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Incorporation of "Risk Factor" in Design Flood Review of Existing Dams

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Abstract: At present there are about 4877 completed large dams in India. More than 75% of Indian dams are at least two decades old and for these dams the original design floods call for revisions. Examination of revised design flood studies carried out for a set of 118 dams under 'Dam Rehabilitation and Improvement Project (DRIP)' reveal that the design flood values have increased substantially with trends indicating that percentage increases in the revised design flood values are greater for lower dams and also for older dams. Paper illustrates that the upward revision in the design flood estimate of existing dam in no way leads to amplification of the actual risk associated with that dam, and it only underlines the gap between the acceptable risk level and existing risk level. The paper shows that flood related risk mitigation of existing dams is a challenging task often facing constraints of technical and economical viabilities. With the substantial data set of design flood revisions of DRIP dams, the paper brings out the skew observed in distribution of revised design floods on account of present-day norms related to computation of design floods, as contained in the Indian Standard IS: 11223 – 1985 (reaffirmed 1995). Paper also proposes amendments in this Standard in respect of existing large dams with an alternative recourse of formulating a new Standard for revision of design floods incorporating the risk factor associated with these large dam structures.

Keywords: Large Dams, Design Flood Review, Dam Failure, Flood Risk Mitigation, Dam Rehabilitation & Improvement Project

1. Introduction

India has invested heavily in infrastructure over the last fifty years which is necessary to store surface runoff in reservoirs formed by large, medium, and small dams with associated appurtenances. In light of the sizeable numbers and wide geographic spread of these dams, an ever-increasing number of people are living and working in areas that would be liable to sudden floods in the event of a dam failure. High safety standards for large dams are thus imperative to prevent failure that would cause extensive environmental and property damage, economic hardships, and, in the worst case, loss of life.

As per the findings of the International Commission on Large Dams, approximately one third of the failures of dam are attributed to the direct result of flood exceeding the capacity of the dam spillway [9]. As per world-wide failure data of large embankment dams, the most common causes of failure are overtopping accounting for 32% failures followed by internal erosion accounting for 27% failures [9]. In comparison, in India, internal erosion (breaching) accounts for about 44% of dam failures followed by overtopping that accounts for about 25% failures. Of the world-wide dam failures caused by overtopping, 73% are due to inadequate spillway capacity and 27% due to spillway gate failure [1]. In India, there is no recorded dam failure directly attributable to gate failure. However, the worst dam failure of India – namely, Machu-II dam failure in 1979 that resulted in loss of lives exceeding 2000 numbers – was on account of overtopping essentially resulting from the situation of inadequate spillway capacity and apparently with an added contribution from the cause of gate failure.

In the world, India now ranks third in terms of number of large dams, after United States and China [10]. There are currently about 4877 completed large dams in India [4]. The total storage capacity of these dams, of which 76% are more than 20 years old, is about 283 billion cubic meters. More than 75% of Indian dams, carrying substantial storage behind them, are thus at least two decades old; and for these dams the original flood peak discharges/volumes were estimated mostly from empirical formulae with applied discretions by experienced designers. For such existing dams, there is an urgent need for the original design flood estimates to be either justified or reviewed based on scientific data collected in-situ, and on the basis of computational procedures that have been improved since then. Even in many a cases of latter-day constructed dams, the original estimate of design floods were based on the scarce observed flood records or on record of extreme rainfall events at that time; and both of these data-sets get strengthened with more values getting added, and hence it will be prudent to review these studies as well.

Checking and upgrading the dam design flood estimates – incorporating the extended data sets and also assimilating the intervening experiences – is thus a key technical priority in India's national dam safety program; and, this activity is also the prime requirement under the ongoing Dam Rehabilitation and Improvement Project (DRIP). DRIP is a World Bank funded project, co-ordinated by Central Water Commission (CWC), under which the dam safety reviews and dam rehabilitation works are being undertaken for 224 selected large dams. Based on the outcomes of the substantial set of design flood reviews for 118 dams under DRIP, this paper attempts to analyzethe trend of design flood revisions in existing dams. Since in majority of review cases the design floods have been subjected to substantial degree of upward revision, the paper further examines the risk perceptions evolving from such upward design flood revisions and the vexed issues of mitigating such risk concerns in existing dams. Finally, the paper highlights the limitations of prevalent guidelines for design flood estimations, while effecting risk mitigation measures in existing dams.

2. Brief Description of DRIP

As a part of continuous strengthening of dam safety activity in India, Dam Rehabilitation and Improvement Project has been taken up with the World Bank assistance for implementation initially in four States – namely: Kerala, Madhya Pradesh (MP), Orissa, and Tamil Nadu (TN) – and in Central Water Commission. Three more States / Organisations (namely: State of Karnataka, Damodar Valley Corporation Ltd., and Uttranchal Jal Vidyut Nigam Ltd.) have joined DRIP at a later stage, for which a provision of unallocated resources had been provided in the project estimate.

Besides seeking rehabilitation of existing dams to current acceptable level, the project also aims for the dam safety institutional strengthening in the participating States and in Central Water Commission. The main implementation agencies for DRIP are the owners of dams – i.e. Water Resources Departments and State Electricity Boards in the participating States. The overall implementation of the project is being coordinated by CWC, and for this purpose CWC is assisted by an Engineering and Management Consulting Firm. DRIP, with an estimated cost of Rs. 2100 crore has become effective from 18th April 2012, and will be implemented over a period of six-years.

The project presently targets for rehabilitation of 224 large dams spread over seven States [5]. Many of these dams were built based on the empirical formulae prevalent at that time and found to be inadequate based on the current design standards and philosophy. Under DRIP, before any rehabilitation and improvement works are undertaken on a dam, the design flood review is to be mandatorily carried out [12]. Thus, under DRIP, design floods of all the 224 select dams shall be reviewed in accordance with IS-11223 (as revised), using the most appropriate and recent available data. The rehabilitation works (structural interventions) or operational procedures (non-structural methods of coping with design floods) proposed under DRIP will have to ensure the safety of the dam and reservoir with this revised design flood.

3. Trends in Design Flood Revisions Under DRIP

An examination of the design flood data of 118 projects indicates thatdesign floods of 32 dams qualify for Probable Maximum Flood (PMF), 67 for Standard Project Flood (SPF) and 19 for 100 Year Flood categories based on the criteria stipulated in Bureau of Indian Standard – IS: 11223 (1985) 'Guidelines for Fixing Spillway Capacity', as reaffirmed in 1995. The State-wise break-up of the categories of design flood for 118 dams are given in Figure 1.

The complete data set of original and revised design flood values for the mentioned 118 DRIP dams is given in *Appendix*. A comparison of the revised design flood values of these DRIP dams with their respective original design flood values indicates that there is an upward revision of over 50% for 63% of the dams and an upward revision of over 100% for 40% of the dams. The State-wise observed upward trend of design flood revisions in case of 118 DRIP dams has been summarized in Figure 2.

