FLOOD MANAGEMENT AT KAMALA DAM

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ABSTRACT

Kamala dam is a 216m high concrete gravity structure planned to be constructed across Kamla river in Arunachal Pradesh, India. It is one of the three large dams envisaged in Subansiri sub-basin of the Brahmaputra river. In addition to power generation, these dams would also provide flood relief in the Brahmaputra valley through integrated operation. The reservoir created by the Kamala dam will have a gross storage of 2.4 billion m^3 and will spread over a length of 67 km. A surcharge storage zone of 15m is provided above the full reservoir level (FRL) for storage of 438 million m^3 of water, exclusively for flood moderation. A part of the conservation storage for power generation is also utilized for flood moderation and a permanent flood control zone of 652 million m^3 is defined to be available during the monsoon months (rainy season). Additionally, 410 million m^3 of active storage for power generation that extends upto the minimum operating level is also available thus providing flexibility in reservoir operation. The spillway is configured 100m below the maximum water level (MWL) to provide the required capacity considering the reservoir size, its operation, sediment inflow and deposition. This provides storage of 2 billion m^3 above the spillway crest ensuring abundant buffer for sustainable use of the reservoir for flood mitigation. Reservoir routing studies have been carried out for moderation of floods and to define the reservoir operation rule curve. Rules of operation provide restriction on the outflow for floods upto 100-year return period. As competing objectives of power generation and flood moderation are to be achieved, an appropriate portion of the cost of the dam is assigned to flood moderation so that the generation cost and tariff are not impacted negatively. This paper discusses the flood management aspects and spillway configuration to ensure acceptable performance under design conditions.

1. INTRODUCTION

1.1 Overview of Kamala dam

Kamala hydroelectric project is conceived to serve twin objectives of power generation and flood moderation and features a 216m high concrete gravity dam planned to be constructed across river Kamla in Arunachal Pradesh state of India. In addition to providing flood relief in the Subansiri and Brahmaputra basins, Kamala dam would enable generation of 1800 MW of hydroelectric power providing a sizeable source of renewable energy. The dam comprises a 112m long central spillway, flanked by non-overflow sections - 236m on the left bank and 280m on the right bank. The spillway is configured 100m below the maximum water level (MWL) and comprises seven deep seated sluice openings, 6m x 10.5m, each and an upper bay, 6m x 13m (Figs 1-2). The spillway is designed for a Probable Maximum Flood (PMF) with peak of 17,416 m^3/s. The reservoir created by the dam will have a gross storage of 2.4 billion m^3 spreading over a length of 67 km at MWL.

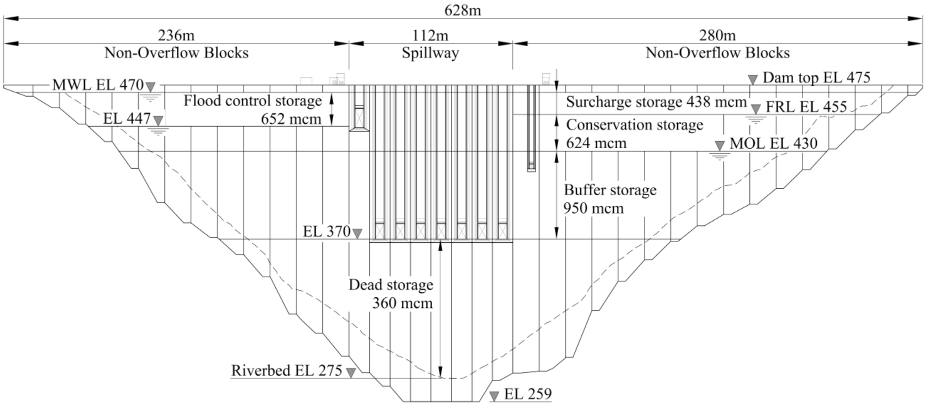

Figure 1 : Kamala dam upstream view.

