Guidelines for Classifying the Hazard Potential of Dams

Doc. No. CDSO_GUD_DS_09_v1.0

November 2020

Dam Rehabilitation & Improvement Project

Central Water Commission
Ministry of Jal Shakti
Department of Water Resources,
River Development & Ganga Rejuvenation
Government of India

Front Cover Photograph: The Tiware dam in Ratnagiri district developed a breach late on 2nd July 2019 after heavy rains. | Photo Credit: Raju Shinde

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सत्यमेव जयते

Government of India
Central Water Commission
Central Dam Safety Organization

Guidelines for Classifying the Hazard Potential of Dams

November 2020

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Government of India
Central Water Commission
Central Dam Safety Organization

Guidelines for Classifying the Hazard Potential of Dams is one in a series of several dam safety guidelines being developed under the Dam Rehabilitation and Improvement Project (DRIP).

Disclaimer

Guidelines for Classifying the Hazard Potential of Dams in no way restricts the dam owner in digressing from it. The Central Dam Safety Organization or the Central Water Commission cannot be held responsible for the efficacy of the studies and reports developed by various dam owners based on these guidelines. Dam owners and operators should exercise appropriate discretion when preparing a Hazard Potential Classification Report for their dams.

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MESSAGE

A large number of guidelines have been prepared under the Dam Rehabilitation and Improvement Project (DRIP). This guideline titled "*Guidelines for Classifying the Hazard Potential of Dams*" is the new addition to those already published. The primary objective of this document is to provide a simple, concise, adaptable and reliable approach to identify those pro-jects whose failure or disruption could potentially lead to most severe consequences and to assist dam authorities to take appropriate measures to deal with such critical issues.

It is important to note that the Hazard Classification of a specified dam is based solely on the potential consequences to downstream life, properties, services and environment that would result from a failure or mis-operation of the dam, and therefore; should not be used as a synonymous of "Risk" or as indication of the condition of the dam. The term "risk" is a more comprehensive aspect which incorporates the probability of occurrence, dam system performance and the potential consequences in a single dam safety indicator.

The importance of the hazard potential classification lies in the fact that it provides a preliminary prioritisation tool for rehabilitation works in existing dams. The new hazard potential classification approach proposed in this Guideline is scalable and could be effectively implemented at different portfolio levels (dam authorities, state, and national).

The proposed Dam Safety Bill, 2019, currently under enactment process, mandates that the State Dam Safety Organisation shall classify each dam under their jurisdiction as per such vulnerability and hazard classification criteria as may be specified by the regulations. Thus, this document will help Indian dam authorities to take appropriate advance action in this di-rection.

I hope, these guidelines will help our dam owners to switch over to risk based decision system. The dams having high-consequences could be assigned higher priority to address safety concerns, preparation of detailed emergency action plans or detailed risk assessments and re-orientation of financial resources accordingly. The Guidelines are very descriptive and include detailed examples. I am sure, this document will prove very useful to Indian dam authorities in coming time.

(R K Jain)
Chairman
Central Water Commission

New Delhi
November 2020

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Foreword

Currently, India ranks third globally having 5334 large dams in operation and 411 under construction. Aspects such as climate change, ageing of the existing dams and high population growth may bring our dams at higher risks in future. In addition, the high number of dams and the system complexity makes the decision-making process more difficult. For this rea-son, this Guidelines is important for our dam owners to assess the hazard potential of their dams.

Globally, it is now acceptable procedures to classify hazard potential of dams based on consequences assessment for taking decisions to ensure better dam safety management. It is important that engineers engaged in hazard classification determinations have a clear understanding of the meaning and purpose of classifications. In order to promote such engagement in India, Central Water Commission (CWC) has developed the Guidelines for Classifying the Hazard Potential of Dams. It has been attempted to move from the traditional prescriptive approach based on dam height or reservoir volume (i.e. implicit approach) to one based on estimated losses as a consequence of dam break in terms of loss of life as well as financial losses.

Hazard classification analyses involve computer modelling of a failure or mis-operation (unscheduled releases), and the downstream flood routing. Also, following the recent trend internationally, the proposed approach is based on critical aspects such as estimated population at risk, wave arrival time, economic and environmental consequences. In order to manage the fuzziness on the definition process of the thresholds between hazard classes, a scoring system approach with a final potential consequences index has been developed, which will improve the hazard classification near the classes' boundaries. Considering the status of development in the field of risk management of dams in the country, the adoption of four hazard categories has been suggested.

Finally, I compliment all the individuals and organisations involved in the preparation of this Guidelines. I hope that dam owners make use of these guidelines for working out the hazard potential of dams in India which will support in taking further decisions related to dam safety management. This Guidelines under DRIP, is a forward-looking step to ensure vibrant dam safety management in India at par with global practices. I also acknowledge the efforts made by members of Review Committee as well as CPMU experts in finalising this document.

(Dr R K Gupta)
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New Delhi
November 2020

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PREFACE

Practices about design, construction, operation, maintenance, and inspection of dams are intended to minimise the risk of dam failures. Despite adequacies of these programs and their implementations, situations may develop sometimes leading to dam failures – structural or operational. The Central Water Commission (CWC) encourages and assists the advancement of dam safety practices that help reduce the risk to lives and property from the consequences of potential dam failures.

In case of a dam break, the losses incurred in terms of lives and property are tremendous. Also, failure of a large dam raises questions about the operation and maintenance related to ensuring dam safety, with far reaching effects on the national pride. Further, in case a dam breach occurs, the services and benefits remain suspended for months and years, leading to additional loss. Also, the cost of reconstructing an old dam commissioned decades earlier to enable serving the needs as before is prohibitive, not only in terms of economics, but also in terms of its environmental and social impacts. Given the variable nature of rainfall in our country, which is becoming further erratic under the influence of climate change, maintaining dams is crucial for ensuring water security.

The hazard potential of dams is taken into consideration by the engineering community from the project conception stage itself. Since practicability of the assessment of losses were limited by the availability of relevant information, hardware and software, proxies like storage volume and dam height were the prime parameters – because it was clearly conceived that the height and velocity of the flood wave due to dam breach would be greater for a high dam and the duration of flooding will be greater for a dam with huge storage. With the advent of advanced computing platforms and software, along with the effortless availability of temporal and spatial information through the internet, detailed analysis for estimation of the losses have become much simpler.

It has been witnessed in other countries that the loss of life due to a dam breach may not be proportional to its storage volume or height, indicating the necessity to carry out analysis for estimation of the potential consequences. This guideline attempts to introduce the concept of hazard potential classification of dams based on consequences. Showing responsiveness to the large number of dams and high density of population, it also endeavours to present higher number of classes than the present three, aimed to optimise resource allocation, following the practice of a few other developed countries that are much ahead in the field of dam engineering. This publication, ***Guidelines for Classifying the Hazard Potential of Dams***, is intended to bridge the gap, taking hazard potential classification of dams in the country to the new level matching other international standards, being useful to the stakeholders in charge of management of the disasters.

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LIST OF ABBREVIATIONS

Abbreviated Form	Full Form
ANCOLD	Australian National Committee on Large Dams
CDSO	Central Dam Safety Organization
CWC	Central Water Commission
D&R	Design and Research
DDMA	District Disaster Management Authority
DEM	Digital Elevation Model
DEWS	Department of Energy and Water Supply
DRIP	Dam Rehabilitation and Improvement Project
DSR	Dam Safety Rehabilitation Directorate
DTM	Digital Terrain Model
EA	Environment Agency
EAP	Emergency Action Plan
FEMA	Federal Emergency Management Agency
IS	Indian Standard
MDDL	Minimum Draw Down Level
MOWR	Ministry Of Water Resources
MWL	Maximum Water Level
NRLD	National Register of Large Dam
PAR	Population at Risk
PLL	Potential Loss of Lives
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
SAR	State of the Art Report

Abbreviated Form	Full Form
SDSO	State Dam Safety Organization
SPF	Standard Project Flood
SPS	Standard Project Storm
USACE	United States Army Corps of Engineers
USBR	United States Bureau of Reclamation
USDHS	United States Department of Homeland Security
USDI	United States Department of the Interior
WSDE	Washington State Department Of Ecology

EXECUTIVE SUMMARY

This document sets forth a hazard potential classification system for dams that is simple, clear, concise, and adaptable to the current system. The intent is to provide straightforward definitions that can be applied uniformly by all central and state dam safety agencies and can be readily understood by the public. It does not establish how the system will be used, such as prescribing specific design criteria or prioritising inspections. Those responsibilities belong to the responsible regulatory authority.

Chapter 1 address the importance of the hazard classification in dams as well as the need for its implementation in India. to consolidate asset consequence information that can assist dam management authorities in identifying the most significant facilities within their corresponding portfolios by establishing common methods, assumptions, and measures to quantify different types of consequence elements consistently. After the enactment of the Dam Safety Bill 2019, already approved by the Parliament's lower house (Lock Sabha), the hazard classification for all large dams in India will become compulsory and under the responsibility of the State Dam Safety Organisations

Chapter 2 describes in general how-to assess the consequences of a potential failure in the dam considering fundamental concepts such as incremental consequences and vulnerability/severity assessment. Also, it describes the data required and scenarios to be considered for a hazard classification process.

Chapter 3 discusses in detail the proposed approach for Dam Hazard Classification in India, which is based on an "additive weighting" and "point index" (Figure E.S.1). The proposed approach aggregates the assessment of the consequences in four major categories: the capital value of the project, potential for loss of life, the potential for property damage and Potential for Environmental and Cultural impact (Table E.S.1.). Figure E.S.2 in following pages illustrates step by step a

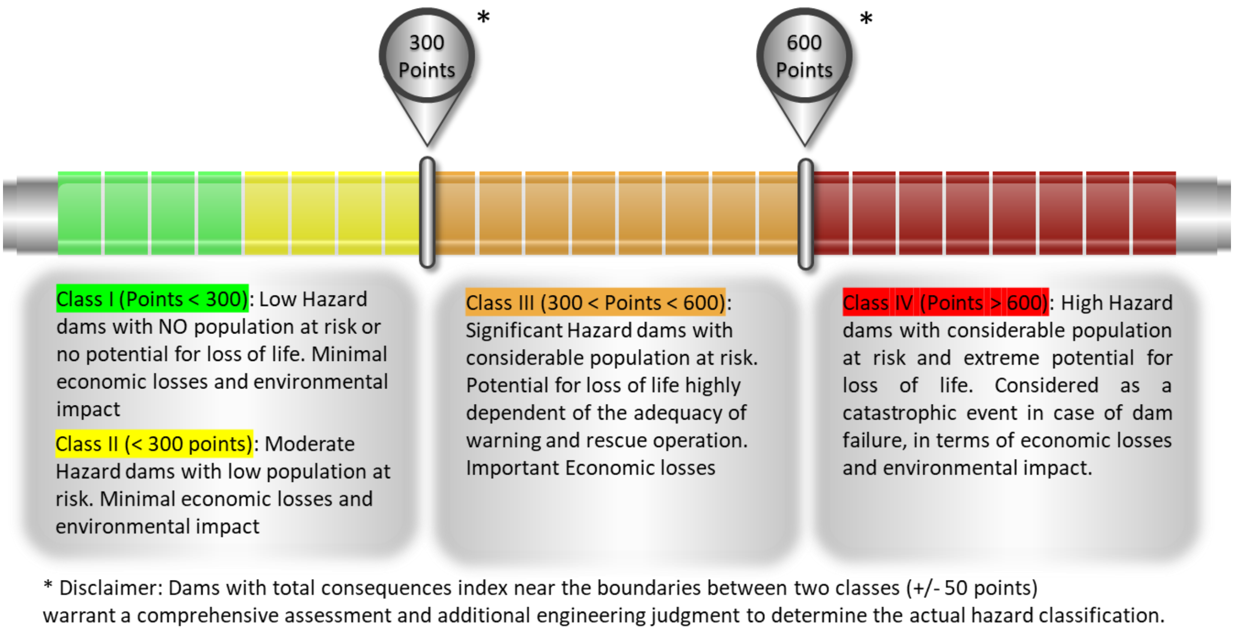

Figure E.S.1.- Summary of the Proposed Hazard Classification for India based on an Additive Weighting or Point Index Scheme

summary of the procedure to classify the dams based on the assessment of the potential consequences of a failure scenario.

Chapter 4 discusses the potential implications of the hazard potential classification in terms of design standards, emergency preparedness, inflow design floods, inspection frequencies, minimum monitoring standards, maintenance requirements, and detailed risk assessments

In *Appendix A,* the reader can find a comprehensive comparison of current international practices in the dam hazard classification process as well as the current practice in India. Also, the need and justification to shift to a consequences-based approach to classify the potential hazard at dams is stressed in this section of the document

Finally, in *Appendix B and C*, the document includes a complete case study where the implementation of the proposed approach is described in detail for easy understanding and application by the competent authorities. Additionally, a complete template for a Dam Hazard Classification Report to be used either by dam's owners or Dam Safety Organisations is included to standardise the outcomes from the hazard classification in the country and facilitate the review process by the State and National regulators.

Table E.S.1.- Consequences Categories in the Proposed Dam Classification

Hazard Potential Class	Consequences Categories			
	Capital Value of Project	**Potential for Loss of Life**	**Potential for Property Damage**	**Potential for Environmental and Cultural Impact**
Class I	Low	None. Occasional or no incremental population at risk, no potential loss of life is expected. No inhabited structures.	Minimal. Limited economic and agricultural development.	None
Class II	Average	Minimal or low population at risk. No potential loss of life is expected even during the worst-case scenario of emergency management	Notable agriculture or economic activities. States highways and/or rail lines.	Minimal incremental damage. Short-Term or reversible impact (less than 2 years)
Class III	Significant	Considerable. several inhabited developments. Potential for loss of life highly dependent of the adequacy of warning and rescue operations.	Significant industry, commercial and economic developments. National and state highways and rail lines.	Limited. Impact have a mid-term duration (less than 10 years) with high probability of total recovery after mitigation measures
Class IV	Critical	Extreme. High density populated areas. Potential for loss of life is too high even during the best scenario of emergency management	Highly developed area in terms of industry, property, transportation and lifeline features	Severe. long-term impact/effects in the protected areas or cultural heritage sites with low probability of recovery.

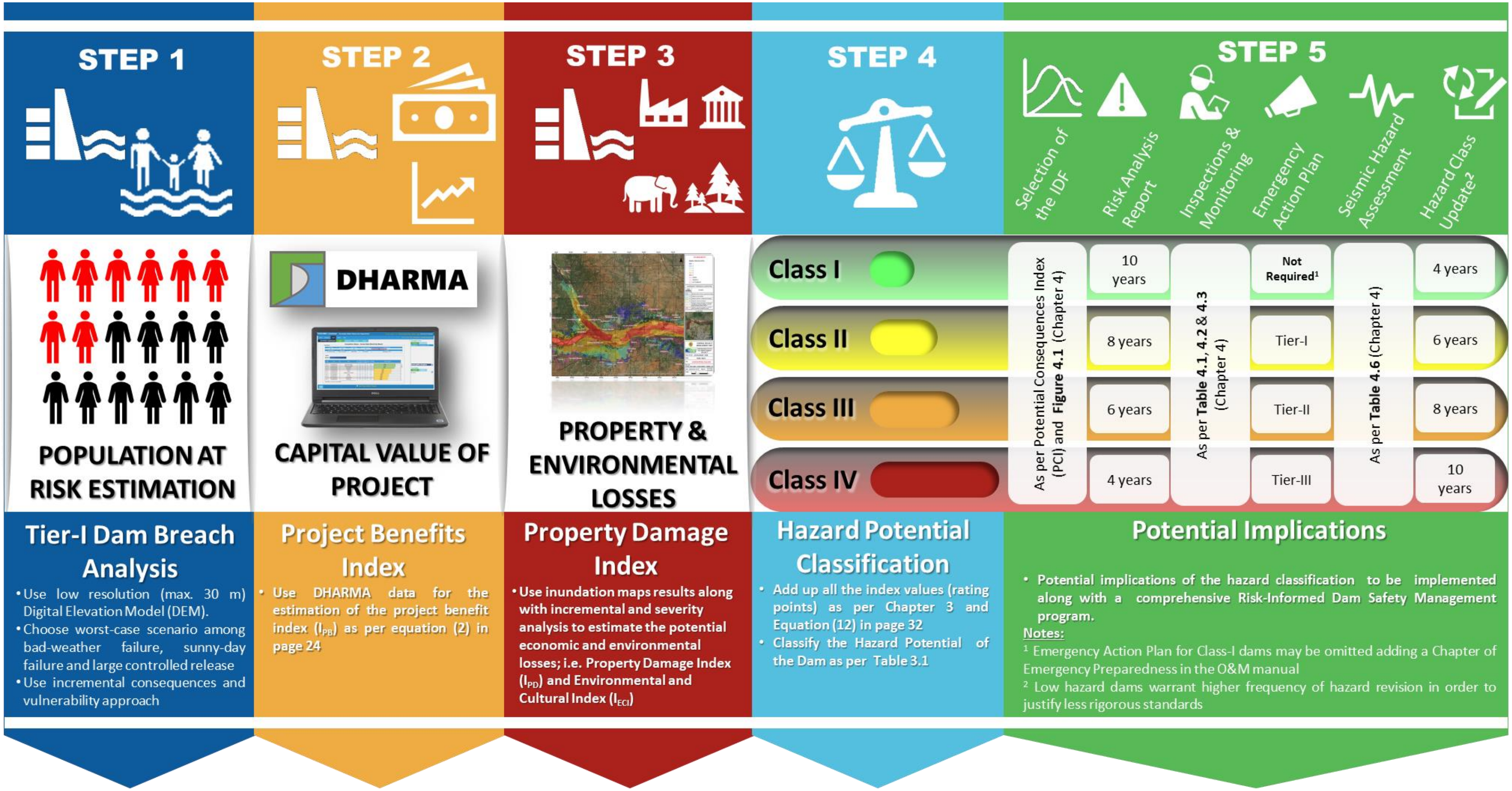

Figure E.S.2.- Stepwise Hazard Potential Classification of dams in India

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Chapter 1. Overview of Dam Hazard Classification

The primary objective of these *Guidelines for Classifying the Hazard Potential of Dams* is to provide dam owners, dam engineers, and other professionals with information to quickly identify those projects whose failure or disruption could potentially lead to the most severe consequences. The methods allow for systematic updates of hazard classification whenever new information becomes available.

The hazard potential classification framework developed here may help to support decisions regarding additional analyses and detailed studies. The dams identified as high-consequence could be assigned with higher priority for the preparation of detailed flood inundation studies or detailed risk assessments (See *Guidelines for Assessing and Managing Risks Associated with Dams, 2019*). This could also help to inform decision-makers about those facilities within the area that should receive special attention from the disaster management agencies because of their potential for significant impacts at the local and regional levels.

In addition, conducting a screening of high-consequence projects provides a great opportunity not only to update project contact information but also consolidate other data that may be extremely relevant in providing a full description of the relative importance of a given project and its primary functions. This information is valuable not necessarily for prioritisation purposes but as part of overall situational awareness that is critically necessary to support and sustain the regional impact assessments that need to be developed by the Central Dam Safety Organization (CDSO) and the State Dam Safety Organizations (SDSOs).

Effective implementation of the hazard potential classification method allows dam owners to achieve a systematic baseline to:

- Establish common methods, assumptions, and measures to consistently quantify different types of consequence elements (human health, economic, environmental, cultural and mission disruption among the most important) leading to a sector-wide prioritisation framework to facilitate comparison of consequence information within the sector.
- Consolidate asset consequence information that can assist dam management authorities in identifying the most significant facilities within their corresponding portfolios in alignment with sector-wide criteria.
- Support the development of accurate estimates for potential national and regional impacts associated with high-consequence projects affected by natural hazards or man-made incidents.
- Support CDSO in national critical infrastructure prioritisation efforts which focus on establishing a cross-sector set of assets with nationally significant consequences.

The Central Dam Safety Organization (CDSO) currently classifies dams into one of three categories based on the hazards they present to life and property. A hazard classification is a rating (e.g., low, significant, or high hazard) that is representative of the probable loss of life and property damage downstream from a dam based on the best available information and visual observation of the dam, and/or an identification of the area downstream that would be inundated. The following definitions of hazard classification now apply to dams in India (CWC, 1987):

1) High hazard dam: a dam whose failure would cause the loss of life and severe

damage to homes, industrial and commercial buildings, public utilities, major highways, or railroads.

2) Significant hazard dam: a dam whose failure would damage isolated homes and highways, or cause the temporary interruption of public utility services.
3) Low hazard dam: a dam whose failure would damage farm buildings, agricultural land, or local roads.

The potential consequences associated with failure, considerable damage, or prolonged disruption of dam facilities could be quite severe and could reach various levels of significance. The new hazard potential classification approach proposed is scalable and could be effectively implemented at different portfolio levels (dam managing organisation, state, and national). This framework could also assist in identifying assets that may be of significance at the state or national level by adopting consequence thresholds that are appropriate for each case.

The information collected/produced through this process must be:

- Generated by the qualified technical personnel in active collaboration with emergency responders and other relevant stakeholders such as the corresponding state dam safety offices, using a reasonable and practical level of resources, and taking full advantage of earlier studies or evaluations.
- Consistent, comparable, and collected using similar assumptions.
- Sufficiently detailed to allow for consequence-based prioritisation.
- Updated through periodic self-reviews voluntarily conducted by authorities/organisations in charge of dam management and dam operators.
- Collected in conformation with the proper information safeguarding procedures available to organisations in charge of dam management and dam operators.

1.1 Dam Hazard Potential Classification

A common practice among central and state dam safety offices is to classify a dam according to the potential impact a dam failure (breach) or mis-operation (unscheduled release) would have on upstream and/or downstream areas or at locations remote from the dam. The existing classification systems are numerous and vary within and between both the central and state sectors. Although differences in classification systems exist, they share a common thread: each system attempts to classify dams according to the potential impacts from a dam failure or mis-operation, should it occur. The most significant problem with these various systems is the use of terms that lack clear definition. In addition, the various systems use different terminology to define similar concepts. This precludes consistency between the various central and state agencies and understanding by the public.

This document sets forth a hazard potential classification system for dams that is simple, clear, concise, and adaptable to the current system. The intent is to provide straightforward definitions that can be applied uniformly by all central and state dam safety agencies and can be readily understood by the public. It does not establish how the system will be used, such as prescribing specific design criteria or prioritising inspections. Those responsibilities belong to the responsible regulatory authority.

The hazard potential classification system currently being followed in the country is based on the recommendations of MOWR (1987). The dams are classified into three categories: low, significant and high based on loss of life and economic losses. The Bureau of Indian Standards (IS: 11223-1985) stipulates classification of dams based on gross storage volume and hydraulic head.

Considering the status of development in the field of risk management of dams in the country, the adoption of 4 categories based on a consequences-index (rating points) approach may be more reasonable. The experience of reviewing the design flood for more than 200 dams spread over different parts of the country indicates that the consideration of hydraulic head as an independent criterion is leading to over-emphasis of some structures over others, which they do not deserve based on the consequences of failure. As ensuring compliance of these old structures to the current design standards through the implementation of structural measures are posing extreme difficulty, in many cases they are left as such, considering non-structural measures to take care of the same. This spreads a sense of inadequacy associated with the threat of failure, which is not based on realty

The approach proposed in this Guideline based on an actual assessment of potential hazard through modelling is anticipated to bring relief from this false fear of failure due to non-compliance to the existing design standards.

With the available tools and techniques, modelling software and hardware, it is imperative to move from the traditional prescriptive approach based on the dam height or the reservoir volume to one based on estimated losses as a consequence of dam break, in terms of loss of life as well as financial loss. *Guidelines for Mapping Flood Risks Associated with Dams*, being published as a part of the same series, provides information on the procedure to be adopted for such assessment.

1.2 Scope

With the rapid pace of development that has taken place downstream of dams, the consequential losses due to a dam failure might be expected to have increased manifold. With the threat of climate change looming large, confidences on the observed rainfall of the past are dwindling by the day. Increase of the frequency of extreme rainfall is no longer a forecast based on model results, but a reality. Therefore, shift to consequence-based dam classification and prioritisation must be the way forward. This will help to prepare the stage for risk-informed analysis, being practised in developed countries.

So, moving away from the contemporary prescriptive approach, this guideline attempts to provide a hazard potential classification framework for the Indian context. Following the recent trend in developed countries, this is based on critical aspects such as estimated population at risk, wave arrival time, economic and environmental consequences. In order to manage the fuzziness on the definition process of the thresholds between hazard classes, a scoring system approach was developed, which will improve the hazard classification near the classes' boundaries.

The guideline also attempts to present a framework about the potential implications of the hazard potential classification on dam safety management.

1.3 Guideline Applicability

The present guideline, and therefore, the proposed hazard classification framework will be applicable for all large dams in India, existing or under construction/design stage.

As per the International Commission of Large Dams (ICOLD, 2011), large dams are defined as follows:

i. Dams above fifteen metres in height, measured from the lowest portion of the general foundation area to the top of dam; or
ii. Dams between five metres to fifteen metres in height impounding more than 3 million cubic metres of water

After the enactment of the Dam Safety Bill 2019, currently under discussion in the Parliament, the hazard classification for all large dams in India will become compulsory and under the responsibility of the State Dam Safety Organisations.

1.4 How to use this Guideline

The following basic sections of this guideline help to assess the hazard potential classification:

- ***Chapter 2*** describes in general how-to assess the consequences of a potential failure in the dam considering fundamental concepts such as incremental consequences and vulnerability/severity assessment. Also, describe the data required and scenarios to be considered for a hazard classification process.
- ***Chapter 3*** discusses in detail the proposed approach for Dam Hazard Classification in India. Figure E.S.2 on page 3, illustrates step by step, a summary of the procedure to classify the dams based on the assessment of the potential consequences of a failure scenario.
- ***Chapter 4*** discusses the potential implications of the hazard potential classification in terms of design standards, inflow design floods, inspection, monitoring, maintenance requirements, and detailed risk assessments.
- ***Appendix A*** presents a comparison of current international practices in the dam hazard classification process in order to propose a suitable approach for India.
- ***Appendix B and C*** include a complete case study and a template for a Dam Hazard Classification Report, respectively.

1.5 Relationship to other Guidelines and Policies

This guideline provides technical advice and guidance on the final classification of hazard potential for large dams in India, and the same should be read in conjunction with:

- *Dam Safety Bill, 2019*. This bill, currently under discussion in the parliament of Government of India, mandates that The State Dam Safety Organisation shall classify each dam under their jurisdiction as per such vulnerability and hazard classification criteria as may be specified by the regulations. Therefore, the Dam Safety Bill 2019 represents the legal justification for the mandatory hazard potential classification of all large dams in the country.
- *Guideline for Mapping Flood Risk Associated with Dams*. This Guideline provides the technical advice for the hazard quantification (dam break analysis) inundation mapping, and consequences evaluation (population at risk and potential loss of life). Therefore, this guideline represents the main input for the hazard classification process.
- *Dam Health and Rehabilitation Monitoring Application (DHARMA),* is a web-based tool to support the effective assets management and dam safety data related to all large dams in India. As the *"Guideline for Mapping Flood Risk Associated with dams"*, DHARMA also represents one of the main sources of information for the hazard classification process.
- Once the hazard potential classification process is completed, potential implications on dam safety management are addressed in detail in:
    - ✓ *Guidelines for Assessing and Managing Risk Associated with Dams*,
    - ✓ *Guidelines for Selecting and Accommodating the Inflow Design Flood*,
    - ✓ *Guidelines for Safety Inspection of Dams*,
    - ✓ *Guideline for Evaluating Geological Conditions and Seismic Hazards at Dams*
    - ✓ *Guidelines for Developing Emergency Action Plans*
    - ✓ *Guideline for Instrumentation of Large Dams*
    - ✓ *Guideline for preparing Operation and Maintenance Manual for Dams*

Figure 1.1 shows the relationship between the documents and regulatory framework mentioned above

1.6 Publication and Contact Information

This document along with other guidelines on dam safety are available on the CWC website

http://www.cwc.gov.in

and the Dam Rehabilitation and Improvement Project (DRIP) website

http://www.damsafety.in

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1.7 Acknowledgements

In preparing these guidelines, works of others in India, the United States, and elsewhere have been drawn from liberally. Grateful appreciation is extended to the following organisations whose publications and websites provided valuable information on classifying potential dam hazards:

- Federal Emergency Management Agency, U.S. Department of Homeland Security
- Office of Infrastructure Protection, U.S. Department of Homeland Security
- U.S. Army Corps of Engineers
- Bureau of Reclamation, U.S. Department of the Interior
- Washington State U.S., Department of Ecology

Figure 1.1.- Relationship to other Guidelines and Policies in the Country

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Chapter 2. CONSEQUENCES AND ITS ASSESSMENT

2.1 Introduction

To develop a systematic categorisation process for a large number of dams present in the country, it is necessary to establish a methodology to identify and sort out the projects whose failure may potentially lead to undesired consequences. Consequence assessment is to be used as a tool to get information and to support decisions regarding the requirement of additional analyses and detailed studies (e.g., detailed flood inundation studies or detailed risk assessments) as well as to prioritize the implementation of Emergency Action Plans or defining the intensity and periodicity of dam safety inspections among other dam safety management issues. Furthermore, the consequence-based hazard potential classification will be a step forward towards the implementation of a portfolio risk management framework.

2.2 Assessment of the Area Affected by Dambreak

The area affected by a dam break flood should be estimated to match the level of detail that is consistent with the type of assessment of the consequences of dam failure. Even though the dam breach affected area is generally located downstream of the dam, the effect on areas receiving water supply from the reservoir or areas with recreational interests that are upstream and/ or distant should also be considered. Topography and flood characteristics govern the width of the zone and the distance from the dam, which will be affected.

While judgement based on experience may suffice for an initial assessment, hydraulic modelling is required for more comprehensive assessments of the affected area. The flood cases analysed for consequence estimation may include the so-called Sunny Day Failure (the reservoir at Full Reservoir Level-FRL, with the minimum inflow into the reservoir), the overtopping failure also called as the flood failure or the severe weather failure (the reservoir at Maximum Water Level (MWL), with the inflow design flood passing through the reservoir) and the case of the flood caused by the largest controlled release that may pass through the gates without any damage to the dam itself . Even when it is not normally the decisive case, another common scenario to evaluate during the hazard classification process might be the flood caused by a gate failure when the dam is comprised of a gated spillway.

INCREMENTAL HAZARD

The incremental hazard is the fraction of the consequences (and therefore, the risk) exclusively produced by the dam failure. It is considered that the balance hazard is not attributable to the dam, because the same would occur even without the existence of the dam infrastructure. Incremental hazard evaluation is part of a risk-informed approach and has been considered as a fundamental aspect in the development of the present Guideline approach. The incremental hazard evaluation begins with a simulation of a dam failure scenario during a hydrologic flooding condition or a normal operating condition. The same event(s) is then carried out considering non-failure conditions.

The consequences attained by both the breach and non-breach events are then compared to determine the increase in consequences (population, economic, social and environmental) from the dam breach. (**Figure 2.1**)

For this Guideline and the proposed hazard classification approach, incremental consequences are considered.

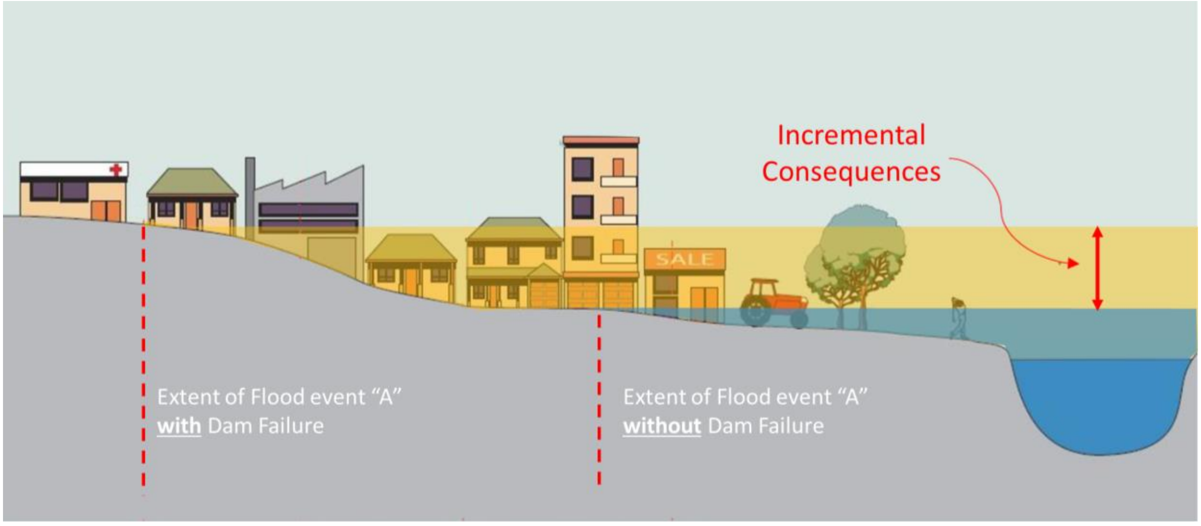

Figure 2.1.- Incremental Hazard (Risk) Assessment.

2.3 Failure Scenario for the Dam Hazard Classification

The hazard potential classification assigned to a dam is based on consideration of the effects of failure or mis-operation during both normal and flood flow conditions. Hence, one of the common questions arising during the hazard classification process is which scenario needs to be considered?

The classification assigned should be based on the worst-case scenario of failure or mis-operation of the dam, i.e., the assigned classification should be based on incremental failure consequences that will result in the assignment of the highest hazard potential classification of all probable failure and mis-operation scenarios. Each element of a project must be evaluated to determine the proper hazard potential classification for the project.

However, there is only one hazard potential classification assigned to the entire project. Individual elements are not assigned separate classifications.

The scenarios considered should be reasonable, justifiable, and consistent with the "*Guideline for Mapping Flood Risk Associated with Dams*" (CWC, 2018) and as was explained in section 2.2 of this chapter.

2.4 Vulnerability/Severity Assessment

It is undeniable that the dam hazard potential classification is a direct result of a flood hazard analysis of different scenarios that can occur .

However, one of the challenges in this type of assessment is the fact that the degree of hazard varies with the severity of flooding and is affected by the flood and its hydraulic behaviour (extent, depth, velocity, duration and rate of rising of the floodwaters), the topography, population at risk and emergency management.

Once the flood hazard of the dam event (failure scenarios) has been quantified, and the timing aspects of flood hazard understood, the potential of the flood flows to cause damage or danger can be indexed against vulnerability curves linked to meaningful hazard thresholds.

The vulnerability of the downstream community and its assets can be described by using thresholds related to the stability of people as they walk or drive through floodwaters, or shelter in a building during a flood. The vulnerability to hazard will also be influenced by whether the primary consideration is, for example, strategic land-use planning, which is aimed at ensuring land use is compatible with the flood risk or assessing development proposals or emergency management planning, which is aimed at addressing residual flood risks.

A flood severity assessment conducted as part of a dam hazard classification process provides information to identify those consequences with the highest significance among the entire floodplain.

As an example, a combined set of hazard curves (vulnerability of people, vehicles and buildings) is presented in **Figure 2.2** and **Table 2.1**

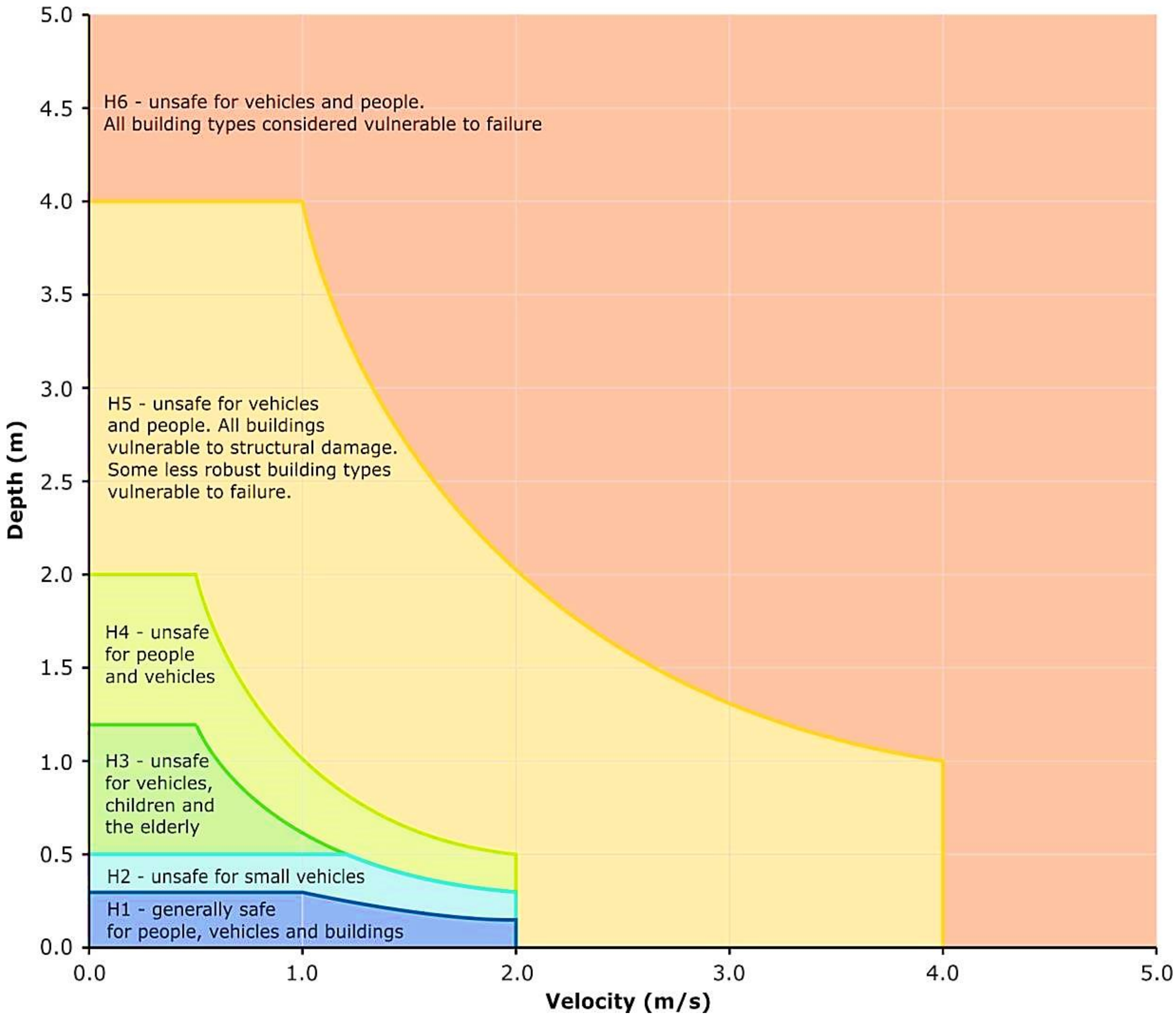

Figure 2.2.- Flood Hazard Vulnerability Curves (Smith et al. 2014)

Table 2.1.- Vulnerability thresholds classification limits [a]

Hazard Vulnerability Classification		Description	Classification Limit (Depth * Velocity)	Limiting Water Depth (m)	Limiting Velocity (m/s)
	H1	Generally safe for vehicles, people and buildings.	D*V ≤ 0.3	0.3	2.0
	H2	Unsafe for small vehicles.	D*V ≤ 0.6	0.5	2.0
	H3	Unsafe for vehicles, children and the elderly.	D*V ≤ 0.6	1.2	2.0
	H4	Unsafe for vehicles and people.	D*V ≤ 1.0	2.0	2.0
	H5	Unsafe for vehicles and people. All buildings are vulnerable to structural damage. Some less robust buildings subject to failure.	D*V ≤ 4.0	4.0	4.0
	H6	Unsafe for vehicles and people. All building types considered vulnerable to failure.	D*V > 4.0	-	-

[a] Combined Hazard – Vulnerability Classification (Smith et al., 2014)

2.5 Limits of the Study Area

In order to establish the limits of the study area for a consequences assessment the following aspects needs to be considered and verified in the dam break analysis, which can help to delimit the boundaries of the model:

a. No downstream presence of dwellings, services and other infrastructures.

b. No future developments are expected downstream of the boundaries of the model

c. Full attenuation of the breach outflow hydrograph along the main river.

d. Channel-conveyance capacity of the mainstream (within the riverbanks) receiving the total outflow in the downstream end of the model.

e. The existence of a downstream dam having a reservoir that lies within the downstream limits of the hydraulic model of the upstream dam, which is either able or unable to absorb the total outflow hydrograph due to the dam breach upstream. In case the reservoir located downstream is not able to absorb the entire volume received from the upstream dam's breach flood, a cascade failure effect should be, at least, scrutinized. If a high likelihood of failure is corroborated for the downstream dam; therefore, the downstream limits need to be extended.

In most situations, the investigation of the impact of failure or mis-operation of a dam on downstream human life, property damage, lifeline disruption, and environmental concerns is sufficient to determine the appropriate hazard potential classification. However, if failure or mis-operation of a dam leads to the failure of a downstream dam(s), the hazard potential classification of the dam should be at least as high as the classification of the downstream dam(s) and should consider the adverse incremental consequences of the domino failures.

The *"Guideline for Mapping Flood Risk Associated with Dams"* (CWC, 2018) in its Appendix-D, presents a flowchart with a proposed procedure to define the downstream boundaries of the hydraulic model in case of a cascade dam system.

2.6 Data Requirement

Assessment of consequences requires information on the effects of a potential dam break, to provide the basis for the level as considered appropriate. Data are required on (ANCOLD, 2012):

- Dam and reservoir
- Topography
- Flood characteristics and inundation maps
- Information about the community residing in the downstream area
- Implications for service and business
- Implications to objects of strategic/ national importance

2.6.1 Dam and reservoir

Dam and reservoir data may include information on dam type, dimensions of the dam such as height, width, and length, spillway characteristics including gates and secondary spillways, relationship showing the reservoir elevation versus storage volume, together with spillway discharge capacity up to the dam crest. It could also include comments on design, foundations and unusual conditions as well as available reports on the design, construction, and management of the dam and information on past incidents.

2.6.2 Topography

Topographic data should cover the river sections where the depth and velocities of the flow may damage people, dwellings and critical infrastructures. The information should be enough to indicate the shape and slope of the valley and, when possible the structures/ surfaces influencing on the downstream flow (e.g., culverts, weirs, bridges, levees, embankments, temporary storage, floodplains, vegetation and other objects affecting the water surface elevations).

Topographic data will also determine the boundary limits of the hydraulic model of the dam break analysis and, therefore, should be enough to represent the entire downstream consequences. (See Section 2.5.- Limits of the Study Area)

It should also include the location of major downstream tributaries that may cause concurrent flooding. Channel cross-sections should be taken at regular intervals along the flood channel. Additional sections may be obtained for areas with a change in the channel profile, e.g., restriction in section profile, like a bridge, confluence of tributaries to the main channel and places with a significant change in the grade or cross-section of the channel.

For the dam classification process, the level of detail of the topography or corresponding digital elevation model (DEM) should be consistent, as a minimum, to a tier-I assessment (See Section 2.7.- Tiered Assessment of Inundated Area and Flood Water Levels and Table 2.2).

2.6.3 Flood characteristics and inundation maps

Information on flood characteristics and inundation maps should include details about historical flood levels. It should also include flood studies based on hydrographic data, as well as results from rainfall run-off modelling pertaining to different return periods. It should also contain results of dam-break flooding under overtopping and non-overtopping conditions. Travel times of flood waves to downstream locations of habitations should also be included.

2.6.4 Information about the community residing in the downstream area

Such information may include location, size and type of areas with human settlements within the possible area of inundation, the vulnerability of various elements of the downstream community and the warning time available. It should also provide details about awareness and flood preparedness of the downstream community and their temporal variation pattern concerning days of the week and months and seasons. It should also describe the areas identified for future development. Along with the land use classes and areas with toxic substances, it should also provide information on the infrastructure that may be affected (e.g., transport, power lines, water supply and sewerage lines, gas pipes).

2.6.5 Implications for service and business

Implications of the dam break consequences for service and business should include the importance of the water storage to the business (e.g., municipal water supply, irrigation or hydropower generation), financial overburden to meet the costs of failure and the value of water in the storage reservoir.

This information will be available shortly from the Dam Health and Rehabilitation Monitoring Application (DHARMA) currently being implemented under DRIP project

2.6.6 Implications to objects of strategic/national importance

It may include inundations of areas that will have consequences of national significance like an inundation of a nuclear power plant or a thermal power plant, or places which if inundated will pose a threat to the national security. It may also include important historical structures and/or biodiversity reserves.

Figure 2.3.- Flood in Patna, Bihar

2.7 Tiered Assessment of Inundated Area and Flood Water Levels

With due considerations of the time requirement and cost of detailed studies needed to delineate areas that would be inundated by a dam breach flood, the *Guidelines for Developing Emergency Action Plans for Dams*, published as a part of the same series, proposes a tiered approach to produce dam-breach inundation zone maps. The level of analysis for the tiered approach is expected to correlate with the sophistication and accuracy of the analyses with the scale and complexity of the dam and downstream area under investigation, as shown in **Table 2.2**.

Only for the Dam Hazard Classification process a Tier-I analysis (**Table 2.2**.) is recommended and would be considered adequate in the following scenarios:

- Dams which, due to their particular location and own characteristics, might be directly inferred as "low hazard". In this case, a Tier-I analysis should confirm the "low hazard" hypothesis
- As the first estimation for any high hazard dam under analysis. If the results obtained through a tier-I analysis are enough to classify the specified dam under the highest hazard class, no further refinement would be required in the classification process.
- For any specified dam, irrespective of its "hazard", only if the results from a Tier-I analysis are reliable enough to conclude that further refinements will not introduce changes in the hazard classification.

A higher level of complexity in the consequence's estimation (i.e. Tier – II and III) might be introduced for the classification process in the following cases:

- Consequences Index (scoring points) obtained through a Tier-I analysis set the Hazard Class near the boundary/threshold of a higher or lower hazard category.
- Better estimate in the population at risk assessment is required since is considered as the critical indicator in the hazard classification process of the specified dam.
- Clearer estimates in the flood severity assessment are desired for the consequences' evaluation, which would make the use of a two-dimensional model a must.

Further discussions on flood mapping and tiered approach are available in the guideline on "*Mapping Flood Risks Associated with Dams*", published under the same series.

2.7.1 Estimating Population at Risk (PAR)

The PAR includes persons directly exposed to flood waters if they are not evacuated (**Figure 2.3**). After the delineation of the area inundated due to dam breach, estimation of the population at risk can be carried out. It should be estimated using demographic data with occupancy rates for residences, number of students at schools, number of persons in industrial, hospital, commercial and retail areas. The PAR estimates may vary according to the time of day, the day of the week and month/ season. Sometimes it is necessary to prepare more than one estimate and select the highest of these for determination of the consequence category of the dam. It is important to consider the visitors to the recreational sports, camps, concert halls, parks and gardens as also those who are driving through the roads or taking a railroad journey which gets inundated due to a dam break flood. The procedures currently applied to estimate PAR have been described in the *Guidelines for Mapping Flood Risks Associated with Dams*, being published as part of the same series.

