Mangla catchment occurs with a similar rainfall in the catchment areas of river Chenab. The time of concentration of flood peaks at Mangla Reservoir and Marala Barrage are similar. The flood waves from these rim stations travel in almost same time to the point of confluence of two rivers i.e. Trimmu Barrage which may cause synchronisation of flood waves and therefore, damage at Trimmu and downstream in river Chenab. Therefore it is essential that any Mangla release scenario should be checked for

possible synchronisation at Trimmu Barrage with outflow hydrograph from Marala Barrage by channel routing using combined hydrodynamic flow model of river Jhelum and river Chenab. A combination of rainfall-runoff, reservoir routing and river flow models should be used for the management of severe floods by considering different reservoir operation scenarios at Mangla Reservoir.

ACKNOWLEDGMENT

The author acknowledges useful suggestions by Mr. Ashfaq Qureshi, Chief Hydrology, National Engineering Services of Pakistan (Pvt.) Limited.

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