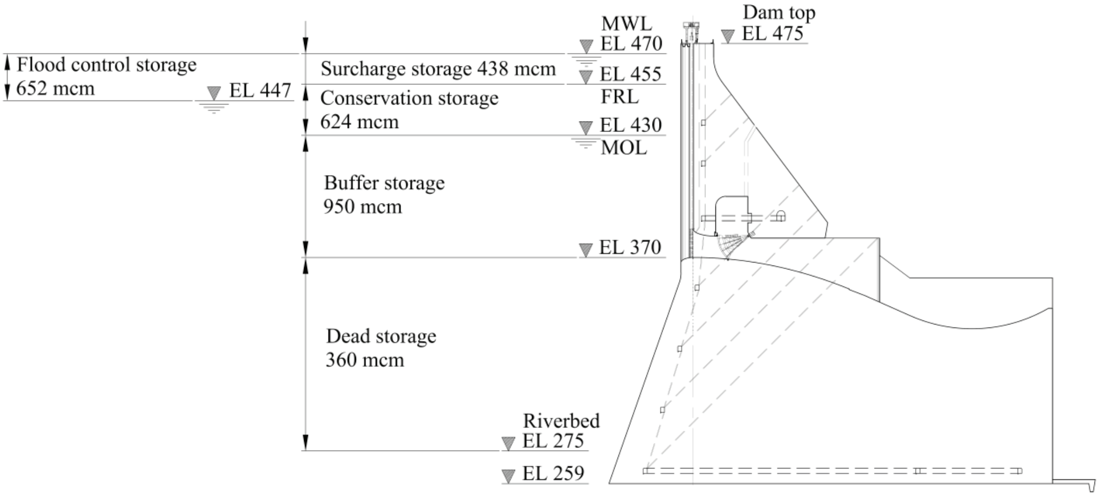

Figure 2 : Kamala dam spillway section.

1.2 Background

Two large storage dam projects were originally conceived in the master plan of Brahmaputra basin, one each in its sub-basins of Subansiri and Siang for flood control benefits as well as to exploit the available power potential. However, after the feasibility studies, the projects could not be taken up for execution as they involved huge submergence including few main cities and consequent displacement of inhabitants. In order to address these concerns, the projects in the two sub-basins were split into cascade developments with three dams in each sub-basin (Fig. 3).

In Subansiri basin, three projects were planned, namely Subansiri Upper, Kamala (formerly Subansiri Middle) and Subansiri Lower. While the Subansiri Lower and Subansiri Upper dams lie on the Subansiri river, Kamala dam was envisaged on Kamla river, a tributary of river Subansiri. Subansiri Lower, the downstream-most project, was planned predominantly as a power generation project whereas the other two upstream projects were planned to ensure moderation of floods along with power generation. The reservoirs of significantly large dams at the two upper projects were envisaged to have dedicated storage for flood moderation.

Development rights of all three projects were originally with a government power utility but later Kamala and Subansiri Upper were transferred to private developers on build, own, operate and transfer basis. The three projects are thus being developed by different parties and a proper coordination would be required for routing of floods. Presently, the Subansiri Lower project is under construction, Kamala is in advanced stage of approval of its Detailed Project Report (Feasibility report) and Subansiri Upper is in feasibility stage.