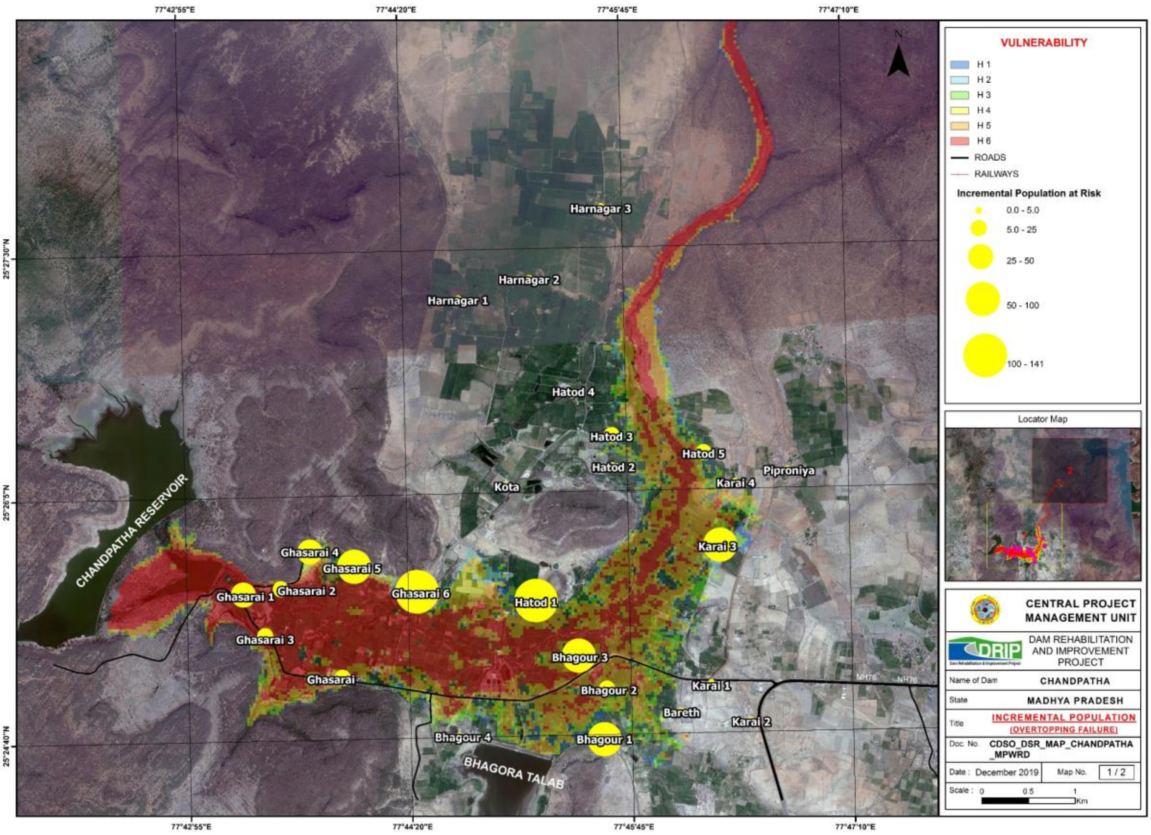

Figure 2.4.-Estimated Incremental Population at Risk due to overtopping failure of Chandpatha Dam, Madhya Pradesh

As mentioned in *Section 2.2.* of this Guideline, incremental analysis is recommended for the estimation of PAR and the rest of the consequences (**Figure 2.4**)

2.7.2 Assessing Potential Damages and Losses

The potential damages and losses due to a dam break may be grouped into classes, including consequences of similar nature for the purpose of risk assessment. It includes total infrastructure costs, losses accrued due to the dam not being able to serve the purposes it is meant to, health and social impacts, and the environmental impacts.

Damages and losses are generally classified as direct or indirect. Direct damages and losses comprise those losses which result from contact with the floodwaters. Indirect damages and losses encompass all other damages and losses. The severity of each of these damages and losses may be either minor, medium, major or catastrophic. Severity may be established for each group of damage/ loss, and summarised to the overall level of severity, with due consideration to the regional or national economic perspective. The infrastructure and agricultural losses and losses due to non-performance of business are easier to estimate, but the health and environmental losses are more difficult. It has been discussed in the Guidelines for *Mapping Flood Risks Associated with Dams*, being published as part of the same series.

2.7.3 Assessment of Health and Social Impacts

The effects of dam break on health and social affairs depend on the nature, location, and extent of the area affected by the dam failure, with regards to the distribution of the human habitation. Human health could be affected by the consumption of polluted drinking water/ food due to contamination of the source/ supply network. It could also be due to failure or shortage of water, sewage, power supplies. Uncontrolled release of sewage, industrial or toxic waste as a result of a dam break may lead to widespread contamination. Social impacts of dam break would depend on demographic characteristics, social and community values, needs and networks, the extent of community support services, the capacity of responding institutions as well as the degree of disaster preparedness and warning time available.

2.7.4 Consideration of Future Developments

The consequence classification for a dam should reflect the current downstream development as well as the future development plans. This is particularly important for a developing country like India, where colossal infrastructure projects like highways and smart cities are being planned.

Once the consequence/ hazard potential class of a dam is established and the design criteria for the dam fixed accordingly, it is extremely difficult and costly to rehabilitate it to higher standards at a later stage. The challenges of this type are being faced in the DRIP project. In some cases, it was not practicable to provide additional spillway capacity to pass the increased design flood (arising out of updates in design flood estimation methodology), which could have been possible at the inception/ design and construction phases. Therefore, it is advisable to investigate the effect that potential future downstream development may have in increasing the hazard potential classification of the dam and consequently, the design criteria.

Table 2.2.- Tiered approach to dam breach inundation mapping

Tier Level	Applications	Topography /Bathymetry	Breach Parameter Prediction	Handling of the Dam Breach Parameters' Uncertainty	Peak Breach Discharge Prediction	Downstream Routing of Breach Outflow Hydrograph	Downstream Risk Evaluation
Tier 1 – Basic level screening and simple analysis	• Hazard Classification Process • First level screening for significant or high hazard dams • Low hazard potential dams	Low resolution terrain data (e.g., SRTM, ASTER, or ALOS), with maximum 30 m resolution. No bathymetry required	Empirical formulae	• Engineering Judgment • Reasonableness of the peak breach discharge and velocities	Empirical formulae if inflow design flood hydrograph is not available, otherwise unsteady flow routing through modelled reach	HEC-RAS, MIKE or similar one dimensional (1D) or two dimensional (2D) unsteady flow numerical models	Peak discharge, water surface elevation, depth*velocity and flood wave travel time
Tier 2 – Intermediate level of analysis	• Large significant hazard dams • All high hazard dams	Medium resolution terrain data (e.g., 10 - 15 m resolution, CartoDEM1) and elevations adjusted through ground control points (GCPs). Bathymetry required	Empirical formulae	• Reasonableness of the peak breach discharge • Sensitivity analysis	Unsteady flow routing through modelled breach	HEC-RAS, MIKE or similar two dimensional (2D) unsteady flow numerical models considering the bathymetry	Peak discharge, water surface elevation, depth*velocity, flood wave travel time, and approximate PAR assessment
Tier 3 – Advanced level of analysis	• Significant hazard dams with complex downstream flooding • High hazard dams with large population at risk (PAR)	High resolution terrain data (Lidar, ALSO enhanced) minimum 5 m resolution. Ground control points (GCPs) required. Bathymetry required	Empirical equations, physically based models (one or two dimensional)	• Probabilistic Analysis (Monte Carlo simulations or similar methods)	Unsteady flow routing through modelled breach	Coupled one-two dimensional (1D-2D) unsteady flow numerical model. Bathymetry also considered	Peak discharge, water surface elevation, depth*velocity, flood wave travel time, and detailed PAR assessment

Chapter 3. CLASSIFYING THE DAMS IN INDIA BASED ON HAZARD POTENTIAL

3.1 Introduction

It has been experienced under DRIP that the dam classification recently followed in India based on IS: 11223 -1985 sometimes leads to the classification of structures into a higher category with reasons that are unjustifiable by the potential consequences. Some structures with minor storage and wide channels were required to be designed for the probable maximum flood, simply because of the criteria on the hydraulic head. Also, it was felt that three categories might not be enough to deal with the different categories of dams, many of which are more than two decades old, in a reasonably sensitive way that is practical as well.

The challenge is to replace a criterion based on hydraulic head and storage volume that is very simple with one that is necessarily more complex, using a number of factors including population at risk, potential life loss, and economic losses. However, this is the pathway that is to be followed to arrive at a classification of the hazard potential dams based on direct assessment of consequences. Moreover, this is the first step towards a risk-based hazard potential classification of dams, the way it is dealt with in the developed world today.

A system too complex it is not likely to work and may invite many disputes. On the other hand, a system too simple might fail to deliver - some reservoirs which ought to be classified under lower hazard category might be misplaced to a category higher up again. Owing to the uncertainties involved in the estimation of potential life loss (discussed in the *Guidelines on Mapping Flood Risks Associated with Dams* being published as part of the same series), it is proposed to base the classification on the population at risk.

3.2 Proposed Hazard Classification for Dams in India

The proposed approach for the hazard classification aggregates the assessment of the consequences in four major categories:

Capital Value of Project: This category would include the capital value of the project's elements which would be destroyed or damaged, and the loss of benefits, services, revenues provided by the dam project.

Potential for Loss of Life: The possible loss of life will be estimated indirectly through the estimation of the total population at risk in the downstream areas. This category will also consider the severity of the breach/failure flood if the quality/type of modelling meets some standards, and the approximate arrival time of the flood wave (to the closest and affected populated area), which is an indirect measure of the available warning time.

Potential for property damage: This category includes the amount of damage to: residential and commercial property, agricultural lands, transportation facilities such as roads and bridges, damage and disruption of lifeline and community service facilities.

Potential for Environmental and Cultural impact: This category includes the amount of damage to protected areas in the country (wildlife sanctuaries, forest reserves, etc.) as well as potential impact to infrastructures of cultural heritage or national importance.

The detailed description of all categories for each of the four (4) proposed hazard classes is presented in **Table 3.1**. These descriptions would establish the foundation and starting point in the development of the new hazard classification framework for India using an additive weighting and point index scheme.

Table 3.1.- Proposed Dam Classification based on the Additive weighting Scheme (Potential Consequences Index)

Hazard Potential Class	Potential Consequences Index (P_{CI})*	Consequences Categories			
		Capital Value of Project	**Potential for Loss of Life**	**Potential for Property Damage**	**Potential for Environmental and Cultural Impact**
Class I	< 300	Low	None. Occasional or no incremental population at risk, no potential loss of life is expected. No inhabited structures.	Minimal. Limited economic and agricultural development.	None
Class II	< 300	Average	Minimal or low population at risk. No potential loss of life is expected even during the worst-case scenario of emergency management	Notable agriculture or economic activities. States highways and/or rail lines.	Minimal incremental damage. Short-Term or reversible impact (less than 2 years)
Class III	$300 < P_{CI} < 600$	Significant	Considerable. several inhabited developments. Potential for loss of life highly dependent of the adequacy of warning and rescue operations.	Significant industry, commercial and economic developments. National and state highways and rail lines.	Limited. Impact have a mid-term duration (less than 10 years) with high probability of total recovery after mitigation measures
Class IV	> 600	Critical	Extreme. High density populated areas. Potential for loss of life is too high even during the best scenario of emergency management	Highly developed area in terms of industry, property, transportation and lifeline features	Severe. long-term impact/effects in the protected areas or cultural heritage sites with low probability of recovery.

* Disclaimer: Dams with total consequences index near the boundaries between two classes (+/- 50 points) warrant a comprehensive assessment and additional engineering judgment to determine the actual hazard classification.

3.3 Additive Weighting and Point Index Scheme

The variety of potential consequences due to a dam failure or its mis-operation makes attempts at using analytical methods for decision making a complicated task because there is no common ground of comparison among the various consequences.

Another complication is the use of fixed thresholds to delimitate the different hazard categories, which creates the problem of "jumps" (potentially leading to different dam safety standards) between dams with similar characteristics.

Some alternatives to these concerns are either the use of the principles of the fuzzy logic, which is of common use in the artificial intelligence field; or the use of the principles of the decision theory to develop a procedure for decision making.

An additive weighting scheme is a simple tool from decision theory which is particularly suited to choosing among a set of alternatives (dam safety or design standards), when the factor to be considered are many and varied (the consequences).

In this guideline, an additive weighting scheme based on the approach followed by the State of Washington, U.S, and explained in the *Appendix. A.3b* of this Guideline has been used as a model to develop a customised scheme for dams' classification in India.

The additive weighting or point index scheme employs numerical ratings of the consequences which reflect the relative importance of each consequence and the range of severity of the impacts. The summation of the rating points from each consequence is then used to establish the characteristics of the consequences of failure of a given dam

The point index curves, as well as the different indicators adopted by Washington State's approach, were either adjusted or removed in order to match with the actual and pertinent conditions in India. Some of the indicators

Table 3.2.- Numerical Rating Points and Categories for Assessing Consequences

Consequences Category	Indicator Parameter	Consequences Rating Points (min-max)	Considerations
Capital Value of Project	Dam Height	20 - 100	Revenue Generation or Value of Reservoir Content depending upon the reservoir purpose (water supply, irrigation, hydropower, etc.)
	Project Benefits	0 - 300	
Potential for Loss of Life	Population at Risk	20 - 600	Incremental Population at Risk under higher flood severity areas. Minimum arrival of the breach/flood wave to the nearest populated area downstream of the dam
	Critical Arrival Time	0 - 100	
Potential for Property Damage	Infrastructures Damaged	0 - 330	Residential and Commercial Properties Roads, Bridges, Transportation Facilities Lifeline Facilities and Community Services
	Services Disrupted	0 - 185	
Potential for Environmental impact	Environmental Impact	0 - 200	Protected Areas and Cultural infrastructures of National importance under higher flood severity areas
	Cultural Heritage	0 - 140	

(e.g. critical arrival time, project benefits, cultural heritage, etc.) were newly introduced as part of the proposed Indian approach.

Table 3.2 shows the overall categories and indicators used in the proposed hazard potential classification for India.

A complete description of the procedures for determining the consequences rating points for each of the indicator parameters is presented in the following section. Also, *Appendix C***.** of this guideline contains an Indian Dam's case study to illustrate the procedure in how to calculate the rating points and select the appropriate Hazard Class.

3.3.1 Capital Value of Project

This category would include the capital value of the project's elements which would be destroyed or damaged, and the loss of benefits, services, revenues provided by the dam project

Two leading indicators are used in this category:

a. Dam Height Index

b. Project Benefits Index

These categories are described below

DAM HEIGHT INDEX (I_{DH})

Dam height can be seen as indicative of the capital value of a dam. In general, Large dams cost more to construct or replace than small darns. However, there are economies of scale effects, as measured by unit costs, which make small dams disproportionately more expensive to construct than large dams. There are also some engineering planning and design costs which do not change significantly with the scale of a project. These factors result in a non-linear type of utility curve (**Figure 3.1**) and give heavier marginal weights to the smaller dams.

Alternatively, the index can be computed numerically according to the following formula:

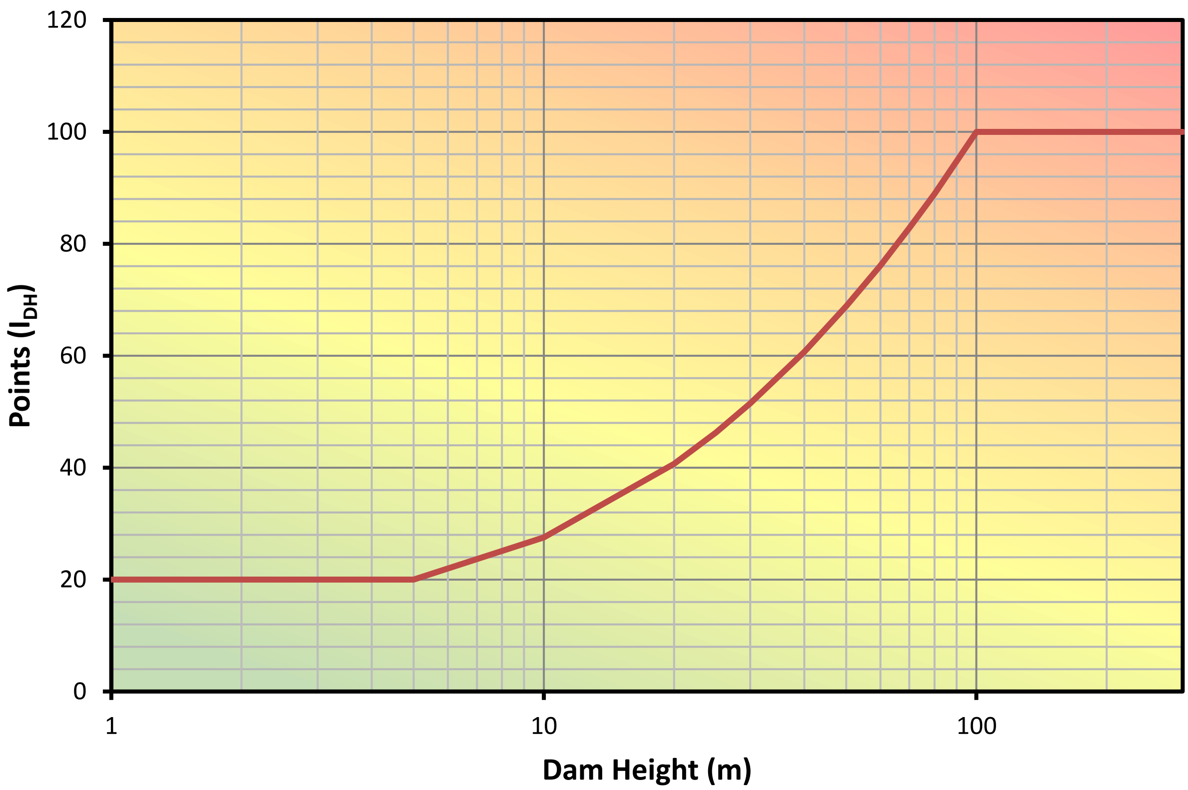

Figure 3.1.- Consequences Rating Points for Dam Height Index (I_{dh})

$$I_{DH} \begin{cases} 20, (for\ h \leq 5) \\ 15.7 + 1.12 * [LN(h)]^{2.8292}, (for\ 5 < h < 100) \\ 100, (for\ h \geq 100) \end{cases}$$

(1)

Where
I_{DH} : Dam height index points, and
h : is the height of the dam in meters

PROJECT BENEFITS INDEX

Another indicator of the capital value of the project is the benefits provided by the project itself. These benefits may be lost entirely or disrupted for some period following a dam failure scenario.

Project benefits index (I_{PB}) is estimated using the following subcategories: reservoir content or water supply index (I_{RES}), irrigation index (I_I), hydropower generation index (I_{HP}), and industrial use index (I_{IU}). Therefore, the total project benefits index can be calculated as follows:

$$I_{PB} = I_{RES} + I_I + I_{HP} + I_{IU} \qquad (2)$$

In case that a cascade failure effect in a dam series is ascertained, the rating points should consider all the affected dams in the system, regardless of the potential dams' ownership conflicts or administrative jurisdiction differences.

The procedure of how to estimate the rating points for each of the subcategories is described below

Reservoir Contents or Water Supply Index (I_{RES}): The value of the reservoir contents is calculated as a function of the time that it would take to fill the reservoir. The time is computed in months, by dividing the reservoir volume in Mm^3 by the average river flow in m^3/s (average of daily means, not daily peaks), and converting the resulting number into months by multiplying it by 0.386.

For instance, if there is a reservoir with 1200 Mm^3, and an average flow of 40 m^3/s. The time to fill the reservoir with the average river flow would then be:

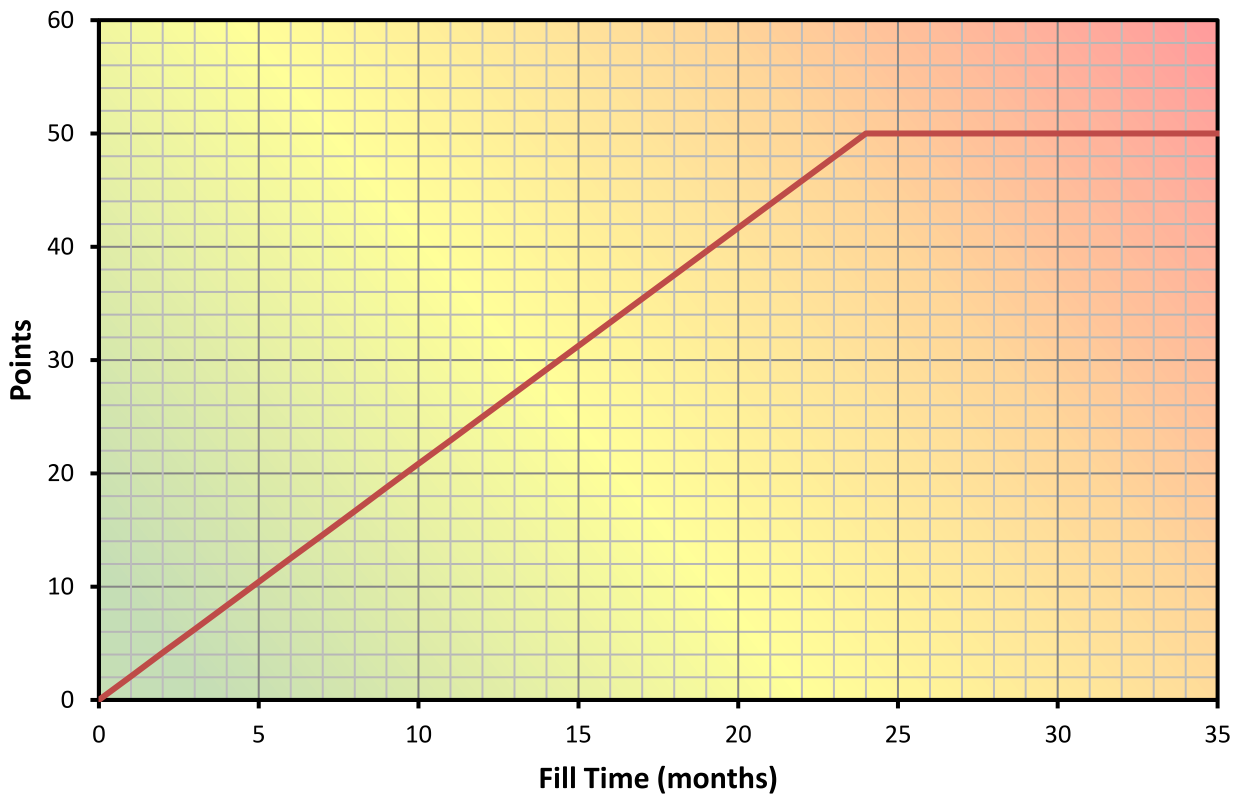

Figure 3.2.- Consequences Rating Points for Reservoir Content Index (I_{RES})

$$T_F = {}^{V}/_{Q} * 0.386 \qquad (3)$$

Where,

T_F = Time to fill the reservoir in months
V = Volume of the reservoir in Mm^3
Q = Average river flow in m^3/s

Applying the equation to the values in the example, we get

Tf = 1200/40*0.386 = 11.5 months

The time to fill is entered into **Figure 3.2**, and for the 11.4 months, we read 23.7 points. An alternative way to compute the number of points is by using the formula:

$$I_{RES} \begin{cases} {}^{50}/_{24} * T_F \,, (for\ T_F\ < 24) \\ 100 \,, (for\ T_F\ \geq 24) \end{cases} \qquad (4)$$

Where,

I_{RES} = Reservoir Content or water supply Index

Irrigation Land Index (I_I)***:*** Irrigation is an essential purpose of India's reservoirs. Failure of a dam could reduce the amount of land substantially under irrigation, and consequently the production of food and its related impact on feeding the population, particularly in the region around the reservoir. The number of points incurred by that failure of an irrigation dam (**Figure 3.3**) is a function of the number of hectares to which the project supplies water.

The number of points for irrigated land is computed as:

$$I_I \begin{cases} area\,, (for\ area\ < 100) \\ 100\,, (for\ area\ \geq 100) \end{cases} \qquad (5)$$

Where,

$area$ = irrigated area in 1,000 ha.
I_I = irrigated land index

Hydropower Generation Index (I_{HP})***:*** The number of points incurred by loss of power generation is a linear function of the installed capacity at the project. Between 0 and 100, the number of points increases linearly until the installed capacity reaches 1000

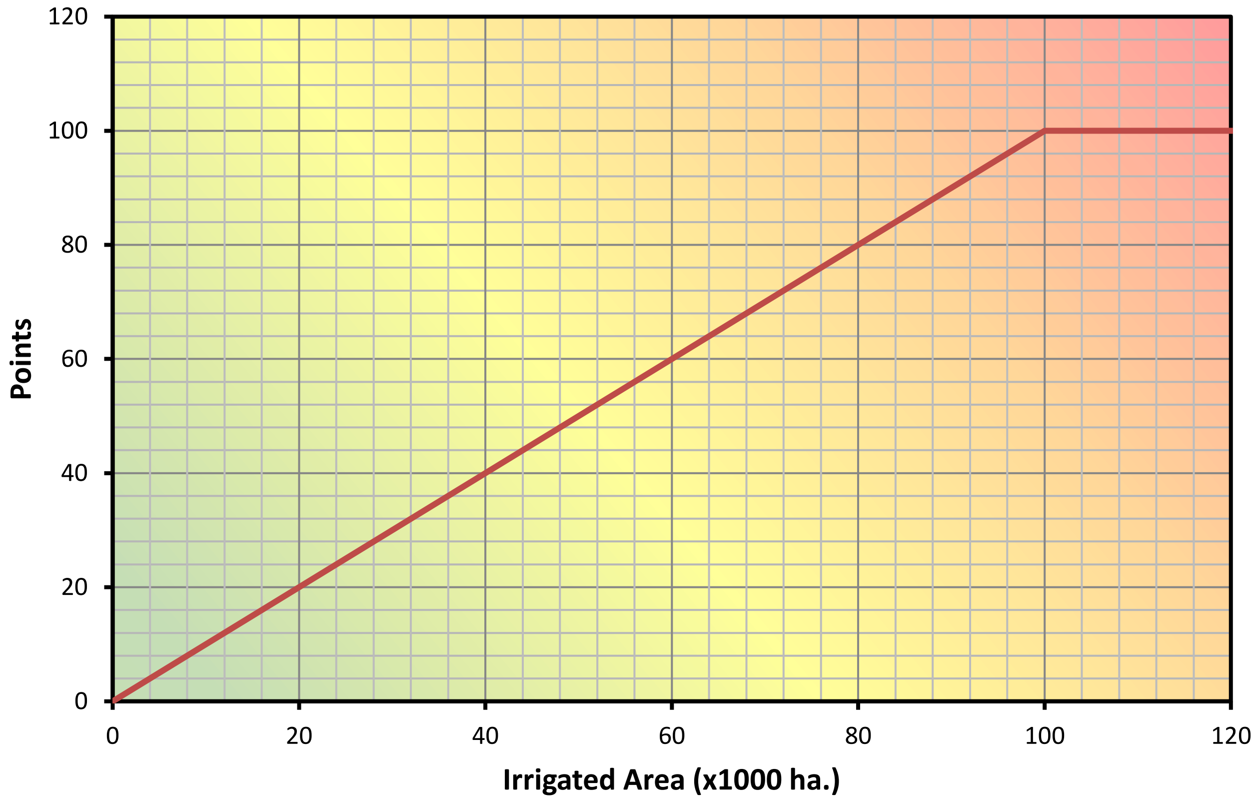

Figure 3.3.- Consequences Rating Points for Irrigated Land Index (I_I)

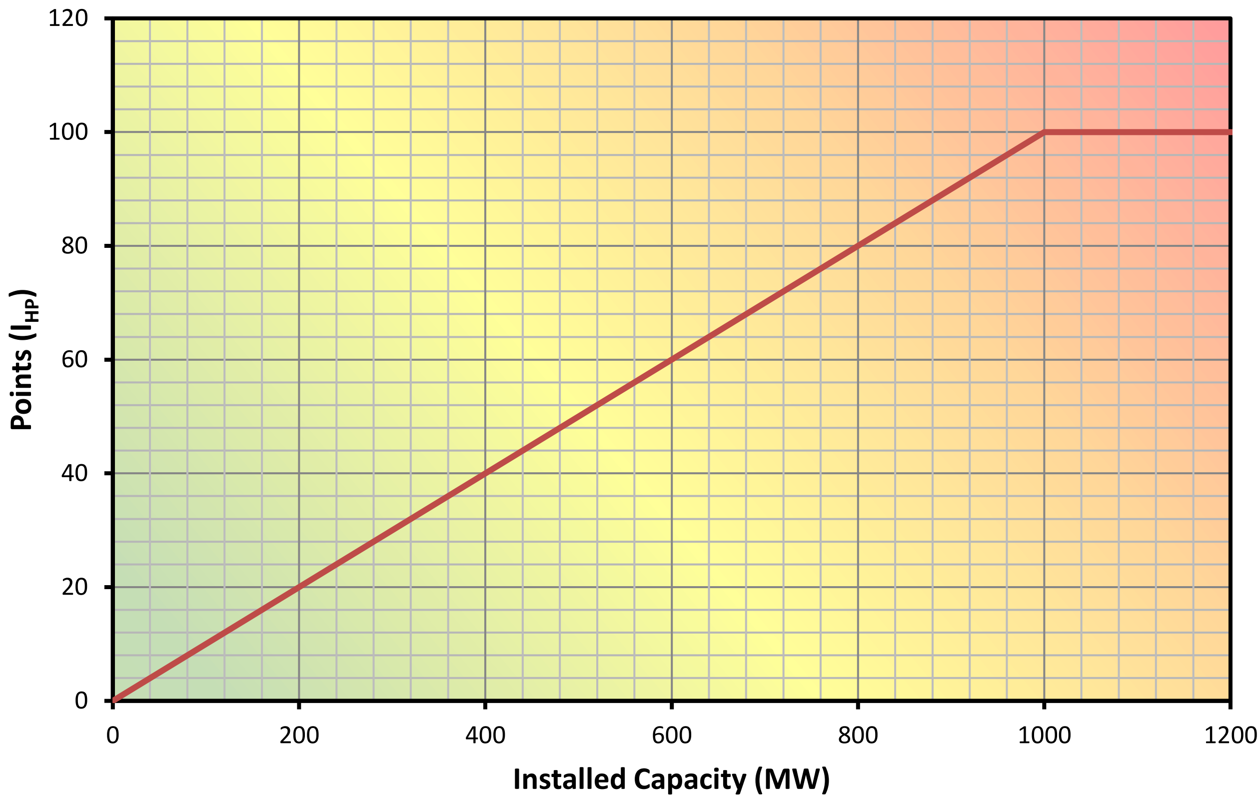

Figure 3.4.- Consequences Rating Points for Hydropower Generation Index (I_{HP})

MW and continues as a constant 100 points for projects with installed capacity higher than 1000 MW (**Figure 3.4**)

The hydropower generation index can also be computed by:

$$I_{HP} \begin{cases} P/_{10}\,,(for\ P\ < 1000) \\ 100\,,(for\ P\ \geq 1000) \end{cases} \quad (6)$$

Where,

P = installed capacity in MW.
I_{HP} = Hydropower index

Industrial Use Index (I_{IU}): The penalty points assigned to industrial purpose are a function of the reservoir volume dedicated to industrial operations. Therefore, the corresponding rating points are calculated using the same methodology as explained for waters supply index (I_{WS}) and shown in **Figure 3.2** and equation (3).

3.3.2 Potential for loss of life

The potential for loss of life will be estimated indirectly through the estimation of the total population at risk in the downstream areas. This category considers the severity of the breach/failure flood, and the approximate arrival time of the flood wave, which is an indirect measure of the available warning time.

In this category, as in the project benefits index (I_{PB}), the evaluation of failure consequences of a dam in a cascade system must include the failure consequences of dams located downstream if such failure would be caused by the dam under scrutiny and if that failure would not otherwise have occurred in the scenario under study. Hence, the rating points should consider the consequences of all dams involved, regardless of the potential dams' ownership conflicts or administrative jurisdiction differences.

In some cases, and if the failure of the downstream dam(s) is ascertained, the highest hazard category might be straight adopted without the need for further justifications.

INCREMENTAL POPULATION AT RISK INDEX (I_{PAR})

India is the second-most populous country in the world and will be the first one in a few years. Dam breaches in most of the country will likely threaten hundreds if not thousands of people.

Development of the utility curve for incremental PAR was based on the information collected by the Bureau of Reclamation in the U.S (Graham,1999) concerning loss of life resulting from dam failures and other natural hazards. In their studies, it was found that the actual loss of life relative to the population at risk dropped dramatically when there is an adequate warning of danger. In particular, there was a significant reduction in fatalities when 5 minutes to 90 minutes of warning was available. An envelope curve for estimating the potential loss of life (PLL) when there is greater than 5 minutes of warning, but less than 90 minutes, can be expressed as a function of the PAR as

$$PLL = PAR^{0.6} \quad (7)$$

Based on this information, equation (7) was used to establish the general shape of the utility curve for the PAR (**Figure 3.5**). The incremental Population at Risk index developed for India varies from 1 to 100,000 people at risk with a minimum index of 20. It then grows exponentially, as shown in **Figure 3.5**, topping at 600 points, for 100,000 or more people at risk. Equation (8) below can also be used for numerical calculation

$$I_{PAR} \begin{cases} 20 * PAR^{0.2954}, (for\ PAR < 100{,}000) \\ 600\ , (for\ PAR\ \geq 100{,}000) \end{cases} \quad (8)$$

Where,

PAR = incremental population at risk

As the equation (8) specified, the incremental population at risk should be used in this proposed approach by subtracting from the consequences of the dam failure the ones that would have happened by the natural flow anyway, that is, even if the dam had not failed.

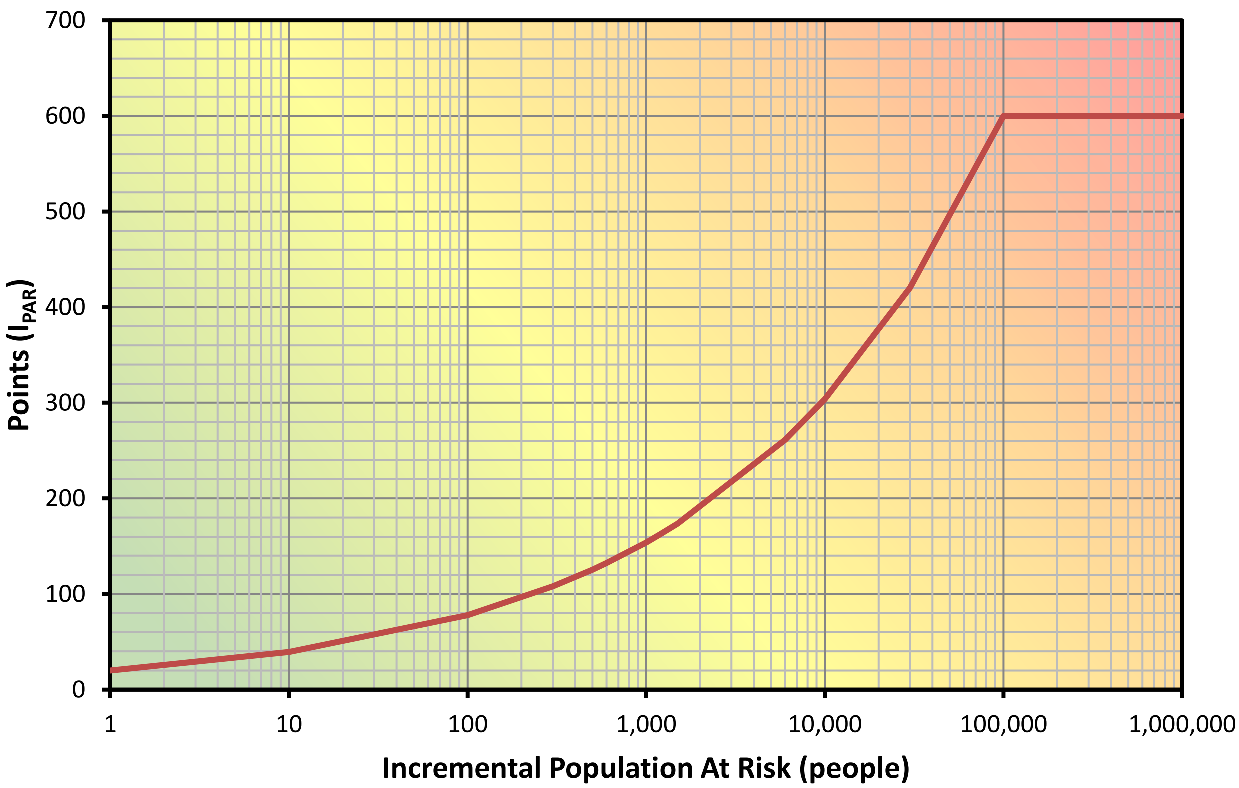

Figure 3.5.- Consequences Rating Points for Incremental Population at Risk (I_{PAR})

Table 3.3.- Highest Severity Categories[1] used to estimate Population at Risk

Hazard Vulnerability Classification[1]		Description	Classification Limit (Depth * Velocity)	Limiting Water Depth (m)	Limiting Velocity (m/s)
	H3	Unsafe for children, elderly and vehicles	D*V ≤ 0.6	1.2	2.0
	H4	Unsafe for vehicles and people.	D*V ≤ 1.0	2.0	2.0
	H5	Unsafe for vehicles and people. All buildings vulnerable to structural damage. Some less robust buildings subject to failure.	D*V ≤ 4.0	4.0	4.0
	H6	Unsafe for vehicles and people. All building types considered vulnerable to failure.	D*V > 4.0	-	-

Notes:
[1]Complete Categories are shown in Figure 2.2 and Table 2.1 (Chapter II)

However, for a sunny-day failure scenario (normal operation), incremental and total consequences are to be considered equal.

Additionally, the population at risk is estimated using the vulnerability approach described in *Section 2.4* (*Vulnerability/Severity Assessment)*. Only the population exposed to the highest hydraulic conditions **(**classes H3 to H6**, Table 3.3**) is considered as at risk, and therefore, counted in the index calculation. It is important to mention, that to obtain a full advantage/benefit of the flood severity analysis, the use of a two-dimensional depth-averaged (2DH) hydraulic model is recommended.

Despite the adequacy of warning to the downstream population is an important factor which directly influences the potential loss of life, the same was not considered for the index estimation of this category. In contrast to the Washington State's methodology, this parameter was skipped from the proposed Indian framework because is considered that adequacy of warning should be one of the primary outcomes after a dam hazard classification and not the other way around (i.e. Adequacy of warning should not influence the Hazard Classification). The inclusion of the actual suitability of the warning protocols in the dam may bias the fundamental concept/purpose of "hazard assessment" process.

A final, but no less important aspect to be considered in the population at risk estimation, is the fact that the population at risk index should reflect the current downstream development as well as the future development plans, especially when this approach is intended to be applied to dams in planning or under construction stage. However, considering future development in the floodplain should not replace the periodical updates of the dam's hazard classification recommended in *0*

Potential Implications of Hazard Potential Classification.

CRITICAL ARRIVAL TIME INDEX (I_{AT})

One of the aspects which affects the potential for loss of life is the effectiveness of the warning and evacuation process. The most relevant flood characteristic is; therefore, the wave arrival time because it influences the possibilities to find shelter on higher grounds. In general, the possibilities for successful evacuation will depend on the time available until the arrival of the floodwater in an area and the time required for evacuation.

Two elements determine the time available for evacuation: (1) The time available between the first signs and the initiation of the flood, i.e. the breach, and (2) The time available between the breach initiation and the arrival of the floodwaters at a certain location (the so-called arrival time). The time lag between first signs and the initiation of a flood depends on the (threatening) type of flood and the availability of warning systems

To incorporate in a simple manner this aspect as part of the hazard assessment and the proposed approach for India, a "critical" arrival time calculation is recommended, understanding as "critical" the minimum wave arrival time computed in the nearest populated area downstream the dam (i.e. town, city, village). This value can be easily obtained after the dam break analysis study is carried out.

As was discussed previously, researches by the U.S Bureau of Reclamation (Graham, 1999) on the field of the potential loss of life, found that with 90 minutes or more of warning time the toll of victims was considerably lower even in cases where thousands had to be evacuated.

Based on this information, the utility curve for the arrival time index was developed (**Figure 3.6**) assigning the highest rating points (100 points) to those cases with less than 90 minutes between the breach initiation process and the moment the nearest population start to be inundated. After 90

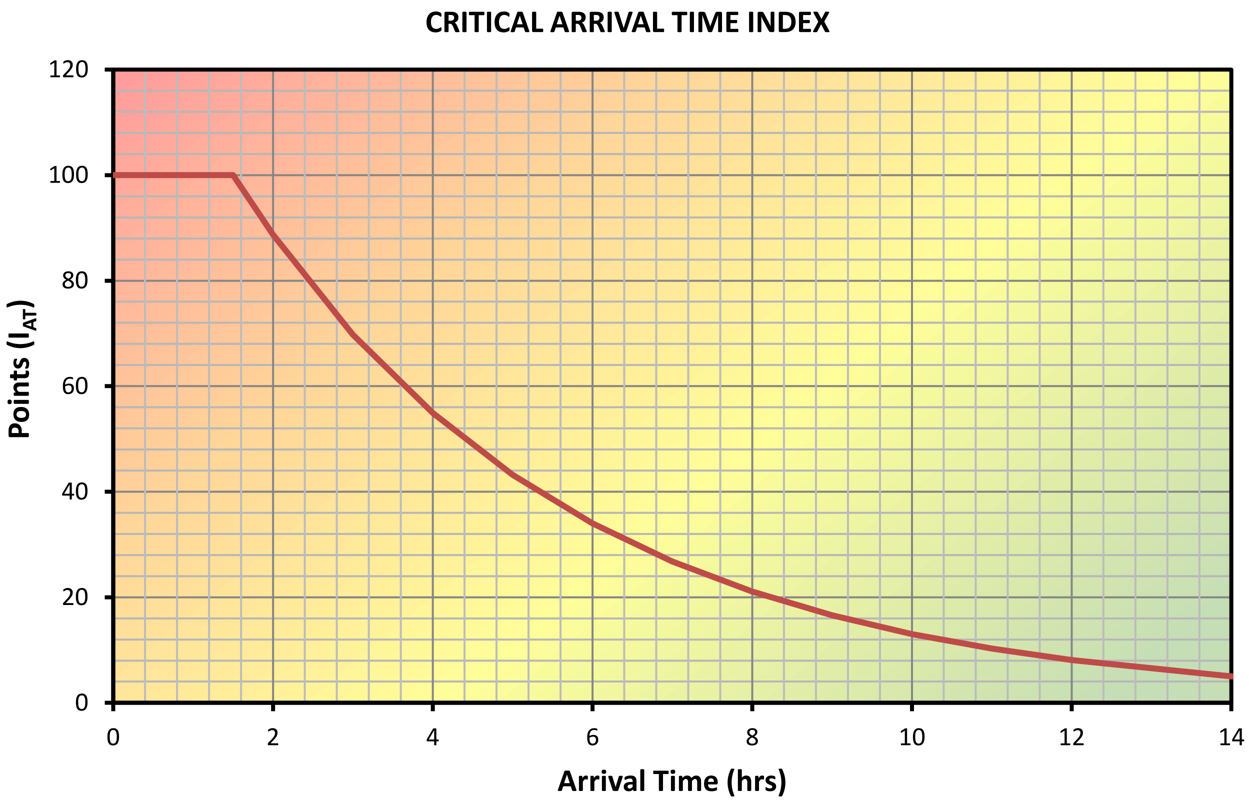

Figure 3.6.- Consequences Rating Points for Critical Arrival Time Index (I_{AT})

minutes, the rating or penalty points are exponentially reduced until a minimum of zero points, when a minimum of 12 hours of arrival time is computed.

If a numerical estimation of the critical arrival index is preferred, equation (9) below can be used

$$I_{AT} \begin{cases} 100, (for\ AT \leq 1.5 \text{ hrs}) \\ 143.28 * (0.7868)^{AT}, (for\ 1.5 < AT < 48) \\ 0, (for\ AT \geq 48 \text{ hrs}) \end{cases} \quad (9)$$

Where,

AT = critical arrival time in hours

I_{AT} = critical arrival time index

3.3.3 Potential for Property Damage

Property damage category would include damage to inhabited dwellings, commercial and industrial developments, agricultural lands and crops, roads, highways and utilities and the associated economic losses both permanent and temporary. This would also include damages to lifeline facilities and economic disruption.

Worth to mention that the indexes described in this category, are meant to identify the relative magnitude of losses against a broad scale of values. No attempt is made to assess

Table 3.4.- Consequences Indexes for Potential Property Damage Category

Indicator Parameter	Type of Property	Index	Rating Points[1]	Flood Severity Class[2]
Transportation Infrastructure	National Highways	I_{NH}	5 - 25	H3 – H6
	State Highways	I_{SH}	3 - 15	H2 – H6
	Railroads	I_R	1 - 20	H3 – H6
Infrastructures Damaged by Land Use	Industrial and Commercial land use	I_{IC}	10- 70	H3 – H6
	Agricultural and Aquaculture land use	I_{AA}	5 - 60	H2 – H6
	Inhabited Residential Areas (Rural)	I_{RAR}	5 - 60	H4 – H6
	Inhabited Residential Areas (Urban)	I_{RAU}	25 - 80	H5 – H6
Services Disrupted	Water Supply/Treatment Facilities	I_{WS}	5 - 25	H3 – H6
	Emergency Response Facilities (Hospital, Relief Units)	I_{ER}	20- 80	H3 – H6
	Electric Power Facilities	I_{EP}	20- 80	H3 – H6

Notes:
[1] Rating points per area/length affected. If there is no item/facility affected within the severity classes zero points should be used
[2] Flood Severity Categories to be considered to estimate final rating points along with relative importance of the item/facility and the extents of the impact

actual market value or actual Indian rupees losses.

A total of 10 sub-indexes were developed to estimate the potential damage to properties. A Summary of all of them is presented in **Table 3.4**

The range of consequences rating points listed in **Table 3.4** reflect both the importance of a facility and the relative magnitude of expected damages based on the hydraulic conditions of the flood (severity). The final value for each index should be selected within the range depending upon the flood severity class obtained from the inundation maps results and the total area affected. **Table 3.4** also presents general guidance in the severity classes to be considered in each case. If any item is located out of those classes, the final index should be considered as zero.