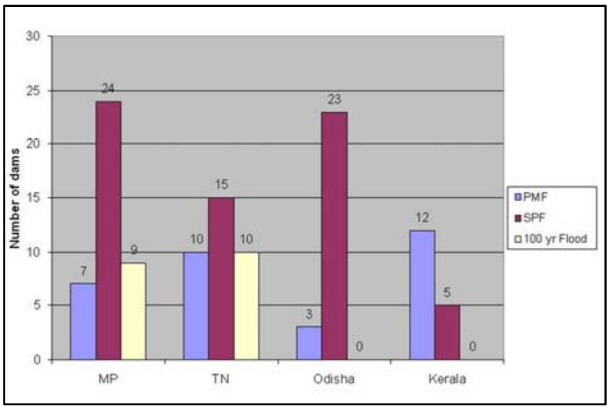

Figure 1. *Design Flood Categorization of Dams under DRIP.*

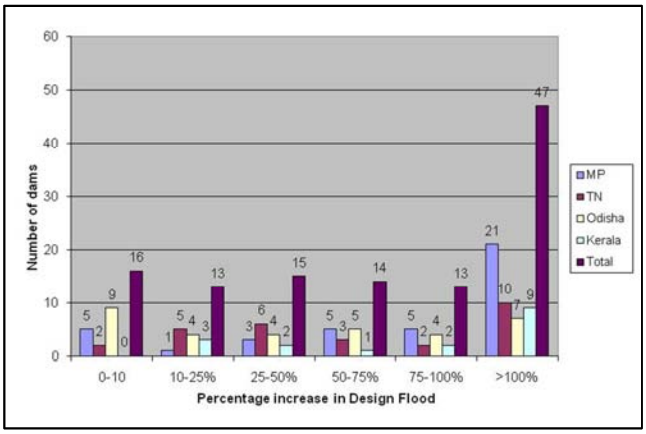

Figure 2. *Observed Extent of Upward Revisions in Design Flood Values.*

For many of the dams, the revised design flood values have exceeded their earlier adopted values by substantial orders. For example, in comparison to the original design flood values, the revised design flood value of Kharadi dam of Madhya Pradesh exceeded by 929%, Sher tank of Madhya Pradesh exceeded by 503%, Manimukhanadhi Dam of Tamil Nadu exceeded by 384%, and Mangalam dam of Kerala exceeded by 525%. There are also few cases where revision has actually ended up in downsizing of the estimated design flood values. Out of 118 dams, there are six cases, where reduction of the order of 10% and less has been observed, while in one case – Siddamalli Dam Project of Tamil Nadu – the reduction in design flood has been of the order of 39%.

Using the data set of revisions of design floods in DRIP dams, an attempt has been made to establish the trends in the observed (percentage) increase in design flood values. Accordingly, scattered plots have been prepared reflecting trends of 'percentage increase in design flood values' vis-à-vis parameters of 'dam height', 'age of dam' and 'gross storage capacity of reservoir'. These plots are presented in Figures 3, 4 & 5 respectively.

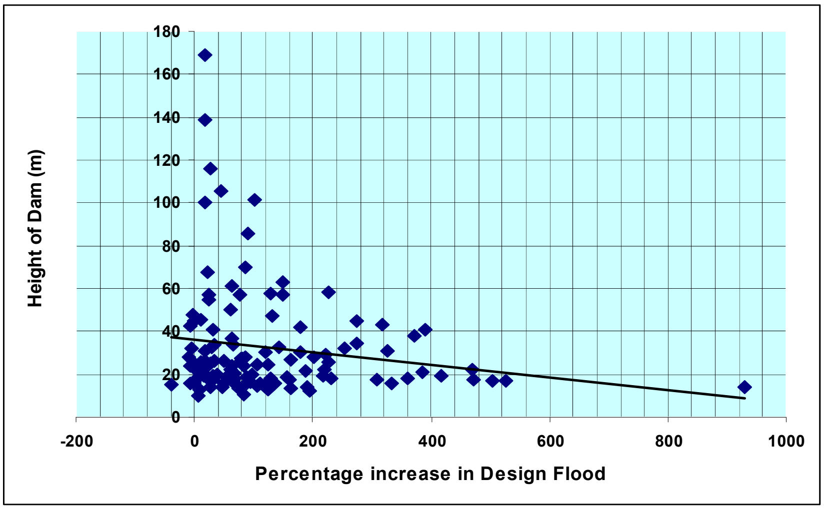

Figure 3. *Scattered Plot of Increase in Design Flood Vs Dam Height.*

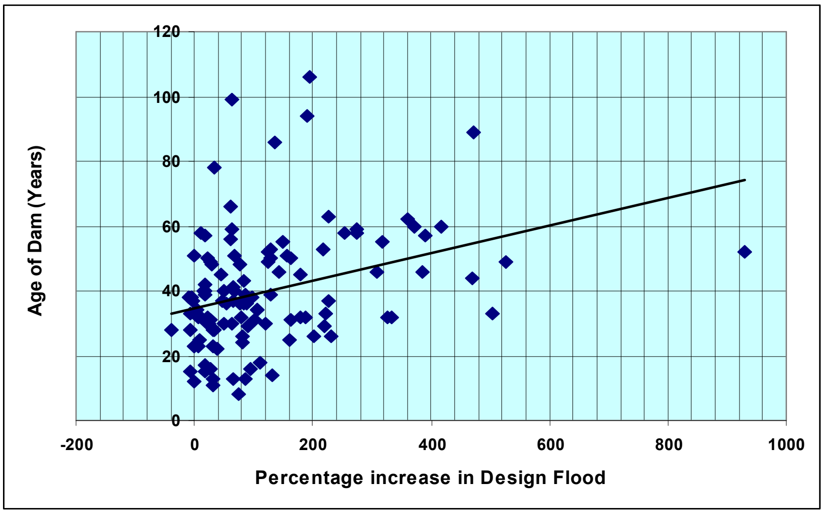

Figure 4. *Scattered Plot of Increase in Design Flood Vs Age of Dam.*

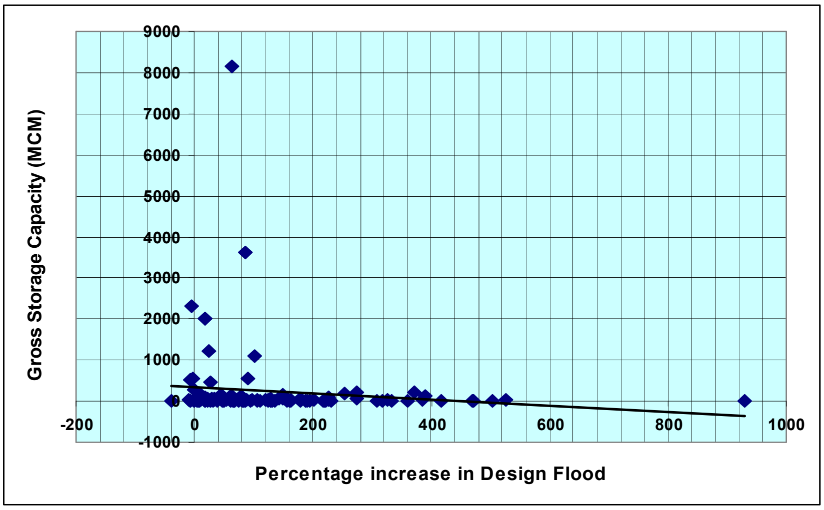

Figure 5. *Scattered Plot of Increase in Design Flood Vs Gross Storage Capacity.*