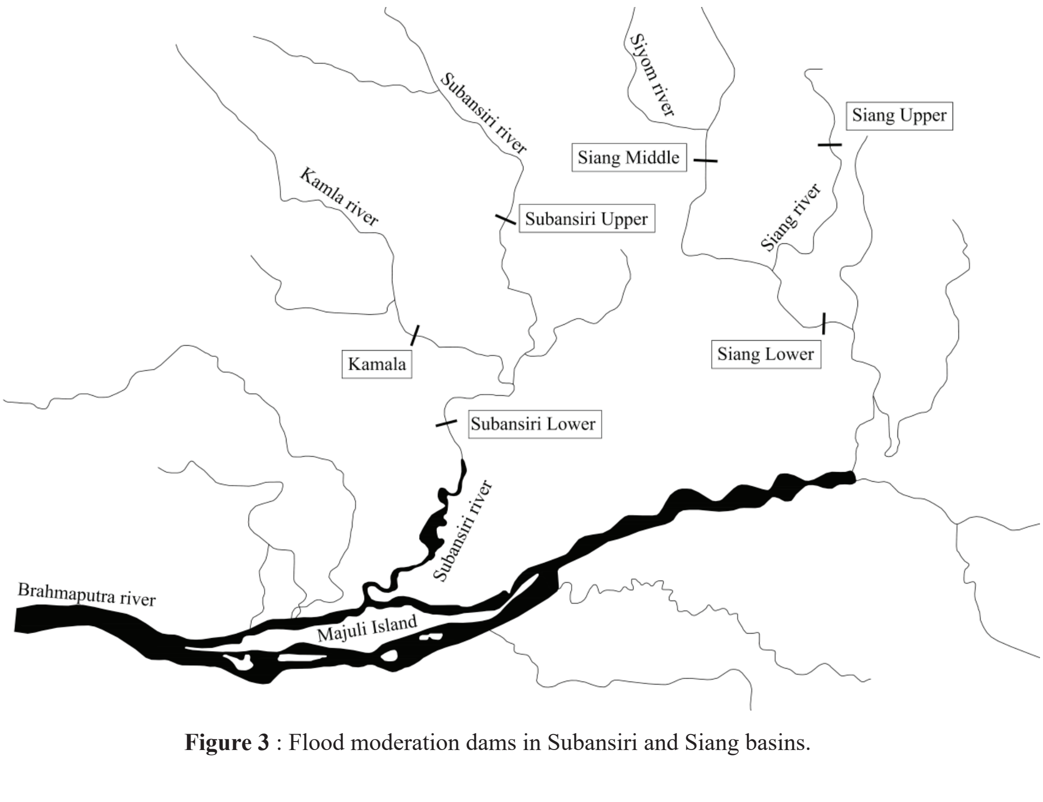

Figure 3 : Flood moderation dams in Subansiri and Siang basins.

2. FLOOD MODERATION IN SUBANSIRI BASIN

2.1 Previous studies

An integrated plan of operation of the upper dams would moderate the flows reaching the lower dam that controls the flow to river Brahmaputra. Since, at one stage the projects belonged to the same government agency, integrated reservoir studies for flood moderation were performed for moderation of floods of 10-year, 25-year and 100-year return periods (NHPC, 2005). Flood cushions of 10m for Subansiri Upper and 15m for Kamala and rule curves for reservoir operation during monsoons for the three dams were defined (Table 1).

Table 1 : Reservoir operation rule curve during monsoon for Subansiri basin dams in previous studies.

Period			Reservoir level, m		
			Subansiri Upper	Kamala	Subansiri Lower
		FRL:	460	460*	205
Jun	I-III		435	431	190
Jul	I-III		435	431	190
Aug	I		447	443	190
	II		447	448	190
	III		451	454	195
Sep	I		453	454	195
	II		453	456	198
	III		455	456	205
Oct	I		455	458	205
	II		458	458	205
	III		460	460	205

*Full reservoir level (FRL) was subsequently reduced by 5m.

2.2 Flood moderation criteria

After the transfer of Kamala to its present developer, designers of the project faced some challenges in planning and firming up the key project parameters. To start with, different statutory government authorities for project approvals had different objectives: while the Ministry of Environment and Forest required FRL of the dam to be lowered in view of reducing the submergence of forest land, government's Standing Committee on Storage required the gross storage of the dam to be enhanced for sustainable reservoir development. After a few deliberations, it was agreed to lower FRL by 5m from El 460m to El 455m.

Another challenge was to integrate flood moderation studies for the two upper dams and finalize the release criterion for each dam during flood events. The Technical Group constituted by the government on flood moderation aspects in the Brahmaputra basin had commented on the previous integrated studies (conducted by the government agency) and required the following two basic criteria to be fulfilled for moderation of floods in the Subansiri basin:

(i) Same flood moderation should be available throughout the monsoon period; and

(ii) Release downstream of the Subansiri Lower dam should not exceed 7000 m^3/s based on the safe discharge capacity of river Subansiri.