Also, utility curves presented in) have been developed for the Indian methodology to serve as a guide in the calculation of rating points of each type of property. A larger or smaller value may be selected depending on the need for conservatism in protecting the facility/area that could be damaged.

Practical illustration in how to use the utility curves included in *Appendix D* and calculation example of the Potential for Property damage Index is included as part of the case study in *Appendix C.* of this Guidelines.

The final property damage index is given by the sum of all the rating points as follows:

$$\boldsymbol{I_{PD} = I_{NH} + I_{SH} + I_{R} + I_{IC} + I_{AA} + I_{RAR} + I_{RAU} + I_{WS} + I_{ER} + I_{EP}} \quad (10)$$

Where,

I_{PD} = Property Damage Index.
I_{NH} = National Highways index
I_{SH} = State Highways index
I_{R} = Railroads index
I_{IC} = Industrial and Commercial use Index
I_{AA} = Agricultural/Aquaculture use Index
I_{RAR} = Residential Areas (Rural) Index
I_{RAU} = Residential Areas (Urban) Index
I_{WS} = Water Supply/Treatment Facilities index
I_{ER} = Emergency Response Facilities index
I_{EP} = Electric Power Facilities

3.3.4 Potential for Environmental Damage

This component of the hazard potential assessment takes into consideration the impact over the environment and cultural heritage sites, specifically to those considered as protected areas in the country.

Conservation or Protected Areas are defined as areas of notable environmental or historical interest or importance which are protected by law against undesirable changes. These areas are conserved by varying levels of legal protection which are given by the policies formulated by the government of India or global conventions.

India possesses above 165,000 Km^2 of protected areas (MoEF, 2019), between national parks (40,501 Km^2), wildlife sanctuaries (119,775 Km^2), conservation reserves (4,357 Km^2), and community reserves (525 Km^2). Additionally, India counts with more than 30 World Heritage sites (UNESCO, 2019), making it one of the most important countries in terms of cultural heritage

The proposed indexes to evaluate the impact under this category are presented in **Table 3.5**. Potential Environment and Cultural index (I_{ECI}) can be calculated as follows:

$$\boldsymbol{I_{ECI} = I_{PA} + I_{CH}} \quad (11)$$

Where,

I_{ECI} = Environmental and Cultural Index.
I_{PA} = Protected Areas Index
I_{CH} = Cultural Heritage Index

Table 3.5.- Consequences Indexes for Potential Environment and Cultural impact

Indicator Parameter	Type of Property	Index	Rating Points[1]	Flood Severity Class[2]
Protected Areas	National Parks, Wildlife Sanctuary, Community Reserve, Conservation Reserve	I_{PA}	5 - 50	H3 – H6
Cultural Heritage	World and National heritage sites (temples, monuments, caves)	I_{CH}	5 - 50	H5 – H6

Notes:
[1] Rating points per item/site affected. If there is no item/site affected within the severity classes, zero points should be used
[2] Severity Categories to be considered to estimate final rating points along with relative importance of the site

3.4 Dam Classification and the Potential Consequences Index (P_{CI})

As part of the final step in the additive weighting scheme described through the Section 3.3, the final hazard potential classification is obtained after adding up all the index values (rating points) for each of the categories. Equation (12) below can be used:

$$P_{CI} = I_{DH} + I_{PB} + I_{PAR} + I_{AT} + I_{PD} + I_{ECI} \quad (12)$$

Where,

P_{CI} = Potential Consequences Index.
I_{DH} = Dam Height index
I_{PB} = Project Benefits index
I_{PAR} = Population at Risk Index
I_{AT} = Critical Arrival time Index
I_{PD} = Property Damage Index
I_{ECI} = Environmental and Cultural Index

The final hazard potential class will be a function of the total rating points, i.e. the value of the Potential Consequences Index (P_{CI}). **Table 3.1** describes the relationship of the consequence's categories with the final hazard class.

Worth to mention that Dams with total consequences index near the boundaries between two classes (+/- 50 points) warrant a comprehensive assessment and additional engineering judgment to determine the actual hazard classification

Figure 3.7 to **Figure 3.9**, illustrate the additive weighting scheme application to 23 Indian dams, under the Dam Rehabilitation and Improvement Project (DRIP). Estimation of the different index values for all 23 dams attempts to validate and illustrates the approach's applicability in the Indian context.

3.5 Procedure for Hazard Potential Classification at a glance

One can arrive at the hazard potential classification of a dam through the following steps:

1. Carry out dam break analysis matching the requirements of a Tier-1 approach (as per **Table 2.2**), or as per recommendations given in ***Section 2.7*** *(Tiered Assessment of Inundated Area and Flood Water Levels)*. Consider, but not limited to, three main scenarios; sunny-day failure, bad-weather failure and large controlled release. Final hazard potential classification would be defined as per the results of the worst-case scenario in terms of incremental population at risk. (See ***Sections 2.2 and 2.3***)
2. Assess the rest of economic/property and environmental losses based on the results of the dam break study, using

an incremental analysis (See INCREMENTAL HAZARD, page 11) and considering the vulnerability /severity curves described in ***Section 2.4***

3. Calculate the rating points for each of the index values in all the categories of the additive weighting scheme (i.e. Capital Value of Project, Potential for Loss of Life, Potential for Property Damage and Potential for Environmental and Cultural impact). See ***Sections 3.3.1*** to ***Section 3.3.4***
4. Sum up all the index values as per **equation (12)** and determine the hazard Potential classification of the dam as per **Table 3.1**
5. Comply with the equivalent dam safety design standards described in the *Chapter 4. Potential Implications of Hazard Potential Classification*

The steps have also been summarised in an infographic (**Figure E.S.2**) included in the executive summary of this guideline

3.6 The transition between the current and proposed approach

At least for the time being, the classification of hazard potential of a dam based on the potential consequences index (capital value of the project, population at risk, economic and environmental losses) may be applied concurrently along with the existing standard, the later defining the lower limit of classification of a dam.

It has been mentioned earlier that the Indian Standard Specification IS: 11223-1985 follows a prescriptive approach based on the hydraulic head and reservoir storage volume, stressing on the criteria that lead to a higher category.

Adoption of this approach (IS: 11223-198) as a minimum limit will ensure that a new dam with significant storage/ head will not be classified into the smallest hazard class simply because of the existence of limited development in the downstream area at the planning stage. Normally, the development of urban areas downstream of a dam proceeds at a rapid pace after completion of its construction. In recent times, construction of national highways and expressways and development of smart cities are being planned at a nationwide scale in a fast-track mode.

Therefore, upgrading of the hazard class and subsequent design parameters and dam safety standards may be warranted, which poses tremendous difficulties once the dam is constructed.

It is recommended that shifting of hazard class of a dam from one with higher hazard to one with lower hazard should only be supported by carrying out detailed analysis matching the requirements for Tier-III level (**Table 2.2**). This is to ensure that chances of under-classification of dams are obviated.

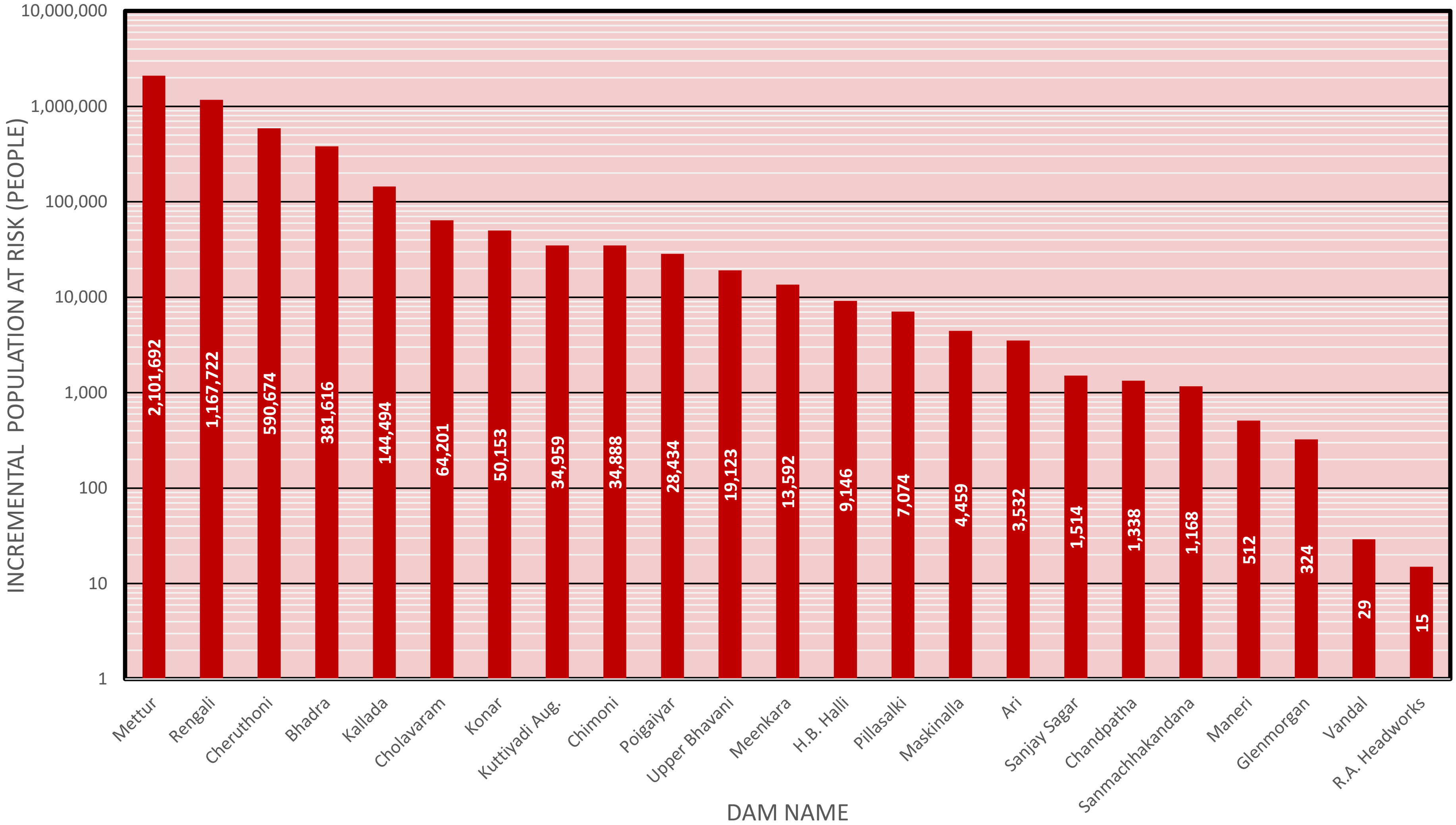

Figure 3.7.- Incremental Population at Risk in selected DRIP dams (worst-case failure scenario).

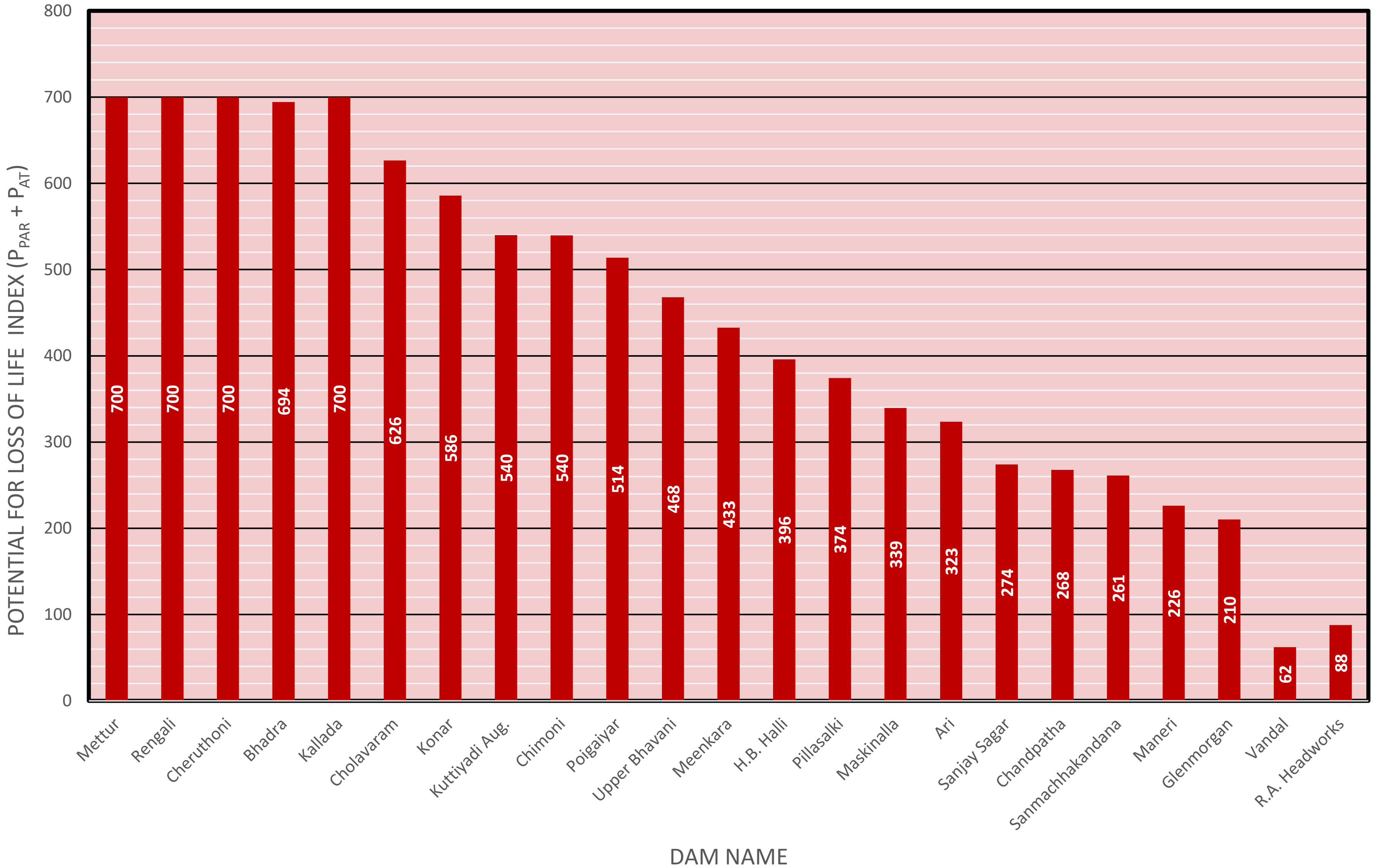

Figure 3.8.- Total rating points for the Population at Risk Index (I_{PAR}) + Critical Arrival Time Index (I_{AT}) of selected DRIP dams.

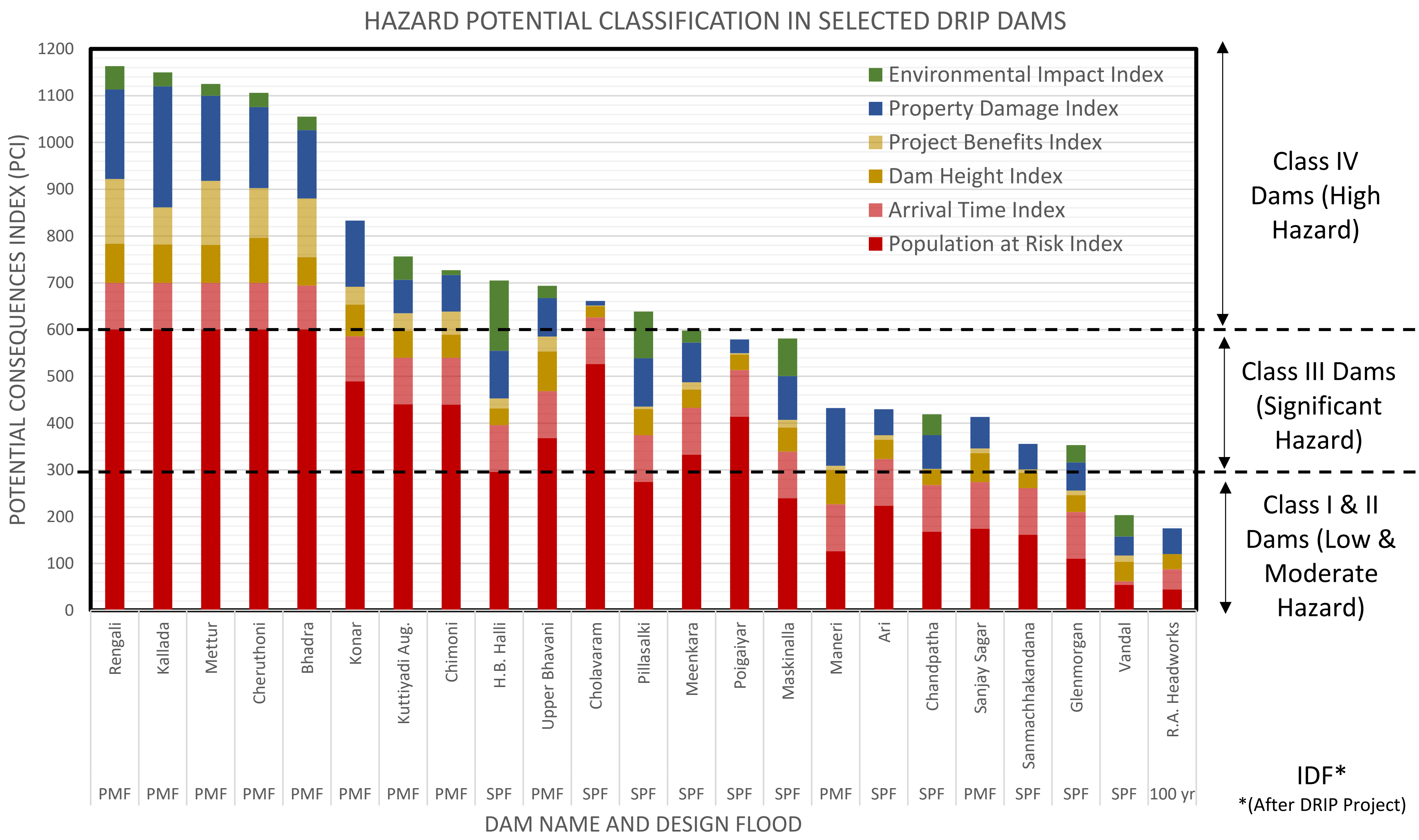

Figure 3.9.- Total Potential Consequences Index (P_{CI}) and Hazard Classification in selected 23 DRIP Dams

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Chapter 4. Potential Implications of Hazard Potential Classification

4.1 Introduction

The hazard potential classification of a dam reflects the effects of its failure or mis-operation based on the probable worst-case scenario that is considered to be reasonable. So, given that a dam is assessed to have major or catastrophic consequences in the event of its failure, it should be designed in a way that may not fail even under the worst possible conditions which may sensibly be expected to occur. This not only implies the adoption of stringent design standards but also the assurance of high standards of inspection and maintenance.

The adoption of uniform standards of hazard potential classification across a portfolio of dams is expected to guarantee optimal prioritisation in emergency preparedness measures. However, since the hazard potential classification does not reflect the current dam's health condition concerning safety, structural integrity, hydrologic or seismic adequacy (dam's performance) neither the probability of occurrence of potential dam failure, it is important to emphasise that to ensure optimal allocation of financial and human resources in the field of dam safety across dams in a region, state and finally, the country as a whole, a proper risk-informed dam safety management program should be implemented.

Therefore, the potential implications discussed in this chapter do not pretend to replace the risk-informed decisions from the overall dam safety management program in the country. Instead, the hazard classification and the potential implication described herein are meant to serve as appraisal level in the decision-making process, before the implementation of a proper risk-informed systematic procedure in the dam owners' organisations.

4.2 Inflow Design Flood

Choice of the magnitude of inflow design flood is critical for a dam, and especially so for an earth dam. It is generally accepted that an earthen embankment will start to erode if it is subjected to overtopping for durations longer than about two hours – leading to a dam breach. So, for dams with earthen embankment components, it is crucially important to select the magnitude of design flood and ensure adequate spillway capacity for its safe passage. It logically follows that earth dams with higher hazard potential should be designed to handle floods of higher magnitudes safely.

The recommended inflow design flood magnitudes corresponding to the four different dam hazard classes have been addressed in the *Guidelines for Selecting and Accommodating Inflow Design Floods for Dams* and have been summarised in **Figure 4.1.** As can be seen in the mentioned figure, the design flood is not a fixed value for each hazard class, but rather is the result of the corresponding potential consequences' index (total rating points).

It is recommended to have the design flood computations based on its annual exceedance probability, except for the Class IV, where the probable maximum flood (PMF) may be adopted. This reclassification is expected to result in a considerable reduction in the cost of rehabilitation of a large number of existing dams by a reduction of hydrologic risk (due to increased design flood beyond original spillway capacity), without compromising on the risk posed to the downstream population or property. Further details on inflow design flood have been presented in the guidelines

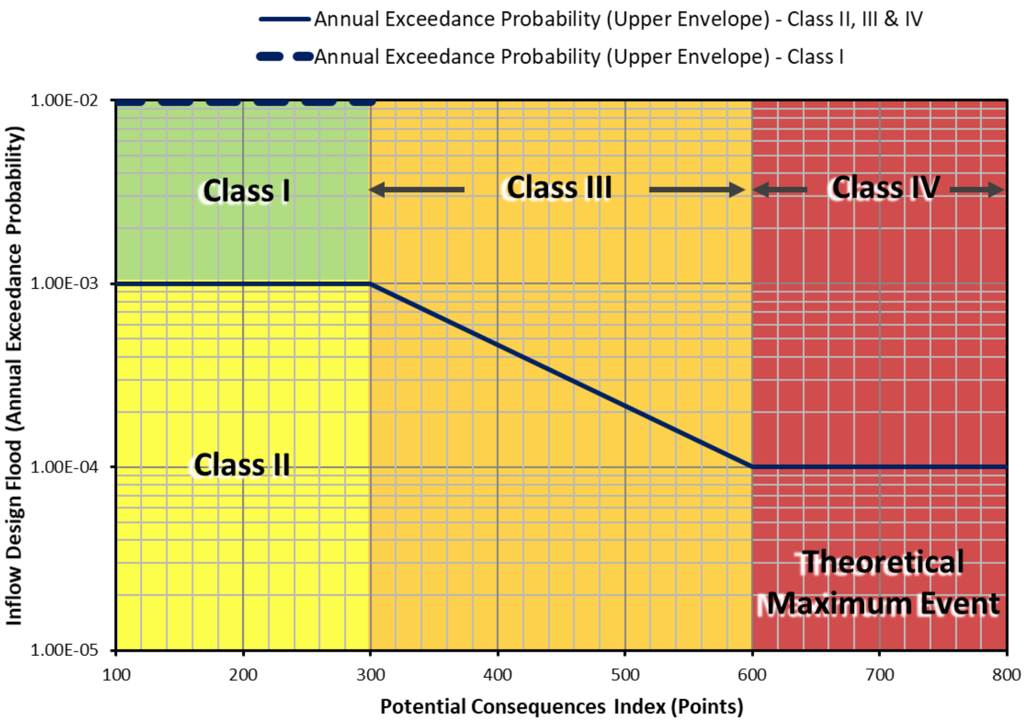

Figure 4.1.- Proposed Inflow Design Floods for different dam hazard classes. (*Source: Guidelines for Selecting & Accommodating the Inflow Design Flood*)

mentioned above, being published under the same series.

As stated in the introduction of this chapter, the recommendations given in **Figure 4.1,** should be taken judiciously and considering the recommended exceedance probabilities as "upper envelopes". However, any attempt to reduce the annual exceedance probability might be possible if a comprehensive risk analysis supports it.

4.3 Requirement of Dam Instrumentation and Frequency of Monitoring

The requirement of dam instrumentation has been discussed in detail in the *Guidelines for Instrumentation of Large Dams* being published as part of the same series. However, other than the height and structural type of the dam, the hazard potential class of the dam may also be considered as a factor of choice for deciding upon the dam instrumentation budget. The type and frequency of monitoring should also depend on the type of dam, its life-phase (first filling, advanced stages of deterioration, etc.), and the construction standards for the dam (Andersen et al., 1999).

For the dams under the higher hazard classes, it may be implied to go for automated monitoring of critical variables (e.g., upstream rainfall and river flow, water level in the reservoir, seismic parameters, rate of leakage etc.) with telemetering facilities to issue warnings at the central control centre indicating exceedance of pre-set critical limits. This is needed to issue evacuation warnings with the least possible delay, in case the situation so arises. The observations may be taken at hourly interval, at least during the flood season/days for which the India Meteorological Department has issued severe weather forecast.

Table 4.1.- Table of Recommended Frequency of observations required for dams under different Hazard Classes

Type of Instrumentation	Phase of Dam Operation			
	First Filling	First Year After Filling	Second and Third Years	Long-Term Operation
Dams in Hazard Class I				
Centralised/Automatic Instruments	Not Required	Not Required	Not Required	Not Required
Manual Readings Instruments	Every 2 days	Weekly	Monthly	Quarterly
Geodesic Instruments[b]	Weekly	Twice a Month	Quarterly	Annual
Dams in Hazard Class II				
Centralised/Automatic Instruments	Daily	Every 2 days	Weekly	Weekly
Manual Readings Instruments	Every 2 days	Weekly	Monthly	Quarterly
Geodesic Instruments[b]	Weekly	Twice a Month	Quarterly	Twice a year
Dams in Hazard Class III				
Centralised/Automatic Instruments	Daily	Every 2 days	Weekly	Weekly
Manual Readings Instruments	Every 2 days	Weekly	Monthly	Monthly
Geodesic Instruments[b]	Weekly	Twice a Month	Monthly	Quarterly
Dams in Hazard Class IV				
Centralised/Automatic Instruments	Daily	Daily	Every 2 days	Weekly
Manual Readings Instruments	Every 2 days	Weekly	Weekly	Twice a Month
Geodesic Instruments[b]	Weekly	Twice a Month	Twice a Month	Monthly

[a] To be implemented/validated along with a risk-informed dam safety management program.
[b]Deformation measurement by georeferenced systems/devices

Proposed frequency of observations for the dams under different hazard classes is presented in **Table 4.1**. Further details on dam instrumentation may be obtained from the *Guidelines for Instrumentation of Large Dams.*

However, the choice regarding manual or automatic observations will have to be made on a case to case basis, with due considerations to the cost involved, the practicality of having automated instruments in place and working for the long run, sensitivity of the correctness of observations in making decisions for emergency evacuations/ huge spillway releases, etc. Nevertheless, it is reiterated that in case of any discrepancy in the requirement of instrumentation between the tentative requirements proposed above and that demanded by the dam structure or other conditions, the stipulations made in the guidelines on dam instrumentation and other relevant Indian standards will prevail.

4.4 Inspection and Maintenance

It follows logically that for the dams with the highest hazard potential, inspection and maintenance requirement should be more stringent than that required for the dams with negligible or minor hazard potential.

According to the *"Guideline for Safety Inspections of Dams"* four types of dam safety inspections are carried out for all dams, regardless of their hazard classification:

1) Comprehensive evaluation inspections
2) Scheduled inspections
3) Special (unscheduled) inspections
4) Informal inspections

The description of the scope and purpose of each inspection is described in detail in the mentioned Guideline. The frequency of these inspections would depend on the hazard potential classification, and **Table 4.2** summarises the proposed approach.

The maintenance program for a dam should be developed based on systematic and frequent inspections (informal and scheduled types), and its implementation should be compulsory regardless of the hazard potential classification. However, the budget or allocation of funds for the maintenance program might be, in an appraisal level, a function of the hazard classification (consequences index) or the result of a dam safety risk assessment when a highest level of prioritisation is required.

In most states, budgets for dam O&M are part of the larger budget for irrigation system maintenance, which is typically decided based on the irrigated area rather than need-based. In practice, irrigation canal maintenance tends to get priority over dam maintenance, which has allowed the deterioration of many dams. Allocations for dam O&M budget need to be more in line with need-based assessments. Still, India has yet to adopt modern asset management planning to guide the efficient operation and especially the maintenance of dams.

Table 4.3 attempts to give some preliminary guidance for the allocation of funds for the maintenance program based solely on the Hazard Potential Classification. However,

Table 4.2.- Frequency of inspections suggested for dams under different hazard classes. [a]

Hazard Classification	Inspection Authority	Inspection Report to be sent to	Type of Inspection			
			Comprehensive	**Scheduled**	**Special**	**Informal**
Class I	Junior Engineer	Sub-Divisional Officer	10 years[b]	Bi-annually[c]	---[d]	Quarterly
Class II	Sub-divisional Officer / Engineer	Executive Engineer	8 years[b]	Bi-annually[c]	---[d]	Monthly
Class III	Executive Engineer	Superintending Engineer	6 years[b]	Quarterly[c]	---[d]	Weekly
Class IV	Superintending Engineer, Test check by Regional Chief Engineer	State Dam Safety Organization (SDSO)	4 years[b]	Monthly[c]	---[d]	Daily

[a] To be implemented/validated along with a risk-informed dam safety management program.
[b] Maximum Frequency of inspections.
[c] Including pre and post monsoon inspections.
[d] Required according to event.

Table 4.3.- Guidance for Preliminary Budget allocation of a Maintenance Program[1]

Hazard Classification	New Projects		Existing Projects (%)[3]
	Hydropower Projects (%)[2]	Irrigation/Water supply and other type of Projects (%)[2]	
Class I	1%	0.5 %	2%
Class II	1%	0.8 %	3%
Class III	2%	1%	4%
Class IV	3%	2%	5%

Notes
[1] Not including major upgrades or rehabilitation measures and to be adjusted after implementation of a risk-informed dam safety management program
[2] Percentage of Dam's construction cost.
[3] Percentage of equivalent annual capital cost of the project.

these values, as was mentioned before, should be adjusted after a proper dam safety risk assessment or risk-informed prioritisation program

For the values presented in **Table 4.3** (existing projects), a comparison study along with a regression analysis of 98 Australian dams (Petheram et al., 2019) was used to estimate the O&M budget range as a percentage of the equivalent annual capital cost of the project, understanding the latter as the annual cost of owning, operating, and maintaining an asset over its entire life (assuming a given discount rate and life span of the asset).

4.5 Requirement for Emergency Action Plans (EAP) and their revision

For dams considered as high hazard potential (Class IV), it should be mandatory to carry out emergency action plans based on dam break analysis matching with a tier-III approach (See **Table 2.2**, page 14). These documents (under Class IV), and their most dynamic elements (notification flowcharts, roles and responsibilities, distribution list, available resources, etc.) should be updated quarterly under the enforcement of the State Dam Safety Organisation.

Table 4.5 shows a summary of the implications in the development and revisions of the emergency action plans after the hazard classification process is completed.

It is also recommended that the Central Dam Safety Organisation should endorse emergency Action Plans for Class IV and III dams, and rest of hazard potential classes either by the State Dam Safety organisation or the Dam's Owner Authority as described in **Table 4.4**

Considering the dam break analysis and corresponding inundation maps are a fundamental input, not only for the Emergency

Table 4.4.- EAPs endorsement

Hazard Class	Responsible for final endorsement of the EAP document
Class I	State Dam Safety Organisation
Class II	State Dam Safety Organisation
Class III	Central Dam Safety Organisation
Class IV	Central Dam Safety Organisation

Table 4.5.- Potential Implications of the Hazard Potential Classification on the development and review of Emergency Action Plan for Dams in India.

Hazard Classification	Dam Break Analysis Tiered approach	Frequency of Updating inundation maps (and Hazard Class) [2]	Frequency of updating dynamic information in the EAP [3]	Awareness Program's frequency	Tabletop exercises' frequency
Class I	Tier-I [1]	4 years	Yearly	Not Required	Not Required
Class II	Tier-I	6 years	Yearly	Every 2 years	Every 3 years
Class III	Tier-II	8 years	Semesterly	Yearly	Every 2 years
Class IV	Tier-III	10 years	Quarterly	Yearly	Yearly

Notes

[1] Tier-I analysis required only for the Hazard Classification process. Emergency Action Plan for Class-I dams may be omitted adding a Chapter of Emergency Preparedness in the O&M manual. (notification flowcharts, available resources, and roles& responsibilities)

[2] Low hazard dams warrant higher frequency of hazard revision in order to justify less rigorous standards

[3] Dynamic information such as notification flowcharts, roles and responsibilities, protocols, contact details, available resources.

Action Plan preparation but also to the overall hazard classification process, it is recommended to update the study periodically as per values shown in **Table 4.5**

For dams with lower hazard potential, it is required a higher update frequency in the hazard classification process and estimation of consequences (i.e. inundation maps). To justify less rigorous standards, these dams require a periodical revision to be in place, to guarantee that the hazard classification has not increased.

4.6 Dam Safety Risk Assessment

The final order of priority among the Classes III and IV within the portfolio of dams would be given by the initial risk-based screening methodology described in the "*Guideline for Assessing and Managing the Risk Associated with Dams*". This initial screening could be based on the consequences index (total rating points) developed in this guideline or any equivalent methodology along with an index (to be developed or adopted) that capture the actual health or condition of the dam.

Once the prioritised dams enter within the Dams Portfolio Risk Management process, periodic updates of reports on Dam Safety Risk Assessment should be made to provide inputs in the decision-making process.

The periodicity of this report would depend on the Hazard Potential Classification and is summarised in **Table 4.6**

4.7 Seismic Hazard Assessment (SHA)

The matrix presented in **Table 4.7** crosses the dam potential hazard class with seismic zones in India (Indian Standards IS1893). It provides a preliminary, simplified guide to determine the extent or type of SHA for different hazard levels.

The simplified correlation presented in **Table 4.7** should be understood as a generic and minimum level of assessment. The actual assessment will be adjusted to integrate and address all specific local conditions. In particular, the cases near the boundaries between two classes warrant additional assessment to determine the actual extent and level of detail.

Table 4.6.- Periodical update of Reports on Dam Safety Risk Assessment under different hazard classes. ***Source: Guidelines for Assessing and Managing Risks Associated with Dams***

Hazard Classification	Periodical update of Reports on Dam Safety Risk Assessment[1]
Class I	10 years
Class II	8 years
Class III	6 years
Class IV	4 years

[1] Maximum Frequency.

.

Table 4.7.- Matrix for Selecting the type of Seismic Hazard Assessment (SHA). ***Source: Guidelines for Evaluating Seismic Hazards and Geological Conditions at dams***

Hazard Classification	Seismic Zone			
	Zone II	Zone III	Zone IV	Zone V
Class I	Basic[1]	Basic[1]	Basic[1]	Simple SHA[2]
Class II	Basic[1]	Basic[1]	Simple SHA[2]	Simple SHA[2]
Class III	Basic[1]	Simple SHA[2]	Simple SHA[2]	Complex SHA[3]
Class IV	Simple SHA[2]	Simple SHA[2]	Complex SHA[3]	Complex SHA[3]

Notes
[1] Basics Analysis using Seismic Hazard Maps
[2] Simple Probabilistic Seismic Hazard Assessment (Site-specific with limited propagation of uncertainties)
[3] Complex Probabilistic Seismic Hazard Assessment (Site-specific with complete propagation of

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Appendix A. DAM HAZARD CLASSIFICATION BASED ON CONSEQUENCES – THE INTERNATIONAL EXPERIENCE

A.1 Introduction

Hazard potential class of a dam may be defined in terms of the potential loss of life, population at risk, property and environmental damage downstream of a dam due to floodwaters released at the dam or waters released by a partial or complete failure of the dam. It does not correspond to the condition of the dam or appurtenant works. It is an index of the relative magnitude of the potential consequences to human life and development in case of failure of a particular dam. It is used as an index for potentially establishing general design requirements and criteria. It is also used as a management tool to allocate time and prioritise the activities related to dam safety like inspection, compliance, and enforcement (WSDE, 2007). It is now recognised that the size of a dam (in terms of storage and dam height) is only one of many factors that influence the hazard potential of a dam (NDNR, 2013).

As was explained in Chapter 2 (Section 2.5.- Limits of the Study Area) in case there are dams in a series on the same river, and the failure of the upstream dam poses a threat of failure to the downstream dam, then the classification for the upstream dam must be as high as or higher than that of the downstream dam/ dams. In general, several cases (e.g., normal reservoir water level or sunny day failure, flood or overtopping failure) may be considered for carrying out the analysis of consequences due to a dam break. Out of these, the worst-case severity level of damage and loss should be considered for consequence categorisation.

A.2 Uncertainties in Consequence Based Classification

The consequence category or hazard potential class is a significant decision- making parameter for dam safety, which influences the allocation of resources to dam safety management. An appraisal of the accuracy of each model used in the estimation should be carried out, particularly for the estimation of the population at risk. The impact of model accuracy on the estimation of PAR is most conspicuous for villages and townships where the population is concentrated. So, it may be justified to improve accuracy in these areas selectively.

Where input data are uncertain with the uncertainty affecting the categorisation of a dam, additional investigations may be required. Such investigations may include comprehensive dam-break modelling with more detailed survey data, detailed assessments of damages and losses and a comprehensive risk assessment exercise. Sensitivity analysis may also be carried out to provide a greater degree of confidence in the assigned consequence category/ hazard potential classification of a dam. Discussions on risk assessment may be found in the "*Guidelines on Assessing and Managing Risks Associated with Dams*", published as part of the same series of guidelines.

A.3 The Methodology Followed in the USA (FEMA)

In the United States, the states have, by law, considerable control on the water resources. Federal guidelines provide a framework upon which the states may develop their own guidelines, but, as guidelines, are not mandatory.

There are several guidelines in the United States. Federal Agencies such as the Federal Emergency Management Agency (FEMA), the Federal Energy Regulatory Commission (FERC), the US Bureau of Reclamation (USBR), the US Park Service, the US Department of Agriculture and the US Army Corps of Engineers (USACE) have their own guidelines. Furthermore, several states have their own norms or guidelines, or no guidelines at all. Below we present one of the Federal guidelines and one State guideline.

Table A.1- Hazard potential classification of dams (adapted from FEMA, 2004b)

Hazard Potential Classifica-	Loss of Human Life	Economic, Environmental, Lifeline Losses
Low	None expected	Low and generally limited to owner
Significant	None expected	Yes
High	Probable. One or more expected	Yes (but not necessary for this classification)

a. FEMA

Federal Emergency Management Agency (FEMA uses three classes (viz., low hazard potential, significant hazard potential, and high hazard potential are used for consequence categorisation of dams (FEMA, 2004b). The classification in tabular form has been reproduced in **Table A.1**.

Low Hazard Potential

Dams, where failure or mis-operation may result in no probable loss of human life and low economic and/ or environmental losses, are classified into the low hazard potential category. In such cases, the losses are expected to be principally limited to the properties of the dam owner.

Significant Hazard Potential

Dams, where failure or mis-operation may result in no probable loss of human life but may cause economic loss, disruption of lifeline facilities, or can impact other concerns, are classified as dams with significant hazard potential. These dams are generally located in rural or agricultural areas but may sometimes be located in areas with population and significant infrastructure.

High Hazard Potential

Dams, where failure or mis-operation may cause loss of human life, are classified as dams with high hazard potential. However, if failure or mis-operation of a dam is likely to contribute to the failure of one or more dams downstream, the hazard potential class of the dam should be at least as high as that of the downstream dam(s), with due consideration of the adverse incremental consequences of the series failure.

b. Washington State

The State of Washington bases its classification on the FEMA guidelines but expands the conditions to which the classification applies. Dam classification for Washington State is unique when it is compared with Federal guidelines since a point value scheme is used to assess the downstream consequences.

Table A.2 shows the Dam Classification for Washington State, and **Table A.3** shows the range of point values for the major categories. **Figure A.2** defines the IDF and corresponding annual probability of exceedance as a function of the cumulative points.

To select the consequence points, the State of Washington Dam Safety Guidelines Technical Note 2 provides a series of graphs and tables that help the engineer assign a point value to each of the consequences (**Table A.3**). For instance, **Figure A.1** in Technical Note 2 shows that a population of 80 people

Table A.2.- Dam Classification (Washington State)

Downstream Hazard Potential	Downstream Hazard Category	Population at Risk	Economic Loss	Environmental Damage
Low	3	0	Minimal. No inhabited structures. Limited agricultural development.	No deleterious material in reservoir contents.
Significant	2	1-6	Appreciable. 1 or 2 inhabited structures. Notable agriculture or work sites. Secondary highway and/or rail lines.	Limited water quality degradation from reservoir contents and only short-term consequences
High	1C	7-30	Major. 3 to 10 inhabited structures. Low density suburban area with some industry and work sites. Primary highways and rail lines.	Severe water quality degradation potential from reservoir contents and long-term effects on aquatic and human life.
High	1B	31-300	Extreme. 11 to 100 inhabited structures. Medium density suburban or urban area with associated industry, property, and transportation features.	
High	1A	More than 300	Extreme. More than 100 inhabited structures. Highly developed, densely populated suburban or urban area with associated industry, property, transportation, and community life line features.	

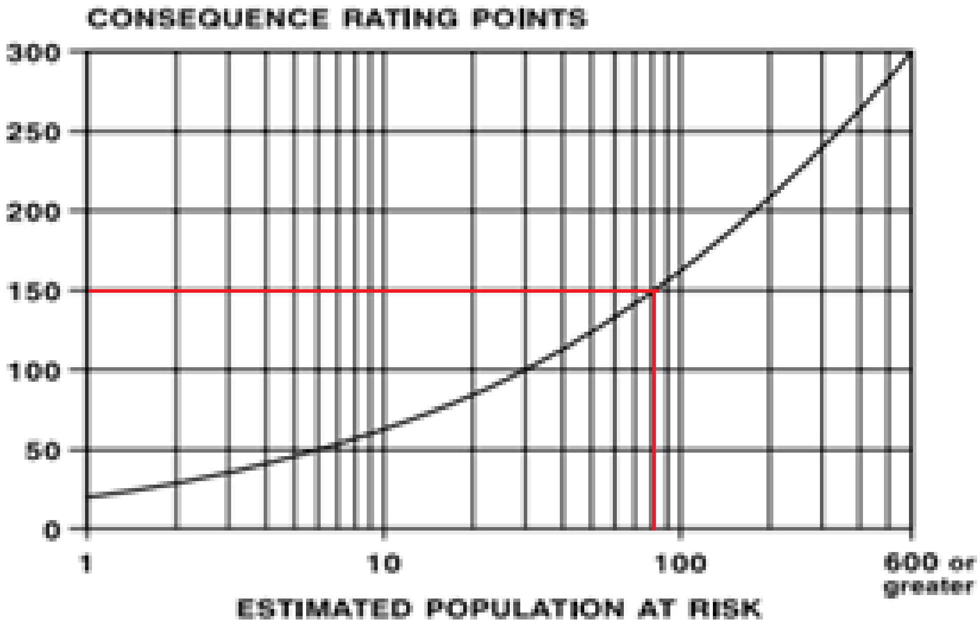

Figure A.1.- Curve to Estimate rating points based on the Population at Risk (Washington State)

Table A.3.- Consequence Point Values (Washington State)

Consequence Categories	Consequence Rating Points	Indicator Parameter	Considerations
Capital Value of Project	0 -150	Dam Height	Capital Value of Dam
	0 - 75	Project Benefits	Revenue Generation or Value of Reservoir Contents
Potential for Loss of Life	0 - 75	Catastrophic index	Ratio of dam peak breach discharge to 100-yr flood
	0 - 300	Population at risk	Population at risk potential for future development
	0 - 100	Adequacy of warning	Likely adequacy of warning in the event of dam failure
Potential for Property Damage	0 -250	Items damaged or services disrupted	Residential and Commercial Property. Roads, bridges, transportation facilities. Lifeline facilities, community services. Environmental degradation from reservoir contents (Tailings, wastes, etc)

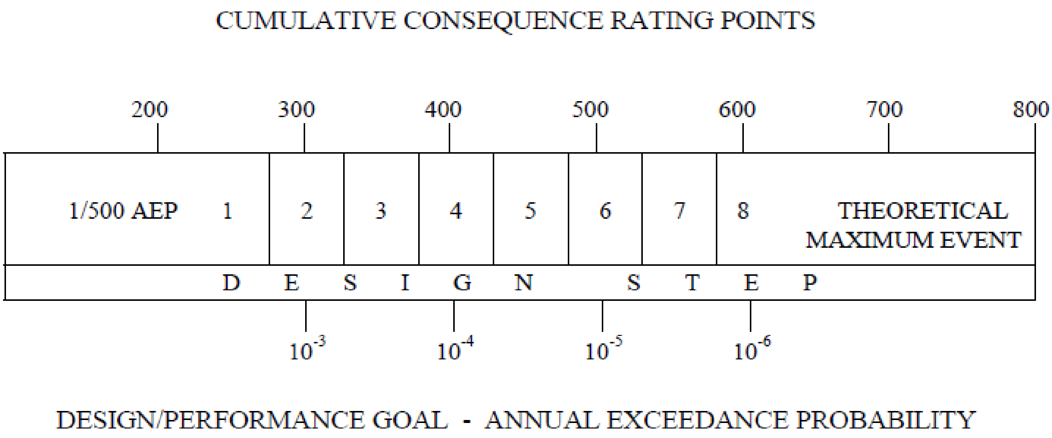

Figure A.2.- Inflow Design Flood and Design Step as a function of Cumulative Consequence Rating Points. (Washington State)

at risk corresponds to a rating point of 150. The process is repeated to each of the consequences, and the point values are computed.

Once the points are computed, the cumulative value is used as a consequences index for the dam hazard classification as well as for selecting the inflow design flood of the corresponding dam.

A.4 The Methodology Followed in the UK

In the UK, the dams have been classified into four hazard categories (EA, 2016). The classification has been reproduced in **Table A.4**. The categorization is based on lives endangered due to a dam breach. The dam threatening more than 10 persons with a threat to life is placed in the highest category.

Category A dams are those a failure of which may endanger the lives of inhabitants of communities (ICE, 2015). A community has been considered to be not less than about 10 persons (e.g., hamlet, school or another social group), as revealed through inspection. Road and rail traffic are not considered. Occasional campsites may be considered if regularly used by school parties, but not if frequented by a few unrelated short-stay individuals.

Category B (i) dams are those a failure of which may endanger the lives of inhabitants of isolated houses (e.g., those associated with treatment works). Category B(ii) dams are those a failure of which may cause extensive damage, including erosion of agricultural lands and the breaking of main road or rail communications or other critical infrastructures like gas mains or transformers.

Category C dams are those a failure of which may create a situation that poses negligible risk to human life. It includes areas inhabited sporadically (e.g., footpaths across the floodplain and playing fields). It also covers damage to important monuments, and loss of livestock, crops and protected natural habitats.

Category D dams comprise those small reservoirs with low earth dams (e.g., ornamental lakes), a failure of which may cause no real problem, except that of replacement. They pose no significant threat to life or property.

A.5 The Methodology Followed in Australia

Seven consequence categories (very low, low, significant, high A, high B, high C and extreme) for dams have been adopted for Australia (ANCOLD, 2012). The categories are based on the severity of the potential damage and loss, along with the estimated population at risk (PAR) or potential loss of life (PLL).