Any apparent trend is not being established in the scattered plot of increase in design flood versus gross storage capacity of reservoir. But, other two plots give the impression of establishing such trends as: (i) Increase in revised design flood values is lower for higher height of dam; and (ii) Increase in revised design flood values is higher for older dams. The importance of above stated trends can not to be downplayed in the context to the occurrence of high degree of upward design flood revisions for existing dams, especially owing to perceptions of heightened risks associated with such upward revisions, and the limited options available in existing dams for mitigation of such risks. The first identified trend in the revision of design floods – in terms of dam heights – points out the possibility of excessive reliance by the earlier designers on the empirical methods for the original design flood estimations of low height dams. On the other hand, the second identified trend of design flood revision – in terms of age of dam – strengthens the argument that availability of additional data is impacting the extent of revision; and this argument can be supported further by the following factors attributable as the cause of upward revisions:

(a) Availability of additional data in respect of observed flood peak used in flood frequency analysis.
(b) Availability of additional data/information about severe most storms from hydro-meteorologically homogeneous regions.
(c) Adoption of different temporal distribution pattern for the standard project storm or probable maximum storm.
(d) Changes in response function, i.e. unit hydrograph, as a result of analysis of more number of flood events.

4. Risk Concerns of Upward Design Flood Revisions

The upward revisions in the design flood estimates of existing dams often lead to perceptions of amplifying the risks associated with such existing dams. However, contrary to these perceptions, the reality is that the revisions in design flood estimate as such do not bring any change in the risk status of an existing dam.

Risk, by definition, is the relationship between the consequences resulting from an adverse event and its probability of occurrence [6]. It includes consideration of both failure likelihood and the consequences of failure. As a measurable index, the risk can be computed as a product of probability of failure and the measure of consequences – higher the index, greater is the risk. Thus in a hypothetical case of an existing dam planned for a design flood of 1 in 1,000 year return period (thereby meaning a flood related failure probability of 0.001) and with an estimate of say 10 fatalities in case of failure (meaning a life related consequence measure of 10), the risk index will be of the order of 0.01. Now, assuming that there is no change in the measure of consequence of dam failure, and assuming that the design flood estimate has been subjected to upward revisions corresponding to 1 in 10,000 year return period, then what happens to the risk factor? There are varied possibilities. Firstly, if additional remedial measures are not taken to account for enhanced design flood level, then the dam continues to retain the same failure probability of 0.001 (corresponding to original design flood level of 1,000 year return period) and the same risk index of 0.01. Secondly, if full remedial measures are undertaken, then the dam's failure probability now stands reduced to 0.0001(corresponding to revised design flood level of 10,000 year return period) and thereby the risk index will reduce to 0.001. The other possibilities include achieving a risk index level anywhere between 0.001 and 0.01, corresponding to the enhanced level of spillway capacity achieved after dam's rehabilitation. But, in no case the risk index will increase beyond its original level of 0.01.

The above hypothetical case clearly illustrates that an upward revision in the design flood estimate of existing dam in no way leads to amplification of the actual risk associated with that dam. Rather, it brings an understanding of the gap between existing risk level and the acceptable risk level (as per present-day norms), and it also provides an opportunity for reducing the existing risk level even further (at par with acceptable risk level). The society in general is risk-averse [7]; whereby meaning: if the consequences of an adverse event (e.g. number of fatalities in an incidence of dam failure) were to increase, the society will desire a decrease in the likelihood of such event. The acceptable risk can be represented as a log-log plot with annual failure probability of the risk-prone event on the vertical axis and consequences of event on the horizontal axis. The Figure 6 shows one such risk guidelines chart for dam safety adopted by the U.S. Bureau of Reclamation [11].

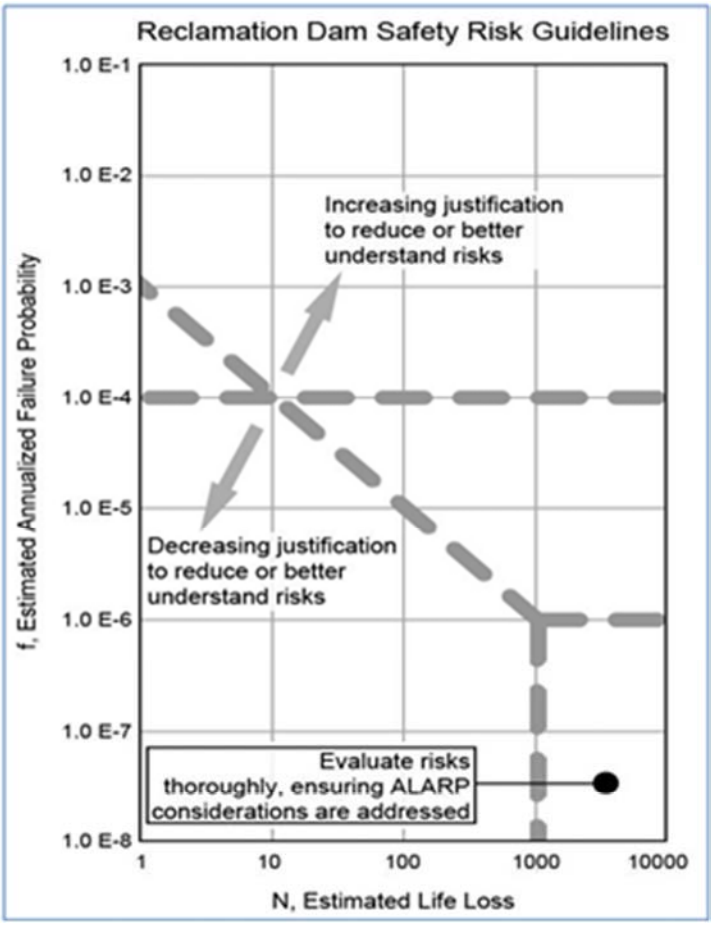

Figure 6. *USBR's Risk Guidelines Chart.*

The acceptable risk as per Reclamation's guidelines is represented by a diagonal line with negative slope – thereby requiring decreasing likelihood of failure with increasing consequences – corresponding to an annualized life loss of 0.001 lives/year. Thus, for a given consequence level, if the likelihood of failure value exceeds the guideline value then there is increasing justification for reducing the risk level; and if the likelihood of failure value falls below the guideline value then there is decreasing justification for taking any action. The risk based guidelines for dam safety are not in place in India so far. However, the World Bank funded DRIP scheme aims to bring Indian dams to internationally acceptable safeguard levels, and in this respect USBR's risk chart can be unquestionably referred for guiding actions for risk mitigation in DRIP dams.