The first criterion guides that the reservoirs be operated at such levels during the months of September-October (end of monsoon season) so as to achieve the same moderation benefits as during June-July (beginning of monsoon season). The second criterion puts a restriction on the release from the upper dams so that the combined flow, including that from the intermediate catchment, does not result in outflow from Subansiri Lower to exceed the permissible release (7000 m^3/s).

Reservoirs, generally, are not designed to provide complete protection against extremely large floods due to techno-economic, social and environmental limitations. Most dams designed for flood moderation are capable to absorb part of the flood and mitigate flood damages downstream rather than completely preventing the damage in case of large floods. Based on worldwide experience, typical flood protection has been provided for return periods between 20 and 200 years (ICOLD Bulletin 125, 2003). Accordingly, Subansiri basin dams are intended to provide protection against floods with return period of 1 in 100-years or lower to ensure reduction of downstream flows to non-damaging levels. The effect of moderation would be less for the larger floods.

3. FLOOD ROUTING STUDIES FOR KAMALA DAM

Releases from the two upper dams depend on the physiographic characteristics of their catchments as well as the provided flood cushions. In the previous studies, an equal and constant release was contemplated from the upper dams.

Mandate of the present developer was not to perform the integrated studies of the entire basin rather follow the defined guidelines set by the authorities. Equal and constant release from the upper dams was, however, maintained.

3.1 Studies using previous rule curve

Since the reservoir rule curve developed from the earlier studies was for a different FRL, as a first step, parametric flood routing studies for the Kamala dam were performed considering the same parameters as in the earlier integrated studies. These parameters comprised: flood cushion of 15m, initial reservoir levels during flood as per the earlier defined rule curve and different constant releases. The updated and approved inflow hydrographs at the time of studies were, however, used. The objective of these studies was to assess if the earlier rule curve met the now defined flood moderation criteria. Summary of results for the 1 in 25-year and 1 in 100-year return period floods are given below in Table 2 and Table 3, respectively.

Table 2 : Flood routing results at Kamala dam for 1 in 25-year return period flood.

Period		Initial reservoir level, m	Maximum reservoir level attained (m) corresponding to release (m^3/s)					
			1000	1250	1500	2000	2500	3000
Jun	I-III	431.00	459.25	457.26	453.33	451.66	448.18	444.86
Jul	I-III	431.00	459.25	457.26	453.33	451.66	448.18	444.86
Aug	I	443.00	468.91	467.04	465.25	461.84	458.63	455.58
	II	448.00	473.03	471.22	469.48	466.16	463.05	460.10
	III	454.00	**478.06**	**476.31**	474.63	471.43	468.42	465.59
Sep	I	454.00	**478.06**	**476.31**	474.63	471.43	468.42	465.59
	II	456.00	**479.76**	**478.03**	**476.36**	473.20	470.23	467.43
	III	456.00	**479.76**	**478.03**	**476.36**	473.20	470.23	467.43
Oct	I	458.00	**481.46**	**479.75**	**478.11**	474.98	472.05	469.28
	II	458.00	**481.46**	**479.75**	**478.11**	474.98	472.05	469.28
	III	460.00	**483.15**	**481.46**	**479.84**	**476.75**	473.85	471.11

Table 3 : Flood routing results at Kamala dam for 1 in 100-year return period flood.

Period		Initial reservoir level, m	Maximum reservoir level attained (m) corresponding to release (m^3/s)					
			1000	1250	1500	2000	2500	3000
Jun	I-III	431.00	466.57	464.60	462.68	458.99	455.48	452.10
Jul	I-III	431.00	466.57	464.60	462.68	458.99	455.48	452.10
Aug	I	443.00	**475.77**	473.92	472.12	468.66	465.38	462.25
	II	448.00	**479.71**	**477.91**	**476.16**	472.80	469.61	466.57
	III	454.00	**484.53**	**482.78**	**481.08**	**477.83**	474.75	471.82
Sep	I	454.00	**484.53**	**482.78**	**481.08**	**477.83**	474.75	471.82
	II	456.00	**486.16**	**484.42**	**482.74**	**479.53**	**476.49**	473.58
	III	456.00	**486.16**	**484.42**	**482.74**	**479.53**	**476.49**	473.58
Oct	I	**458.00**	**487.80**	**486.08**	**484.42**	**481.24**	**478.23**	**475.36**
	II	**458.00**	**487.80**	**486.08**	**484.42**	**481.24**	**478.23**	**475.36**
	III	**460.00**	**489.44**	**487.73**	**486.08**	**482.93**	**479.96**	**477.12**