The hazard potential assessment of dam failures is based on the difference between the consequences of the dam breach flood and normal conditions existing prior to dam failure, including rainfall and flood event without dam break, tidal effects, and riparian flows. For dams with multiple component structures (e.g., saddle dams), based on their location and downstream consequences, the individual structures may require the assignment of separate consequence categories. The consequence categories are described underneath:

Very Low

Applies to the dams with negligible consequences of failure be (e.g., small farm dams in remote regions).

Low, Significant, High A, High B & High C

Provide a graded range between the Very Low Category and Extreme Category.

Extreme

Includes dams with severe consequences (in terms of damage to property and infrastructure) of a failure. Many lives may be

Table A.4.- Dam categories in the UK (adapted from EA, 2016)

Dam Category	Downstream Effects
A	Where a breach could endanger lives in a community*
B	Where a breach (i) could endanger lives not in a community or (ii) could result in extensive damage
C	Where a breach would pose negligible risk to life and cause limited damage
D	Special cases where no loss of life can be foreseen as a result of a breach and very limited additional flood damage would be caused

** A community in this context is considered to be 10 or more persons affected*

Table A.6.- Consequence categories followed in Australia based on incremental potential lives lost (adapted from ANCOLD, 2012)

Incremental Potential Loss of Life (PLL)	Severity of Damage and Loss			
	Minor	**Medium**	**Major**	**Catastrophic**
<0.1	Very Low	Low	Significant	High C
≥0.1 to <1	Significant	Significant	High C	High B
≥1 to <5		High C	High B	High A
≥5 to <50	(Note 1)	High A	High A	Extreme
≥50		(Note 1)	Extreme	Extreme

Note 1: With an incremental PLL equal to or greater than one, it is unlikely that damage will be minor. With an incremental PLL in excess of 50 it is unlikely that the damage will be classified as medium.

Table A.5.- Consequence categories followed in Australia based on PAR (adapted from ANCOLD, 2012)

Population at Risk	Severity of Damage and Loss			
	Minor	**Medium**	**Major**	**Catastrophic**
<1	Very Low	Low	Significant	High C
≥1 to <10	Significant (Note 2)	Significant (Note 2)	High C	High B
≥10 to <100	High C	High C	High B	High A
≥100 to 1,000	(Note 1)	High B	High A	Extreme
≥1000		(Note 1)	Extreme	Extreme

Note 1: With a PAR in excess of 100, it is unlikely that damage will be minor. With a PAR in excess of 1,000 it is unlikely that the damage will be classified as medium.
Note 2: Change to High C where there is a potential of one or more lives being lost.

put at risk, with the potential for large loss of life. Large dams upstream of major population centres are under this category.

The categorisation of consequences based on the estimated population at risk as adapted from ANCOLD (2012) has been shown in **Table A.5**. The classification of consequence categories based on the incremental PLL is shown in **Table A.6**.

A.6 The Methodology Followed in Canada

All dams in Canada are classified according to their potential consequence of failure. In British Columbia, the consequences are categorised into five classes viz., low, significant, high, very high and extreme (DSP, 2017). It has been reproduced in **Table A.7**. For dams under the consequence category low, there is no possibility of loss of life. If there exists a low potential for multiple loss of life, it is categorised under significant. Up to 10 lives may be potentially lost in case of a dam under high consequence category. If there are chances of up to 100 lives being lost, the dam is classified into the very high consequence category. In case the estimated potential loss of life exceeds 100, the dam should be considered into the consequence category class extreme.

A.7 The Methodology Followed in China

In China, dam classification is based on the main characteristics of the system (e.g. reservoir capacity) as well as economic impact

Table A.7.- Downstream consequence classification guide in Canada (adapted from DSP, 2017)

Dam failure consequences classification	Population at risk	Consequences of failure		
		Loss of life	**Environment and cultural values**	**Infrastructure and economics**
Low	None[1]	No possibility of loss of life other than through unforeseeable misadventure	Minimal short-term loss or deterioration and no long-term loss or deterioration of fisheries habitat or wildlife habitat, rare or endangered species, unique landscapes, or sites having significant cultural value	Minimal economic losses mostly limited to the dam owner's property, with virtually no pre-existing potential for development within the dam inundation zone
Significant	Temporary only[2]	Low potential for multiple loss of life	No significant loss or deterioration of important fisheries habitat or important wildlife habitat, rare or endangered species, unique landscapes, or sites having significant cultural value, and restoration or compensation in kind is highly possible	Low economic losses affecting limited infrastructure and residential buildings, public transportation or services or commercial facilities, or some destruction of or damage to locations used occasionally and irregularly for temporary purposes
High	Permanent[3]mmm	10 or fewer	Significant loss or deterioration of important fisheries habitat or important wildlife habitat, rare or endangered species, unique landscapes or sites having significant cultural value, and restoration or compensation in kind is highly possible	High economic losses affecting infrastructure, public transportation or services or commercial facilities, or some destruction of or some severe damage to scattered residential buildings
Very high	Permanent[3]	100 or fewer	Significant loss or deterioration of critical fisheries habitat or critical wildlife habitat, rare or endangered species, unique landscapes, or sites having significant cultural value, and restoration or compensation in kind is possible but impractical	Very high economic losses affecting important infrastructure, public transportation or services or commercial facilities, or some destruction of or some severe damage to residential areas
Extreme	Permanent[3]	more than 100	Major loss or deterioration of critical fisheries habitat or critical wildlife habitat, rare or endangered species, unique landscapes, or sites having significant cultural value, and restoration or compensation in kind is impossible	Extremely high economic losses affecting critical infrastructure, public transportation or services or commercial facilities, or some destruction of or some severe damage to residential areas

[1]There is no identifiable population at risk.
[2]People are only occasionally and irregularly in the dam-breach inundation zone, for example stopping temporarily, passing through on transportation routes or participating in recreational activities.
[3]The population at risk is ordinarily or regularly located in the dam-breach inundation zone, whether to live, work or recreate.

Table A.8.- China - Classification of water conservancy and hydropower projects

Rank of project	Storage capacity (hm³)	Flood prevention		Water logging	Irrigation	Water supply	Water power
		Cities and industrial areas	Farmland (10^3 ha)	Logged area (10^3 ha)	Area (10^3 ha)	Cities and mines	Installed capacity (MW)
1	> 1000	Very Important	> 333	> 133.3	> 100	Very Important	> 750
2	100-1000	Important	67 - 333	40 - 133.3	33.3 - 100	Important	250 - 750
3	10-100	Moderately Important	20 - 67	Oct-40	3.3 - 33.3	Moderately Important	25 - 250
4	01-Oct	Less Important	3.3 - 20	2.0 - 10	0.3 - 3.3	Less Important	0.5 - 25
5	< 1		< 3.3	< 2.0	< 0.3		< 0.5

Notes

- The storage capacity of reservoir means the storage of reservoir below check flood level
- The irrigation and waterlogged areas refer to design areas
- The rank of tide prevention projects may be defined referring to the stipulations for flood prevention. Where disasters of tide are very serious, the rank may be raised properly
- The importance of water supply works are defined according to their scale, economic and social benefit.

indicators which try to estimate the potential consequences on the regional and national economy. **Table A.8** summarises the elements considered for the dam classification in China. (Liu, 2002).

A.8 The Current Practice in India

The hazard potential classification formerly being practised in India is that stipulated by the Ministry of Water Resources (MOWR, 1987). In this, the dams were classified into three categories – low, significant and high (**Table A.9**). However, this approach proposed by MOWR is not being actively used in the country. Instead, the criteria given by the Bureau of Indian Standards (BIS) guideline IS: 11223-1985 "Guidelines for fixing spillway capacity" are followed for classifying dams in practice (**Table A.10**). The Bureau of Indian Standards (BIS) guideline does not explicitly deal with the hazard potential downstream because dams have been categorised by size using the hydraulic head as well as the gross water storage capacity at the full reservoir level. Classification of a dam follows the parameter that results in a more severe category.

For the purpose of classification, the hydraulic head is to be considered as the difference between the maximum water level in the reservoir and the annual average flood level on the downstream side. Since this involves preselection of design flood for assessment of the MWL, an alternate definition (vide Amendment No. 2, Sep 1991) has been presented which considers the difference between the FRL and the minimum tailwater level downstream of the dam as the hydraulic

Table A.9.- Former Hazard potential classes for dams in India (adapted from MOWR, 1987)

Category	Loss of Life (Extent of Development)	Economic Loss (Extent of Development)
Low	None expected (no permanent structures for human habitation)	Minimal (undeveloped to occasional structures or agriculture)
Significant	Few (no urban developments and no more than a small number of inhabitable structures)	Appreciable (notable agriculture, industry or structures)
High	More than few	Excessive (extensive community, industry or agriculture)

Table A.10.- Existing dam classification for selection of inflow design flood in India (adapted from IS: 11223-1985)

Class	Gross storage capacity (Mm^3)	Hydraulic head (m)	Inflow Design Flood (IDF)
Small	0.5 to 10	7.5 to 12	100-year flood[a]
Intermediate	10 to 60	12 to 30	Standard Project Flood (SPF)
Large	> 60	> 30	Probable Maximum Flood (PMF)
[a]The flood having an annual exceedance probability of 0.01 (1%)			

head. The classification scheme is shown in **Table A.10**.

A.9 The Merits and Demerits of the Current Approach in India

The categorisation recommended by the MOWR is not based on limits pre-defined. While this helps to serve the purpose of classification over time with the increasing spread of the population and the reducing value of the currency, it remains difficult to apply because of the subjectivity involved.

The current classification system stipulated by the Bureau of Indian Standards is simple, being based on unambiguous parameters like gross storage and hydraulic head. Moreover, they barely change with time, in theory, obviating the need for costly updating. Also, it recognises the development plans and allows the designer to choose higher standards justifiable.

However, observations have established that the loss of life resulting from a dam failure and the economic impacts may not be directly related to the height of the dam or the volume of the storage reservoir. Graham and Yang (1996) revealed that the failure of Teton Dam claimed 11 lives whereas the failure of Kelly Barnes dam claimed 39 lives, even though the former was about 9 times as high and at the time of failure was storing about 400 times more water than the latter. The number of people occupying the floodplain below the first dam was about 100 times that of the second.

Classifying a dam with limited potential consequences into a higher category only because of its hydraulic head (as dictated by the prescriptive approach followed currently) may not lead to an optimal allocation of resources for its rehabilitation. On the other hand, huge loss of life caused by a dam of a lower category, because of the lower attention received for its surveillance and allocation for maintenance may not be justifiable on any grounds. It may be morally and financially more justifiable to arrange for relocation/ modification/ strengthening of habitations obstructing the pathway of the flood to reduce life loss than depend on post-disaster rehabilitation measures alone.

A.10 Previous Attempts To shift to a Consequences-based Approach in the country

State of The Art Report (CWC, 2010) proposed four hazard classes based on the potential loss of life and financial consequences, rather than the prescriptive approach being followed till date. The report proposed four classes of very high, high, moderate and low hazard (Table A.11**)**.

Even though this classification appears to be based on the population at risk and economic and social consequences, the categorisation based on economic and social consequences is not clearly defined in numerical terms.

Working further in this line, Pandya et al. (2014) propose categorisation into 5 classes. They advocate the introduction of two more classes with the only purpose to introduce two more levels of design flood category. One between the 100-year flood and Standard Project Flood (SPF) categories, corresponding to 500 year return period flood, and one more level of flood category between SPF and PMF, corresponding to an average of SPF and PMF floods.

This last classification attempt is not very clear, and it does not deal with the hazard potential of the dams. It summarises the experiences gained through DRIP but deviates from the current practice of assessment of the hazard potential of dams through an evaluation of the consequences directly. It continues to classify the dams based on gross storage and dam height (apparently a deviation from the hydraulic head currently followed in India).

This provides the background of the hazard potential classification scheme being

Table A.11.- Consequence classes for dams (adapted from SAR, 2010)

Consequence category	Potential Incremental Consequences of Failure	
	Population at Risk	**Economic and Social**
Very high	>1,00,000	Very high economic losses affecting infrastructure, public and commercial facilities in inundation area. Typically includes destruction of or extensive damage to large residential areas, concentrated commercial land uses, highways, railways, power lines and other utilities.
High	Between 10,000 to 1,00,000	Substantial economic losses affecting infrastructure, public and commercial facilities in inundation area. Typically includes destruction of or extensive damage to concentrated commercial land uses, highways, railways, power lines and other utilities. Scattered residences may be destroyed or severely damaged.
Moderate	Between 2,000 to 10,000	Moderate to low economic losses to limited infrastructure, public and commercial activities.
Low	<2,000	Minimal economic losses typically limited to owners property. Virtually no potential for future development of other land uses within the foreseeable future.

proposed in the present guideline – which would have four classes but would be based on the estimated consequences derived through dam breach modelling, instead.

A.11 Hazard Potential Classification. Summary of International Practices

After reviewing the different international dam hazard classification systems, all countries consider the potential consequences of a dam failure implicitly or explicitly. Even when most countries have their ways to classify the dams, the different methods of classification can be divided into two main approaches:

- Dam classification based on the system's characteristics, such as dam height and type, reservoir volume, etc. This approach takes implicitly into account the possible impacts of a dam failure and the risk associated with such event;
- Dam classification based on dam failure consequences. This explicit approach considers the evaluation (quantitative or qualitative) of the one or several types of consequences of a dam failure explicitly. The economic aspect of the consequence of a dam failure can be part of the classification, and sometimes a hybrid approach is used for the dam classification, combining the characteristics of the dam and the consequences of the dam failure. Bulletin 170 (ICOLD, 2015) presents a summary of the international criteria applied in 30 countries to decide their dam hazard classification system. This summary is reproduced and adapted in **Table A.12**

It is seen that the classification being currently followed in the selected countries place the highest importance on the consequences-based approach (**Figure A.3**), with special emphasis in the estimation of the population at risk (PAR) and probable loss of life (PLL) categorisation of dam hazard.

Bulletin 170 (ICOLD, 2015) also shows that among the 30 countries/agencies whose regulations are discussed, those currently using an implicit approach based on the system's characteristics are developed countries with relatively low population density, except for the case of India. (**Figure A.4** and **Figure A.5**)

A.12 Pathway to Hazard Classification for India

As an obvious conclusion from the international comparison, it is felt that India should also move out from the height and storage volume based prescriptive approach to categories based on explicit failure consequences, with due importance given to population at risk and potential loss of lives. With the availability of data, software, and hardware, this is no longer a task beyond reach. Comprehensive results might be through dam breach

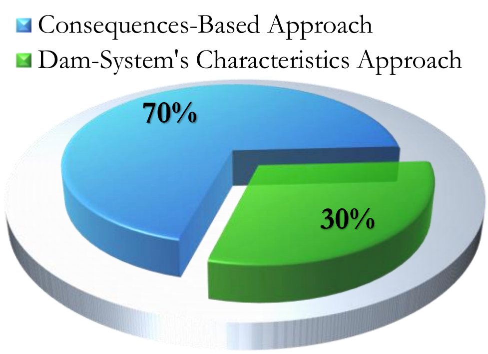

Figure A.3.- Two main approaches followed internationally for dam classification (Based on selected 30 countries from Bulletin 170, ICOLD)

modelling with the application of limited efforts.

On the other hand, given the population density of India, adoption of the categorisation followed by some of these countries (e.g. USA, Canada) would lead to the classification of almost all the dams into the highest category of hazard class – which is impractical.

To address the issue of public safety and security with the due regards it deserves, it is proposed to have four categories – so that optimisation in resource utilisation may be achieved reasonably.

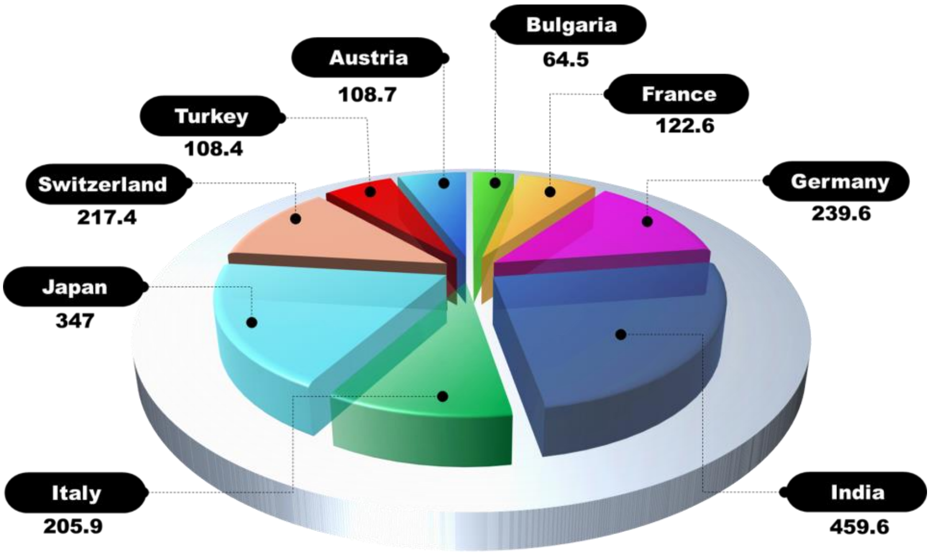

Figure A.4.- Density population (per sq. km) in Countries using Dam-System's Characteristics Approach for Dam Classification (Based on selected 30 countries from Bulletin 170) ICOLD)

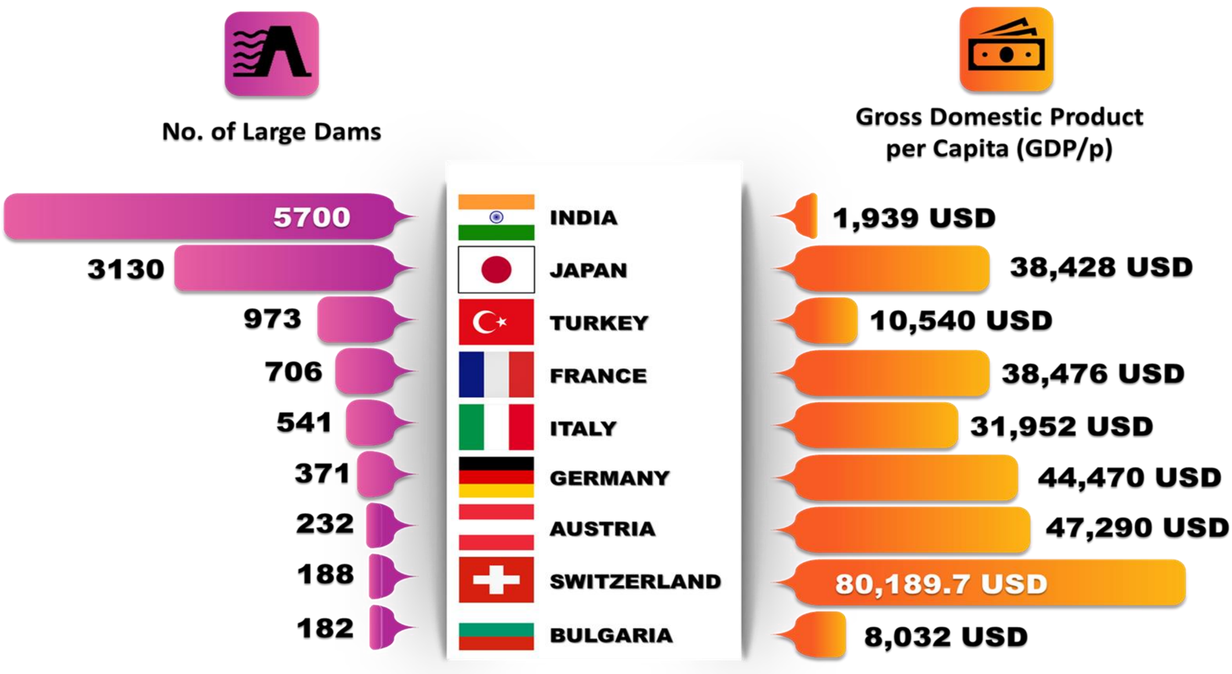

Figure A.5.- No. of Large Dams vs Gross Domestic Product (GDP) in Countries using Dam-System's Characteristics Approach for Dam Classification (Based on selected 30 countries from Bulletin 170)

Table A.12.- International Comparison of the criteria considered to evaluate the potential hazard (based on ICOLD bulletin 170)

Country	System's Characteristics Approach[1]	Consequences-based Approach[2]					
		PLL[3]	PAR[4]	Economic	Social	Environment	Flooded area
Australia			●	●			
Austria	●						
Brazil		●					
Bulgaria	●						
Canada		●		●		●	
Canada-Quebec			●	●			
China				●			
Czech		●	●	●		●	
Finland		●	●			●	
France	●						
Germany	●						
India	●						
Ireland		●					
Italy	●						
Japan	●						
New Zealand		●		●			
Norway			●				
Panama		●		●	●	●	
Poland			●				●
Portugal		●		●			
Romania				●			
Russia				●			
South Africa		●		●			
Spain			●	●	●	●	
Sweden			●	●		●	
Switzerland	●						
Turkey	●						
UK		●	●	●			
USA/FEMA		●		●		●	
USA/USBR		●					

Notes
[1] Consequences of a potential Dam failure are considered implicitly
[2] Consequences of a potential Dam failure are considered explicitly
[3] Potential Loss of Life
[3] Population at Risk

Appendix B. TEMPLATE FOR HAZARD CLASSIFICATION REPORT

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Report on Dam Hazard Potential Classification

Name of Dam

Project Identification Code

Dam Picture

Prepared for ***Dam Owner Name***
Prepared by ***Name***

Date

Revision Number

Revisions of Hazard Potential Classification

Report Date	Reason for Revision	Main changes made	Author
Revision date	*It can be: First Hazard Classification/ Periodic Update / Update on new studies / Other (Specify)*	*Brief description of updated parts within the report*	*Author*

Date of next Hazard Potential periodic update:

Date of Last Complete Report Update + 4-10 years

(see Figure E.S.2 on page 3 of Guideline)

Table of Contents

Executive Summary

Summary of main findings and recommendations.

1. INTRODUCTION

1.1. DAM DESCRIPTION

General description of the dam (typically 1-3 pages), including:

- *Main dam characteristics: dam owner, typology, height, crest length, crest level, Maximum Operation Level, reservoir volume, year of construction, purposes, river, etc.*
- *Location map.*
- *General layout plan.*
- *Cross-section drawings.*
- *Description of outlet works and spillways.*

1.2. AFFECTED AREA DESCRIPTION

General description of the affected district(s), including:

- *Hydraulic floodplain characteristics: basin and river characteristics, average annual flow, rainfall, river slopes, hydraulic regime, average cross-section characteristics*
- *Socio-Economic floodplain characteristics: topography, geography, land use, main district(s), panchayat(s), village(s) affected, population/demography, economic development*
- *Protected Areas*
- *Cultural Heritage.*

2. METHODOLOGY

Brief description of the hydraulic modelling including but not limited to

- *Tier approach used with a brief description of the input data (topography, digital elevation model, bathymetry, population density), and hydraulic modelling approach (one-dimensional, two-dimensional, coupled modelling)*
- *Model (software selection)*
- *Dam breach Scenarios considered*
- *Dam Breach Parameters Justification*
- *Boundaries of the Study Area*
- *Discussion about uncertainties*

Herein the most important aspects of the entire study should be developed in detail: including, but not limited to, model selection, dam breach scenarios, boundaries of the study area, input data, model development and validation process, results, and discussion about uncertainty.

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3. CONSEQUENCES - POINT INDEX CALCULATION (WORKSHEETS)

3.1. CAPITAL VALUE OF THE PROJECT

A.- DAM HEIGHT INDEX (I_{DH})

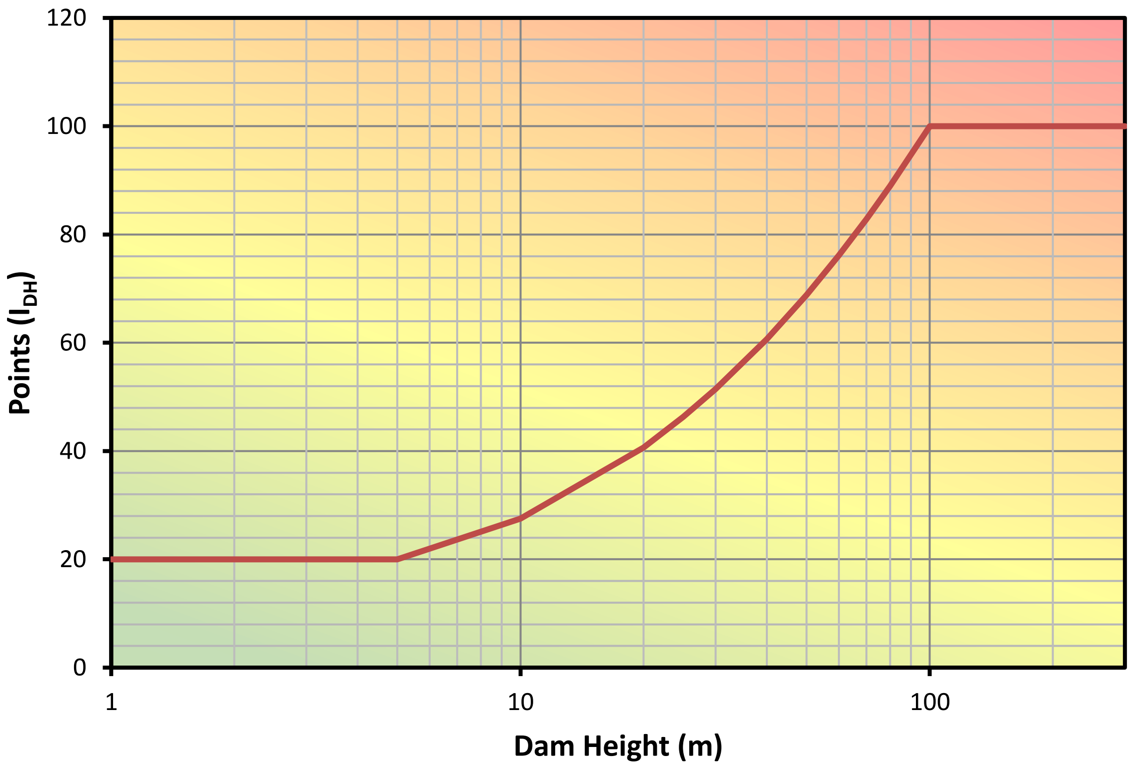
	Dam Height (m)	Rating Points
Maximum Dam Height………………..	________________	____________________
	Total (A) =	**[A]**

$$I_{DH}\begin{cases} 20, (for\ h \leq 5) \\ 15.7 + 1.12 * [LN(h)]^{2.8292}, (for\ 5 < h < 100) \\ 100, (for\ h \geq 100) \end{cases} \quad (1)$$

Where

I_{DH} : Dam height index points, and

h : is the height of the dam in meters



B.- PROJECT BENEFITS INDEX (I_{PB})

Annual Average River Flow at dam site (m³/s): ____________________

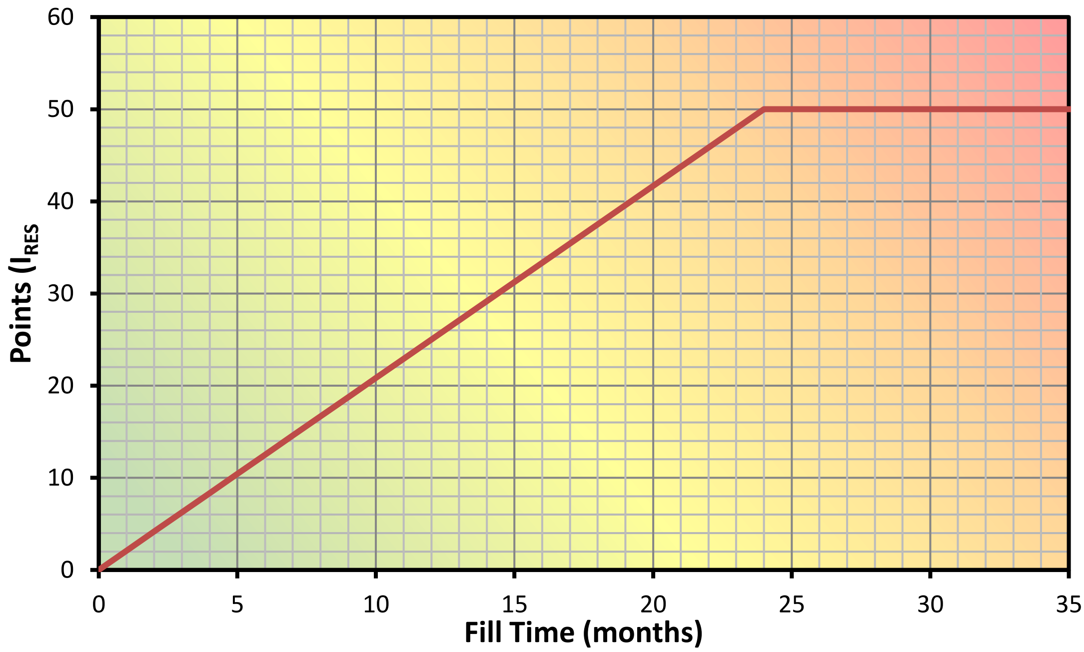
	Volume (Mm3)	Rating Points [1]
Reservoir Volume (Gross Storage in Mm³)	________________	____________________
Reservoir Volume – Water Supply Use (Mm³)	________________	____________________
Reservoir Volume – Industrial Use (Mm³)	________________	____________________
	Sub-Total (Σ [1]) =	**[B1]**

$$T_F = {}^{V}/_{Q} * 0.386 \quad (3)$$

$$I_{RES} \begin{cases} {}^{50}/_{24} * T_F \,, (for\ T_F < 24) \\ 100 \,, (for\ T_F \geq 24) \end{cases} \quad (4)$$

Where,

I_{RES} = Reservoir Content, water supply or industrial use Index
T_F = Time to fill the reservoir in months
V = Volume of the reservoir in Mm³
Q = Average river flow in m³/s



	Area (Ha.) / Installed Capacity (Mw)	Rating Points [1]
Irrigated Land (Ha x 1000) …………..	________________	___________________
Installed Capacity (Mw) ……………..	________________	___________________
Sub-Total (Σ [1]) =		**[B2]**
Total Project Benefits Index (B1+ B2) =		**[B]**
Total Capital Value of Project's Category (A+B) =		___________________

$$I_I \begin{cases} area\,,(for\ area\ < 100) \\ 100\,,(for\ area\ \geq 100) \end{cases} \qquad (5)$$

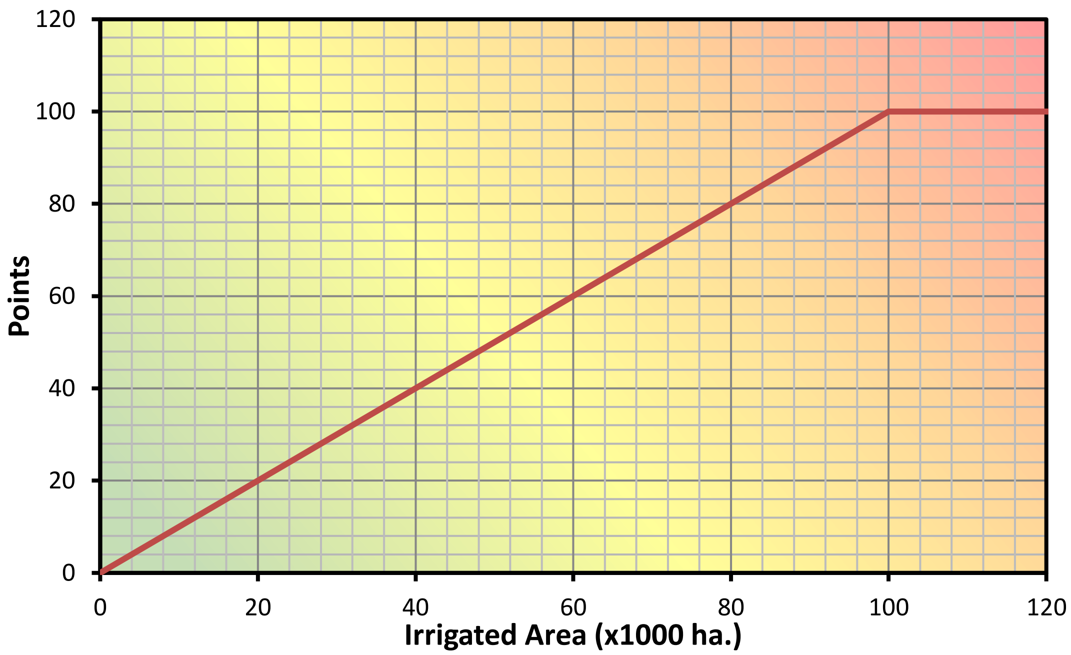
Where,

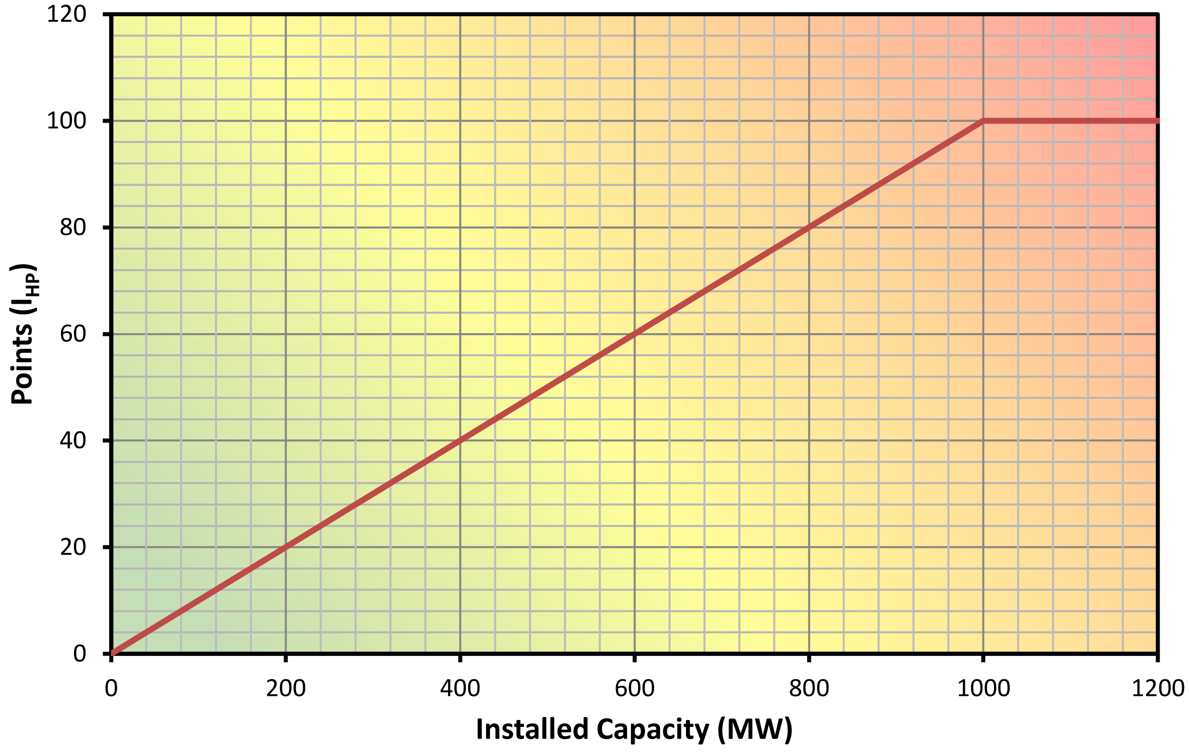
$area$ = irrigated area in 1,000 ha.
I_I = irrigated land index

$$I_{HP} \begin{cases} P/_{10}\,,(for\ P\ < 1000) \\ 100\,,(for\ P\ \geq 1000) \end{cases} \qquad (6)$$

Where,

P = installed capacity in MW.
I_{HP} = Hydropower index





3.2. POTENTIAL FOR LOSS OF LIFE

C.- INCREMENTAL POPULATION AT RISK INDEX (I_{PAR})

Scenario No.1 Description *(e.g. Sunny-day Failure)*: ______________________

Flood Severity Class	Population at Risk (people)		
	No Dam Failure *[1]*	With Dam Failure *[2]*	
H1			
H2			
H3			
H4			
H5			
H6			Incremental Population at Risk (People)
Sub-Total (H3 to H6) =	Σ [1] H3:H6	Σ [2] H3:H6	*PAR 1 (H3:H6) = Σ [2] - Σ [1]*
Total (H1 to H6) =	Σ [1] H1:H6	Σ [2] H1:H6	

Scenario No.2 Description *(e.g. Flood Failure Scenario):* ______________________

Flood Severity Class	Population at Risk (people)		
	No Dam Failure *[1]*	With Dam Failure *[2]*	
H1			
H2			
H3			
H4			
H5			
H6			**Incremental Population at Risk (People)**
Sub-Total (H3 to H6) =	***Σ [1] H3:H6***	***Σ [2] H3:H6***	***PAR 2 (H3:H6) = Σ [2] - Σ [1]***
Total (H1 to H6) =	***Σ [1] H1:H6***	***Σ [2] H1:H6***	

Scenario No.3 Description *(e.g. Gate(s) failure or Large controlled release):* ______________________

____

Flood Severity Class	Population at Risk (people)		
	No Dam Failure *[1]*	With Dam Failure *[2]*	
H1			
H2			
H3			
H4			
H5			
H6			**Incremental Population at Risk (People)**
Sub-Total (H3 to H6) =	***Σ [1] H3:H6***	***Σ [2] H3:H6***	***PAR 3 (H3:H6) = Σ [2] - Σ [1]***
Total (H1 to H6) =	***Σ [1] H1:H6***	***Σ [2] H1:H6***	

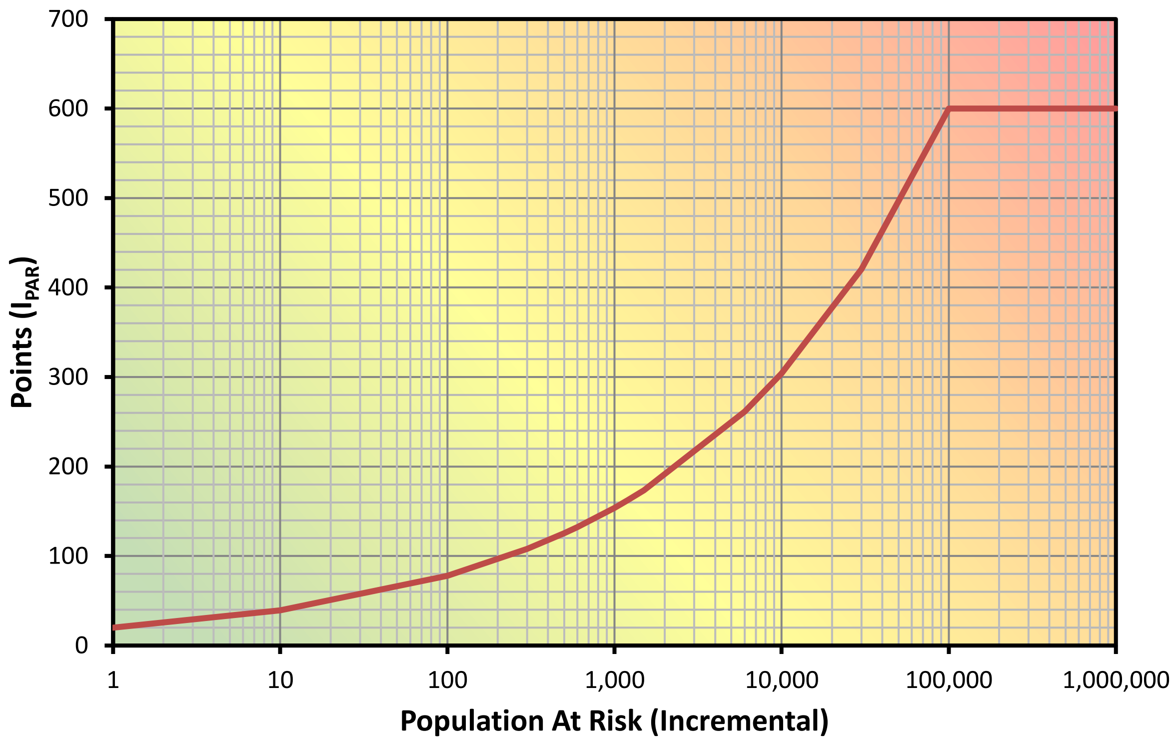
Worst-Case Scenario *(comparison between Scenarios No. 1 to No. 3):* ***max (PAR 1, PAR 2 and PAR 3)***

	No. of People	Rating Points *(See Figure)*
Incremental Population at Risk (PAR)………	***max (PAR)***	
	Sub-Total (C) =	**[C]**

$$I_{PAR}\begin{cases}20 * PAR^{0.2954}, (for\ PAR < 100{,}000)\\ 600\ , (for\ PAR\ \geq 100{,}000)\end{cases} \quad (8)$$

Where,

PAR = incremental population at risk



D.- CRITICAL ARRIVAL TIME INDEX (I_{AT})

Nearest Downstream Settlement *(Village, City's name):* ____________________

Distance to the Dam in Kilometres: ____________________

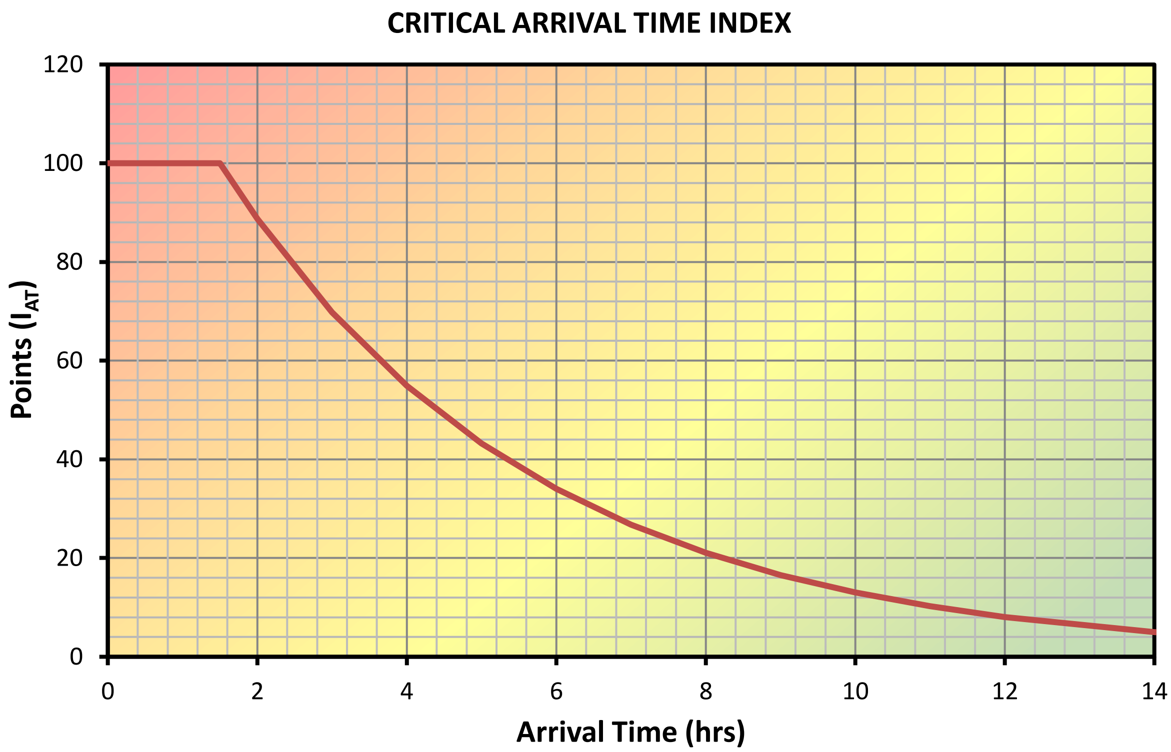
	Arrival Time (hours)	Rating Points *(See Figure)*
Critical Arrival Time (AT)…………………....	________	________
	Sub-Total (D) =	[D]
	Total Potential for Loss of Life's Category (C + D) =	________

$$I_{AT}\begin{cases} 100, (for\ AT \leq 1.5 \text{ hrs}) \\ 143.28 * (0.7868)^{AT}, (for\ 1.5 < AT < 48) \\ 0, (for\ AT \geq 48 \text{ hrs}) \end{cases} \quad (9)$$

Where,

AT = critical arrival time in hours

I_{AT} = critical arrival time index



3.3. POTENTIAL FOR PROPERTY DAMAGE

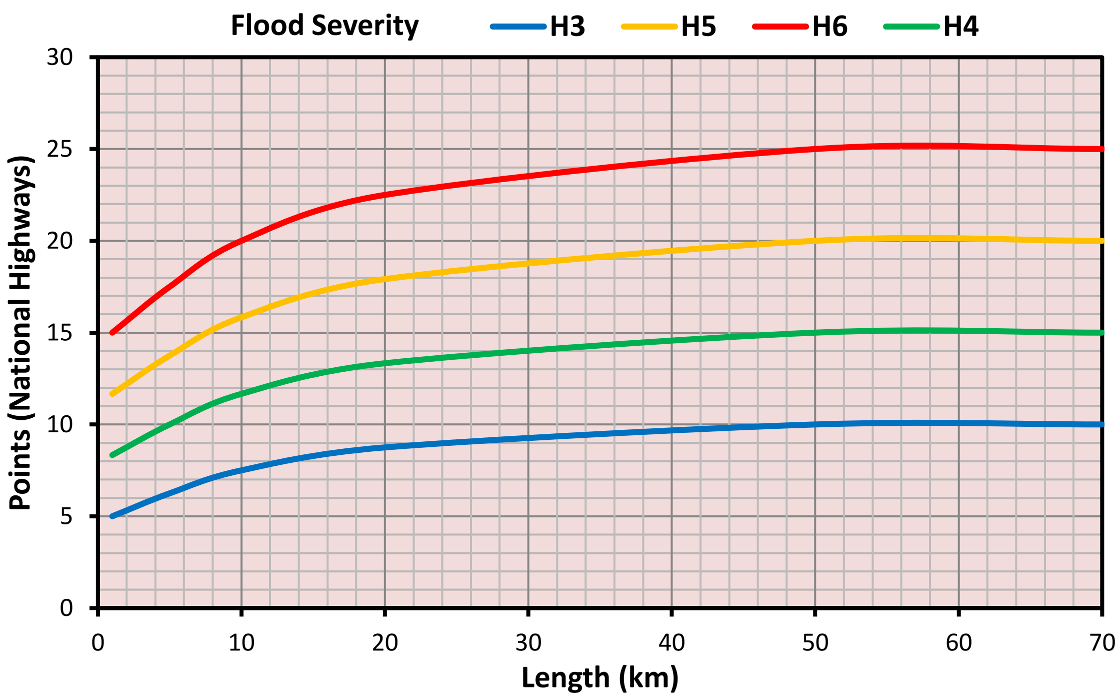
E.- TRANSPORTATION INFRASTRUCTURES

National Highways Affected *(e.g NH54, NH4, etc.)* ______________________

SI.	Affected length (Km) No Dam Failure *[1]*	With Dam Failure *[2]*	Incremental Consequences (Km) *[3] = [2] – [1]*	Rating Points (5 -25 points) *[5] = See Figure*	Weighted Rating Points *[6] = ([3]/[4]) * [5]*
H1				----	----
H2				----	----
H3					
H4					
H5					
H6					