However, the bigger challenge for alleviating risk concerns of DRIP dams in the indicated manner is the absence of readily available risk based data (i.e. data concerning likelihood of dam failure and the estimate of loss of life in case of failure). The generation of data for potential fatalities calls for a hypothetical dam break analysis, estimation of inundation extent, and the assessment of impact of inundation on the downstream habitat – and these works are yet to be taken for most of the dams. On the other hand, and as per the provisions of Bureau of Indian Standard (BIS) IS-11223 [2], the return period (likelihood) design flood concept gets applied only in case of small [1] dams, while the intermediate[2] and large[3] dams are required to be designed for the Standard Project Flood (SPF) and Probable Maximum

1Dams with hydraulic head of 7.5m to 12m, or gross storage of 0.5 Mm^3 to 10 Mm^3, are classified under small category, and are required to be designed for 1 in 100 year flood.

2Dams with hydraulic head of 12m to 30m, or gross storage of 10 Mm^3 to 60 Mm^3, are classified under intermediate category.

3Dams with hydraulic head exceeding 30m, or gross storage exceeding 60 Mm^3, are classified under large category.

Flood (PMF) respectively. Apart from this limitation of the prevalent guidelines for design flood estimation, its other limitations in guiding risk mitigation of existing dams are discussed in detail in subsequent paragraphs.

5. Design Flood Risk Mitigation Measures Under DRIP

As brought out above, the data for guiding dam specific risk based actions are not readily available for DRIP dams; and in many a cases this data will be developed as an outcome of DRIP activity, which may thus become available only by the end of project period. Realizing this limitation very early, the World Bank, Central Water Commission and the DRIP States have agreed to a standardized approach for mitigating the risks arising out of design flood. The design flood risk mitigation approach – involving both structural and non-structural measures – as brought out in the Project Implementation Plan of DRIP [3] is summarized below:

a. Once the reviewed design flood is found to be significantly higher than the original design flood, adequacy of spillway capacity needs to be thoroughly reviewed. When it is found that the revised design flood hydrograph cannot be routed through the spillway without encroaching into the free board as per the norms, then various alternatives are available to make the dam hydrologically safe. The solution to be adopted will vary from case to case, and following list of alternatives will be taken up during implementation of DRIP for mitigating the increased design flood:
   (1) Augmenting [4] the existing spillway capacity through addition of more spillway bays of the same type as existing.
   (2) Provision of breaching sections or fuse plugs. If suitable sites are available it is preferable to locate such breaching sections on a saddle rather than on the main dam section. However, it is required to investigate the alignment of the surplus channel till it meets the main channel to assess the likely damages in the surrounding valley in the event of design flood causing a breach.
   (3) Increasing the freeboard above FRL of the dam by provision of parapets including strengthening of sections where necessary so that the flood cushion available will be increased.
   (4) Establishment of Early Warning System. An early warning system involving flood forecasting by utilizing real time data of rainfall, stage and discharge at upstream stations will greatly help in evacuating the downstream habitat area in anticipation of severe flood inflows into the reservoir.
   (5) Increasing the flood storage by lowering the conservation storage level, so that flood moderation will be enhanced. However, this may also result in some reduction in benefits and on the positive side it will involve little investment required for modification.
b. A suitable alternative is to be chosen by considering various options that are feasible and working out the relative benefit cost and the most favorable is to be chosen.
c. In order to accommodate the revised design flood magnitudes, there may be cases where the dam height (but not the spillway height and so there will be no increase in reservoir capacity) may have to be increased if freeboard is not sufficient to allow temporary heightening of the reservoir level. In such a rare event, an adequate public warning system must be in place to warn people living around the reservoir. The option of increasing of dam height resulting in the increase in storage volume or head will not be considered under DRIP.
d. If the maximum water level in the reservoir were temporarily to be increased during peak floods, structural stability analysis will be made to ensure the stability of the dam against the increased water load, and the safety of the structure must be confirmed. Also, in the event of the revised design flood exceeding the spillway capacity (with normal freeboard) by more than 50 percent, a comprehensive warning system will also have to be put in place, and an awareness campaign will be conducted, in accordance with the emergency action plan.
e. Many a times structural interventions are not possible owing to topographical and/or structural constraints. In such a case it is often found difficult to increase the capacity of an existing spillway to suit the revised design flood. In such cases, routing trials can be carried out for identification of lower reservoir levels during the flood season. Even this, in some cases, is found to be costly and unviable in terms of loss of power and irrigation benefits and, therefore other non-structural options can be considered for the safe operation of the reservoir. It has been learned from the past experiences that the best results in flood mitigation can be achieved by combining structural measures and non-structural measures. Emergency action planning in terms of Emergency Action Plan (EAP), implemented with Early Warning System (EWS) where necessary, are non-structural measures to minimize flood impacts and play an important roles in emergency planning in case of dam break induced flood event. Emergency action plans for downstream flood plains, including warning and evacuation plan is a special risk mitigation procedure. In fact, public risk protection and EAP are very important dimensions in any risk and crisis management methodology.

4 In an earlier dam safety program "Dam Safety Assurance & Rehabilitation Project" assisted by the World Bank and implemented in four States of the India during the period of 1991 to 1999, flood handling capabilities of several dams had been upgraded by way of augmenting the existing spillway capacities.

f. Even though floods of the order of PMF have only very low exceedance probabilities, their possibility cannot be ruled and in order to counter such emergency situations there is a need to adopt both well thought out structural remedies and also an emergency action plan to be set in motion as soon as an event unfolding is perceived. There is a provision in DRIP that whenever revised design flood exceeds the spillway capacity by more than 50 percent, the emergency action plan will have to be prepared by the State project authorities. However, it is worth mentioning that an emergency action plan is not a substitute for proper maintenance or remedial construction, but it facilitates the recognition of dam safety problems as they develop and establishes non-structural means to minimize the risk of loss of life and reduce property damage.

6. Limitations of Present Guidelines for Design Flood Risk Mitigation of Existing Dams

From the narration contained in this paper up till this point it can be inferred that: (i) a substantial proportion of DRIP dams are getting subjected to extensive upward revisions in their design floods; (ii) these revisions underline the large gap between the existing risk levels and the acceptable risk levels; and (iii) under DRIP, suitable structural measures, non-structural measure, or a combination of two measures will be required to be undertaken to mitigate the identified flood related risks. However, the depths/ degrees of concerns marked under these three inferences (i.e. extent of upward revision, gap from acceptable risks, and complexities of remedial measures) relate to a common factor, namely the present-day norms related to computation of design floods. These norms are contained in the Indian Standard–Guidelines for Fixing Spillway Capacity (IS: 11223 – 1985, reaffirmed in 1995). This Standard lays down the guidelines for fixing spillway capacity consistent with the safety of the dam; and towards this intent it also lays down the norm for inflow design flood of dam. Some of the limitations of this Standard, in general as well as in specific context to existing dams – supported by inferences drawn from DRIP dams – are discussed below.