As observed from the above tables (highlighted), the maximum water level exceeds the 15m flood cushion mark i.e. El 475m, originally. For the 100-year flood, the reservoir attains a maximum elevation varying from El 489.44m to El 477.12m corresponding to constant downstream release of 1000 m^3/s to 3000 m^3/s. Similarly, for the 25-year flood the reservoir maximum water level reaches upto El 483.15m to 471.11m. It is evident that the original reservoir rule curve did not meet the flood moderation criteria. As per this rule curve, the reservoir level was being gradually raised from August and brought to FRL in October. Same flood moderation benefits would thus not be available from June to October if this rule curve was to be followed. Moreover, raising the water level close to FRL in September was not rational from flood management view point as probability of 100-year flood occurring during these months could not be ruled out, particularly in the North-Eastern part of India that witness's heavy rainfall even during late September and early October. Clearly, a new reservoir operation philosophy was to be developed conforming to the requirements set out by the flood moderation criteria.

3.2 Flood routing with revised FRL

Further studies were performed with the revised FRL (reduced by 5m from the original value) to determine the reservoir operation level during monsoon for different releases from the upper dams for the 100-year flood. The studies also considered the likely coincident flood hydrographs of the uncontrolled drainage area of the intermediate catchment and travel time of flow released from the upper dams reaching the Subansiri Lower dam. The objective was to estimate the reservoir levels during monsoon for different constant releases (Table 4) and the index levels that define the reservoir levels when the inflow exceeding the power discharge is to be released from the reservoir. Inflows in-excess of the power discharge of the projects are held in the upper reservoirs and are envisaged to be released in such a way that these outflows when combined with the intermediate catchment hydrograph on its recession limb do not result in outflow from Subansiri Lower to exceed the permissible limits. Typical routing of the 100-year flood hydrograph at Kamala dam is shown in Figure 4.

Table 4 : Kamala reservoir levels during monsoon.

Release	Reservoir level
m^3/s	m
1500	440.00
2000	443.00
2500	445.50
3000	447.00

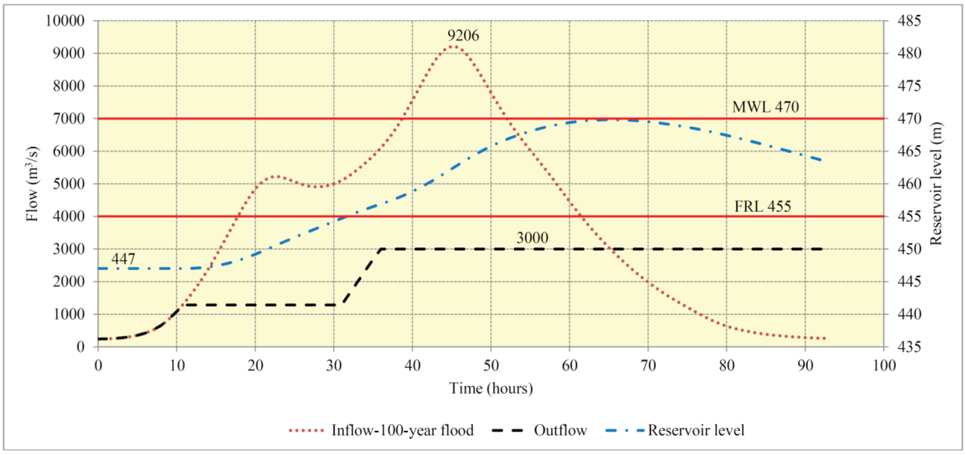

Figure 4 : Routing of 100-year flood hydrograph at Kamala dam

Flood moderation at Subansiri Lower dam for the maximum regulated outflows from upper dams during the 100-year flood event is shown in Figure 5. It is assessed that storage of about 75 million m^3 is required at the Subansiri Lower reservoir for restricting the downstream release to the prescribed limit of 7000 m^3/s. The available reservoir storage upto MWL is, however, higher. Although, Subansiri Lower was conceived mainly as a power generation project, its reservoir has additional storage that would contribute significantly to moderation of flood events.