Sub-Total (H3 to H6) = __*[4] = Σ [3]*__ __*[E1] = Σ [6]*__

Total (H1 to H6) = ______________



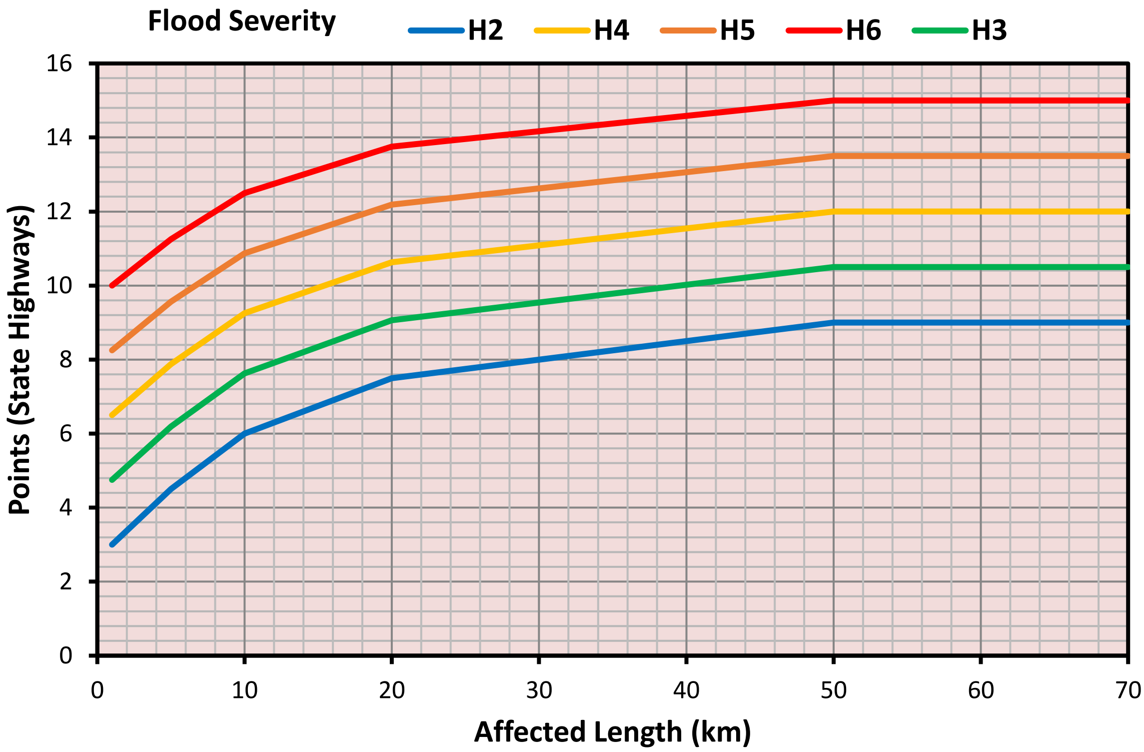
Note: A larger or smaller value may be selected depending on the need for conservatism in protecting the infrastructure that could be damaged

State Highways Affected *(e.g SH24, SH15, etc.)* ______________________________

Flood Severity Class	Affected length (Km) No Dam Failure [1]	Affected length (Km) With Dam Failure [2]	Incremental Consequences (Km) [3] = [2] – [1]	Rating Points (3 -15 points) [5] = See Figure	Weighted Rating Points [6] = ([3]/[4]) * [5]
H1				----	----
H2					
H3					
H4					
H5					
H6					

Sub-Total (H2 to H6) = ___*[4] = Σ [3]*___ ___*[E2] = Σ [6]*___

Total (H1 to H6) = ______________



Note: A larger or smaller value may be selected depending on the need for conservatism in protecting the infrastructure that could be damaged

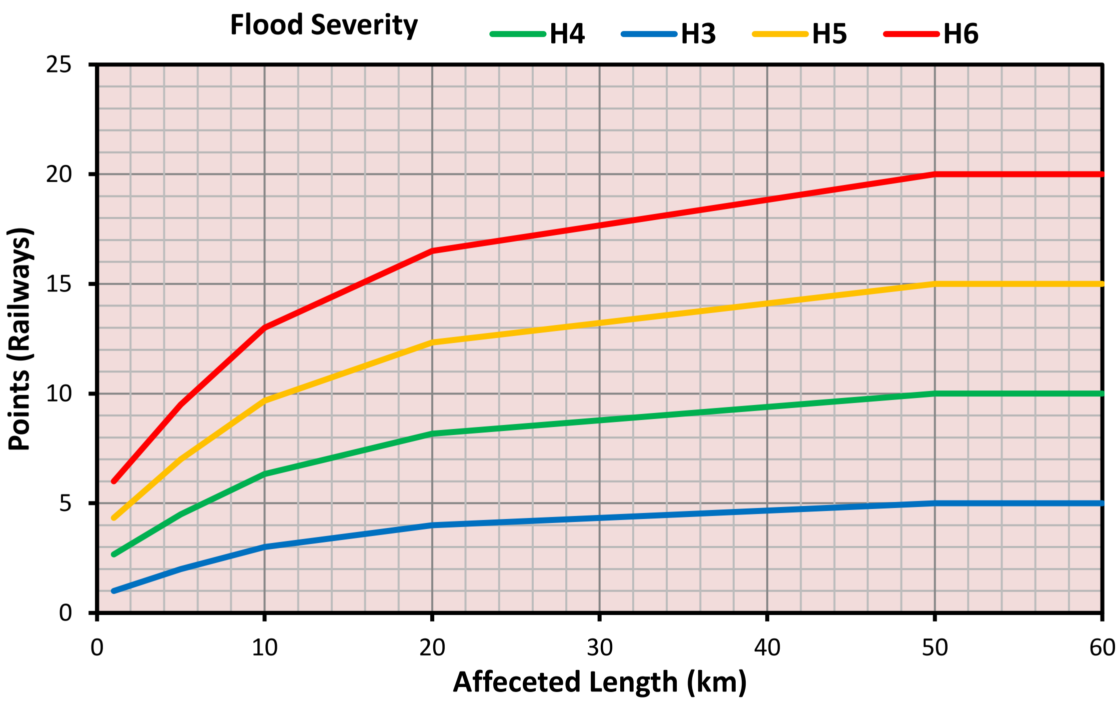
Railways Affected *(e.g Mumbai Rajdhani Express.)* ______________________

Flood Severity Class	Affected length (Km)		Incremental Consequences (Km)	Rating Points (1 -20 points)	Weighted Rating Points
	No Dam Failure *[1]*	With Dam Failure *[2]*	*[3] = [2] – [1]*	*[5] = See Figure*	*[6] = ([3]/[4]) * [5]*
H1				----	----
H2				----	----
H3					
H4					
H5					
H6					

Sub-Total (H3 to H6) = *[4] = Σ [3]* *[E3] = Σ [6]*

Total (H1 to H6) = ____________

Sub-Total Transportation Infrastructures (E1+E2+E3) = [E]



Note: A larger or smaller value may be selected depending on the need for conservatism in protecting the infrastructure that could be damaged

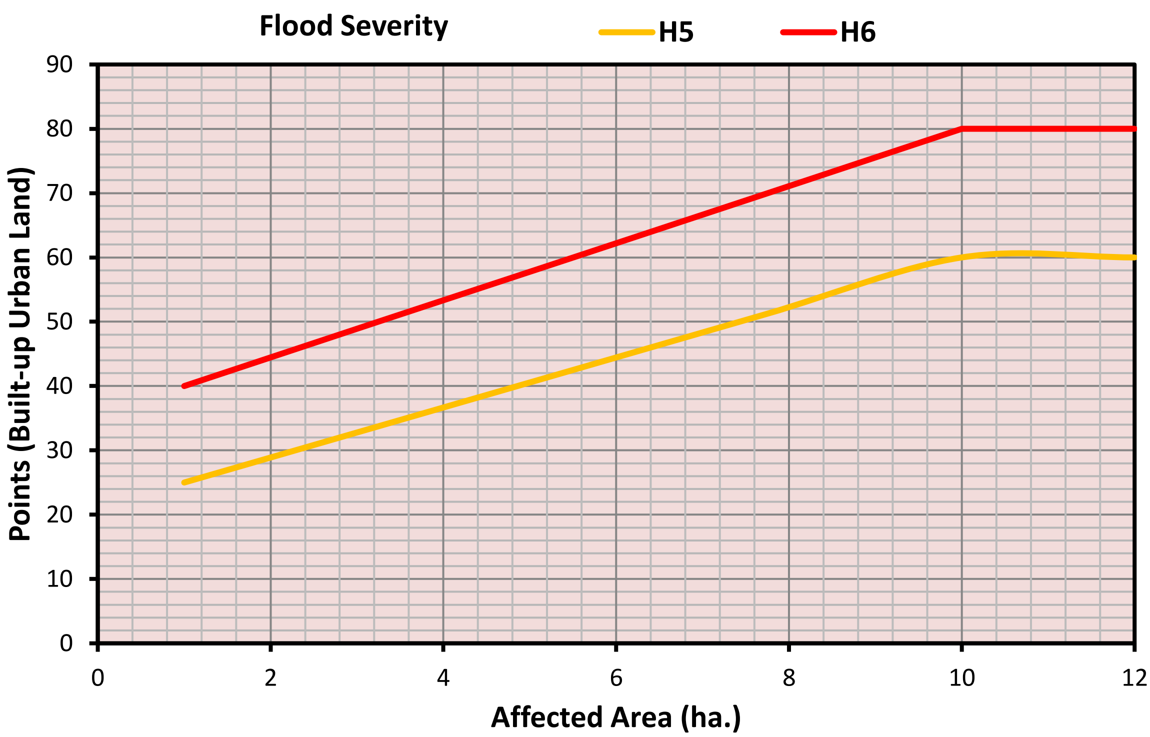
F.- INFRASTRUCTURES BY LANDUSE

Built-Up Urban Areas *(e.g Bhuwaneswar, Cuttack, etc.)* ______________________________

Flood Sever-ity Class	Affected Area (ha.)		Incremental Consequences (ha.)	Rating Points (25 -80 points)	Weighted Rating Points
	No Dam Failure *[1]*	With Dam Failure *[2]*	*[3] = [2] – [1]*	*[5] = See Figure*	*[6] = ([3]/[4]) * [5]*
H1				----	----
H2				----	----
H3				----	----
H4				----	----
H5					
H6					

Sub-Total (H5 to H6) = *[4] = Σ [3]* *[F1] = Σ [6]*

Total (H1 to H6) = ______________



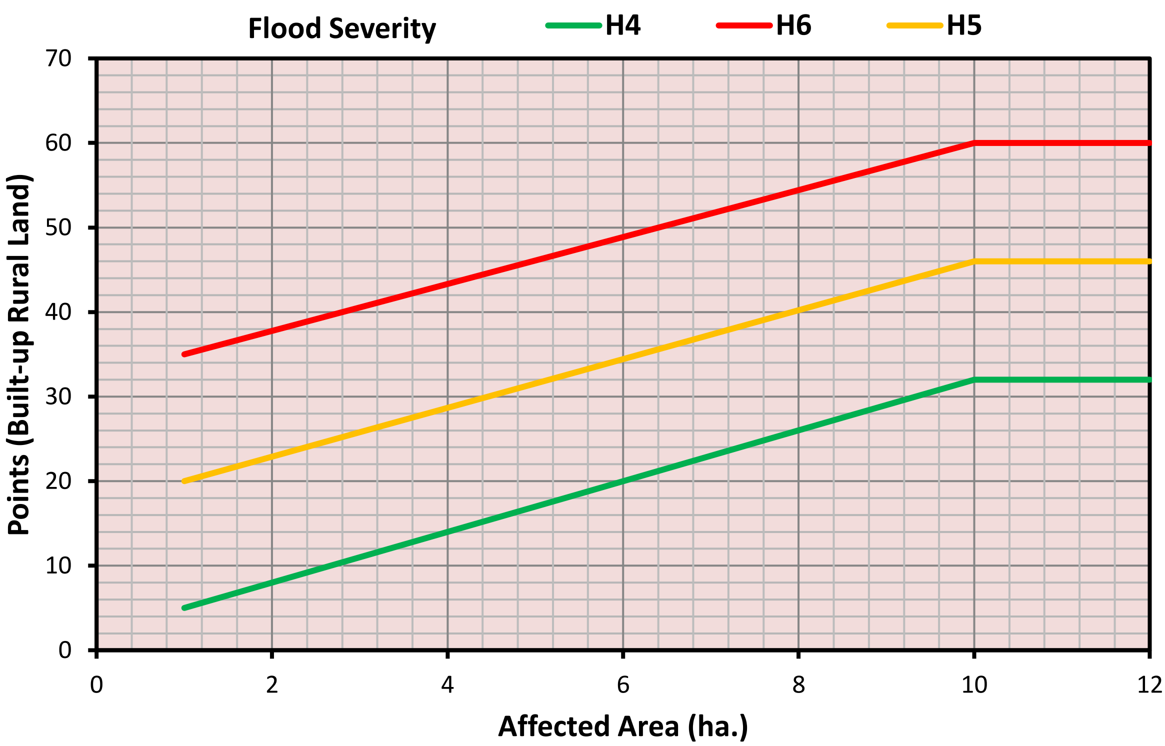
Note: A larger or smaller value may be selected depending on the need for conservatism in protecting the infrastructure that could be damaged

Built-Up Rural Areas *(e.g Balaghat, Lalbarra, etc.)* ______________________________

Flood Severity Class	Affected Area (ha.)		Incremental Consequences (ha.)	Rating Points (5 -60 points)	Weighted Rating Points
	No Dam Failure *[1]*	With Dam Failure *[2]*	*[3] = [2] – [1]*	*[5] = See Figure*	*[6] = ([3]/[4]) * [5]*
H1				----	----
H2				----	----
H3				----	----
H4					
H5					
H6					

Sub-Total (H4 to H6) = *[4] = Σ [3]* *[F2] = Σ [6]*

Total (H1 to H6) = ______________



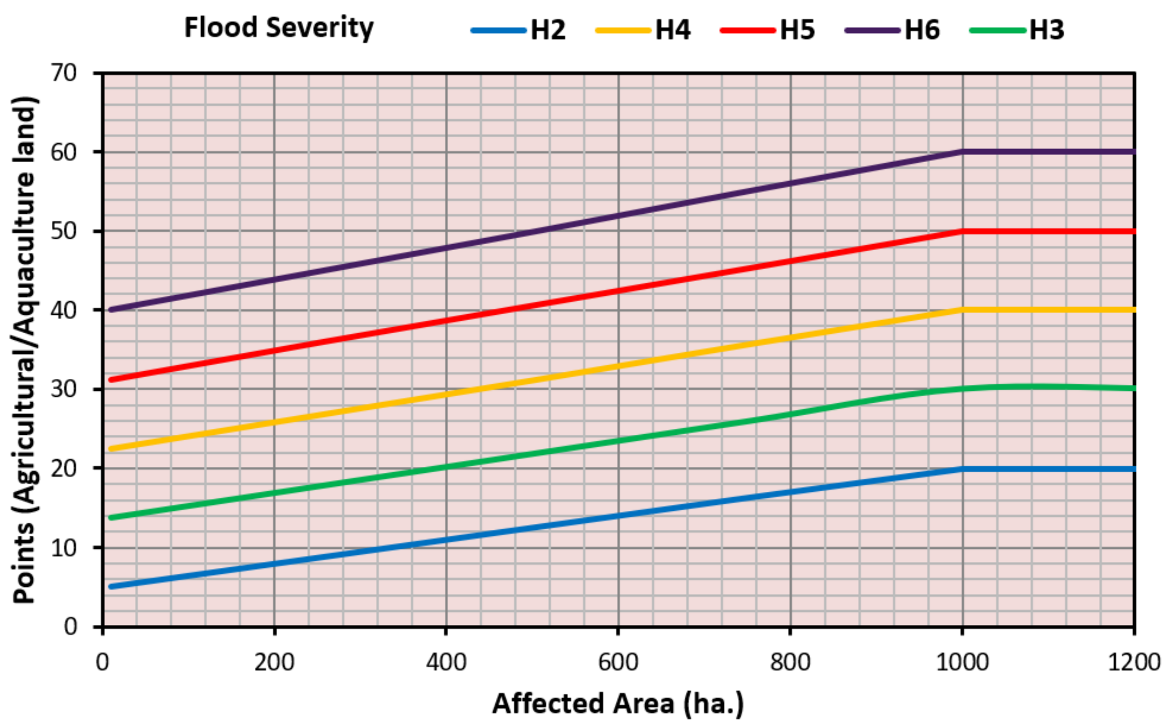
Note: A larger or smaller value may be selected depending on the need for conservatism in protecting the infrastructure that could be damaged

Agriculture / Aquaculture Land Use *(e.g Balaghat, Lalbarra, etc.)* ____________________

Flood Sever-ity Class	Affected Area (ha.)		Incremental Consequences (ha.) *[3] = [2] – [1]*	Rating Points (5 - 60 points) *[5] = See Figure*	Weighted Rating Points *[6] = ([3]/[4]) * [5]*
	No Dam Failure *[1]*	With Dam Failure *[2]*			
H1				----	----
H2					
H3					
H4					
H5					
H6					

Sub-Total (H2 to H6) = *[4] = Σ [3]* *[F3] = Σ [6]*

Total (H1 to H6) = ____________



Note: A larger or smaller value may be selected depending on the need for conservatism in protecting the infrastructure that could be damaged

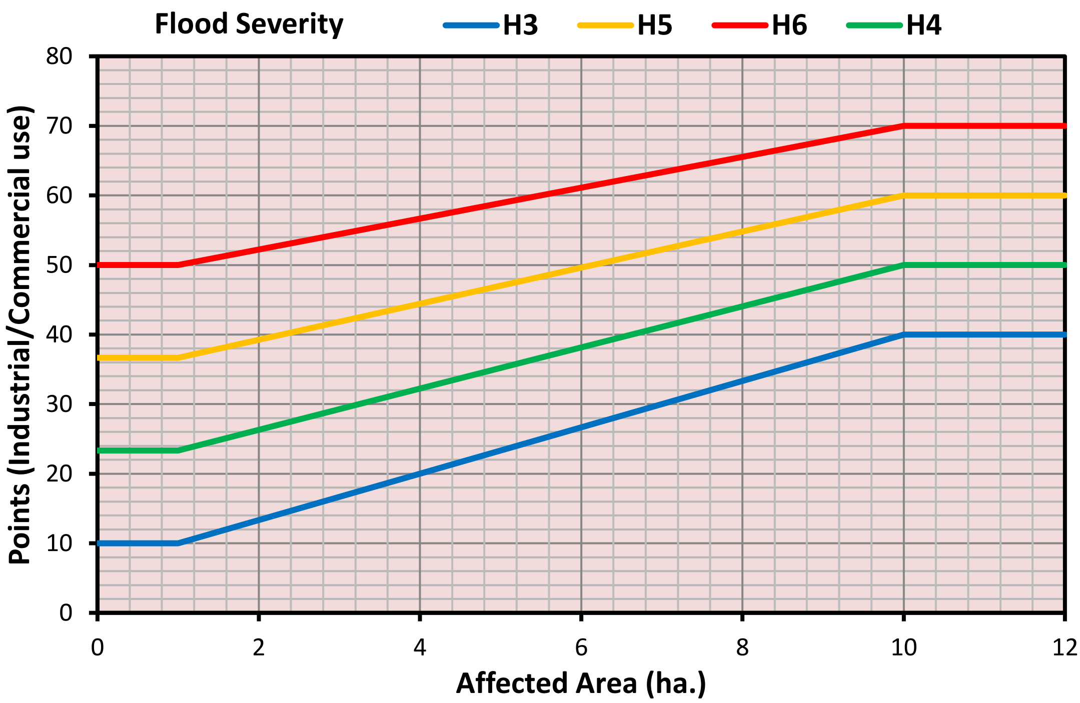
Industrial / Commercial Land Use *(e.g Balaghat, Lalbarra, etc.)* ____________________

Flood Sever-ity Class	Affected Area (ha.)		Incremental Consequences (ha.)	Rating Points (10 - 70 points)	Weighted Rating Points
	No Dam Failure *[1]*	With Dam Failure *[2]*	*[3] = [2] – [1]*	*[5] = See Figure*	*[6] = ([3]/[4]) * [5]*
H1				----	----
H2				----	----
H3					
H4					
H5					
H6					

Sub-Total (H3 to H6) = *[4] = Σ [3]* *[F4] = Σ [6]*

Total (H1 to H6) = ____________

Sub-Total Infrastructures by Land Use (F1+F2+F3 +F4) = **[F]**

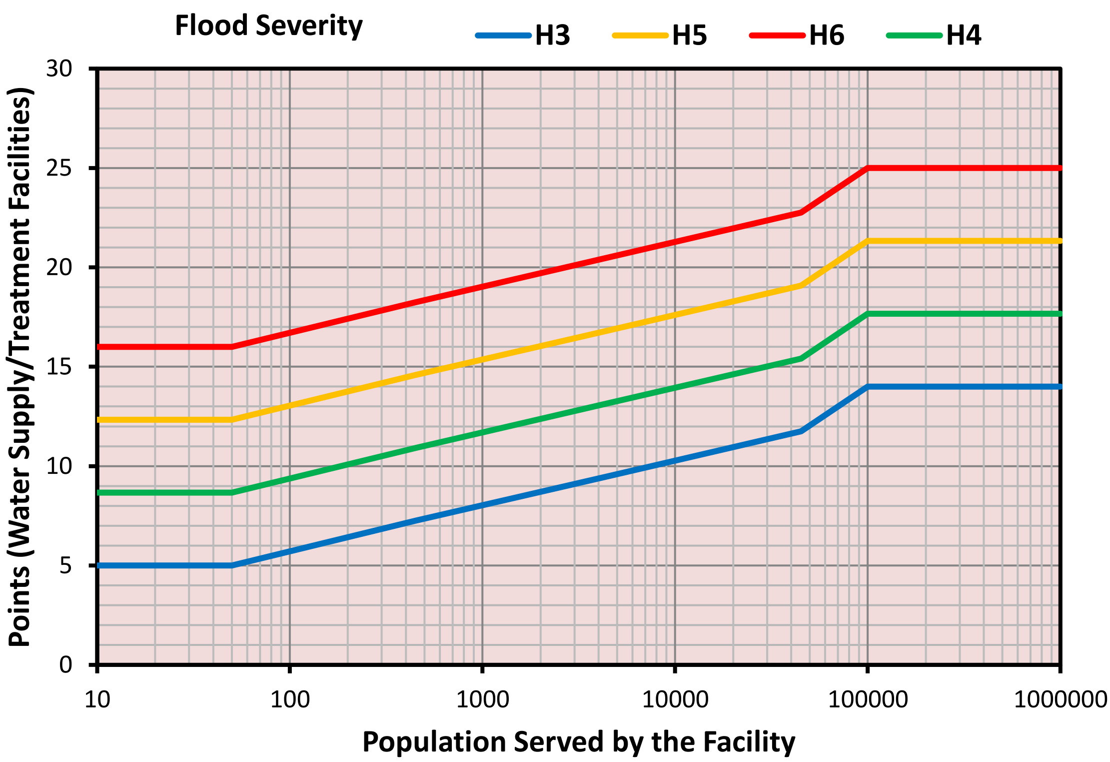


Note: A larger or smaller value may be selected depending on the need for conservatism in protecting the infrastructure that could be damaged

G.- ESSENTIAL SERVICES

Water Supply or Water Treatment Facilities affected *(e.g. Coimbatore Water Supply Plant.)*

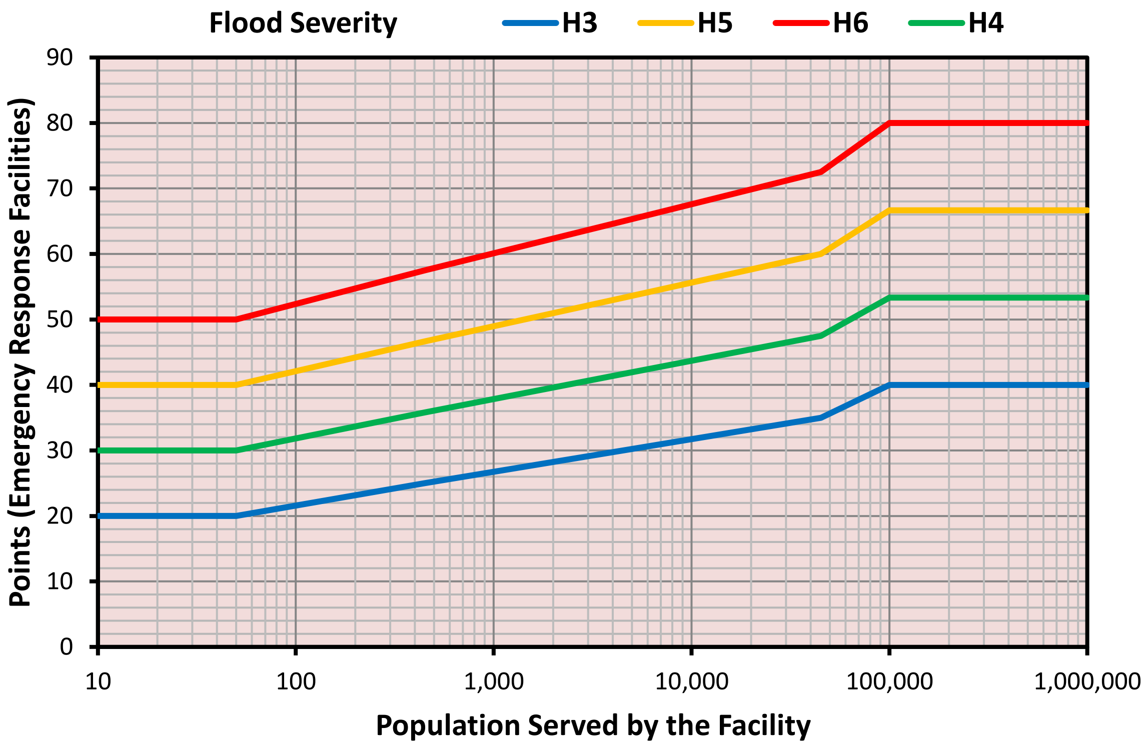
SI.	Facility Name	Flood Severity Class	Rating Points (5 - 25 points) *[1] = See Figure*	Weighted Rating Points *[3] = ([1]/[2]) * [1]*
1				
2				
3				
⋮				
n				
		Total =	*[2] = Σ [1]*	*[G1] = Σ [3]*



Note: A larger or smaller value may be selected depending on the need for conservatism in protecting the infrastructure that could be damaged

Emergency Response Facilities *(e.g. Police/Fire Department Facilities, Hospitals, Relief Camps/Shelters, etc.)*

SI.	Facility Name	Flood Severity Class	Rating Points (20 - 80 points) *[1] = See Figure*	Weighted Rating Points *[3] = ([1]/[2]) * [1]*
1				
2				
3				
⋮				
n				
		Total =	*[2] = Σ [1]*	*[G2] = Σ [3]*



Note: A larger or smaller value may be selected depending on the need for conservatism in protecting the infrastructure that could be damaged

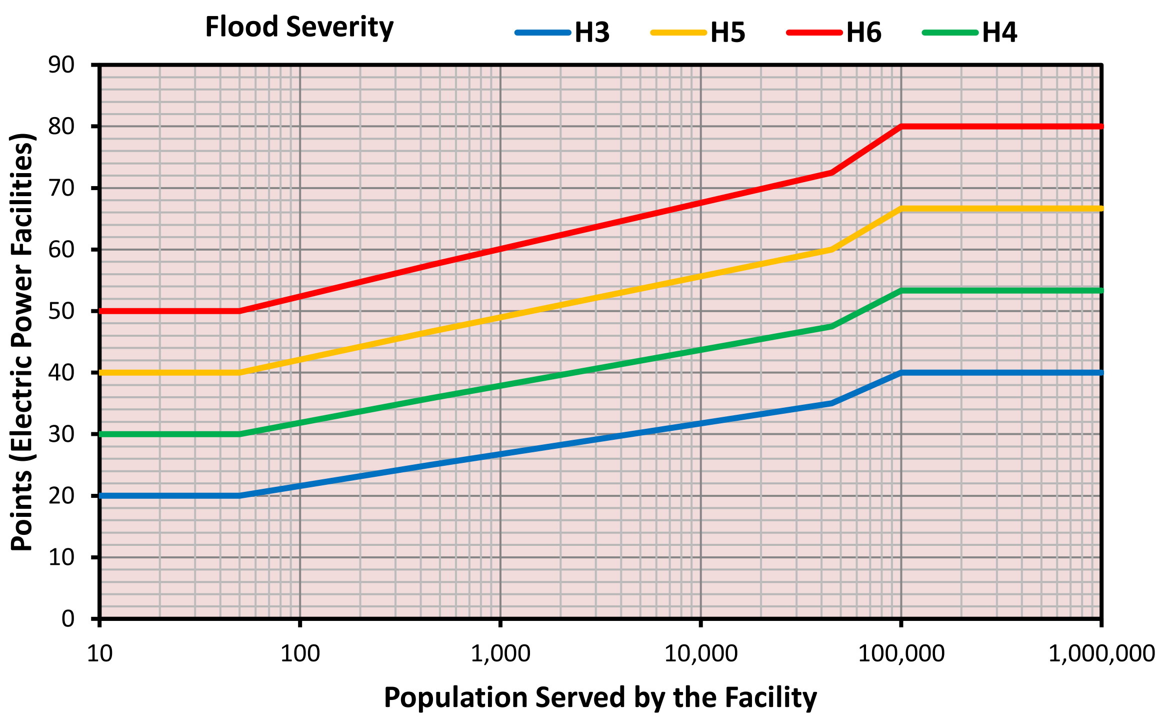
Electric Power Facilities *(e.g. Substation, transmission/distribution towers, etc.)*

SI.	**Facility Name**	**Flood Severity Class**	**Rating Points (20 - 80 points)** *[1] = See Figure*	**Weighted Rating Points** *[3] = ([1]/[2]) * [1]*
1				
2				
3				
⋮				
n				

Total = *[2] = Σ [1]* *[G3]= Σ [3]*

Sub-Total Essential Services (G1+G2+G3) = [G]

Total Potential for Property Damage's Category (E+F+G) = ________________



Note: A larger or smaller value may be selected depending on the need for conservatism in protecting the infrastructure that could be damaged

3.4. Potential for Environmental and Cultural Impact

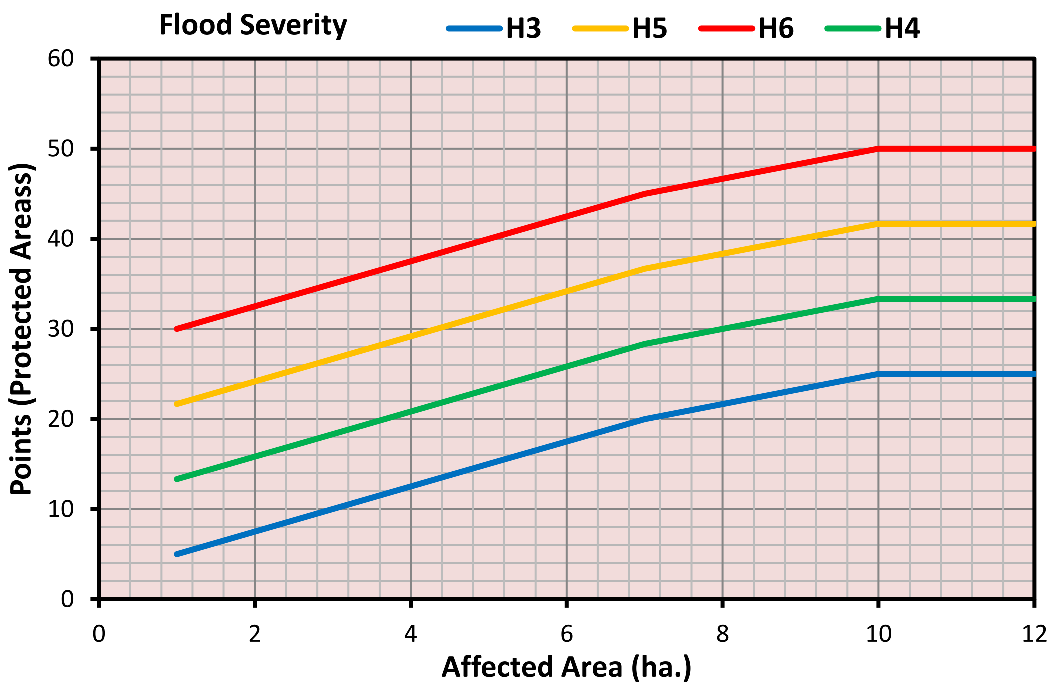
H.- PROTECTED AREAS INDEX (I_{PA})

Protected Areas *(e.g Wildlife Sanctuaries, Community Reserve, etc.)* ________________

Flood Sever-ity Class	Affected Area (ha.)		Incremental Consequences (ha.)	Rating Points (5 - 50 points)	Weighted Rating Points
	No Dam Failure *[1]*	With Dam Failure *[2]*	*[3] = [2] – [1]*	*[5] = See Figure*	*[6] = ([3]/[4]) * [5]*
H1				----	----
H2				----	----
H3					
H4					
H5					
H6					

Sub-Total (H3 to H6) = *[4] = Σ [3]* *[H] = Σ [6]*

Total (H1 to H6) = ______________



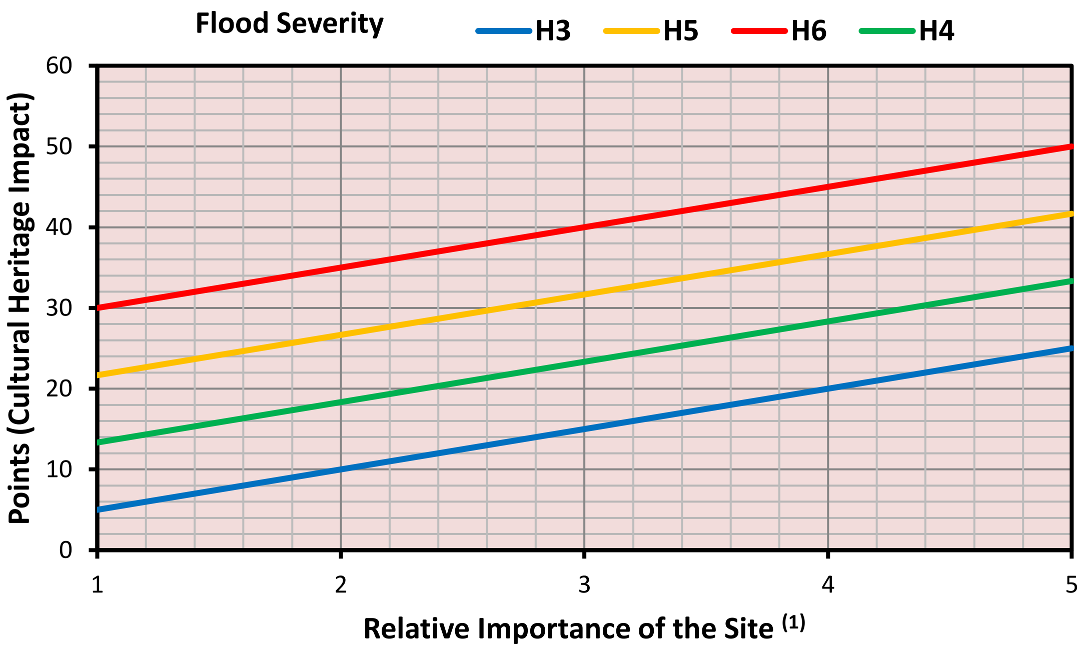
Note: A larger or smaller value may be selected depending on the need for conservatism in protecting the infrastructure that could be damaged

I.- CULTURAL HERITAGE INDEX (I_{CH})

Cultural Heritage Sites Affected *(e.g. Temples, Monuments, Tombs, Caves, etc.)*

SI.	Site Name	Flood Severity Class	Rating Points (5 - 70 points) *[1] = See Figure*	Weighted Rating Points *[3] = ([1]/[2]) * [1]*
1				
2				
3				
⋮				
n				
		Total =	*[2] = Σ [1]*	*[I]= Σ [3]*

Total Environmental and Cultural Impact's Category (H+ I) = ________________

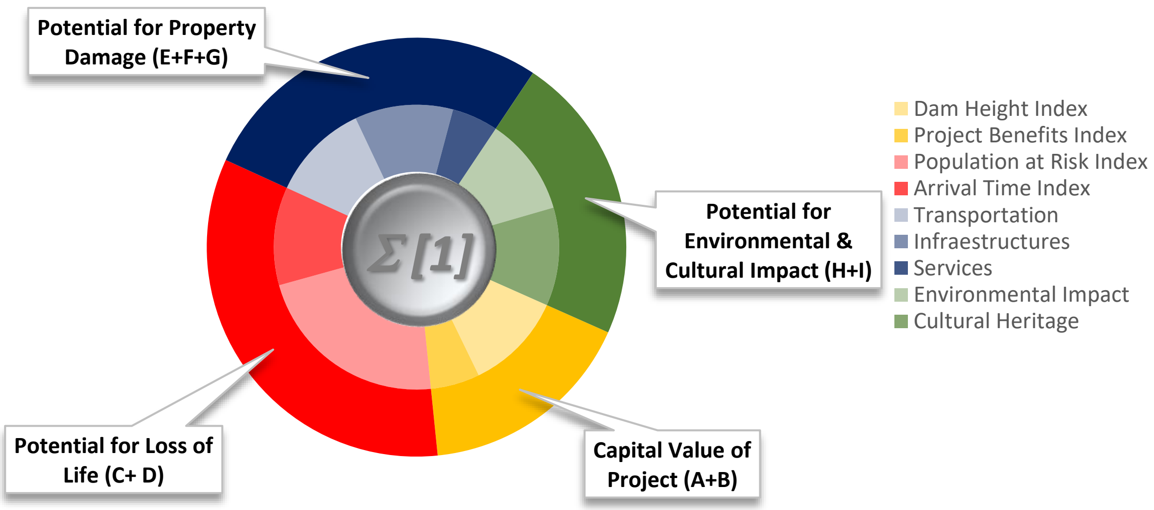


(1) Relative Importance to the broad range of sites within the region. An Example to decide the relative importance may be as follows:

Relative Importance				
1 *Strongly Not Important*	2 *Not Important*	3 *Undecided*	4 *Important*	5 *Strongly Important (UNESCO Site)*

4. Potential Hazard Classification

Consequences Category	Indicator Parameter	Consequences Rating Points *[1]*	Key Remarks
Capital Value of Project	Dam Height (I_{DH})	*[A]*	*(e.g. Dam Project contributes to the xx% of the irrigation/water supply/ generation of the City/District/State.)*
	Project Benefits (I_{PB})	*[B]*	
Potential for Loss of Life	Population at Risk	*[C]*	*{e.g. Total population at risk is concentrated in the main villages/cities/Districts namely [Village/City/District Name]and [Village/City/District Name]. Loss of life is expected even during the worst-case scenario of emergency management}*
	Critical Arrival Time	*[D]*	
Potential for Property Damage	Transportation	*[E]*	*{e.g. Notable agriculture and commercial development in the affected area, especially in the [District's name] District}*
	Infrastructure Damaged	*[F]*	
	Services Disrupted	*[G]*	
Potential for Environmental impact	Environmental Impact	*[H]*	*{e.g. Minimal incremental damage. Short-Term or reversible impact is expected (less than 2 years)}*
	Cultural Heritage	*[I]*	
Total Potential Consequences Index (P_{CI}) =		*Σ[1]*	
Potential Hazard Class =			*{ e.g. Class IV}*



5. Conclusions and Recommendations

Main conclusions obtained from the hazard classification process.

- *Summary of Hazard Classification outcomes.*
- *Summary of recommendations regarding Hazard Classification process (e.g. additional studies or input data required, need of a risk assessment on an urgent basis, etc.)*
- *Summary of potential implications of the hazard classification in the dam project*
- *Other conclusions obtained from hazard classification results.*

6. APPENDIXES

Include support material to justify the consequences index calculation.

- *Maps with labels, legend and coordinates related with each hazard indicator (i.e. Population at Risk, Infrastructure damage by land use, environmental impact, etc.) .*
- *Tables*
- *Figures*
- *Screenshots*
- *Documents for justification*

Appendix C. CASE STUDY. HAZARD CLASSIFICATION FOR MASKINALLA DAM (KARNATAKA)

Disclaimer: The following Case Study was developed with the limited information available in the public domain and the salient features available in the Central Project Management Unit of DRIP project. Therefore, the report presented herein along with the results obtained are meant to provide an illustrative example of the hazard potential classification procedure and are not intended to replace the actual hazard classification report and corresponding conclusions of the specified dam.

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Report on Dam Hazard Potential Classification

Maski Nala Dam

Project KA06MH0209

Prepared for: ***Karnataka Water Resources Department***
Prepared by: ***Central Project Management Unit (DRIP)***

April 2020

Version No. 1.0

Revisions of Hazard Potential Classification

Report Date	Reason for Revision	Main changes made	Author
04/2020	First Hazard Classification Report	Hazard Potential Classification done by Central Project Management Unit (DRIP Project) based on a Tier-I dam break analysis	D. Gonzalez (CPMU Consultant)

Date of next Hazard Potential periodic update: 04/2021 (*Tier-II / III analysis is recommended within one year*)

Table of Contents

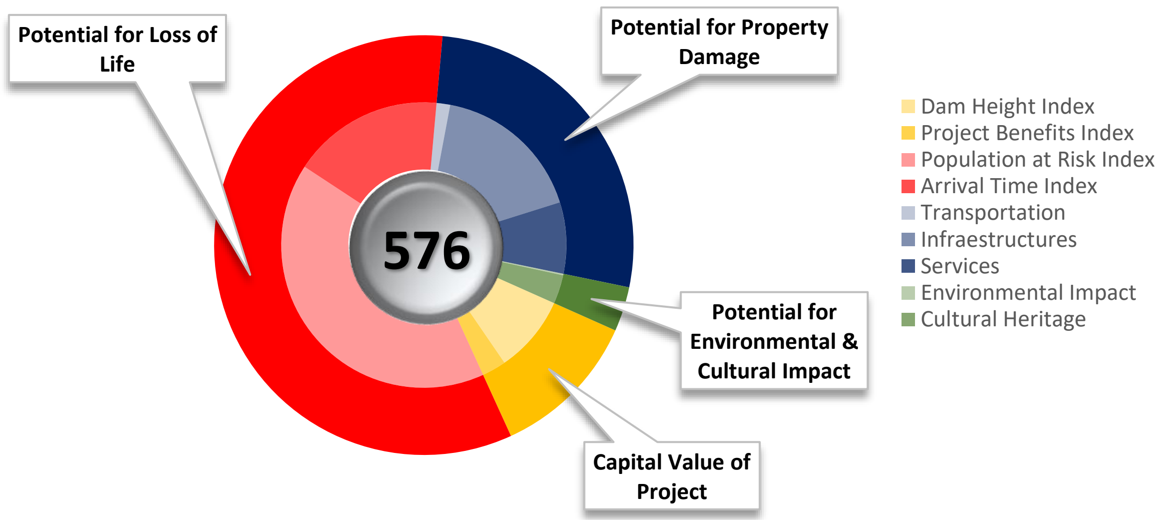
Executive Summary

This Hazard Potential Classification Report is for Maski Nala Dam, which is one of the 22 dams under DRIP in the state Karnataka. The Dam Safety Review Panel (DSRP) inspected the dam in September 2015 and recommended both structural & non-structural measures to be taken up by the dam authorities. Non-structural measures included review of design flood, reservoir siltation surveys; dam stability analysis and preparation of EAP and O&M manual.

As part of the non-structural measures, a hazard potential classification is necessary to provide dam owners, dam engineers and other professionals with a simple, concise, adaptable and reliable approach to identify those projects whose failure or disruption could potentially lead to most severe consequences. This will lead to an improvement in the emergency preparedness and implementation of further risk-informed dam safety management programmes.

As per *Guidelines for Classifying the Hazard Potential of Dams* published by CWC, a first appraisal level analysis has been utilised (tier-I) for the hazard potential Classification of Maskinala Dam; as a result, Maskinala has been classified as a Class III dam with a potential consequences index of 576. The most important parameter contributing to the hazard classification is the potential for loss of life, which represents 58% of the total index. Major population at risk is concentrated in Maski and Balaganur villages in Raichur District and the potential for loss of life is highly dependent on the adequacy of warning and rescue operations.

Since the overall consequences index is located near the threshold between Class III and IV of Hazard Categories (600 points), it is recommended to refine the estimation using a Tier-II or Tier-III analysis, especially during the population at risk assessment.



1. Introduction

1.1. Dam description

Maski Nala dam is situated at Latitude 16° 00' 40" North and Longitude 76° 33' 30" East, in the village area of Maraladinni (Then in Lingasugur Taluk) Maski taluk of Raichur district. See location and vicinity map in Figure 1 below.