As per internationally accepted practice, the norms for inflow design floods are developed primarily on the basis of hazard categorization[5] of dams. Thus, floods of greater return periods are considered as acceptable design floods for dams posing larger hazard potentials in terms of loss of lives or economic losses. In these norms, secondary importance is also given to the parameters of dam height and dam storage because these can play proportional role in the severity of the hazard (in terms of level, velocity, and duration of submergence flows) brought about by dam failure. Evidently, in the international norms – applying the risk based approach for dam safety – the probability of occurrence of design flood (indicative of the probability of dam failure due to floods) gets decided by the measure of consequences of failure. However, in India, the system of hazard classification of dams is still not in place; and in light of this constraint the desired primary basis of developing design flood norms (namely, the hazard categorization of dam) has not been applied in the case of IS: 11223. Instead, the Indian norms for inflow design floods have been developed solely on the basis of the height and storage parameters of the dam. This limitation of the Indian Standard apparently brings unwarranted skew in the distribution of the estimates of design flood values, often raising issues of technical and economical viability of meeting the requirements of the Standard.

The IS: 11223 Standard has provision for only three categories of inflow design floods – namely, 100 year return period flood, Standard Project Flood (SPF) and Probable Maximum Flood (PMF). The SPF (computed by using the Standard Project Storm) is expected from the most severe combination of hydrological and meteorological factors, and may match to a flood of the order of 1,000 year return period. On the other hand, the PMF (computed by using the Probable Maximum Storm) corresponds to the physical upper limit to maximum precipitation, and may match to a flood of the order of 10,000 year return period or even higher.

Though SPF and PMF values are not truly the probabilistic estimates of the design flood, even then it can be safely concluded that only three acceptable levels of design flood probabilities have been considered and that too with substantial jump – from 1-in-100, to 1-in-1000, and finally to 1-in-10000. And these abrupt jumps are linked only to the hydraulic head (related to dam height) and gross storage parameters of the dam in the manner indicated in Table 1 below. As per this Standard, the hydraulic head criteria and the gross storage criteria need to be fulfilled in isolation (and not concurrently) for arriving at the design flood level of the dam.

Table 1. *Inflow Design Flood (as per IS: 11223-1985).*

Dams with gross storage	Dams with hydraulic head	Inflow Design Flood
0.5 Mm^3 to 10Mm^3	7.5m to 12m	100 year flood
10 Mm^3 to 60Mm^3	12 m to 30 m	SPF
Greater than 60Mm^3	Greater than 30 m	PMF

Though the Standard, in full earnest, also provides for use of a larger or smaller magnitude floods based on high or low hazard potential of the dam, but this adjustment is perhaps never made owing to the absence of hazard rating and also because of insufficient clarity on the application of this clause. A cursory examination of the Table will thus show that a dam with height of 12m will have an acceptable design flood level of 100 year return period, while a marginally higher dam of 12.5 m will invariably call for a design flood

5Hazard categorization is a system of classifying dams according to the degree of adverse incremental consequences of failure or misoperation of a dam. The hazard categorization does not reflect in any way on the current condition of the dam (i.e. safety, structural integrity, flood routing capacity etc.).

of the order of 1,000 year return period (corresponding to SPF); and similar anomaly will be encountered for dams of height bordering 30m. On the same lines, the design flood values arrived on the basis of gross storage will show skew in its distribution.

As pointed out earlier, the analysis of the recently completed design flood studies (applying IS: 11223) of 118 DRIP dams indicates that about 25% of them come under PMF category, about 55% under SPF category, and about 20% under 100 year return period category. In this manner, about 80% of the dams are being (re)classified under the categories of very high design floods –corresponding to 1,000 year or 10,000 year return periods. And, this is being done without having even an indicative assessment of the consequences of respective dam failures. As explained earlier, these large revised estimates are merely creating wide gaps between the existing spillway capacities of the dams and their design floods, without any alteration in the actual risk factors. As described, efforts are being made under DRIP to augment the spillway capacities of these dams to their revised design flood levels, but in many a cases it may not be possible to bridge the gap or to even reduce it in significant manner. Consequentially, substantial efforts are also likely to get directed towards non-structural interventions for mitigation of design flood risks. It is generally felt by the officials concerned with the DRIP that an imbalance is being encountered in DRIP activities on account of high design flood revisions, reasons for which can be attributed to the limitations of the Indian Standard as elucidated above. Since in terms of varied parameters, the portfolio of DRIP dams presents a close sample of the total basket of Indian dams, the prevalence of this challenge in respect of balance dams of the country cannot be ruled out.

The ultimate remedy for the above problem lies in the establishment of proper hazard classification system and hazard categorization of the dams, followed by risk based amendments of the Indian Standards. However, till such times, some amendments may also be required in the current Standards to improve upon the mentioned skewed situation for at least the existing large dams of the country. With this perspective and since absolute reliance has been placed on the criteria of dam height and gross storage for determination of design flood, an attempt has been made to establish the correlation of computed design floods with the parameters of dam height and gross storage capacity. Accordingly, scattered plots have been developed to establish mentioned correlations and these plots are shown in Figures 7 & 8.