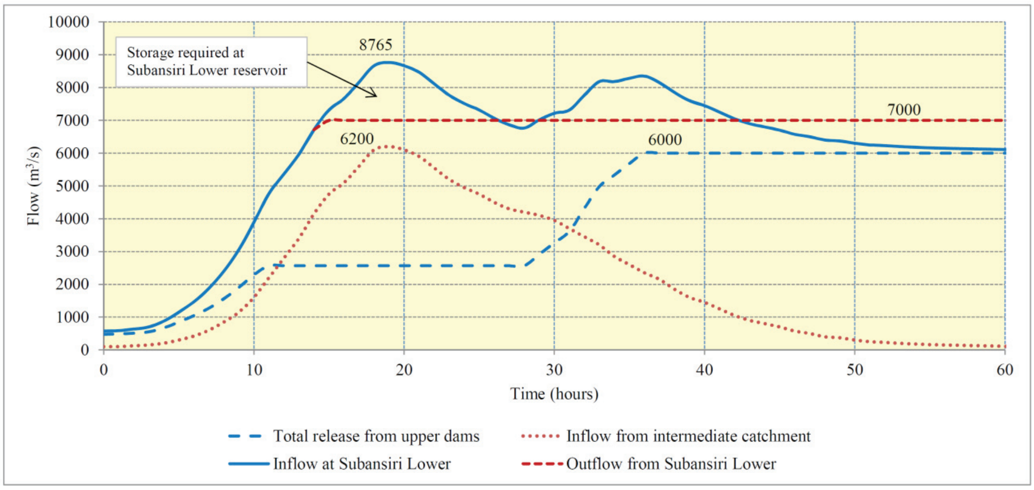

Figure 5 : Flood moderation at Subansiri Lower dam for the regulated outflows from upper dams.

3.3 Rule curve for Kamala reservoir

The two demands from the reservoir i.e. power generation and flood moderation are competing and conflicting. While flood moderation requires low reservoir levels, power generation interests require as high a level as attainable. The rule curve should provide a balance between the two objectives. In multi-purpose reservoirs like Kamala, some part of the conservation storage space for power generation is sacrificed for flood moderation during the early stages of the monsoon. This space is filled up progressively towards the receding monsoon months. Discussions with Central Water Commission led to finalization of the reservoir level and release criteria for the Kamala dam during monsoons. It was decided to keep the reservoir level of Kamala dam at El 447m from 1st June to 10th October and thereafter raise it to El 455m (the FRL). Thus, a permanent flood control zone of 652 million m^3 is defined to be available during the monsoon months. This includes the surcharge storage zone of 15m height above FRL with storage capacity of 438 million m^3 and a part of the conservation storage. The maximum release was fixed at 3000 m^3/s once the index level is reached, which was worked out as El 456.50m.

The regulation plan so developed is able to attenuate a 100-year peak inflow of 9200 m^3/s to 3000 m^3/s downstream of the Kamala dam. For the control point downstream of the Subansiri Lower dam, the 100-year flood peak of 19,600 m^3/s gets reduced to 7000 m^3/s, thus respecting the criterion. The dams therefore would provide attenuation of about 65% of the 100-year flood peak.

4. ROUTING OF INFLOW DESIGN FLOOD

Operation of reservoirs based on historical data and fixed operation rule curves often poses difficulty in making appropriate reservoir release decisions due to uncertainty in the probability of occurrence of the flood event and also occurrence of flood event similar to the designed. Reservoir operation is an operation in real time in which water release decisions are to be taken at each instant of time with reliable inputs from flood forecasting system and rainfall-runoff models. A regulation plan to cover all the complex situations may be difficult to evolve but, generally, it should be possible by following the principle that lower portion of the flood reserve is used effectively to achieve the maximum moderation benefits by controlling the earlier part of the flood. Thereafter, releases are increased as scheduled to utilize the full storage capacity. For Kamala dam, rules of operation, as developed in these studies, provide the stipulated restriction on the outflow for floods upto 100-year return period. For larger floods, the outflow could be increased but at a controlled rate.