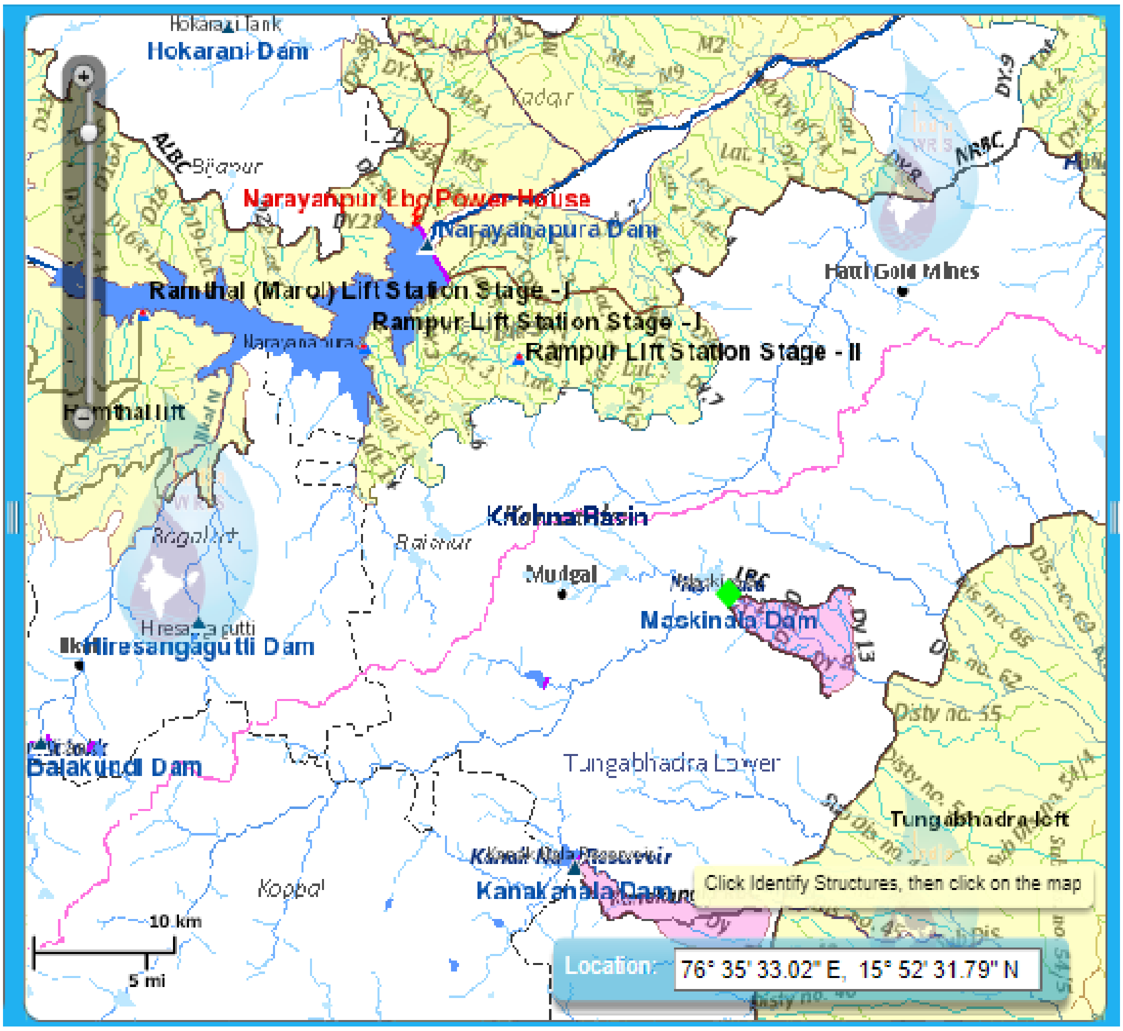


Figure C-1. Krishna Basin Map

The main design features and components of Maski Nala Dam are as follows:

a. Components: The dam consists of a spillway portion for a length of 57.00m (From Ch.341.50 Mtrs. to 398.50 Mtrs) in the centre of the Nala gorge, with Earthen Dam on either side. The earthen dam of 265.30 m (Ch. 76.20 m to Ch. 341.50 m) on the left flank, and 491.50 (Ch.398.50 m to Ch.890.00 m) on the right flank. The total length of the dam including all sections is 813.80 m.

b. Earthen Dam: The earthen dam has been designed as Zonal section comprising of hearting and casing materials. It has a maximum height of 23.74 m and top width of 3.66 M at RL 474.880 M. This gives a freeboard of 2.76 M. For earthen dam portion, necessary cut off trench has been provided to a depth of 0.50 H or 0.60 M. in which even is earlier.

Also, 1.40 M thick inclined filter is provided to keep the phreatic line well within the section. 1.40 M thick longitudinal drain, cross drain and toe drains are also provided. Lead of the seepage water 2.00 M below rock toe on the downstream side 0.45 M thick revetment over 0.45 M thick filter has also been provided. On left flank from Ch.210.00 M to 300.00 M and right flank from Ch.420.00 M to 570.00 M, an impervious blanket of 1.50 M thick has been provided to a width of 4 h to 5 h. Hearting of the dam is provided with the impervious material from a borrow area. The hearting section provided has a top width of 2.44 M at RL 472.620, i.e. 0.50 M above M.W.L. 472.120 with side slope 0.50:1.

c. Spillway Dam Section: The Concrete spillway of length 57 M constructed in the gorge portion from Ch.341.50 M to 398.50 M. with 4 Nos of radial crest gates of size 12 m X 8.50 M to surplus a capacity of 2590 cumecs (91500 Cusecs). At the toe of the spillway, hydraulic jump type horizontal stilling basin with chute blocks, baffle blocks and dentate end sills etc., provided for the purpose of energy dissipation. At the junction of earthen dam and spill-way, wing walls are provided on the U/S side and training walls on the D/S side with key wall and abutment black.

d. Irrigation Sluices: Two (2) irrigation sluices one on left side and another on right side are provided. The irrigation sluice consists are one vent of size 1.00 X 0.80 M box type. A central well with the provision of an emergency gate and a main gate is provided on U/S portion of the sluice barrel for regulating flow through the sluice. Sluice gates operated manually for the sluices release water for the canals.

Table 1 Salient Features of Maski Nala Dam

Sl. No	Items	Details
	A. General	
1	Location of Dam	On Maskinal near Maraladinni village in Maski Taluk (then in Lingasugur Taluk) of Raichur district at: Latitude 16° 00' 40" N Longitude 76° 33' 30" E
2	Means of Access	The site about 1.00 Km from Maraladinni village which is about 14 miles from Lingasugur. And 15.00 KMs from Maski. The dam site is approachable by a road taking off from mile No. 10/6 of Lingasugur – Maski – Sindhanur road. (NH 150A)
	B. Geophysical Features	
1	Catchment area	800 Sq.Km. (309.00 Miles)
2	Nature of catchment	Average.
3	Climate	Moderate.
4	Annual mean temperature	Varies from 63.90°F (in winter) to 103.70°F (in Summer)
5	Mean annual precipitation	Varying from 18" to 20"
6	Net yield Dam site at 75 % dependability	34.66 M cum (1223 M. cft.)

7	Silt charge per year	1.926 Acre ft/sq.mile
8	Geological features at dam site	Metamorphic terrain with pink granite, gneisis, hornblende, schist and quartzite.
	C. Technical Details of Dam	
1	Gross Storage Capacity	14.04 Mcum (0.50 TMC)
2	Dead Storage	2.42 M.cum (0.10 TMC)
3	Lowest Foundation Level (El.)	445.00 m (1456 ft)
4	Lowest River Bed Level (El.)	452.66 m
4.a	Sill of Irrigation Sluice (El.)	463.30 m
5	Dead Storage Level at MDDL (El.)	463.30 m
6	Full Reservoir Level (FRL) (El.)	472.12 m
7	Maximum Water Level (MWL) (El.)	472.12 m
8	Crest level (El.)	463.62 m
9	Top Level of Dam (El.)	474.88 m Earthen Dam
10	Maximum area of water spread	172.80 Ha (1.728 Sq.Km)
11	Length of dam	813.80 m
12	Maximum height of dam above the lowest foundation level	29.88 m
13	Height of dam above the lowest River Bed Level	23.74 m
14	Top width of dam	3.66 M
15	Designed flood intensity	2950 cumec (91500 cusecs)
16	No. & size of spillway crest gates	4 Nos. of 12 M x 8.50 M gates Radial Type
17	No. and dimensions of irrigation sluice gates	2 Nos. of 1.00 m x 0.80 m Box type vertical lift
	D. Details of submergence	
1	Total area of submergence (Gross)	142.00 Ha
2	Villages submerge	Nil
3	Population affected	Nil
4	Road	Village road

1.2. AFFECTED AREA DESCRIPTION

Basin and River Characteristics

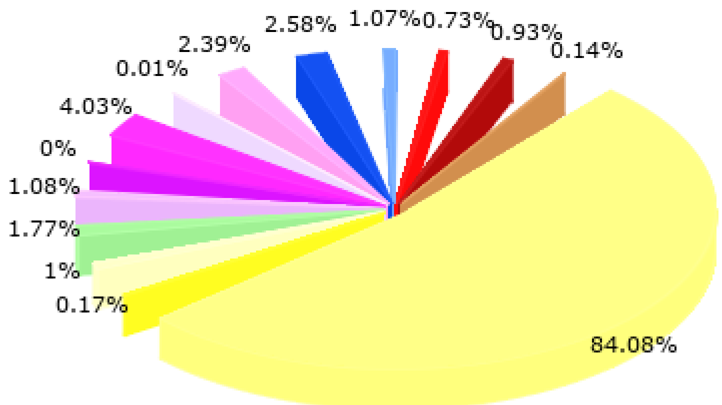
The Maskinala stream which flows in Koppal and Raichur district rises in the hilly region between Kushtagi and Gajendragada, and between Kushtagi and Yalburga at the height of about 685.80 m (2250 Ft.) above mean sea level. The river is a seasonal one. It is a tributary to river Tungabhadra. Since the Maskinala originates in the Kushtagi taluka of (Then Raichur) Koppal district and joins the Tungabhadra river in Manvi taluk of Raichur district, therefore no interstate problems arise. However, since this valley forms a small portion of the Krishna basin (Tungabhadra sub-basin) the water proposed to be utilized will be part of the total water allotted for utilization in the Karnataka state from the Krishna basin. i.e., an allocation made for Maski Nala Project is 22.08 M.Cum (0.78 TMC).

Rainfall

The region around Lingsugur gets the least amount of rainfall in the district while towards the south as well as the east, rainfall increases. During the south-west monsoon months, viz., June to September, the district received about 71% of the annual rainfall, September being the month with the highest rainfall. In the post-monsoon months of October and November also, the district receives some rain. The variations in the annual rainfall from year to year are large, as is the case in the neighbouring districts.

Demographics and Land Use

According to the 2011 census Raichur district has a population of 1,928,812. This gives it a ranking of 246th in India (out of a total of 640). The district has a population density of 228 inhabitants per square kilometre (590/sq mi). Its population growth rate over the decade 2001-2011 was 15.27%. Raichur has a sex ratio of 992 females for every 1000 males, and a literacy rate of 60.46%.



LULC Class	Area (Sq.Km)	LULC Class	Area (Sq.Km)
Builtup,Urban	49.56	Builtup,Rural	63.7
Builtup,Mining	9.79	Agriculture,Crop land	5741.19
Agriculture,Plantation	11.42	Agriculture,Fallow	68.16
Forest,Scrub Forest	121.12	Barren/unculturable/ Wastelands, Salt Affected land	73.86
Barren/unculturable/ Wastelands, Gullied/Ravinous Land	0.21	Barren/unculturable/ Wastelands, Scrub land	275.47
Barren/unculturable/ Wastelands, Sandy area	0.47	Barren/unculturable/ Wastelands, Barren rocky	163.44
Wetlands/Water Bodies, River/Stream/canals	176.26	Wetlands/Water Bodies, Reservoir/Lakes/Ponds	73.35
Total			**6828**

Figure C-2. Land Use Information (2015-16) for Raichur District. (Source: Bhuvan, NRSC)

Socio-Economic Development

The Raichur district's gross domestic product (GDP) contributes around 1.74% to the total GSDP of Karnataka (State and District Domestic Product of Karnataka 2012-13). Main economic activities are agriculture, industry and services

Description	INR Crore	Contribution (%)
Agriculture and Allied (animal husbandry, forestry, fishing)	*1,321*	*25.3* (1)
Industry (manufacturing, construction, mining)	*1,424*	*27.3* (1)
Services (Real State, Hotels and Restaurants, banking and legal services)	*2,466*	*47.2* (1)
Total District GDP	*5,215*	*1.74* (2)

(1) *Contribution to the District GDP*

(2) *Contribution to the State GDP*

Raichur District is also known as the "Rice bowl" of India since 438,045 ha. of land is used for the cultivation of paddy. Within the major crops produced we can find cereals (Paddy, bajra, sorghum), pulses (red gram, horse gram, cowpea), oilseeds (sunflower, groundnut, castor, sesame), vegetables (Brinjal, chilli, cucumber, gourds, leafy vegetables), fruits (sweet lime, mango, pomegranates, papaya).

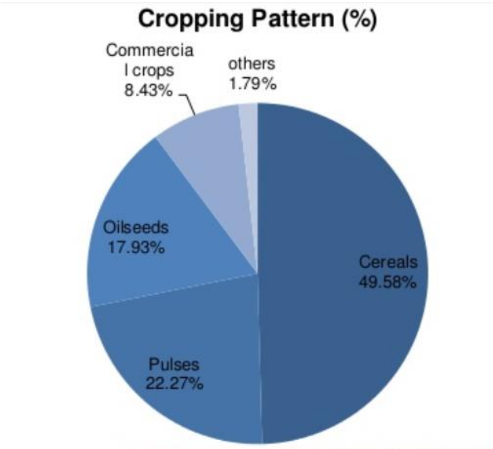


Figure C-3.- Cropping Patterns Raichur District

Table 2.- Private Sector Healthcare Facilities (Raichur District)

Healthcare Facilities	No.
Primary Health centres	53
Community Health Centres & PHCs	52

Table 3.- Public Sector Healthcare Facilities (Raichur District)

Healthcare Facilities	No.
Indian System of Medicine Hospital	21
Government Hospitals	64

Protected Areas

Maski is a village located downstream of Maski Nala dam, and it is considered an archaeological site in the Raichur district. One of the most important sites in Maski is a minor rock edict of Emperor Ashoka discovered by C. Beadon in 1915. It was the first edict of Emperor Ashoka that contained the name Ashoka in it instead of the earlier edicts that referred him as *Devanampiye piyadasi*.

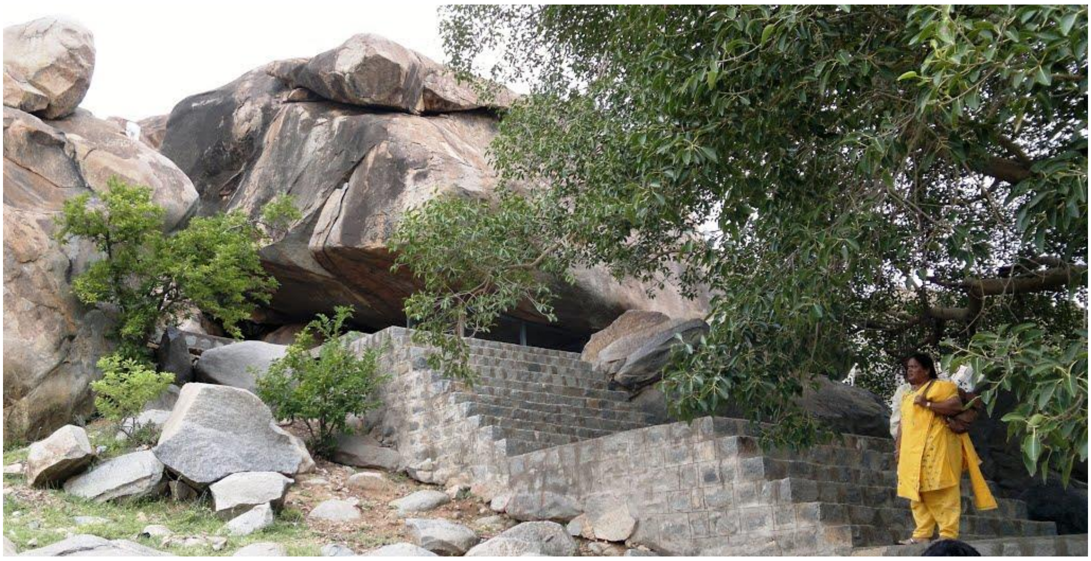


Figure C-4. Ashokan Minor Rock Edict at Maski, Raichur District (Source: Mapio.net)

2. METHODOLOGY

Tiered Approach

Dam Hazard classification process described in this document is based on a Tier-I analysis as specified in the *"Guideline for Classifying the Hazard Potential of Dams"* (CWC, 2020). A fully two-dimensional depth average hydraulic model was developed using a low-resolution digital elevation model.

Dam Breach Floods Scenarios

Inundation maps have been prepared for the following two causes of flooding:

1. A dam failure caused by overtopping from the inflow design flood leading to breaching and uncontrolled release of impounded water.
2. A failure with the reservoir at full supply level (often called a "sunny-day failure") leading to breaching and uncontrolled release of impounded water.

Dam failure floods resulting in breaching from overtopping by floodwaters (flood-induced failure) and from non-flood failures (sunny-day failure) were simulated by solving numerically the two-dimensional, depth-averaged flow equations on an unstructured computational mesh using the HEC-RAS computer program. Breaches were modeled as trapezoidal openings that form at the crest of the dam and then grow in size, first vertically downward until the specified breach bottom elevation is reached, and then horizontally as outflows continue to widen the opening. Breach parameters required by the model are summarized in Table 4.

Table 4.- Trapezoidal Dam Breach Model Parameters[a] and Calculated Dam Breach Flood Peak Discharges

Breach parameter	Units	Dam Failure Mode	
		Flood-induced Failure	Sunny-Day Failure
Breach Height	**m**	**29.88**	**29.88**
Breach Bottom width	**m**	**84**	**50**
Average side slope (horz : vert)	**--**	**1:1**	**0.6 : 1**
Formation time	**Hrs.**	**0.74**	**0.65**
Calculated peak discharge	**m^3/s**	**12,752**	**7,918**
[a] Parameters of the trapezoidal dam breach model used in HEC-RAS (Brunner 2016)			

Dam breach parameters were estimated using the Froehlich's Equations for embankment dams mentioned below (Froehlich, 2016), which is included in the Guidelines for Mapping Flood Risks Associated with Dams (CWC, 2018) along with a detailed description of assumptions, procedures and examples in the dam breach parameters estimation process.

$$B_{avg}=0.28\times K_m \times K_h \times V_W^{1/3}\times W_{avg}^{-(1/6)}\times H_b^{1/6}$$

Where,

$$K_m = \begin{cases} 1.0, for\ internal\ erosion\ failures \\ 1.5, for\ overtopping\ failures \end{cases}$$

$$K_h = \begin{cases} \left(\frac{H_b}{H_s}\right)^{1/2}, for\ H_b < H_s \\ 1.0, for\ H_b \geq H_s \end{cases}$$

$$H_s = \begin{cases} 6.1\ m, for\ SI\ units \\ 20\ ft, for\ U.S\ customary\ units \end{cases}$$

B_{avg} = expected value of average breach width in meters.
V_W =Volume of water above breach bottom in m³.
H_b = Height of breach in meters.
W_{avg}= Average Embankment Width at Top (m).

$$t_f = 50 \times \sqrt{\frac{V_w}{g\ {H_b}^2}} \times \left(\frac{W_{avg}}{H_b}\right)^{1/4}$$

$$m \cong \begin{cases} 0.6, for\ internal\ erosion\ failures \\ 1.0, for\ overtopping\ failures \end{cases}$$

Where,
t_f= expected value of breach formation time in seconds.
m = expected average side-slope ratio for the breach.
g = gravity acceleration.

Uncertainties
To manage the uncertainty of the dam breach parameters, the same were adjusted through a monitoring process of the velocities and peak outflows in the mathematical model. The parameters were modified based on a confidence interval of 95% in a normal distribution, which was calculated using the standard error given by Froehlich in his investigation [$\sigma_{ln(Bavg)}$ = 0.391 = standard error of estimate of the regression model for Ln(B_{avg}), $\sigma_{ln(tf)}$ = 0.210 = standard error of estimate of the regression model for Ln(t_f)]

Digital Elevation Model Description
The digital elevation model (DEM) used to prepare the two-dimensional computational mesh used to simulate flooding was derived from the Japan Aerospace Exploration Agency (JAXA) global digital surface model (DSM) dataset with a horizontal resolution of approximately 30 meters (1 arc-sec) (Takaku et al. 2014). The dataset is based on the DSM dataset (5-meter mesh version) of the "World 3D Topographic Data", which is the most precise global-scale elevation data at this time, and its elevation precision is also at a world-leading level as a 30-meter mesh version (Tadono et al. 2014). The height accuracy of the 30-meter DEM is 5 meters (root-mean-square-error).

Land Cover / Land Use Data Description. (Roughness Coefficients)
Glob Cover 2009 v2.3 dataset developed by the European Space Agency (ESA) was used to estimate the Roughness coefficients of the hydraulic model. The dataset consists of a GeoTIFF format file with 300 m. spatial resolution of global composites and land cover maps with a total of 22 thematic classes. This dataset was built using as inputs observations from the MERIS sensor on board the ENVISAT satellite mission. Assigned Manning's n coefficients for each class are summarised in Table 2.

Table 5.- Manning's n assigned for each Land Cover Class

Value	Glob Cover global legend		Manning's n
11	Post-flooding or irrigated croplands		0.034
14	Rainfed croplands		0.06
20	Mosaic Cropland (50-70%) / Vegetation (grassland, shrubland, forest) (20-50%)		0.034
30	Mosaic Vegetation (grassland, shrubland, forest) (50-70%) / Cropland (20-50%)		0.034
40	Closed to open (>15%) broadleaved evergreen and/or semi-deciduous forest (>5m)		0.1
50	Closed (>40%) broadleaved deciduous forest (>5m)		0.1
60	Open (15-40%) broadleaved deciduous forest (>5m)		0.05
70	Closed (>40%) needleleaved deciduous forest (>5m)		0.11
90	Closed (>40%) needleleaved deciduous or evergreen forest (>5m)		0.15
100	Closed to open (>15%) mixed broadleaved and needleleaved forest (5m)		0.11
110	Mosaic Forest/Shrubland (50-70%) / Grassland (20-50%)		0.035
120	Mosaic Grassland (50-70%) / Forest/Shrubland (20-50%)		0.035
130	Closed to open (>15%) shrubland (<5m)		0.07
140	Closed to open (15%) grassland		0.05
150	Sparse (>15%) vegetation (woody vegetation, shrubs, grassland)		0.09
160	Closed (>40%) broadleaved forest regularly flooded – Fresh water		0.04
170	Closed (>40%) broadleaved semi-deciduous and/or evergreen forest regularly flooded – Saline water		0.1
180	Closed to open (>15%) vegetation (grassland, shrubland, woody vegetation) on regularly flooded or waterlogged soil – Fresh, brackish or saline water		0.02
190	Artificial surfaces and associated areas (urban areas > 50%)		0.4
200	Bare areas		0.035
210	Water bodies		0.04
220	Permanent snow and ice		0.04

Estimated Population

Estimated population for each settlement/location was obtained using the Version 2.0 of WorldPop 2017 for India (www.worldpop.org - School of Geography and Environmental Science, University of Southampton). This version estimates for numbers of people per pixel (ppp) and people per hectare (pph), for 2010, 2015 and 2020, with national totals adjusted to match United Nations (UN) population division estimates (http://esa.un.org/wpp/). and remaining unadjusted. An additional dataset is included for the census year, on which 2010, 2015 and 2020 estimates are based.

The spatial resolution of this dataset is of 0.000833333 decimal degrees (approx. 100m at the equator), and for this study, the 2020 estimates were used.

Flood Severity/Vulnerability

A general classification was used to represent the vulnerability and severity of the inundated areas considering parameters such as people, vehicles and buildings stability under flooded conditions. Table 3 presents the description and thresholds values assumed.

Table 6.- Vulnerability thresholds classification limits [a]

Hazard Vulnerability Classification	Description	Classification Limit (Depth * Velocity)	Limiting Water Depth (m)	Limiting Velocity (m/s)
H1	Generally safe for vehicles, people and buildings.	D*V < 0.3	0.3	2.0
H2	Unsafe for small vehicles.	D*V < 0.6	0.5	2.0

Hazard Vulnerability Classification	Description	Classification Limit (Depth * Velocity)	Limiting Water Depth (m)	Limiting Velocity (m/s)
H3	Unsafe for vehicles, children and the elderly.	D*V < 0.6	1.2	2.0
H4	Unsafe for vehicles and people.	D*V < 1.0	2.0	2.0
H5	Unsafe for vehicles and people. All buildings vulnerable to structural damage. Some less robust buildings subject to failure.	D*V < 4.0	4.0	4.0
H6	Unsafe for vehicles and people. All building types considered vulnerable to failure.	D*V > 4.0	-	-

a Combined Hazard – Vulnerability Classification (Smith et al., 2014)

Boundaries of the Study Area

No downstream projects are located downstream of Maski Nala dam; therefore, the limits of the hydraulic model were established in the confluence of Maski stream into Tungabhadra river, attending to the following aspects:

a. Full attenuation of the breach outflow hydrograph along the main river.

b. Channel-conveyance capacity of the mainstream (within the riverbanks) receiving the total outflow in the downstream end of the model

3. Consequences - Point Index Calculation (Worksheets)

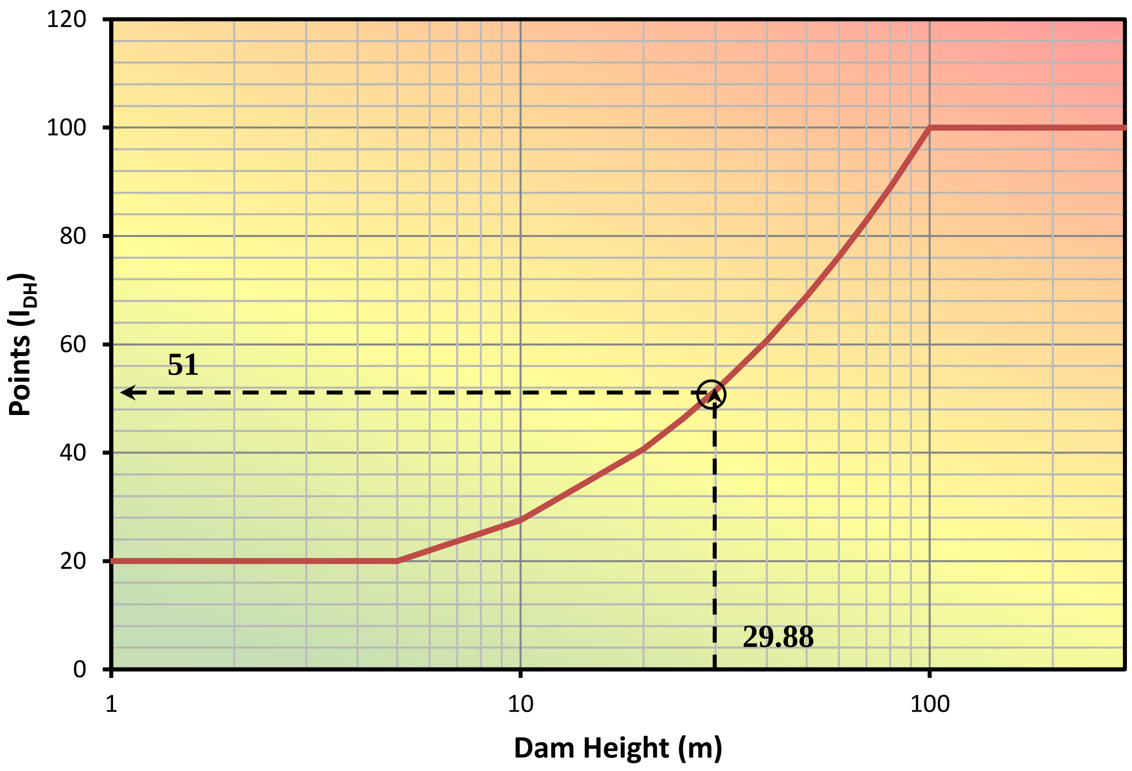
3.1. Capital Value of the Project

A.- DAM HEIGHT INDEX (I_{DH})

	Dam Height (m)	Rating Points
Maximum Dam Height………………..	29.88	51
	Total (A) =	**51**

$$I_{DH} \begin{cases} 20, (for\ h \le 5) \\ 15.7 + 1.12 * [LN(h)]^{2.8292}, (for\ 5 < h < 100) \\ 100, (for\ h \ge 100) \end{cases} \quad (1)$$

Where
I_{DH} : Dam height index points, and
h : is the height of the dam in meters



B.- PROJECT BENEFITS INDEX (I_{PB})

Annual Average River Flow at dam site (m^3/s): 0.83 (based on 25.76 Mm^3 average annual run-off at dam site)

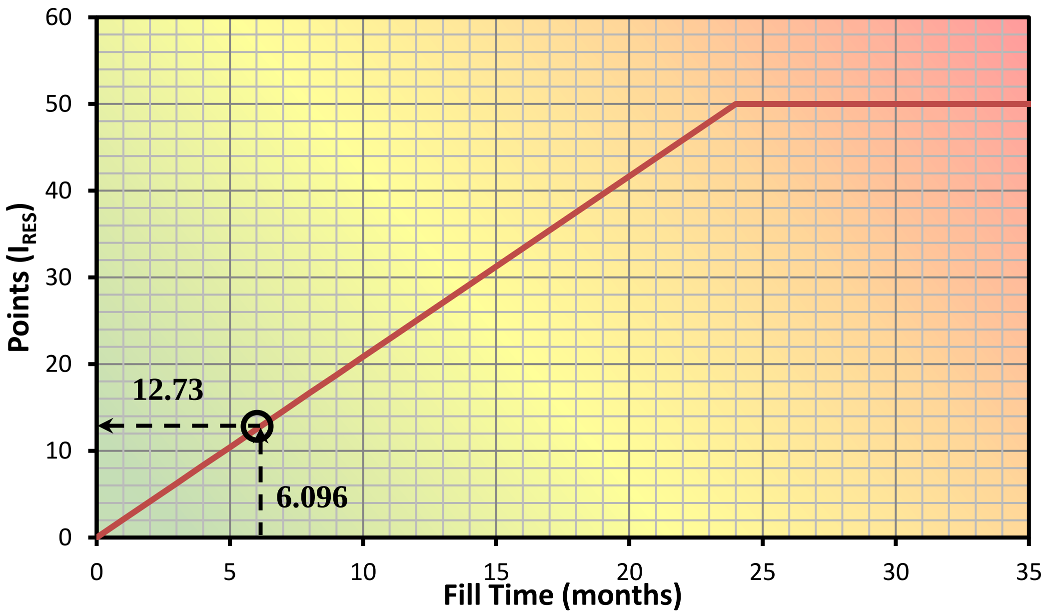
	Volume (Mm3)	Rating Points [1]
Reservoir Volume (Gross Storage in Mm^3)	13.11	12.73
Reservoir Volume – Water Supply Use (Mm^3)	Nil	0
Reservoir Volume – Industrial Use (Mm^3)	Nil	0
	Sub-Total (Σ [1]) =	**12.73**

$$T_F = {}^{V}/_{Q} * 0.386 = {}^{13.11}/_{0.83} * 0.386 = 6.096 \ months \quad (3)$$

$$I_{RES} \begin{cases} {}^{50}/_{24} * T_F , (for\ T_F < 24) \\ 100 , (for\ T_F \geq 24) \end{cases} \quad (4)$$

Where,

I_{RES} = Reservoir Content, water supply or industrial use Index
T_F = Time to fill the reservoir in months
V = Volume of the reservoir in Mm^3
Q = Average river flow in m^3/s



	Area (ha.) / Installed Capacity (Mw)	Rating Points [1]
Irrigated Land (ha.) ……………..………..	3,652	3.65
Installed Capacity (Mw) ………………..	Nil	0
Sub-Total (Σ [1]) =		**3.65**
Total Project Benefits Index (12.73 + 3.65) =		**16.38**
Total Capital Value of Project's Category (51 +16.38) =		**67.38**

$$I_I \begin{cases} area \, , (for \; area \; < 100) \\ 100 \, , (for \; area \; \geq 100) \end{cases} \tag{5}$$

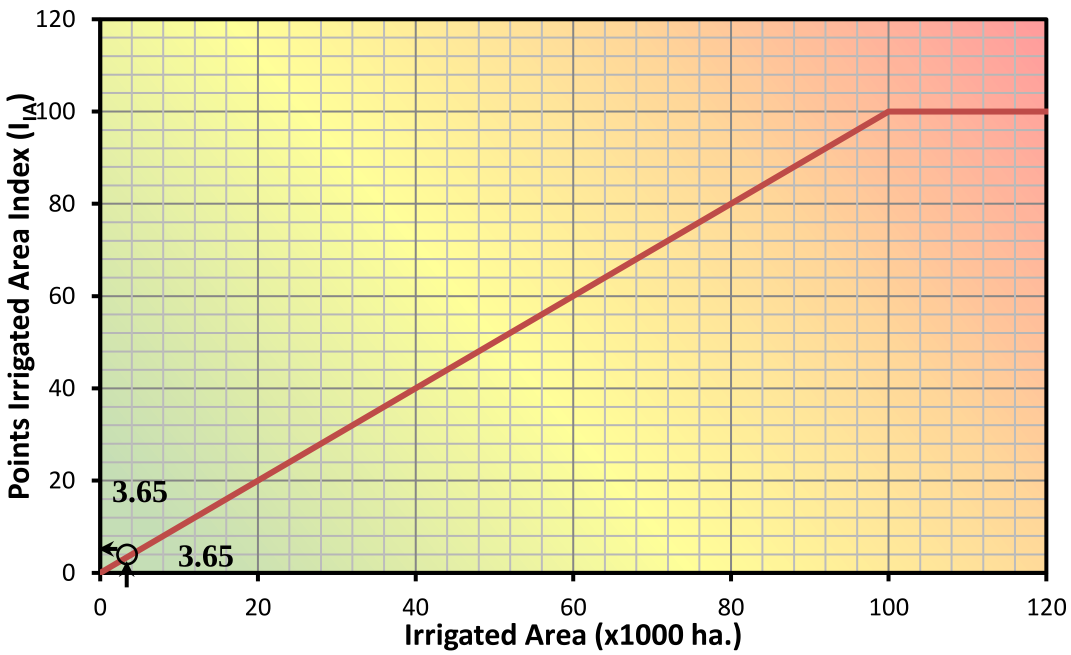
Where,

$area$ = irrigated area in 1,000 ha.
I_I = irrigated land index

$$I_{HP} \begin{cases} {}^{P}\!/_{10} \, , (for \; P \; < 1000) \\ 100 \, , (for \; P \; \geq 1000) \end{cases} \tag{6}$$

Where,

P = installed capacity in MW.
I_{HP} = Hydropower index



3.2. POTENTIAL FOR LOSS OF LIFE

C.- INCREMENTAL POPULATION AT RISK INDEX (I_{PAR})

Scenario No.1 Description: Sunny-Day Failure

Flood Severity Class	Population at Risk (people): No Dam Failure *[1]*	Population at Risk (people): With Dam Failure *[2]*	Incremental Population at Risk (People)
H1	0	1,099	
H2	0	708	
H3	0	1,100	
H4	0	1,045	
H5	0	1,849	
H6	0	465	
Sub-Total (H3 to H6) =	0	4,459	4,459
Total (H1 to H6) =	0	6,266	

Scenario No.2 Description: Flood Failure Scenario (with IDF flood routing)

Flood Severity Class	Population at Risk (people): No Dam Failure *[1]*	Population at Risk (people): With Dam Failure *[2]*	Incremental Population at Risk (People)
H1	1,293	1,315	
H2	880	835	
H3	1,357	1,220	
H4	1,396	1,431	
H5	3,100	5,186	
H6	423	1,965	
Sub-Total (H3 to H6) =	6,277	9,802	3,525
Total (H1 to H6) =	8,449	11,951	

Worst-Case Scenario: Sunny Day Failure

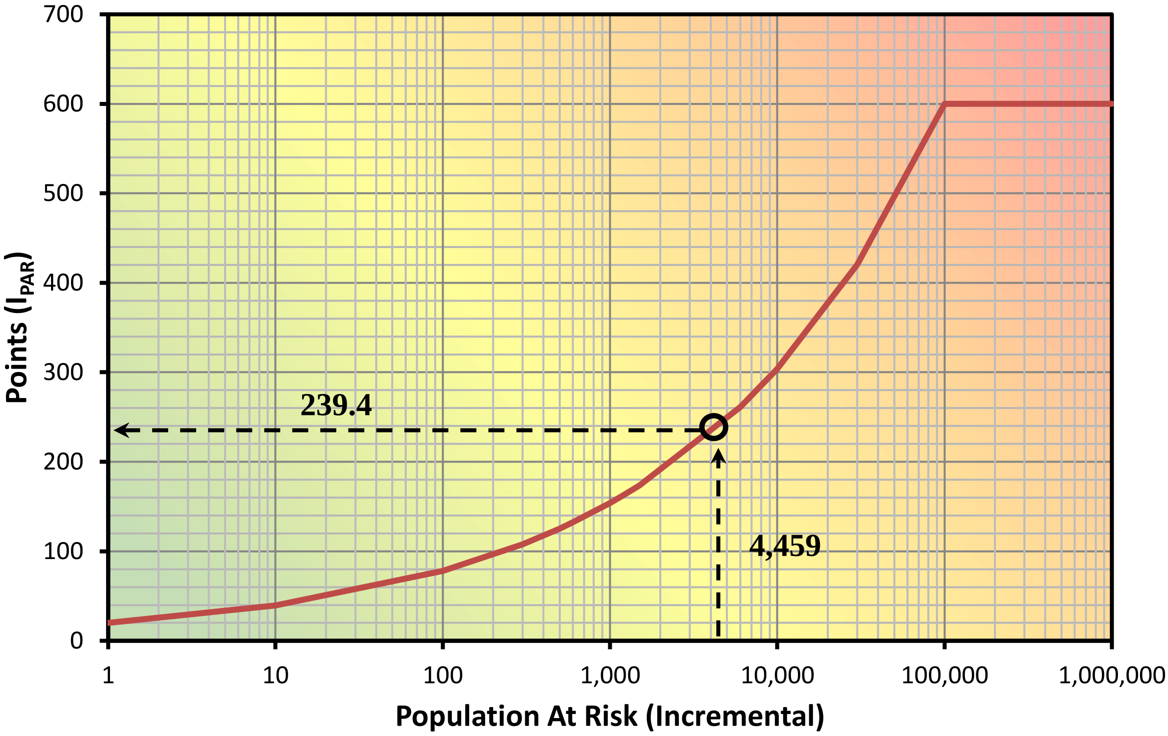
	No. of People	Rating Points *(See Figure)*
Incremental Population at Risk (PAR)………	4,459	239.4
	Sub-Total (C) =	239.4

Since Population at risk (PAR) is less than 100 people, then:

$$I_{PAR} = 20 * PAR^{0.2954} = 20 * (4{,}459)^{0.2954}$$
$$I_{PAR} = 239.4$$

Where,

PAR = incremental population at risk



D.- CRITICAL ARRIVAL TIME INDEX (I_{AT})

Nearest Downstream Settlement Maraldinni Village

Distance to the Dam in Kilometres: 1.3 Km.

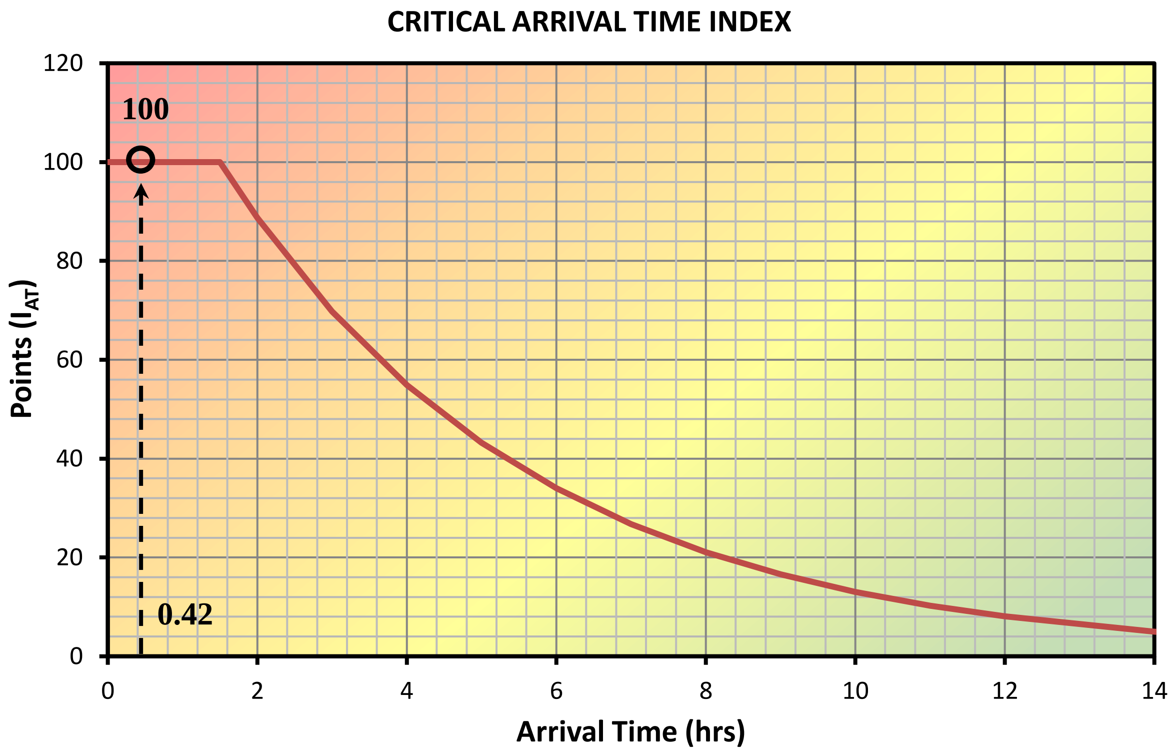
	Arrival Time (hours)	Rating Points *(See Figure)*
Critical Arrival Time (AT)…………………...	0.42	100
	Sub-Total (D) =	100
	Total Potential for Loss of Life's Category (C + D) =	339.4

$$I_{AT}\begin{cases} 100, (for\ AT \leq 1.5\ \text{hrs}) \\ 143.28 * (0.7868)^{AT}, (for\ 1.5 < AT < 48) \\ 0, (for\ AT \geq 48\ \text{hrs}) \end{cases} \quad (9)$$

Where,

AT = critical arrival time in hours

I_{AT} = critical arrival time index



3.3. POTENTIAL FOR PROPERTY DAMAGE

E.- TRANSPORTATION INFRASTRUCTURES

National Highways Affected: No National Highways have been affected

Railways Affected: No Railways have been affected

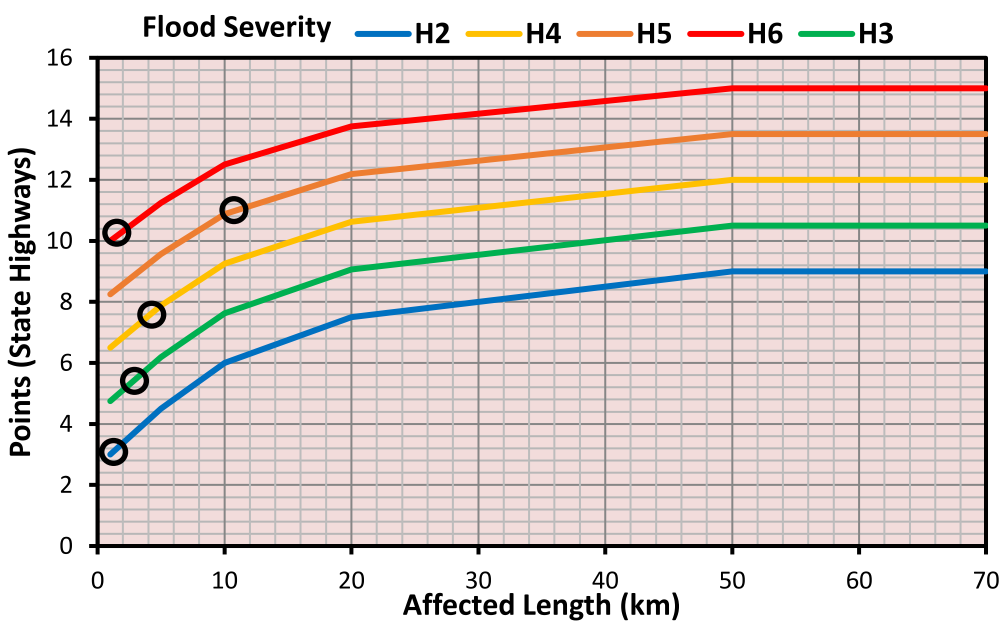
State Highways Affected: Main roads affected are SH-14, Maski-Balaganur Road (SH-14), SH-19, MNP road, SH-23, and SH-128

Flood Sever-ity Class	Affected length (Km)		Incremental Consequences (Km) *[3] = [2] – [1]*	Rating Points (3 -15 points) *[5] = See Figure*	Weighted Rating Points *[6] = ([3]/[4]) * [5]*
	No Dam Failure *[1]*	With Dam Failure *[2]*			
H1	0	4.09	4.09	----	----
H2	0	2.45	2.45	3.5	0.40
H3	0	2.74	2.74	5.4	0.69
H4	0	4.05	4.05	7.5	1.42
H5	0	10.86	10.86	11.0	5.56
H6	0	1.37	1.37	10.1	0.65

Sub-Total (*[4] = Σ [row H2 : row H6]*) = 21.47   Total Points *[E2]* = 8.72

Total (*[7] = Σ [row H1 : row H6]*) = 25.56

Sub-Total Transportation Infrastructures (E1+E2+E3) = 8.72



F.- INFRASTRUCTURES BY LANDUSE

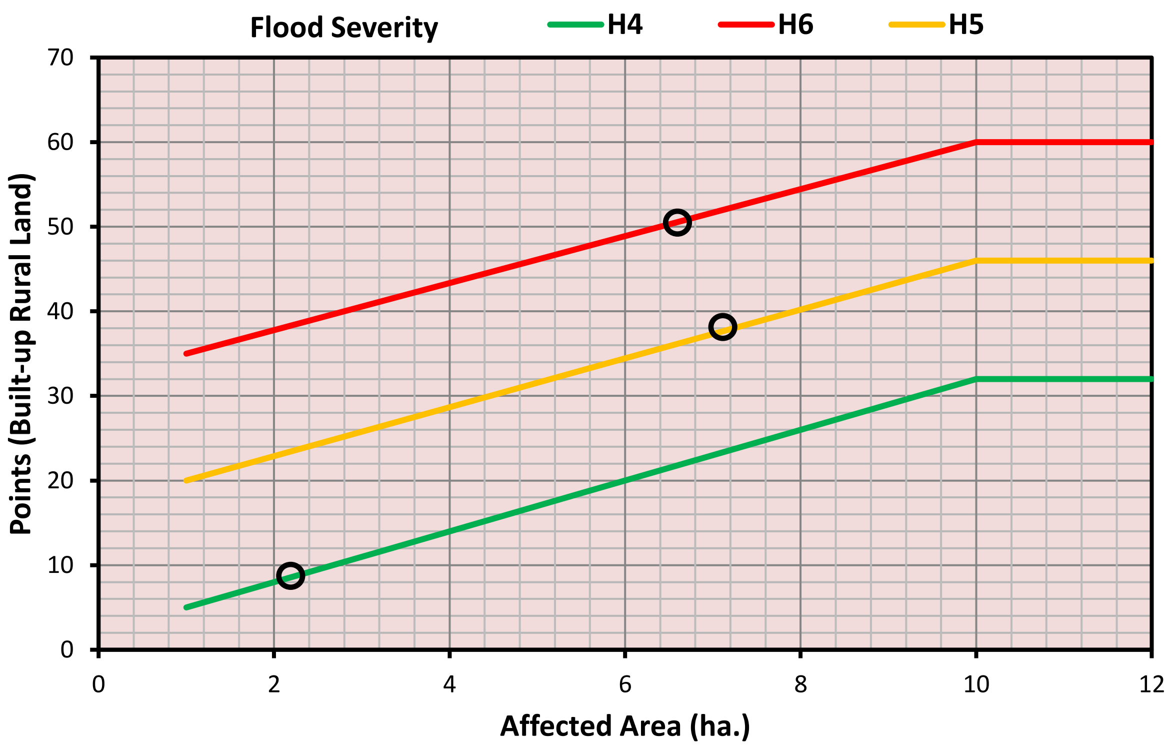
Built-Up Urban Areas: No Built-up Urban areas were affected