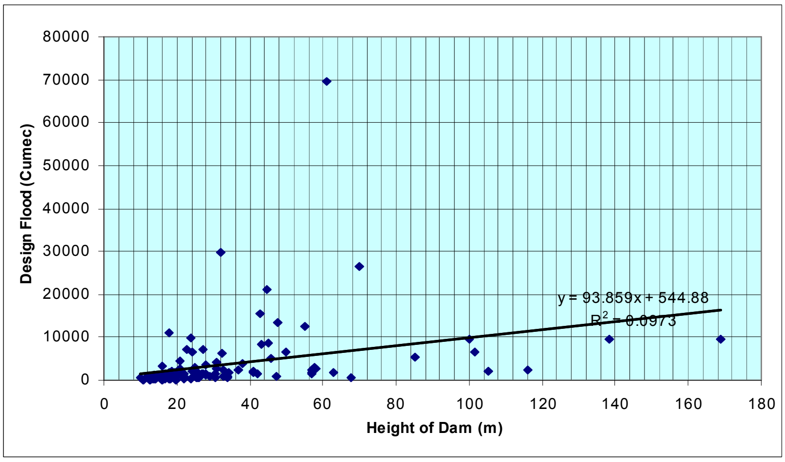

Figure 7. *Scattered Plot of Design Flood Vs Dam height.*

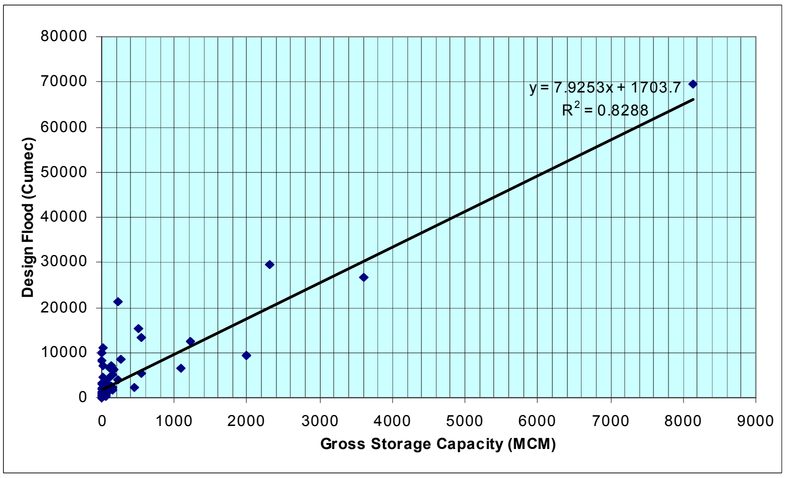

Figure 8. *Scattered Plot of Design Flood Vs Dam Storage.*

From the computed values of Coefficient of Determination[6] it is observed that a strong correlation is established between the design flood and the gross storage capacity – i.e. estimate of design flood closely increases with the increase in design storage capacity of the dam. However, very poor correlation exists between the design flood and the dam height – i.e. estimate of design flood increases or decreases at random with the increase in dam height. Evidently it means that the application of dam height criteria (when it is not being applied as a parameter influencing the failure consequences) in isolation for the determination of design flood may not be appropriate.

A remedy for this anomaly can be found in the concurrent application of the hydraulic head criteria with the gross storage criteria for arriving at the desired design flood levels of existing large dams. Assuming the minimum design flood criteria of 100 year return period for any large dam, the application of this slightly modified approach in the data set of DRIP dams show a marked improvement in the distribution of design flood as brought out in Table 2 below:

Table 2. *Design Flood Distribution.*

Inflow Design Flood	Number (& percentage) of dams	
	with isolated application of dam height and gross storage criteria	with concurrent application of dam height and gross storage criteria
100 year flood	19 (16%)	65 (55%)
SPF	67 (57%)	34 (29%)
PMF	32 (27%)	19 (16%)

It is also felt that there is scope for the introduction of two more levels of flood category; one between 100 year flood and SPF categories, and another between SPF and PMF categories. Between the 100 year and SPF categories, it is proposed to introduce '500 year flood' category. Between SPF and PMF categories, a category of '3000 year flood' may be introduced; alternatively 'average of SPF and PMF' may be considered under this level. In order to make a clear distinction between the actual design flood capacity and the acceptable design flood of a dam, it is further suggested to use a new nomenclature of 'Safety Basis Flood (SBF)'. Appropriate norms proposed for computation of Safety Basis Flood of Large Dams[7]are summarized in Table 3 below:

The nomenclature of 'Design Flood' shall be retained to indicate the actual spillway routed capacity of the dam, as built. The SBF shall be computed on return-period basis (i.e. in terms of probability) so as to enable meaningful risk assessment of existing dams; and the actual (routed) design flood capacities of existing dams shall be expressed as percentage of SBF so as to systematically highlight the gap between actual and acceptable flood risks. It is also proposed to compute the PMF for every large dam so as to assess the upper bound (or envelop) of the potential flood at the dam site and thereby giving an understanding of the dam's ultimate risk potential; and present the SBF as percentage of PMF so as to point out the level of risk-acceptance in relation to ultimate-risk.

Table 3. *Safety Basis Flood for Large Dams.*

Large Dam Criteria		Safety Basis Flood
Dam Height (H)	Dam's Storage (S)	
> 30m	> 100 Mm^3	PMF
> 30m	60 Mm^3 to 100 Mm^3	Return Period: 3000 yrs
15m to 30m	>30 Mm^3	Return Period: 1000 yrs
15m to 30m	10 Mm^3 to 30 Mm^3	Return Period: 500 yrs
< 15m	< 30 Mm^3	Return Period: 100 yrs

Based on the above discussion, it is proposed to suitably amend the IS: 11223 Standard for existing large dams, or to formulate a new Standard for revision of design floods of existing large dams.

7. Conclusions

Examination of revised design flood studies carried out for a set of 118 dams under 'Dam Rehabilitation and Improvement Project' reveal that the design flood values invariably increase as a result of reviews as per IS: 11223 Standard except for few cases. In majority of cases, the upward revision in design flood is on very high side, exceeding the 50% mark. The observed trends indicate that the percentage increases in the revised design flood values are greater for lower (height) dams and for older dams. However, the upward revision in the design flood estimate of existing dam in no way leads to amplification of the actual risk associated with that dam. Rather, it brings an understanding of the gap between existing risk level and the acceptable risk level thereby providing an opportunity for reducing the existing risk level even further (at par with acceptable risk level). But, risk mitigation (for floods) in existing dams is a challenging task calling for structural as well as non-structural alternatives, often facing constraints of technical and economical viability. The challenge is compounded by the skewed distribution of revised design floods on account of present-day norms related to computation of design floods, as contained in the Indian Standard – Guidelines for Fixing Spillway Capacity (IS: 11223 – 1985). After examining in detail the limitations of the Standard, the paper brings out proposal for its suitable amendments in respect of existing large dams incorporating: (i) concurrent application of the hydraulic head criteria with gross storage criteria for deciding the design flood category

6 Coefficient of Determination (R^2) is a parameter which gives the strength of correlation between the two variables. $0 \leq R^2 \leq 1$.

7A Large dam, as per the definition given by ICOLD [8], means a dam with a maximum height of more than 15 metres from its deepest foundation to the crest. A dam between 10 and 15 metresin height from its deepest foundation is also included in the classification of a large dam provided it complies with one of the following conditions: (a) length of crest of the dam is not less than 500 metres or (b) capacity of the reservoir formed by the dam is not less than one million cubic metres or (c) the maximum flood discharge dealt with by the dam is not less than 2000 cubic metres per second or (d) the dam has specially difficult foundation problems, or (e) the dam is of unusual design.

of a dam; and (ii) introduction of two more design flood categories – namely, '500 year flood' to be placed between 100 year and SPF categories, and 'average of SPF and PMF' to be placed between SPF and PMF categories. Alternatively the recourse of formulation of a new Standard for revision of design floods of existing large dams has been proposed.

Appendix

Original and Revised Design flood Values for 118 DRIP Dams.