4.1 Spillway Configuration

Design flood for the safety of Kamala dam is the PMF, which has been assessed with peak as 17,416 m^3/s. The dam lies in a region of high rainfall intensity where the possibility of floods occurring in succession cannot be ruled out. To assess this possibility, the design condition also includes extreme flood events which is the occurrence of PMF preceded, or followed, by a 25-year flood.

The spillway capacity and its performance during a flood is governed by factors such as rules of operation of the reservoir, inflow design flood, initial level of reservoir at the beginning of flood, storage characteristics of the reservoir, functioning of spillway including consideration of non-availability of a portion of the spillway, and freeboard. Initial reservoir level (before the spillway design flood impinges) has been considered as higher of the FRL or the level at which 50% of the flood storage space is occupied i.e. El 459.25m. Even though the contemplated plan of operation is such that a portion of the storage capacity below the FRL probably would be available at the beginning of the design flood, the possibility of improper operation of gates as a result of incorrect flood prediction and mechanical difficulties justifies the above assumption. For the extreme flood scenarios, the initial level is considered as the rule curve level during monsoon.

The Kamala dam spillway has seven deep seated sluice openings (6m x 10.5m, each) configured 100m below MWL i.e. at El 370m and an upper bay, 6m x 13m, at El 446m. The spillway system is designed for the following conditions (Table 5).

Table 5 : Design conditions for safety of the Kamala dam.

Design condition	Inflow design flood	Initial reservoir level, m	Freeboard corresponding to
Design flood	PMF	459.25	2/3 of maximum wind
Design flood + gate malfunction	PMF	459.25	1/2 of maximum wind
Extreme flood	25-year + PMF	447	1/2 of maximum wind
Extreme flood + gate malfunction	25-year + PMF	447	minimum 1m freeboard

Studies have been performed with varied outflow rates and rate of increase in outflow. Principle of effective use of available flood control storage space by restricted release is followed for deciding the spillway capacity. For the gate malfunction condition, 10% of the gates with minimum one gate with the largest capacity is considered inoperative. A reduced freeboard is acceptable under this condition as probability of simultaneous occurrence of extreme flood, gate malfunctioning and extreme wind is not significant. At MWL, the spillway has a discharge capacity of 16,800 m^3/s with all gates operative and 14,500 m^3/s with one gate inoperative.

Reservoir routing in the scenario with 25-year flood and PMF occurring in succession along with malfunctioning of gate is shown in Figure 6. Obviously, the effect of moderation is less pronounced than that for the 100-year flood.

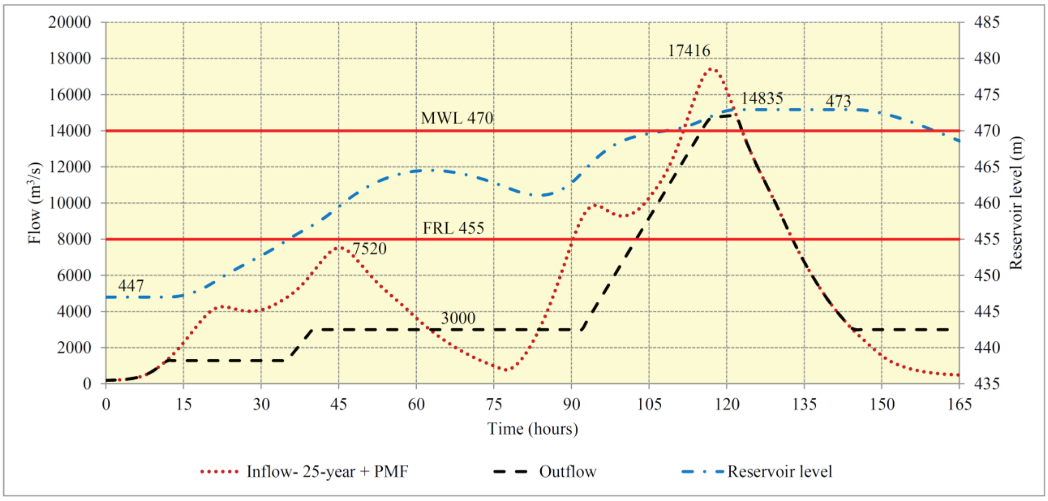

Figure 6 : Routing of extreme flood hydrograph with one gate inoperative at Kamala dam.