Built-Up Rural Areas: Main rural areas affected within Raichur district are Maraldinni, Benkanhal, Belladamaradi, Maski, Sunkunur, and Balaganur villages

Flood Severity Class	Affected Area (ha.)		Incremental Consequences (ha.)	Rating Points (5 -60 points)	Weighted Rating Points
	No Dam Failure *[1]*	With Dam Failure *[2]*	*[3] = [2] – [1]*	*[5] = See Figure*	*[6] = ([3]/[4]) * [5]*
H1	0	2.14	2.14	----	----
H2	0	2.65	2.65	----	----
H3	0	4.73	4.73	----	----
H4	0	2.22	2.22	8.7	1.2
H5	0	7.53	7.53	38.9	17.8
H6	0	6.66	6.66	50.7	20.6

Sub-Total (*[4] = Σ [row H4 : row H6]*) = 16.41 Total Points *[F2]* = 39.6

Total (*[7] = Σ [row H1 : row H6]*) = 25.92

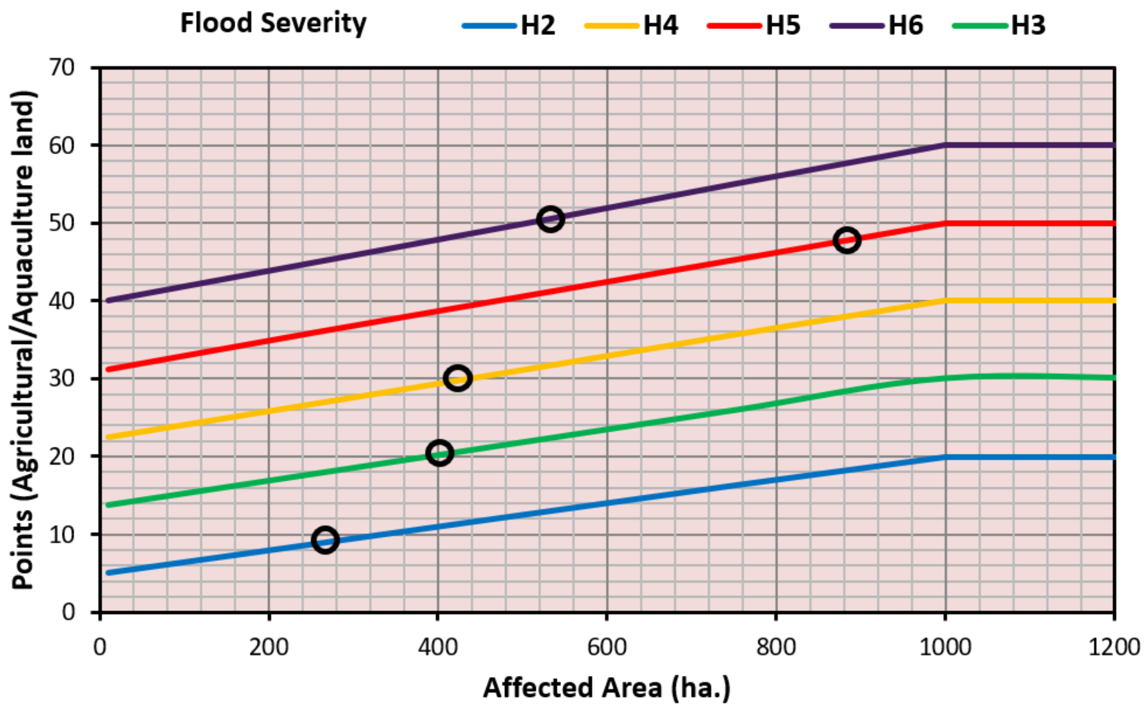


Agriculture / Aquaculture Land Use: Main agricultural developments affected within Raichur district are Maraldinni, Benkanhal, Belladamaradi, Maski, Sunkunur, and Balaganur villages

Flood Sever-ity Class	Affected Area (ha.)		Incremental Consequences (ha.)	Rating Points (5 - 60 points)	Weighted Rating Points
	No Dam Failure *[1]*	With Dam Failure *[2]*	*[3] = [2] – [1]*	*[5] = See Figure*	*[6] = ([3]/[4]) * [5]*
H1	0	414	414	----	----
H2	0	274	274	9	1.0
H3	0	406	406	20.3	3.3
H4	0	428	428	29.9	5.1
H5	0	881	881	47.7	16.7
H6	0	528	528	50.5	10.6

Sub-Total [4] (H2 to H6) = 2,517 36.7

Total (H1 to H6) = 2,932



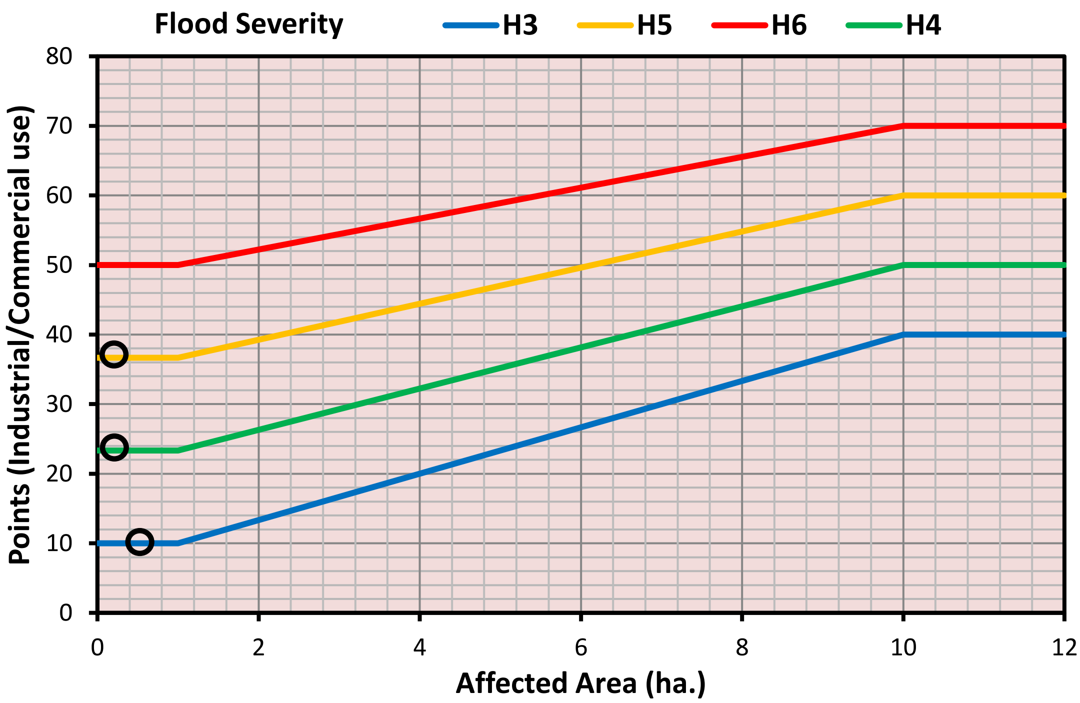
Industrial / Commercial Land Use: major industrial areas are located in Maski village

Flood Severity Class	Affected Area (ha.) No Dam Failure [1]	Affected Area (ha.) With Dam Failure [2]	Incremental Consequences (ha.) [3] = [2] – [1]	Rating Points (10 - 70 points) [5] = See Figure	Weighted Rating Points [6] = ([3]/[4]) * [5]
H1	0	0.70	0.70	----	----
H2	0	0.87	0.87	----	----
H3	0	0.50	0.50	10	5.7
H4	0	0.18	0.18	23	4.8
H5	0	0.19	0.19	37	8.1
H6	0	0	0	0.0	0.0

Sub-Total [4] (H3 to H6) = 0.87   18.6

Total (H1 to H6) = 2.4

Sub-Total Infrastructures by Land Use (F1+F2+F3 +F4) = 94.9



G.- ESSENTIAL SERVICES

Water Supply or Water Treatment Facilities affected: No water supply/treatment plant were identified within the inundation area

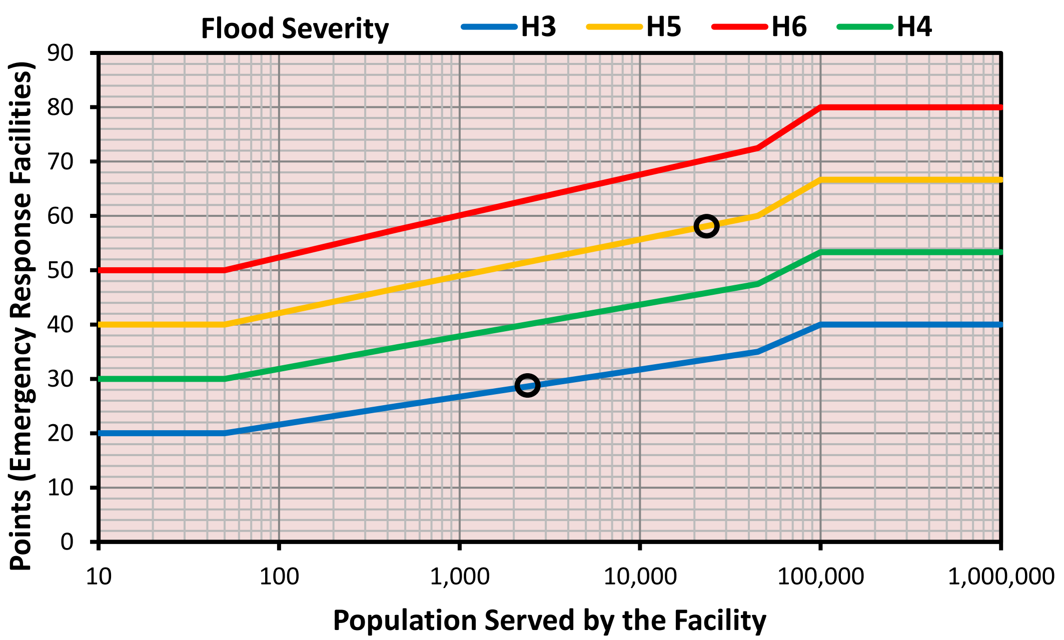
Electric Power Facilities: No water supply/treatment plant were identified within the inundation area

Emergency Response Facilities:

SI.	Facility Name	Popu-lation Served	Flood Severity Class	Rating Points (20 - 80 points) *[1] = See Figure*	Weighted Rating Points *[3] = ([1]/[2]) * [1]*
1	Police Station - Maski	23655	Not in-undated	0	0
2	Police Station - Balaganur	7405	Not In-undated	0	0
3	Annapurna Nursing Home	23655	Not In-undated	0	0
4	Govt. High School Maraladinni (Shelter)	2500	3	27.5	9
5	Sanjeevini Hospital (Maski)	23655	5	56.5	38
			Total =	84	47

Sub-total Essential Services (G1+G2+G3) = 47

Total Potential for Property Damage's Category (E+F+G) = 151



3.4. POTENTIAL FOR ENVIRONMENTAL AND CULTURAL IMPACT

H.- PROTECTED AREAS INDEX (I_{PA})

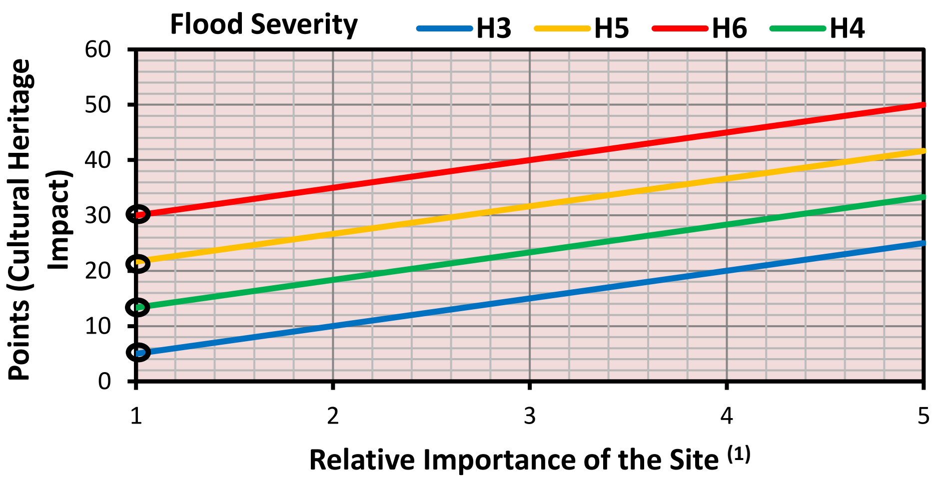
No Protected Areas were identified within the inundation area

I.- CULTURAL HERITAGE INDEX (I_{CH})

Cultural Heritage Sites Affected *(e.g. Temples, Monuments, Tombs, Caves, etc.)*

SI.	Site Name	Relative Im-portance	Flood Severity Class	Rating Points (5 - 70 points) *[1] = See Figure*	Weighted Rating Points *[3] = ([1]/[2]) * [1]*
1	Masjid E Kausar	1	4	13	1.8
2	Hanumantha Temple	1	6	30	9.7
3	Anjaneya Or Hanuman Temple	1	5	22	5.2
4	Vishnu Linga Ashrama Jala-wadagi	1	3	5	0.3
5	Sri Hanuman Temple	1	3	5	0.3
6	Vasavi Kanyaka Temple	1	3	5	0.3
7	Sri Mallikarjun Temple	1	4	13	1.8
			Total =	93	19.4

Total Environmental and Cultural Impact's Category (H+ I) = 19

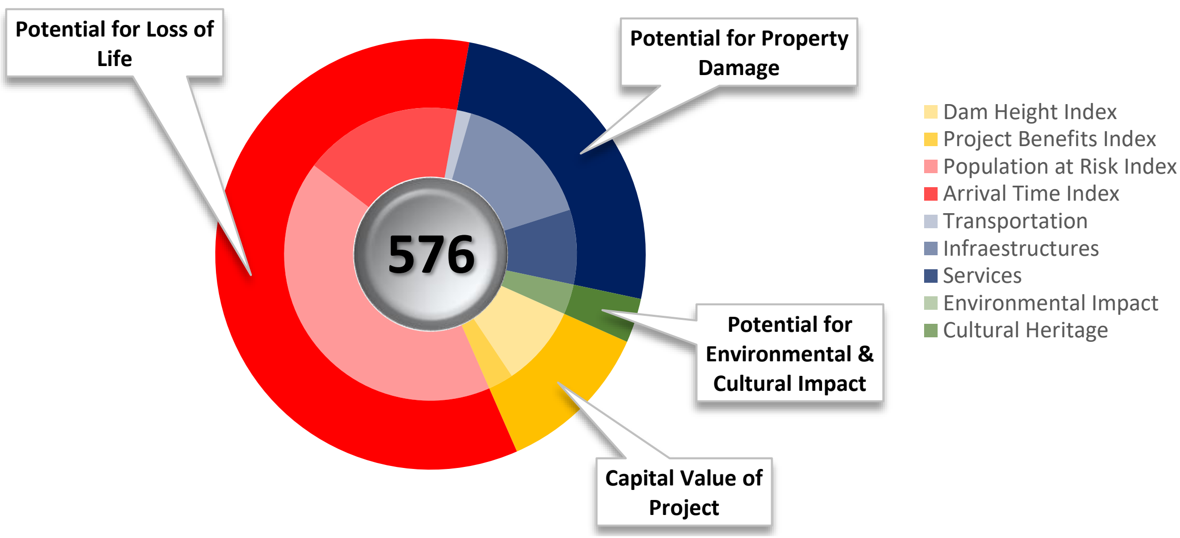


(1) Relative Importance to the broad range of sites within the region. An Example to decide the relative importance may be as follows:

Relative Importance				
1	*2*	*3*	*4*	*5*
Strongly Not Important	*Not Important*	*Undecided*	*Important*	*Strongly Important (UNESCO Site)*

4. Potential Hazard Classification

Consequences Category	Indicator Parameter	Consequences Rating Points *[1]*	Key Remarks
Capital Value of Project	Dam Height (I_{DH})	51	Medium Irrigation Project with a benefited area of 3,652 ha., which represents less than 3% of the total served area of Medium Projects operated by the Water Resources Dept. in Krishna Basin
	Project Benefits (I_{PB})	16	
Potential for Loss of Life	Population at Risk	239	Major population at risk is concentrated in Maski and Balaganur villages in Raichur District. Potential for loss of life is highly dependent on the adequacy of warning and rescue operations.
	Critical Arrival Time	100	
Potential for Property Damage	Transportation	9	Major consequences restricted to rural areas and agricultural land use. No national Highways are affected
	Infrastructure Damaged	95	
	Services Disrupted	47	
Potential for Environmental & Cultural Impact	Environmental Impact	0	Minimal incremental damage. Short-Term or reversible impact is expected (less than 2 years)
	Cultural Heritage	19	
Total Potential Consequences Index (P_{CI}) =		***576***	
Potential Hazard Class =		***Class III***	



5. CONCLUSIONS AND RECOMMENDATIONS

Hazard Potential Classification of Maski Nala Dam was developed using the recommended approach described in the "*Guidelines for Classifying the Hazard Potential of Dams".* A Tier-I dam break analysis has been used to assess the potential consequences and results obtained from the hazard classification process can be used by dam authority to guide and define future activities within the dam safety management program.

With the available level of information and the inherent limitations of the study, the following conclusion and recommendations can be derived

- Using the additive weighting scheme (consequences index), Maski Nala dam is classified as a ***Class-III*** dam with a total of ***576 points***. The overall consequences index is comprised by the Capital Value of the Project Index (67 points, 12%), Potential for Loss of Life Index (339 points, 59%), Potential for Property Damage Index (151 points, 26%) and Potential for Environmental & Cultural impact Index (19 points, 3%)

- Most critical parameter influencing the overall hazard potential classification of Maski Nala dam is the potential for loss of life. A total of 4,459 people has been identified as population at risk, mainly concentrated in Maski and Balaganur villages in Raichur District. It is considered that the potential for loss of life is highly dependent on the adequacy of warning and rescue operations in the affected area.

- Since the overall consequences index (576 points) is located near the threshold between the Class III and IV (600 points), it is recommended to refine the index estimations using a Tier-II or Tier-III approach, especially in the populations at risk assessment. The updated version of the hazard classification report it is recommended to be finalized within one year after approval of the present version.

- Preparation of the Emergency Action Plan for Maski Nala dam needs to be in line with the level of detail of a Tier-II or Tier-III analysis as per recommendations of the *Guidelines for Classifying the Hazard Potential of Dams*

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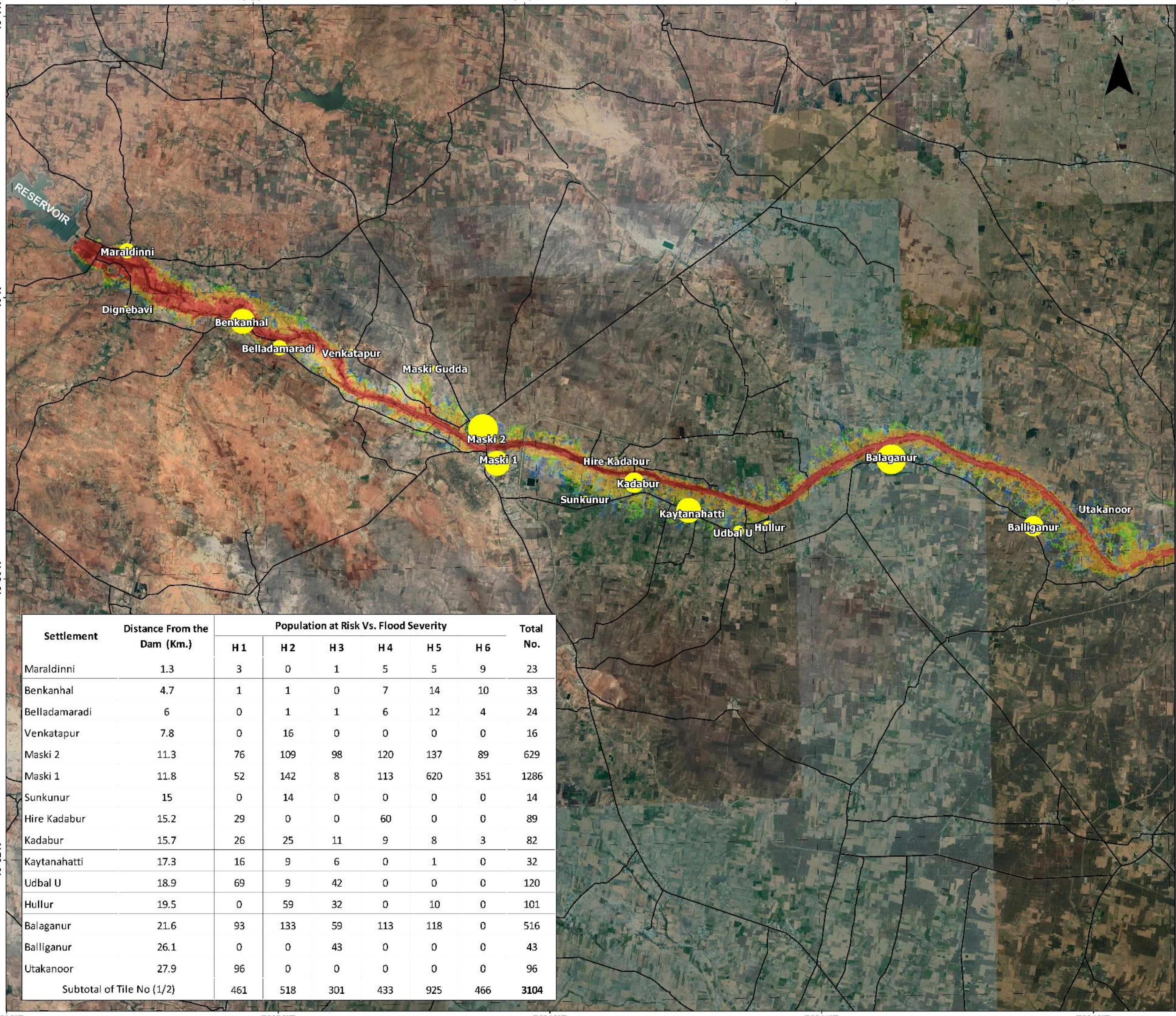
APPENDIX 1. (CASE STUDY).

POPULATION AT RISK



Settlement	Distance From the Dam (Km.)	Population at Risk Vs. Flood Severity						Total No.
		H 1	H 2	H 3	H 4	H 5	H 6	
Maraldinni	1.3	3	0	1	5	5	9	23
Benkanhal	4.7	1	1	0	7	14	10	33
Belladamaradi	6	0	1	1	6	12	4	24
Venkatapur	7.8	0	16	0	0	0	0	16
Maski 2	11.3	76	109	98	120	137	89	629
Maski 1	11.8	52	142	8	113	620	351	1286
Sunkunur	15	0	14	0	0	0	0	14
Hire Kadabur	15.2	29	0	0	60	0	0	89
Kadabur	15.7	26	25	11	9	8	3	82
Kaytanahatti	17.3	16	9	6	0	1	0	32
Udbal U	18.9	69	9	42	0	0	0	120
Hullur	19.5	0	59	32	0	10	0	101
Balaganur	21.6	93	133	59	113	118	0	516
Balliganur	26.1	0	0	43	0	0	0	43
Utakanoor	27.9	96	0	0	0	0	0	96
Subtotal of Tile No (1/2)		461	518	301	433	925	466	**3104**

VULNERABILITY

- H 1
- H 2
- H 3
- H 4
- H 5
- H 6
- ROADS
- RAILWAYS

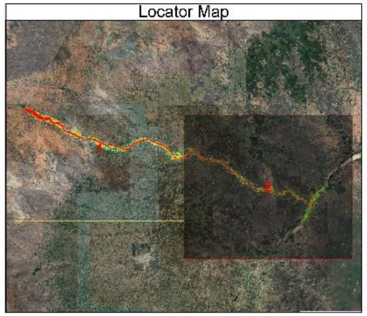
SETTLEMENTS

Incremental Population at Risk

- 0.0 - 25
- 25 - 50
- 50 - 100
- 100 - 250
- 250 - 500
- 500 - 1784

Note: Print on A0 size sheet is suggested.

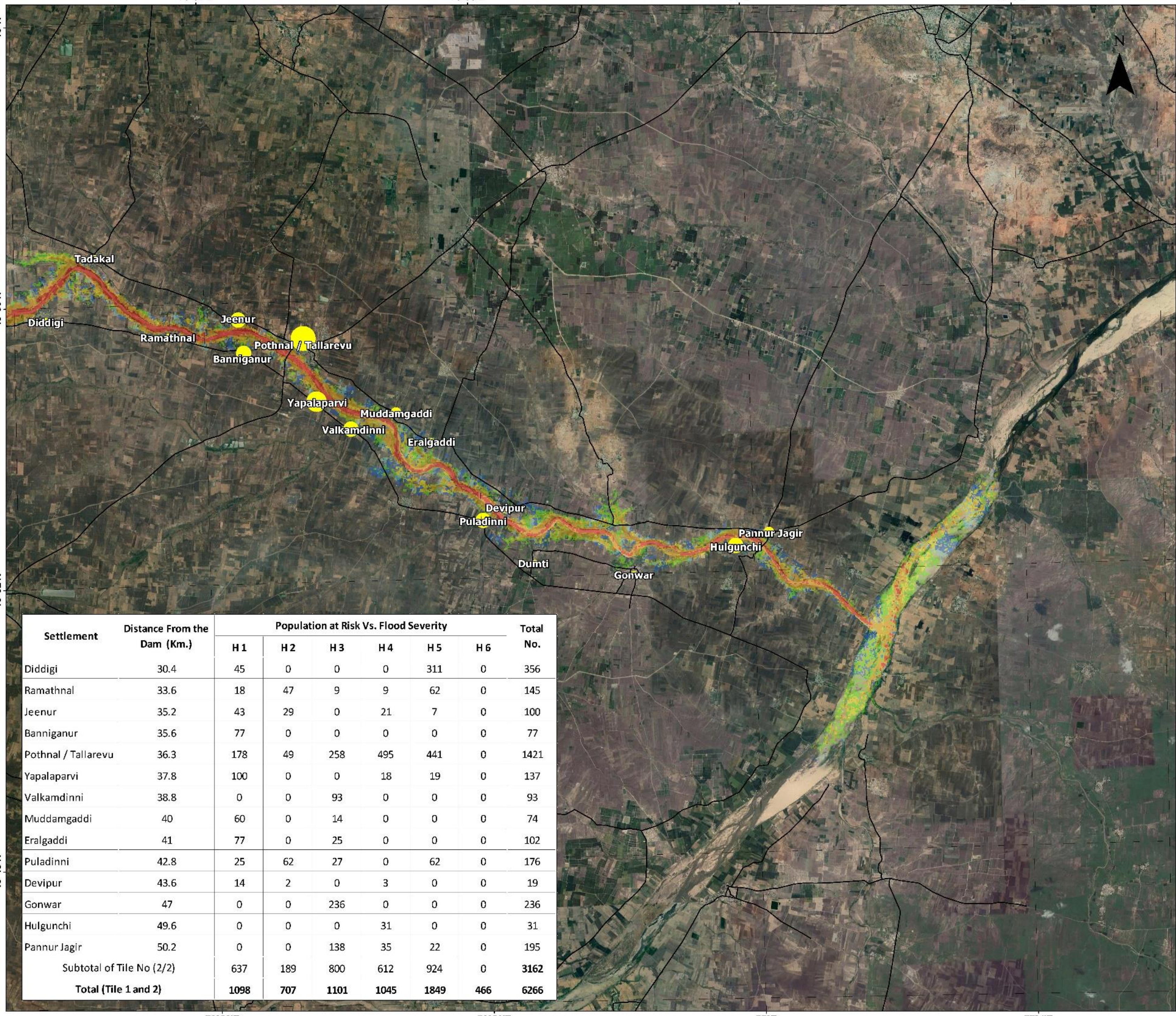
Locator Map



CENTRAL PROJECT MANAGEMENT UNIT

DAM REHABILITATION AND IMPROVEMENT PROJECT

Name of Dam	**MASKI NALA**
State	**KARNATAKA**
Title	**SUNNY DAY FAILURE**
Doc. No.	**CDSO_DSR_MAP_MASKI NALA__KAWRD**
Date :	February, 2020 — Map No. 1 / 2
Scale :	0 1 2 4 Km



Settlement	Distance From the Dam (Km.)	Population at Risk Vs. Flood Severity						Total No.
		H 1	H 2	H 3	H 4	H 5	H 6	
Diddigi	30.4	45	0	0	0	311	0	356
Ramathnal	33.6	18	47	9	9	62	0	145
Jeenur	35.2	43	29	0	21	7	0	100
Banniganur	35.6	77	0	0	0	0	0	77
Pothnal / Tallarevu	36.3	178	49	258	495	441	0	1421
Yapalaparvi	37.8	100	0	0	18	19	0	137
Valkamdinni	38.8	0	0	93	0	0	0	93
Muddamgaddi	40	60	0	14	0	0	0	74
Eralgaddi	41	77	0	25	0	0	0	102
Puladinni	42.8	25	62	27	0	62	0	176
Devipur	43.6	14	2	0	3	0	0	19
Gonwar	47	0	0	236	0	0	0	236
Hulgunchi	49.6	0	0	0	31	0	0	31
Pannur Jagir	50.2	0	0	138	35	22	0	195
Subtotal of Tile No (2/2)		637	189	800	612	924	0	**3162**
Total (Tile 1 and 2)		**1098**	**707**	**1101**	**1045**	**1849**	**466**	**6266**

VULNERABILITY

- H 1
- H 2
- H 3
- H 4
- H 5
- H 6
- ROADS
- RAILWAYS

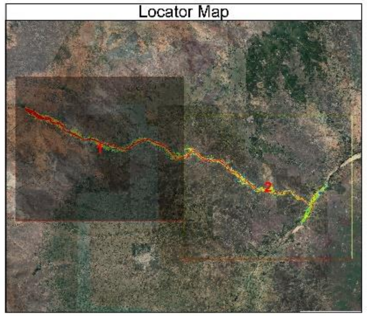
SETTLEMENTS

Incremental Population at Risk

- 0.0 - 25
- 25 - 50
- 50 - 100
- 100 - 250
- 250 - 500
- 500 - 1784

Note: Print on A0 size sheet is suggested.

Locator Map



CENTRAL PROJECT MANAGEMENT UNIT

DAM REHABILITATION AND IMPROVEMENT PROJECT

Name of Dam	**MASKI NALA**
State	**KARNATAKA**
Title	**SUNNY DAY FAILURE**
Doc. No.	**CDSO_DSR_MAP_MASKI NALA__KAWRD**
Date : February, 2020	Map No. 2 / 2
Scale : 0 1 2 4 Km	

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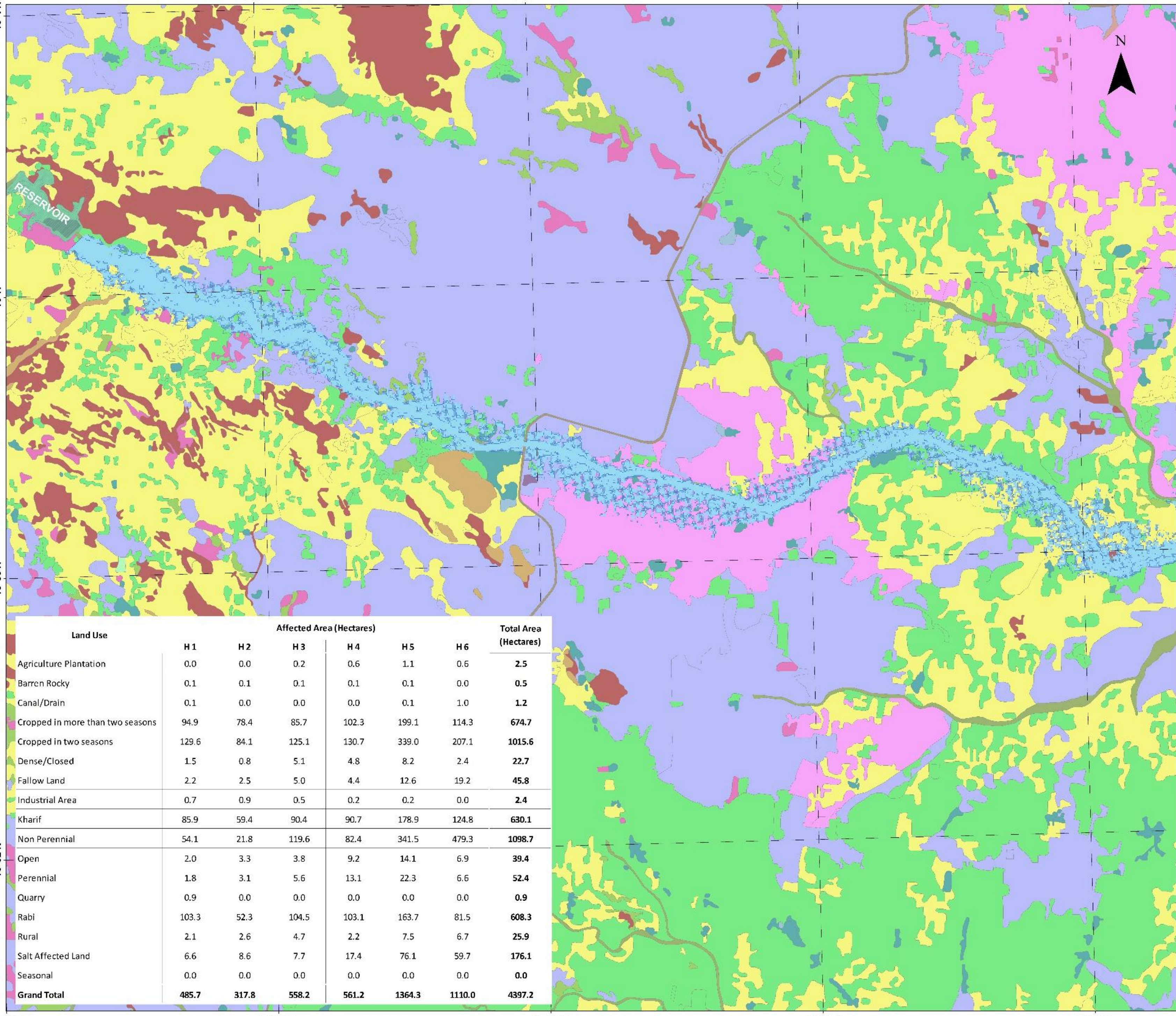
APPENDIX 2. (CASE STUDY).

AFFECTED AREA BY LAND USE



Land Use	Affected Area (Hectares)						Total Area (Hectares)
	H 1	H 2	H 3	H 4	H 5	H 6	
Agriculture Plantation	0.0	0.0	0.2	0.6	1.1	0.6	**2.5**
Barren Rocky	0.1	0.1	0.1	0.1	0.1	0.0	**0.5**
Canal/Drain	0.1	0.0	0.0	0.0	0.1	1.0	**1.2**
Cropped in more than two seasons	94.9	78.4	85.7	102.3	199.1	114.3	**674.7**
Cropped in two seasons	129.6	84.1	125.1	130.7	339.0	207.1	**1015.6**
Dense/Closed	1.5	0.8	5.1	4.8	8.2	2.4	**22.7**
Fallow Land	2.2	2.5	5.0	4.4	12.6	19.2	**45.8**
Industrial Area	0.7	0.9	0.5	0.2	0.2	0.0	**2.4**
Kharif	85.9	59.4	90.4	90.7	178.9	124.8	**630.1**
Non Perennial	54.1	21.8	119.6	82.4	341.5	479.3	**1098.7**
Open	2.0	3.3	3.8	9.2	14.1	6.9	**39.4**
Perennial	1.8	3.1	5.6	13.1	22.3	6.6	**52.4**
Quarry	0.9	0.0	0.0	0.0	0.0	0.0	**0.9**
Rabi	103.3	52.3	104.5	103.1	163.7	81.5	**608.3**
Rural	2.1	2.6	4.7	2.2	7.5	6.7	**25.9**
Salt Affected Land	6.6	8.6	7.7	17.4	76.1	59.7	**176.1**
Seasonal	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
Grand Total	**485.7**	**317.8**	**558.2**	**561.2**	**1364.3**	**1110.0**	**4397.2**

INUNDATED AREA

.

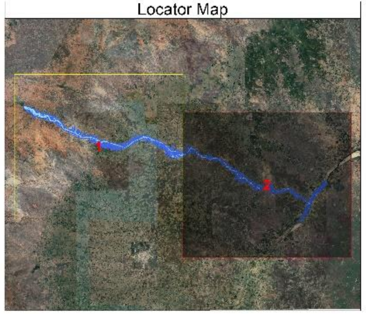
LANDUSE

Landuse

- Active
- Agri. Plantation
- Aquaculture
- Ash & Waste
- Barren Rocky
- Canal/Drain
- Coastal
- Compact (Cont)
- Croped 2 seasons
- Croped > 2 seasons
- Dense/Closed
- Fallow Land
- Forest Plantation
- Gullied
- Industrial Area
- Kharif
- Kharif Extent
- Lagoon, Mud Flat etc.
- Mining - Abandoned
- Non Perennial
- Open
- Waterlogged etc.
- Perennial
- Permanent
- Quarry
- Rabi
- Ravenous
- Riverine
- Rural
- Salt Affected Land
- Saltpan
- Scrub Forest
- Seasonal
- Sparse-Discontinuous
- Sparse Veg/Open Area
- Temperate/Sub Tropical
- Waterlogged etc.
- Zaid

Note: Print on A0 size sheet is suggested.

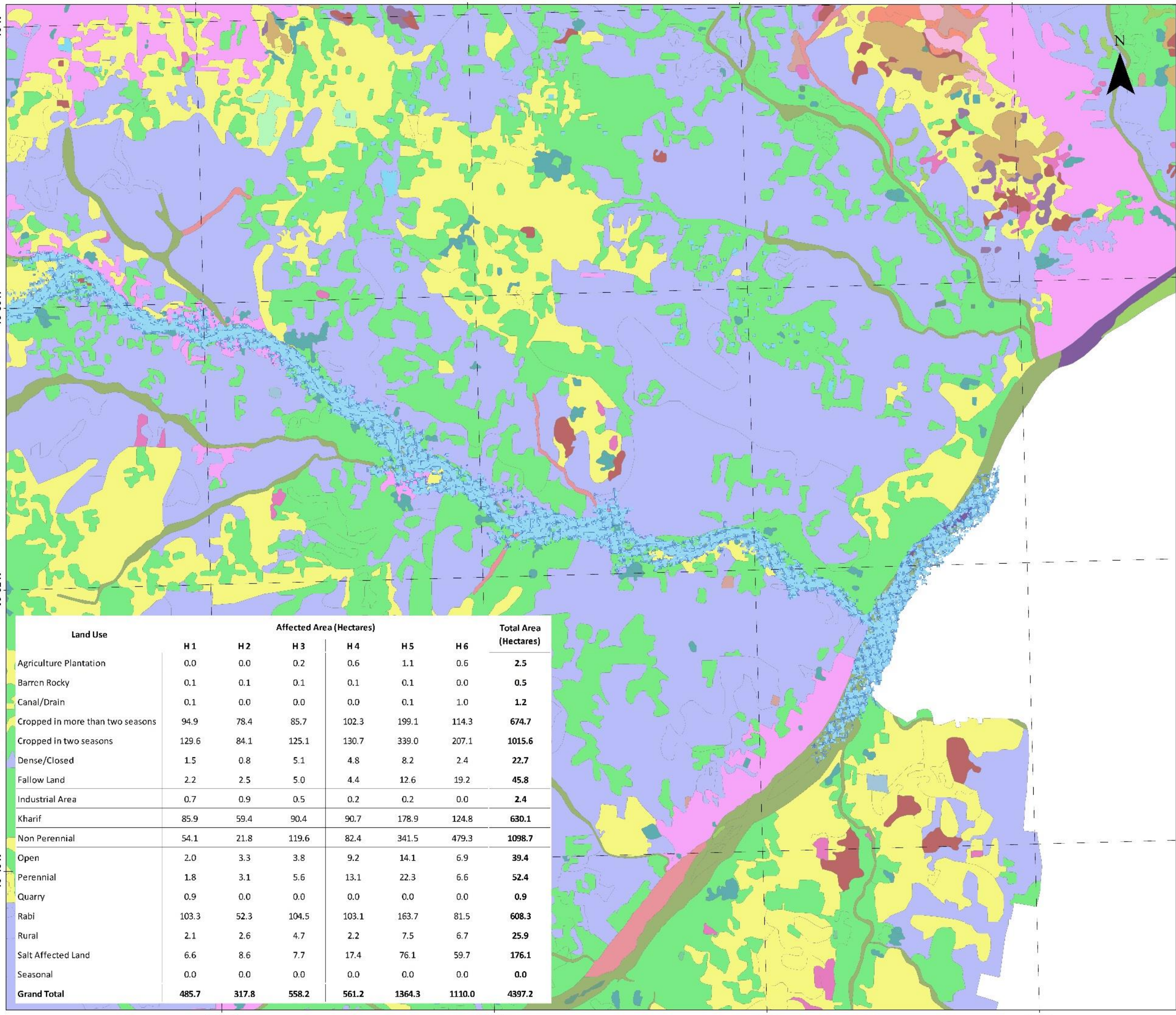
Locator Map



CENTRAL PROJECT MANAGEMENT UNIT

DAM REHABILITATION AND IMPROVEMENT PROJECT

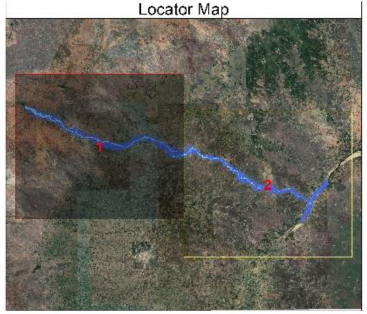
Name of Dam	**MASKI NALA**
State	**KARNATAKA**
Title	**NON - FLOOD FAILURE**
Doc. No.	**CDSO_DSR_MAP_MASKI NALA__KAWRD**
Date :	February, 2020 Map No. 1 / 2
Scale :	0 1 2 4 Km



Land Use	Affected Area (Hectares)						Total Area (Hectares)
	H 1	H 2	H 3	H 4	H 5	H 6	
Agriculture Plantation	0.0	0.0	0.2	0.6	1.1	0.6	**2.5**
Barren Rocky	0.1	0.1	0.1	0.1	0.1	0.0	**0.5**
Canal/Drain	0.1	0.0	0.0	0.0	0.1	1.0	**1.2**
Cropped in more than two seasons	94.9	78.4	85.7	102.3	199.1	114.3	**674.7**
Cropped in two seasons	129.6	84.1	125.1	130.7	339.0	207.1	**1015.6**
Dense/Closed	1.5	0.8	5.1	4.8	8.2	2.4	**22.7**
Fallow Land	2.2	2.5	5.0	4.4	12.6	19.2	**45.8**
Industrial Area	0.7	0.9	0.5	0.2	0.2	0.0	**2.4**
Kharif	85.9	59.4	90.4	90.7	178.9	124.8	**630.1**
Non Perennial	54.1	21.8	119.6	82.4	341.5	479.3	**1098.7**
Open	2.0	3.3	3.8	9.2	14.1	6.9	**39.4**
Perennial	1.8	3.1	5.6	13.1	22.3	6.6	**52.4**
Quarry	0.9	0.0	0.0	0.0	0.0	0.0	**0.9**
Rabi	103.3	52.3	104.5	103.1	163.7	81.5	**608.3**
Rural	2.1	2.6	4.7	2.2	7.5	6.7	**25.9**
Salt Affected Land	6.6	8.6	7.7	17.4	76.1	59.7	**176.1**
Seasonal	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
Grand Total	**485.7**	**317.8**	**558.2**	**561.2**	**1364.3**	**1110.0**	**4397.2**

Note: Print on A0 size sheet is suggested.

Locator Map



CENTRAL PROJECT MANAGEMENT UNIT

DAM REHABILITATION AND IMPROVEMENT PROJECT

Name of Dam: **MASKI NALA**

State: **KARNATAKA**

Title: **NON - FLOOD FAILURE**

Doc. No. **CDSO_DSR_MAP_MASKI NALA_KAWRD**

Date : February, 2020 — Map No. 2 / 2

Scale : 0 1 2 4 Km

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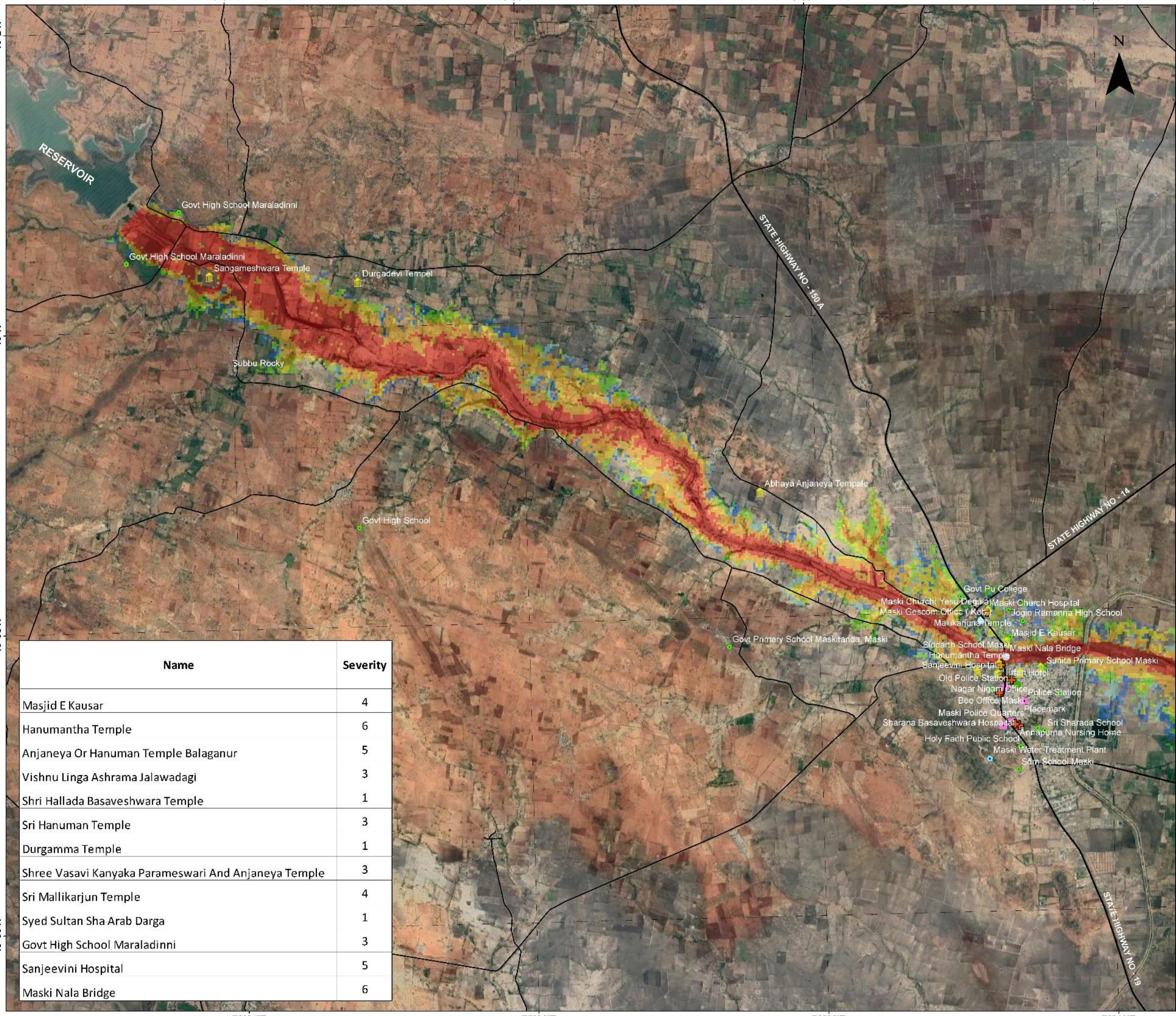
APPENDIX 3 (CASE STUDY).