Sl. No.	Name of Dam	State/ Organization*	Original Design Flood (Cumec)	Revised Design Flood (Cumec)
1	Sanjay Sarovar (Bhim Garh Project)	Madhya Pradesh	16652	15428
2	Ari Project	Madhya Pradesh	240	1241
3	Tawa Project	Madhya Pradesh	30800	29619
4	Jirbhar Project	Madhya Pradesh	373.5	1074
5	Thanwar Tank	Madhya Pradesh	3993.2	7137
6	Sakhiya Sagar (Chanda Patha Project)	Madhya Pradesh	424	1226
7	Barna Project	Madhya Pradesh	13557	13235
8	Kankarkhera Tank Project	Madhya Pradesh	144	625
9	Gopi Krishan Sagar Project	Madhya Pradesh	3605	4209
10	Kharadi Project	Madhya Pradesh	100	1029.8
11	Nahlesara Project	Madhya Pradesh	271.68	1543.6
12	Chandra Keshar Project	Madhya Pradesh	870.84	1644
13	Sagarnadi Project	Madhya Pradesh	186	758
14	Kolar Project	Madhya Pradesh	8605	8605
15	Sarathi Tank Project	Madhya Pradesh	289	1651
16	Sampana Project	Madhya Pradesh	492	788
17	Mooram Nallah Project	Madhya Pradesh	185	852
18	Chawarpani Project	Madhya Pradesh	202.53	453.8
19	Bundala Tank	Madhya Pradesh	838	1512
20	Marhi Tank	Madhya Pradesh	296.7	952
21	Kunwar Chain	Madhya Pradesh	1310	1733
22	Makroda Tank	Madhya Pradesh	598.41	2554
23	Sanjay Sagar Tank project	Madhya Pradesh	1565	2039
24	Sher Project	Madhya Pradesh	120	724
25	Sundrel	Madhya Pradesh	60.81	66.05
26	Gangulpara	Madhya Pradesh	191.73	607
27	Guradia Surdas	Madhya Pradesh	110	215.57
28	Manjhikhedi	Madhya Pradesh	88.52	123.23
29	Lasudiakanger	Madhya Pradesh	68.74	179.98
30	Dhablamata	Madhya Pradesh	72.44	133.08
31	Deogaon	Madhya Pradesh	182.2	476.16
32	Birpur	Madhya Pradesh	423.99	737
33	Birnai	Madhya Pradesh	81.13	268
34	Umrar	Madhya Pradesh	479.78	1449
35	Kamera	Madhya Pradesh	279.99	825
36	Arniya Bahadurpur	Madhya Pradesh	533	818
37	Tigra	Madhya Pradesh	4067	6672
38	Dholawad Tank	Madhya Pradesh	1473	2396
39	Kanhargaon Tank	Madhya Pradesh	736	1621
40	Kachan	Madhya Pradesh	485	1586
41	Banksal Dam Project	Odisha	420	868
42	Kalo Dam Project	Odisha	965	1997
43	Nesa Dam Project	Odisha	351	364
44	Sanamachhakandana Dam Project	Odisha	226	374
45	Padampurnalla	Odisha	303	443
46	Budhabudhiani	Odisha	401	903
47	Balaskumpa	Odisha	132.48	302
48	Ashokanalla	Odisha	69.34	221
49	Daha	Odisha	1380	1828
50	Derjang	Odisha	3952	3590
51	Dhanel	Odisha	733	1230
52	Pillasalki	Odisha	793	1054
53	Salia	Odisha	1019.42	2464
54	Sarafgarh	Odisha	695	819
55	Satiguda (Malkangiri)	Odisha	1060	1883
56	Talsara	Odisha	820	913

Sl. No.	Name of Dam	State/ Organization*	Original Design Flood (Cumec)	Revised Design Flood (Cumec)
57	Hirakud	Odisha	42450	69632
58	Balimela	Odisha	14300	26603
59	Bhaskel	Odisha	566	1482
60	Damsel	Odisha	436	732
61	Jhumuka	Odisha	188	343
62	Pitamahal	Odisha	716	833
63	Sapua	Odisha	535	626
64	Satiguda (UKP)	Odisha	319	479
65	Sundar	Odisha	812	1610
66	Upper Kolab	Odisha	10020	12569
67	Nambiyar Reservoir Project	Tamil Nadu-WRD	1053.9	1053.9
68	Mordhana Reservoir Project	Tamil Nadu-WRD	10541.1	9820
69	Poigaiyar Reservoir Project	Tamil Nadu-WRD	164.45	208
70	Adavainainarkoil Reservoir Project	Tamil Nadu-WRD	356	826
71	Vadakkupachayar Reservoir Project	Tamil Nadu-WRD	715.77	1338
72	Kudumudiyar Reservoir Project	Tamil Nadu-WRD	573.95	947.92
73	Rajathopekanar Reservoir Project	Tamil Nadu-WRD	81.89	172
74	Gomukhinadhi Dam Project	Tamil Nadu-WRD	2834	2834
75	Siddamalli Dam Project	Tamil Nadu-WRD	1920	1162
76	Vidur Dam Project	Tamil Nadu-WRD	6167	7228
77	Kodaganar Reservoir Project	Tamil Nadu-WRD	8500	11147
78	Manimuthar Dam Project	Tamil Nadu-WRD	4522	4969
79	Manimukhanadhi Dam Project	Tamil Nadu-WRD	926.06	4484
80	Thirumurthy	Tamil Nadu-WRD	447.65	1672
81	Amaravathy	Tamil Nadu-WRD	4062	6544
82	KullarSandhai	Tamil Nadu-WRD	635	673
83	NoyyalAthupalayam	Tamil Nadu-WRD	92.72	169
84	Shoolagirichinnar	Tamil Nadu-WRD	547.1	689
85	PilavukkalPeriyar	Tamil Nadu-WRD	286.57	474
86	PilavukkalKovilar	Tamil Nadu-WRD	223	333
87	Anaikuttam	Tamil Nadu-WRD	1708	2096
88	Golwarpatti	Tamil Nadu-WRD	3207.5	3207.5
89	Gundar	Tamil Nadu-WRD	264.68	243
90	Keravarapalli	Tamil Nadu-WRD	2490	2641
91	Sathanur	Tamil Nadu-WRD	5664	21181
92	Vaigai	Tamil Nadu-WRD	1783	6316
93	Sholayar	Tamil Nadu-WRD	1475	2139
94	Mukurthy Dam Project	Tamil Nadu-EB	425	567
95	Servalar Dam Project	Tamil Nadu-EB	1982	2454
96	Porthimund Dam Project	Tamil Nadu-EB	241	297
97	Glenmorgan Dam Project	Tamil Nadu-EB	46	108
98	Avalanche Dam Project	Tamil Nadu-EB	705	1765
99	Kadamparai Dam Project	Tamil Nadu-EB	517.8	632
100	Emerald	Tamil Nadu-EB	705	1765
101	Western Catchment Weir No 1	Tamil Nadu-EB	106	243
102	Malampuza Irrigation Project	Kerala-WRD	849.506	4007
103	Peechi Irrigation Project	Kerala-WRD	368.119	1799
104	Neyyar Irrigation Project	Kerala-WRD	809.4	2643
105	Chulliar	Kerala-WRD	223.7	624
106	Meenakara	Kerala-WRD	472.6	1209
107	Pothudy	Kerala-WRD	682.44	875
108	Kallada	Kerala-WRD	2830	5380
109	Mangalam	Kerala-WRD	245	1533
110	Kanjirapuzha	Kerala-EB	512.5	1427
111	Kakki-Anathodu Dam	Kerala-EB	1784	2283
112	Pamba	Kerala-EB	911.8	1614
113	Ponmudi	Kerala-EB	1359	3104
114	Idamallyar	Kerala-EB	3248	6547
115	Cheruthoni	Kerala-EB	8019	9402
116	Idukki	Kerala-EB	8019	9402
117	Kallarkutti	Kerala-EB	1982	8290
118	Kuamavu	Kerala-EB	8019	9402

Continue. Original and Revised Design flood Values for 118 DRIP Dams.