5. COST APPORTIONMENT

As competing objectives of power generation and flood moderation are to be achieved at Kamala, the project cost therefore is apportioned among the two. The costs allocated to flood moderation include the cost of 15m additional height of the dam and appurtenances for providing surcharge storage; cost related to additional time required to construct a higher dam; and cost towards loss of annual energy generation attributable to reservoir operation at lower level in monsoons.

With the increasing role of private entities in developing hydropower plants and dams in India, projects with multipurpose benefits have to be supported by the government. Costs related to providing benefits other than power should be shared by the government so that the hydro tariff remains competitive. A policy framework must be put in place for such projects for aiding the decision making process. It is understood that the government has taken some steps in this direction.

6. SUSTAINABLE USE OF RESERVOIR

For integrated operation of the Subansiri reservoirs, a regulating mechanism and a detailed coordination plan of operation would require to be developed, and followed, to ensure optimum benefits of flood mitigation. The initial reservoir regulation strategies developed to meet the objectives established during planning studies would need to be continually reviewed and adjusted to reflect the changing conditions and priorities.

The minimum operating level of the Kamala reservoir has been set at El 430m that provides storage of about 1.1 billion m^3 above this level. Storage of 410 million m^3 below the operating level during monsoons i.e. El 447m provides sufficient flexibility in operation of the reservoir. The spillway configured at El 370m provides storage of 2 billion m^3 ensuring abundant buffer for sustainable use of the reservoir for flood mitigation. With reliable real time flood forecasting systems, the reservoir level can be lowered than the licensing conditions to make room for unexpected extreme events. With provision of the deep seated spillway, the reservoir regulation rule curve and release criteria could be adjusted to meet the future demands, if required, to take care of the climate changes, changes in design floods based on new hydrological information available since the initial design of dam, changes in analysis methods and new safety concepts, new risks like development of the flood plains and reservoir sedimentation etc. Cost apportionment for the change of reservoir use would have to be judiciously reworked and managed accordingly.

7. CONCLUSION

Once constructed, the upper dams in Subansiri basin, Kamala and Subansiri Upper, along with the under construction Subansiri Lower dam would provide flood relief in the Brahmaputra basin through integrated operation of their reservoirs. It is anticipated that integrated operation of these reservoirs would provide a reduction of about 65% in the flood peak for the 100-year return period flood. A regulating mechanism and a detailed coordination plan of operation together with emergency release plans, reliable flood warning systems, emergency action and evacuation plans would require to be developed and followed to ensure that optimum benefits of flood mitigation are realized. Ideally, a common regulation entity should be constituted to take appropriate reservoir control decisions to ensure apportionment of releases from the three reservoirs for equitable distribution of water within the system for optimum flood control benefits.

Kamala dam is provided with large capacity deep seated sluice spillway to service the objectives of controlled depletion and preserve significant part of storage above the spillway crest through efficient sediment management. Subansiri Upper and Subansiri Lower are also designed with similar provisions. The Subansiri basin dams would ensure abundant allowances and flexibility to take care of future changing requirements and address hydrological changes including the impact of climate change to ensure sustainable use of the reservoirs for flood mitigation.

Extent of flood damages in recent years indicate that in future it would be imperative to increase measures to prevent and reduce damages that include construction of dams with dedicated flood storage provisions together with improvements in flood forecasting system for increased reliability. For multi-purpose dams with flood mitigation as one of the core objectives, the government should develop an equitable cost sharing framework and provide relevant financial support to the developer.

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