Sl. No.	Design Flood Category	% Increase in Design Flood	Height (m)	Gross Storage Capacity (Mm^3)	Age
1	PMF	-7.35	42.67	507	28
2	SPF	417.08	19.5	15.3	60
3	PMF	-3.83	32	2311.54	38
4	SPF	187.55	21.33	11.19	32
5	PMF	78.73	27.1	139.2	32
6	SPF	189.15	13.81	7.79	94
7	PMF	-2.38	47.7	539	37
8	100 Year Flood	334.03	15.65	4.83	32
9	PMF	16.75	30.8	85.01	17
10	SPF	929.80	14.17	14.73	52
11	SPF	468.17	21.89	16.143	44
12	SPF	88.78	18.9	30.07	36
13	SPF	307.53	17.21	5.13	46
14	PMF	0.00	45	270	23
15	SPF	471.28	17.68	17.05	89
16	SPF	60.16	21.95	16.9	56
17	SPF	360.54	18.1	5.9	62
18	SPF	124.07	12.95	3.75	52
19	SPF	80.43	27.3	20.41	26
20	SPF	220.86	28.94	14.24	33
21	SPF	32.29	18.28	26.66	11
22	SPF	326.80	30.97	46.57	32
23	SPF	30.29	40.85	37.51	13
24	SPF	503.33	17	3.53	33
25	100 Year Flood	8.62	12.6	0.874	25
26	100 Year Flood	216.59	19.51	11.38	53
27	SPF	95.97	16.58	3.18	16
28	100 Year Flood	39.21	19.76	2.74	22
29	100 Year Flood	161.83	13.41	3.12	31
30	100 Year Flood	83.71	10.67	2.755	36
31	100 Year Flood	161.34	17.43	0.413	25
32	100 Year Flood	73.82	13.49	5.469	8
33	100 Year Flood	230.33	18.26	1.661	26
34	SPF	202.01	27.76	18.9	26
35	SPF	194.65	12	3.37	106
36	SPF	53.5	18.90	25.23	36
37	PMF	64.05	24.08	130	99
38	SPF	62.66	36.86	54.27	30
39	SPF	120.24	30.31	26.97	30
40	SPF	227.01	25.45	40.27	37
41	SPF	106.67	14.63	4.98	34
42	SPF	106.94	24.24	29.7	34
43	SPF	3.70	18	7.8	34
44	SPF	65.49	16.15	4.53	37
45	SPF	46.20	14.17	7.103	37
46	SPF	125.19	24.39	22	49
47	SPF	127.96	17.69	1.15	39
48	SPF	218.72	22.08	0.57	29
49	SPF	32.46	19.3	28	28
50	SPF	-9.16	27.81	46	38
51	SPF	67.80	20.57	15.32	51
52	SPF	32.91	26.5	19.2	28
53	SPF	141.71	32.91	60.66	46
54	SPF	17.84	26	13.75	31
55	SPF	77.64	25.5	76.2	36
56	SPF	11.34	25.82	19.85	32
57	PMF	64.03	60.96	8136	59
58	PMF	86.03	70	3610	39
59	SPF	161.84	26.86	29.82	50

Sl. No.	Design Flood Category	% Increase in Design Flood	Height (m)	Gross Storage Capacity (Mm^3)	Age
60	SPF	67.89	18.25	0.27	40
61	SPF	82.44	23.68	6.22	43
62	SPF	16.34	18.96	23.62	40
63	SPF	17.01	25.55	8.5	15
64	SPF	50.16	26.14	1.75	30
65	SPF	98.27	20	47	38
66	PMF	25.44	55	1215	31
67	100 Year Flood	0.00	16.15	2.33	12
68	SPF	-6.84	23.89	7.4	15
69	SPF	26.48	13.7	2.97	16
70	PMF	132.02	47.2	4.97	14
71	SPF	86.93	27.8	12.5	13
72	SPF	65.16	33.8	3.58	13
73	100 Year Flood	110.04	15.94	0.6	18
74	SPF	0.00	24.83	15.86	51
75	100 Year Flood	-39.48	15.15	6.42	28
76	SPF	17.20	22.55	17.13	57
77	SPF	31.14	17.75	12.3	23
78	PMF	9.89	45.72	156.07	58
79	SPF	384.20	21	20.85	46
80	SPF	273.51	34.14	54.8	58
81	PMF	61.10	50	114.61	66
82	100 Year Flood	5.98	10	3.59	32
83	100 Year Flood	82.27	14.06	6.66	24
84	100 Year Flood	25.94	25.3	2.3	31
85	100 Year Flood	65.40	17	5.44	41
86	100 Year Flood	49.33	16	3.77	40
87	100 Year Flood	22.72	18.7	3.56	30
88	100 Year Flood	0.00	15.9	5.05	23
89	SPF	-8.19	15.7	0.707	33
90	SPF	6.1	20.90	136.12	23
91	PMF	273.95	44.81	228.91	59
92	SPF	254.23	32.31	172.4	58
93	SPF	45.01	105.16	152.7	45
94	PMF	33.41	34	50.98	78
95	PMF	23.81	57	34.7	30
96	PMF	23.24	18	60	50
97	SPF	134.78	16	0.74	86
98	PMF	150.35	57	61.47	55
99	PMF	22.05	67.5	30.85	32
100	PMF	150.35	63	156.2	55
101	SPF	129.25	18	0.126	50
102	PMF	371.69	38.10	228.40	60
103	PMF	388.70	40.85	110.44	57
104	PMF	226.54	58.08	106.20	63
105	SPF	178.95	30.50	13.70	45
106	SPF	155.82	18.90	11.33	51
107	SPF	28.22	32.61	50.91	48
108	PMF	90.11	85.35	536.00	29
109	SPF	525.71	16.92	25.34	49
110	PMF	178.44	42.13	70.83	32
111	PMF	27.97	116.13	455.02	49
112	PMF	77.01	57.00	39.22	48
113	SPF	128.40	57.61	51.54	53
114	PMF	101.57	101.60	1089.8	31
115	PMF	17.24	138.38	1996	40
116	PMF	17.24	169	1996	42
117	PMF	318.26	42.97	6.8	55
118	PMF	17.24	99.97	1996	39

*WRD: Water Resources Department, EB: Electricity Board

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