AFFECTED SERVICES, ROADS AND CULTURAL SITES



Name	Severity
Masjid E Kausar	4
Hanumantha Temple	6
Anjaneya Or Hanuman Temple Balaganur	5
Vishnu Linga Ashrama Jalawadagi	3
Shri Hallada Basaveshwara Temple	1
Sri Hanuman Temple	3
Durgamma Temple	1
Shree Vasavi Kanyaka Parameswari And Anjaneya Temple	3
Sri Mallikarjun Temple	4
Syed Sultan Sha Arab Darga	1
Govt High School Maraladinni	3
Sanjeevini Hospital	5
Maski Nala Bridge	6

VULNERABILITY

- H 1
- H 2
- H 3
- H 4
- H 5
- H 6
- ROADS
- RAILWAYS

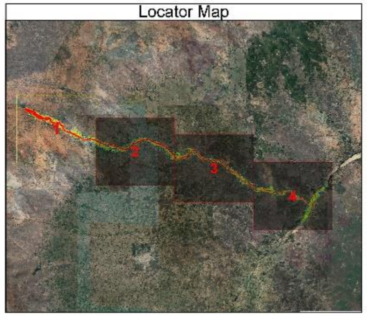
Locations

Class

- Bridge
- School / College / Universities
- GESCOM Office
- Gram Panchayat
- Hospital
- Police Station
- Post Office
- Temple / Mosque / Church
- Water Treatment Plant

Note: Print on A0 size sheet is suggested.

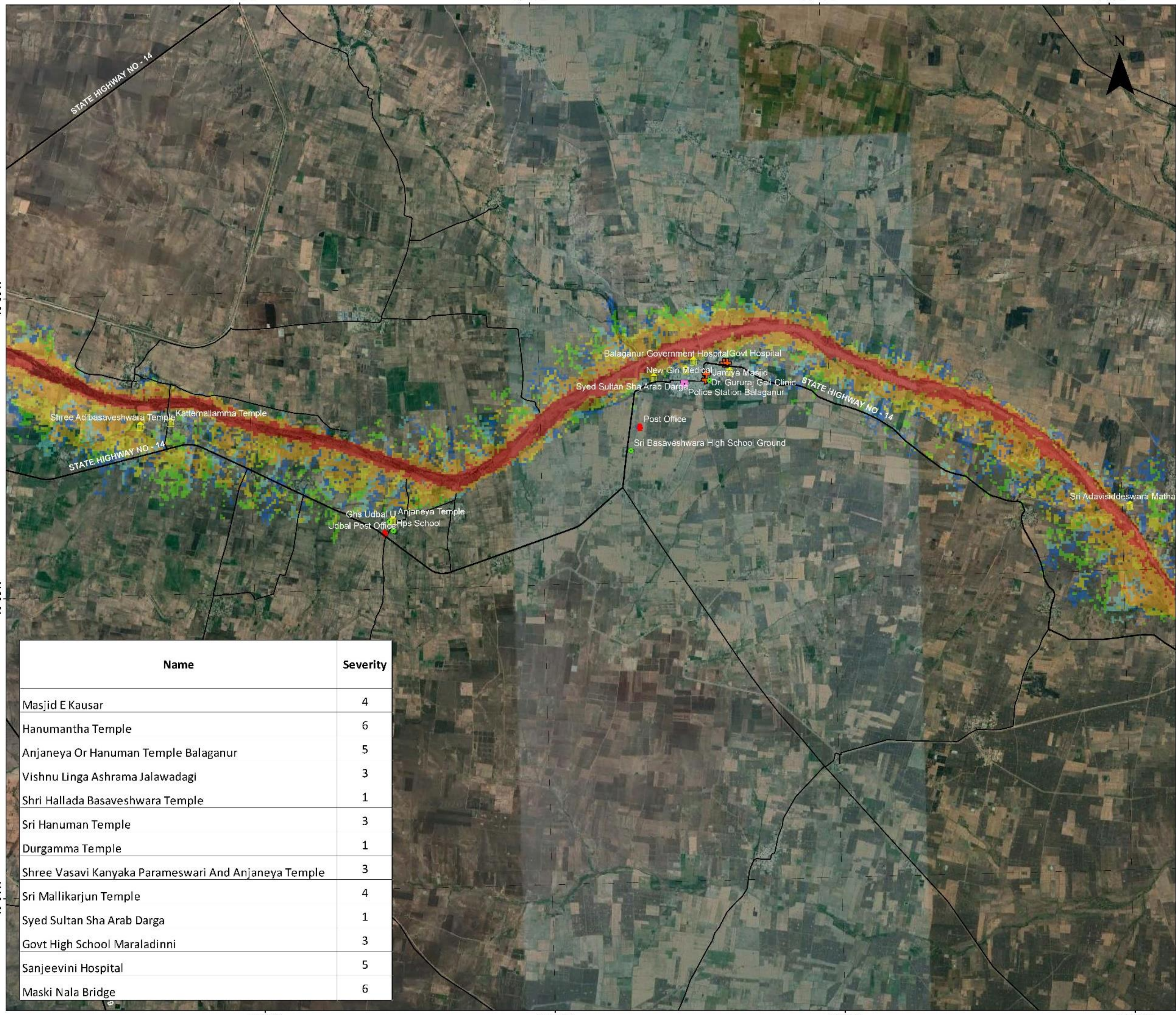
Locator Map



CENTRAL PROJECT MANAGEMENT UNIT

DAM REHABILITATION AND IMPROVEMENT PROJECT

Name of Dam	MASKI NALA
State	KARNATAKA
Title	SUNNY DAY FAILURE
Doc. No.	CDSO_DSR_MAP_MASKI NALA__KAWRD
Date :	February, 2020
Map No.	1 / 4
Scale :	0 0.5 1 2 Km



Name	Severity
Masjid E Kausar	4
Hanumantha Temple	6
Anjaneya Or Hanuman Temple Balaganur	5
Vishnu Linga Ashrama Jalawadagi	3
Shri Hallada Basaveshwara Temple	1
Sri Hanuman Temple	3
Durgamma Temple	1
Shree Vasavi Kanyaka Parameswari And Anjaneya Temple	3
Sri Mallikarjun Temple	4
Syed Sultan Sha Arab Darga	1
Govt High School Maraladinni	3
Sanjeevini Hospital	5
Maski Nala Bridge	6

VULNERABILITY

- H 1
- H 2
- H 3
- H 4
- H 5
- H 6
- ROADS
- RAILWAYS

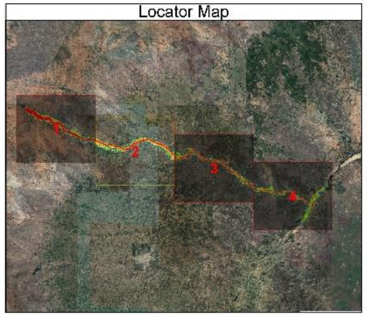
Locations

Class

- Bridge
- School / College / Universities
- GESCOM Office
- Gram Panchayat
- Hospital
- Police Station
- Post Office
- Temple / Mosque / Church
- Water Treatment Plant

Note: Print on A0 size sheet is suggested.

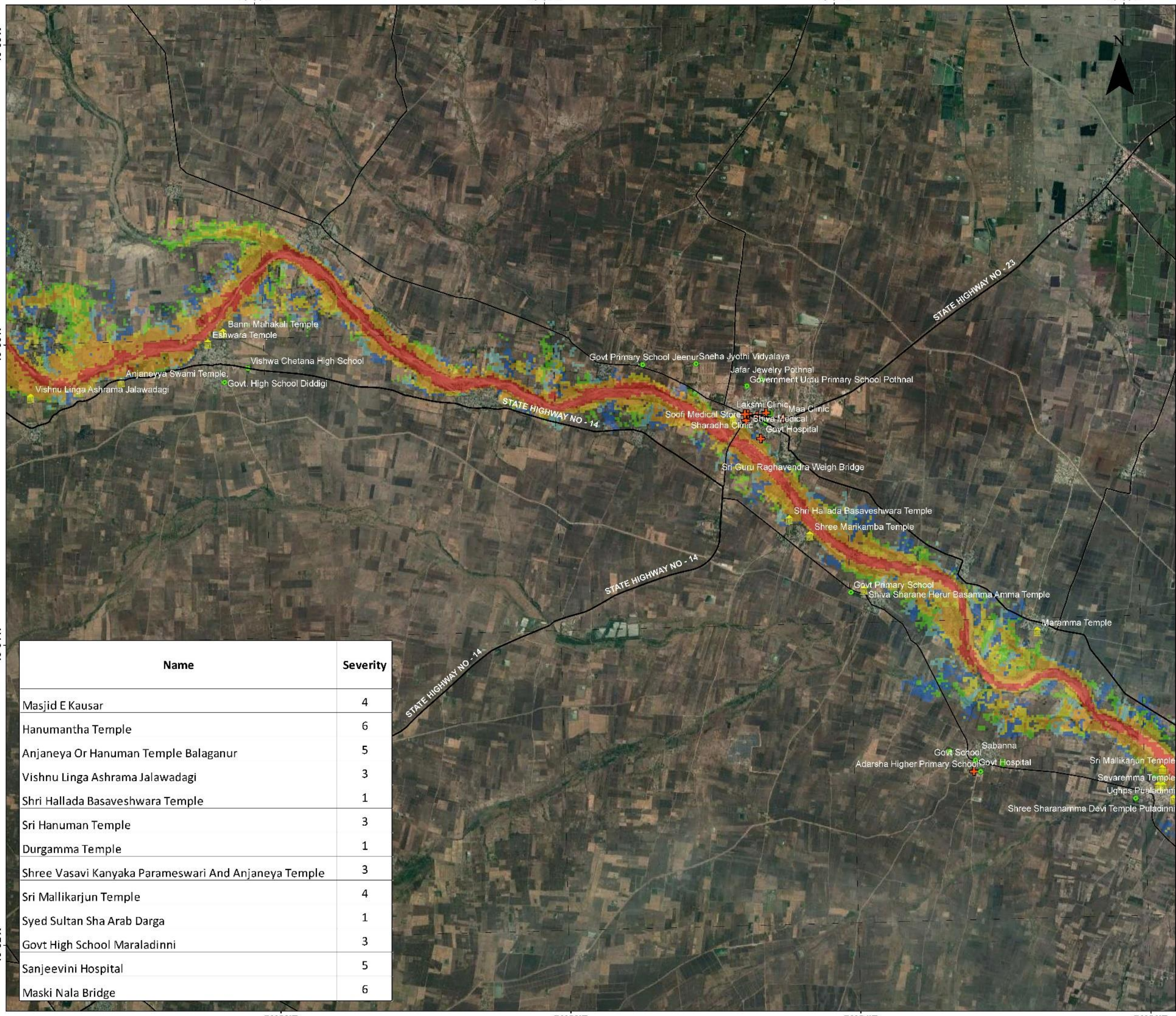
Locator Map



CENTRAL PROJECT MANAGEMENT UNIT

DAM REHABILITATION AND IMPROVEMENT PROJECT

Name of Dam	**MASKI NALA**
State	**KARNATAKA**
Title	**SUNNY DAY FAILURE**
Doc. No.	**CDSO_DSR_MAP_MASKI NALA__KAWRD**
Date :	February, 2020
Map No.	2 / 4
Scale :	0 0.5 1 2 Km



Name	Severity
Masjid E Kausar	4
Hanumantha Temple	6
Anjaneya Or Hanuman Temple Balaganur	5
Vishnu Linga Ashrama Jalawadagi	3
Shri Hallada Basaveshwara Temple	1
Sri Hanuman Temple	3
Durgamma Temple	1
Shree Vasavi Kanyaka Parameswari And Anjaneya Temple	3
Sri Mallikarjun Temple	4
Syed Sultan Sha Arab Darga	1
Govt High School Maraladinni	3
Sanjeevini Hospital	5
Maski Nala Bridge	6

VULNERABILITY

- H 1
- H 2
- H 3
- H 4
- H 5
- H 6
- ROADS
- RAILWAYS

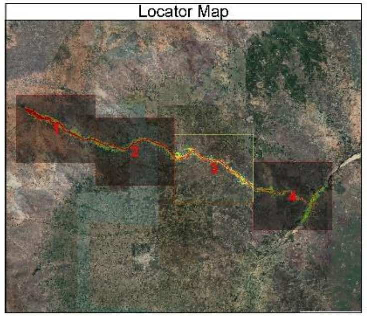
Locations

Class

- Bridge
- School / College / Universities
- GESCOM Office
- Gram Panchayat
- Hospital
- Police Station
- Post Office
- Temple / Mosque / Church
- Water Treatment Plant

Note: Print on A0 size sheet is suggested.

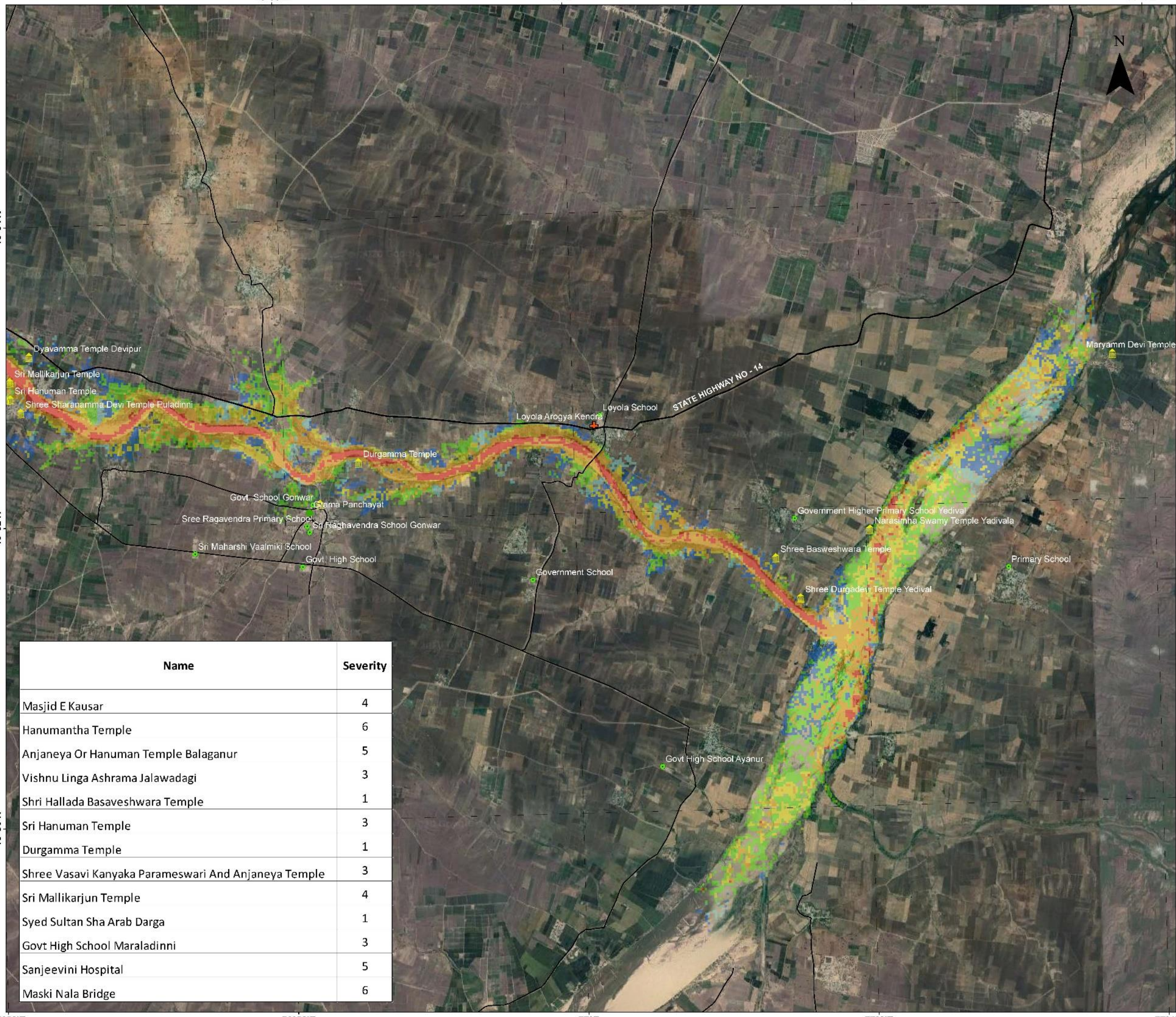
Locator Map



CENTRAL PROJECT MANAGEMENT UNIT

DAM REHABILITATION AND IMPROVEMENT PROJECT

Name of Dam	MASKI NALA
State	KARNATAKA
Title	SUNNY DAY FAILURE
Doc. No.	CDSO_DSR_MAP_MASKI NALA_ _KAWRD
Date :	February, 2020 — Map No. 3 / 4
Scale :	0 0.5 1 2 Km



Name	Severity
Masjid E Kausar	4
Hanumantha Temple	6
Anjaneya Or Hanuman Temple Balaganur	5
Vishnu Linga Ashrama Jalawadagi	3
Shri Hallada Basaveshwara Temple	1
Sri Hanuman Temple	3
Durgamma Temple	1
Shree Vasavi Kanyaka Parameswari And Anjaneya Temple	3
Sri Mallikarjun Temple	4
Syed Sultan Sha Arab Darga	1
Govt High School Maraladinni	3
Sanjeevini Hospital	5
Maski Nala Bridge	6

VULNERABILITY

- H 1
- H 2
- H 3
- H 4
- H 5
- H 6
- ROADS
- RAILWAYS

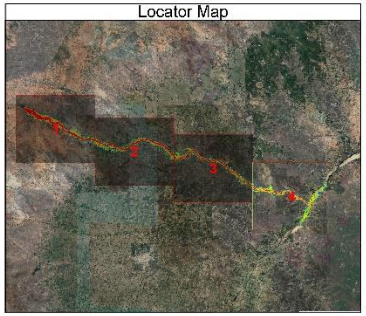
Locations

Class

- Bridge
- School / College / Universities
- GESCOM Office
- Gram Panchayat
- Hospital
- Police Station
- Post Office
- Temple / Mosque / Church
- Water Treatment Plant

Note: Print on A0 size sheet is suggested.

Locator Map



CENTRAL PROJECT MANAGEMENT UNIT

DAM REHABILITATION AND IMPROVEMENT PROJECT

Name of Dam	MASKI NALA
State	KARNATAKA
Title	SUNNY DAY FAILURE
Doc. No.	CDSO_DSR_MAP_MASKI NALA__KAWRD
Date :	February, 2020 — Map No. 4 / 4
Scale :	0 0.5 1 2 Km

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Appendix D. SUMMARY OF UTILITY CURVES FOR POINTS SCORE ESTIMATION (PROPERTY DAMAGE AND ENVIRONMENTAL/CULTURAL IMPACT)

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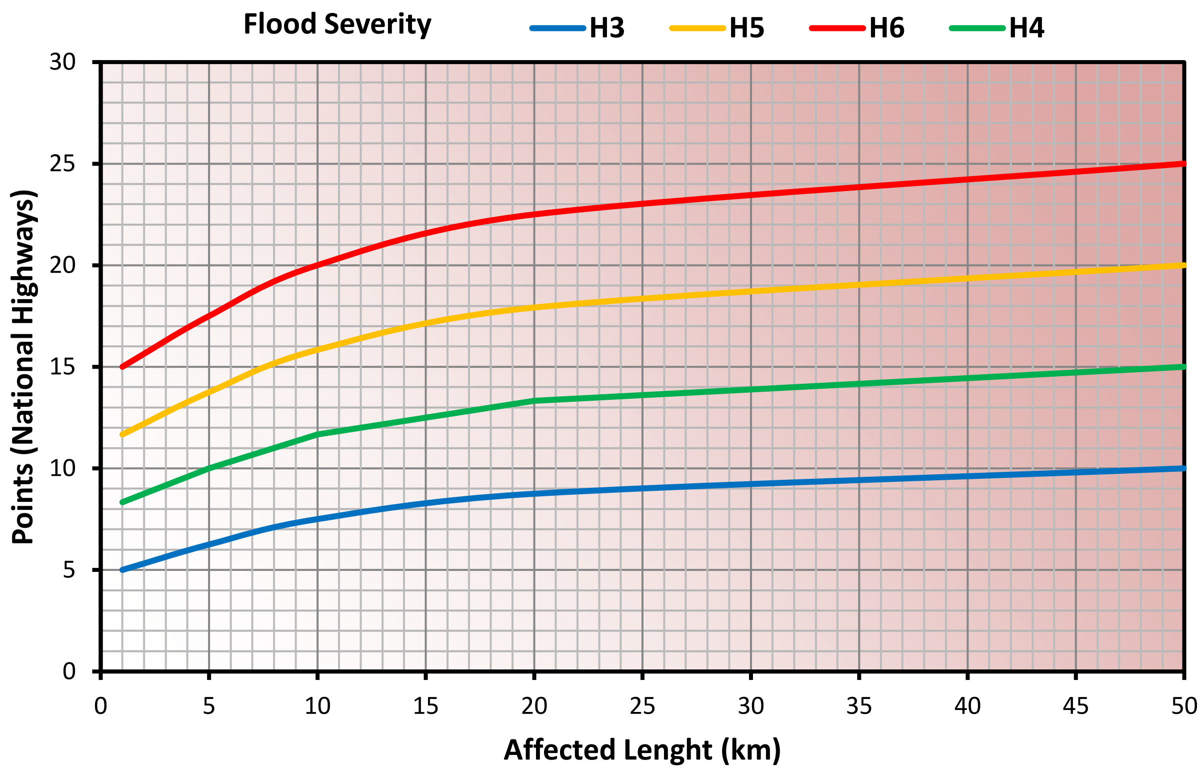

Figure C.1.- Utility Curves for Point Score Estimation of National Highways

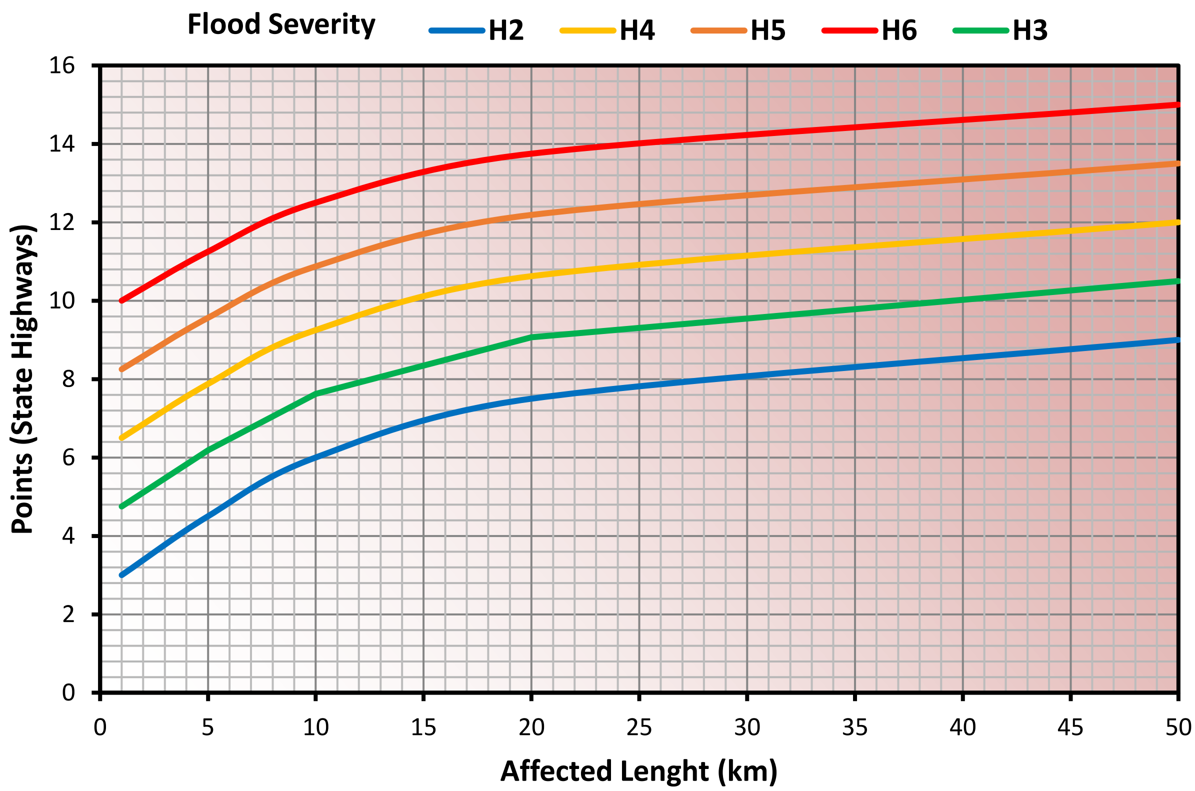

Figure C.2.- Utility Curves for Point Score Estimation of State Highways

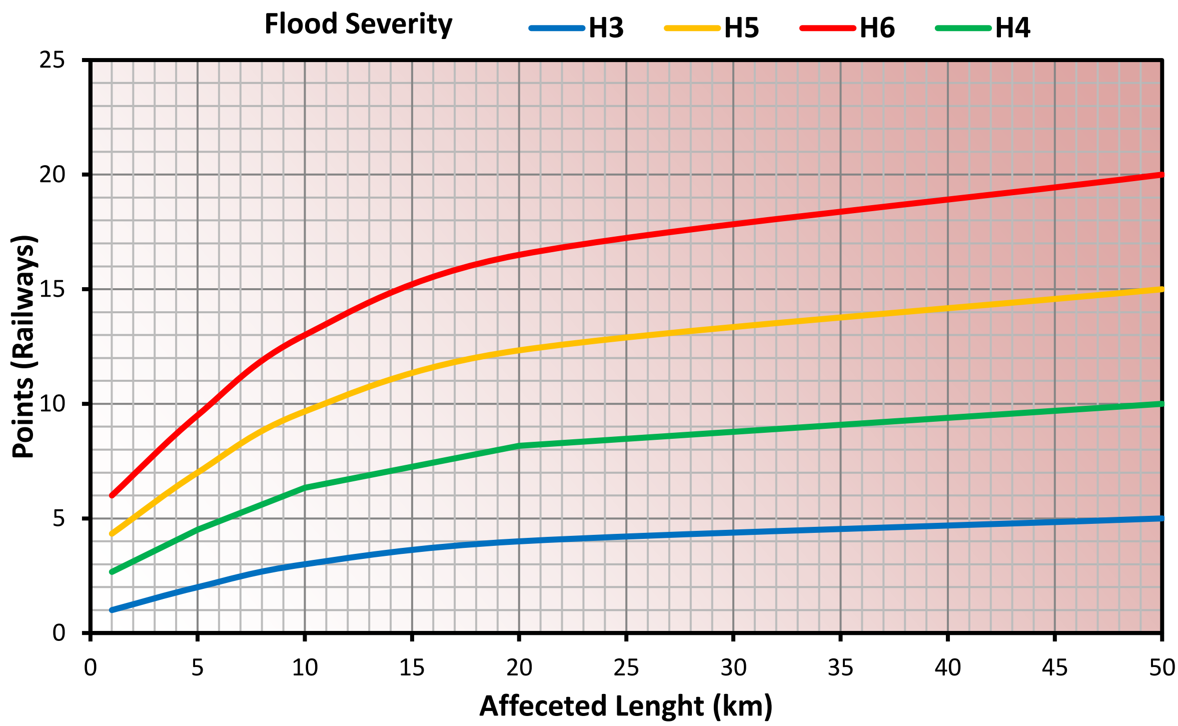

Figure C.3.- Utility Curves for Point Score Estimation of Railways

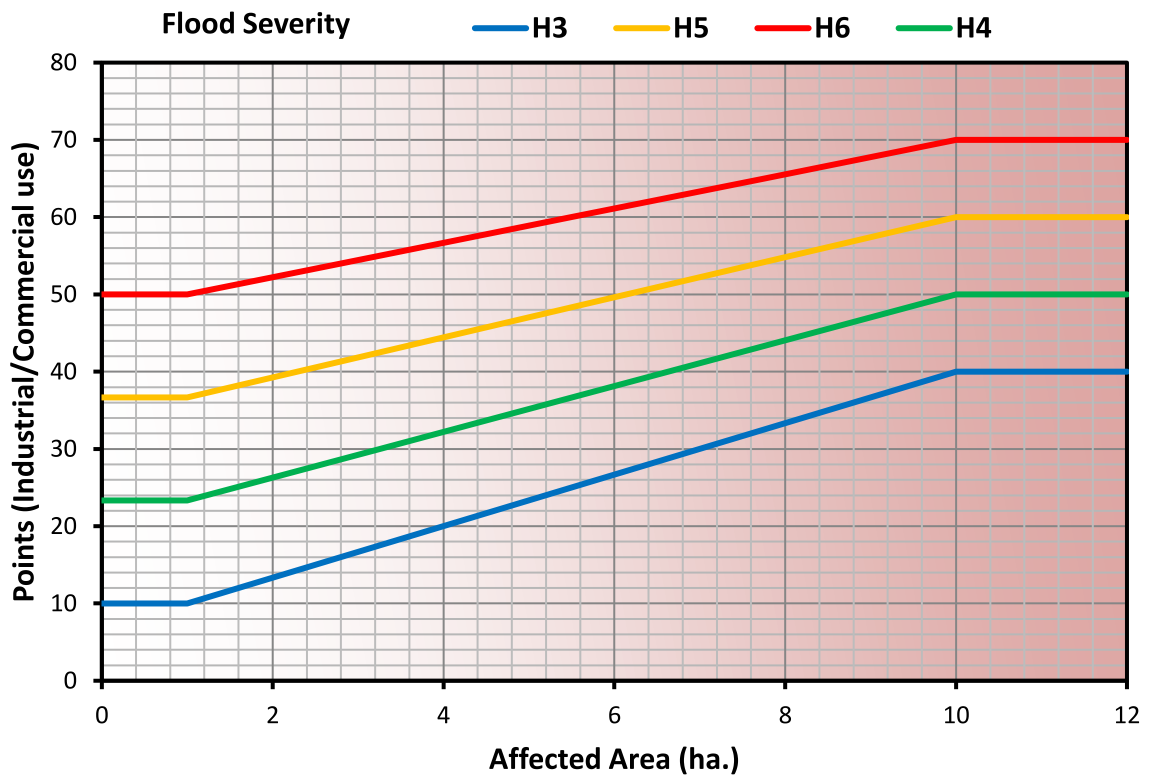

Figure C.4.- Utility Curves for Point Score Estimation of Industrial & Commercial Land Use

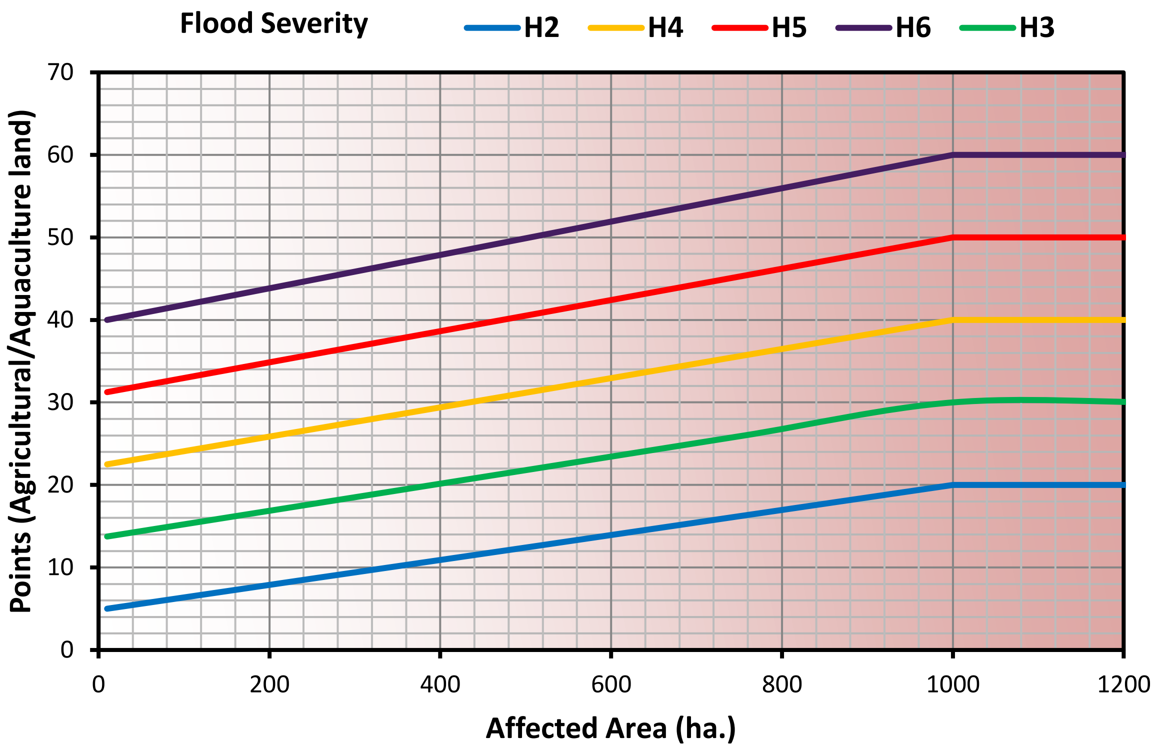

Figure C. 5.- Utility Curves for Point Score Estimation of Agricultural Land Use

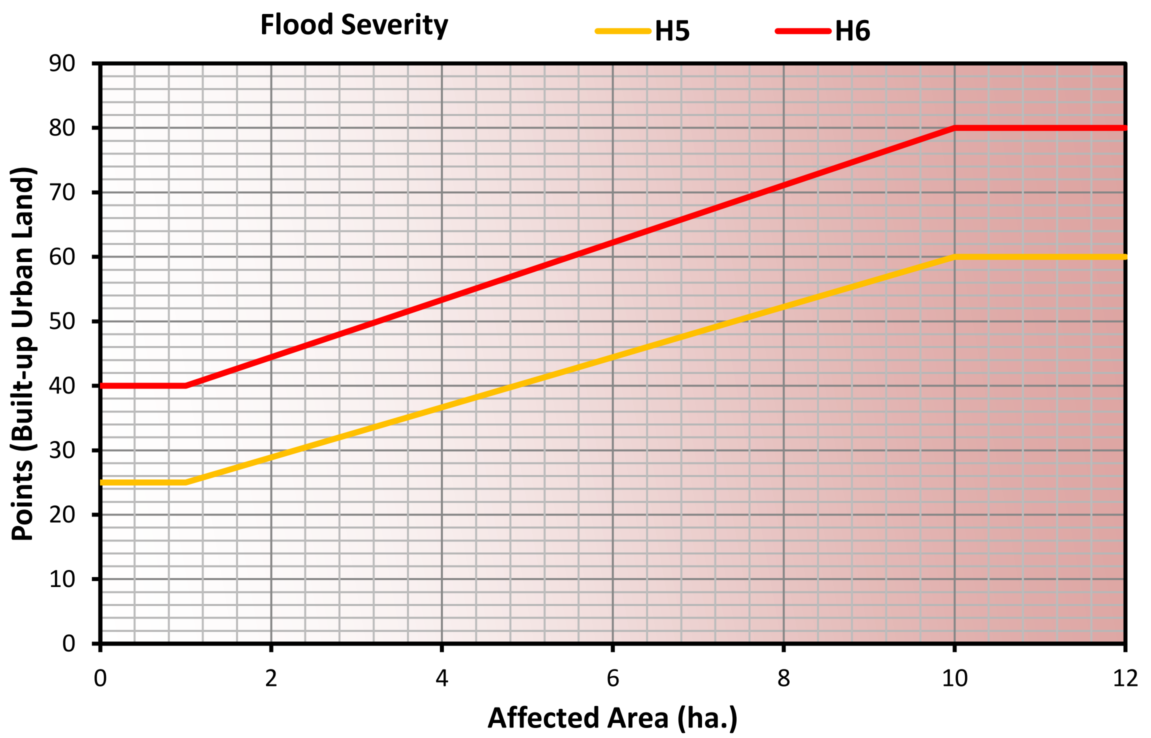

Figure C.6.- Utility Curves for Point Score Estimation of Built-up Urban Land Use

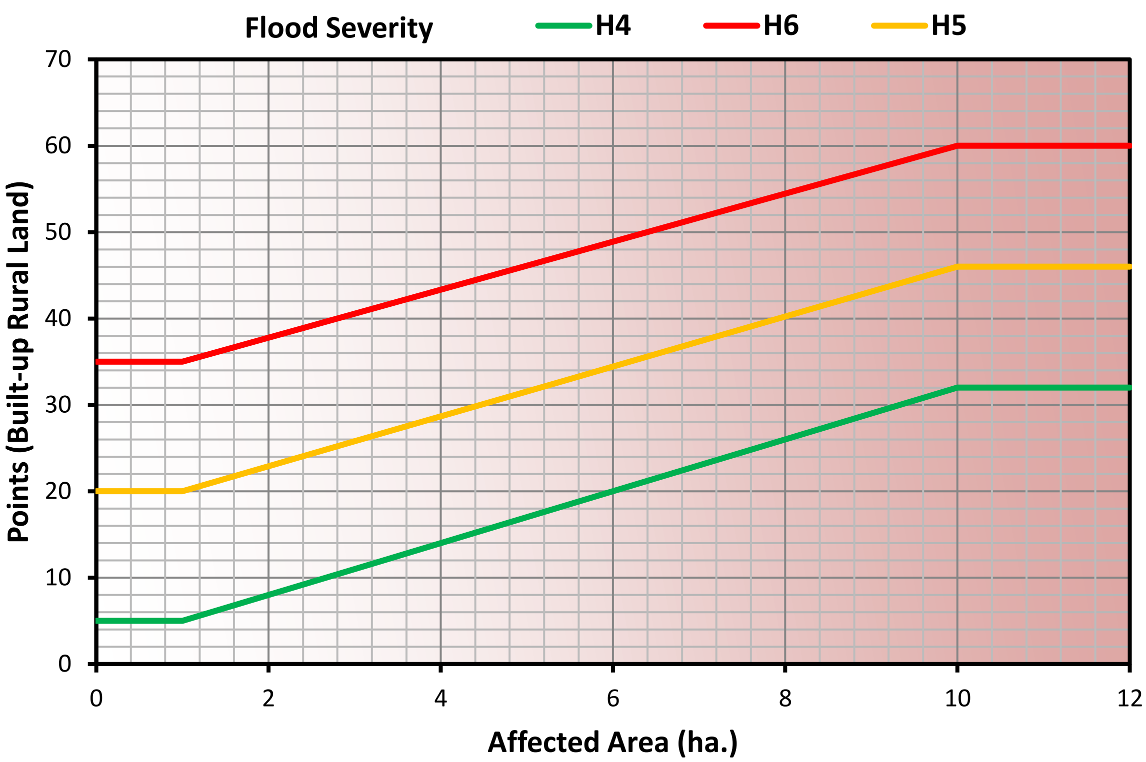

Figure C.7.- Utility Curves for Point Score Estimation of Built-up Rural Land Use

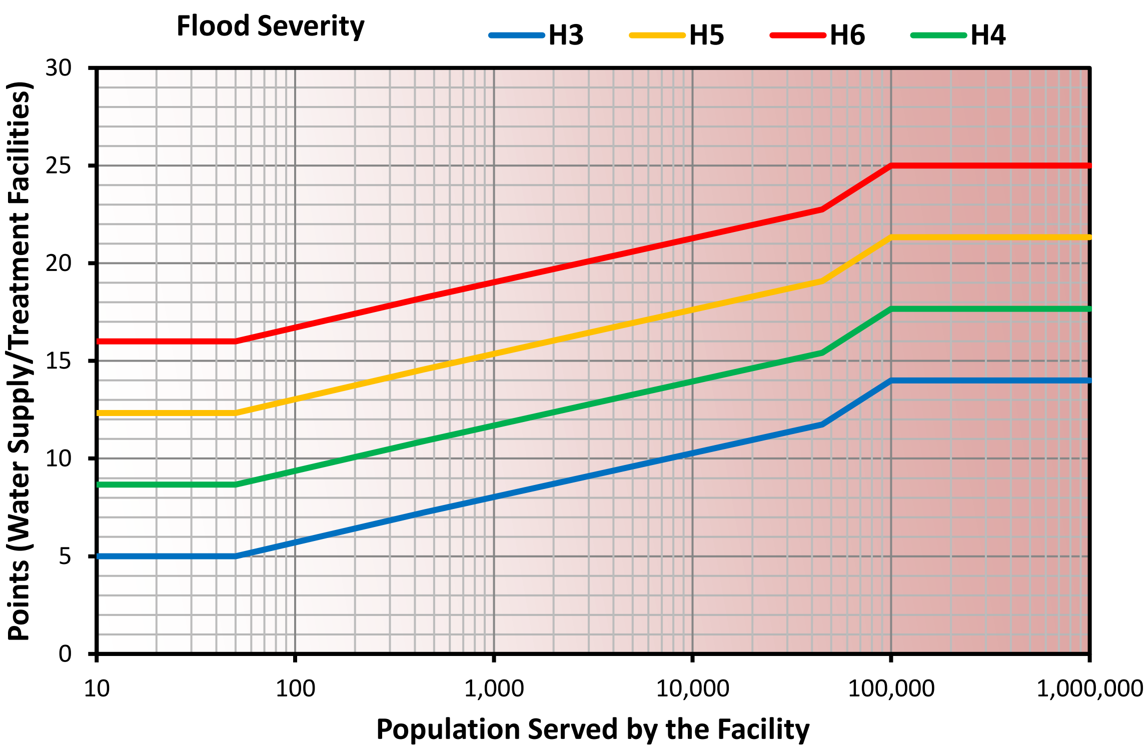

Figure C.8.- Utility Curves for Point Score Estimation of Water Supply/Treatment Facilities

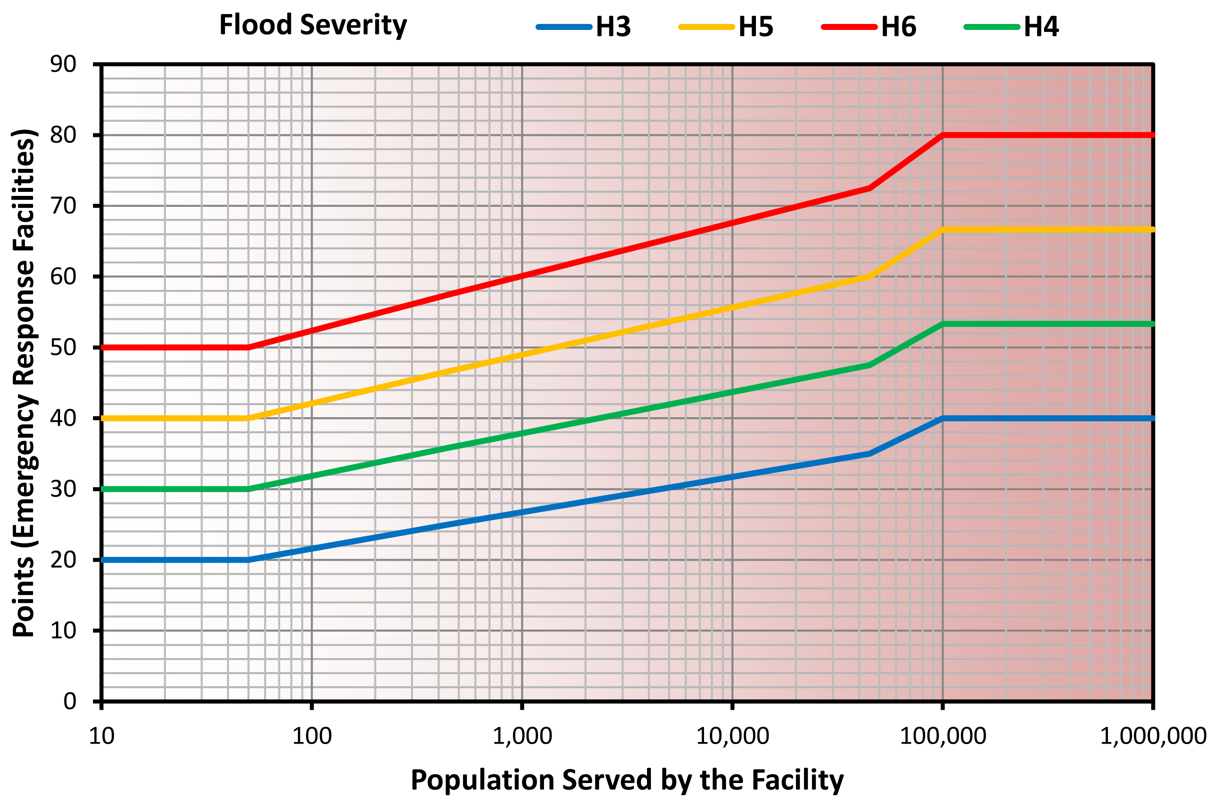

Figure C.9.- Utility Curves for Point Score Estimation of Emergency Response Facilities

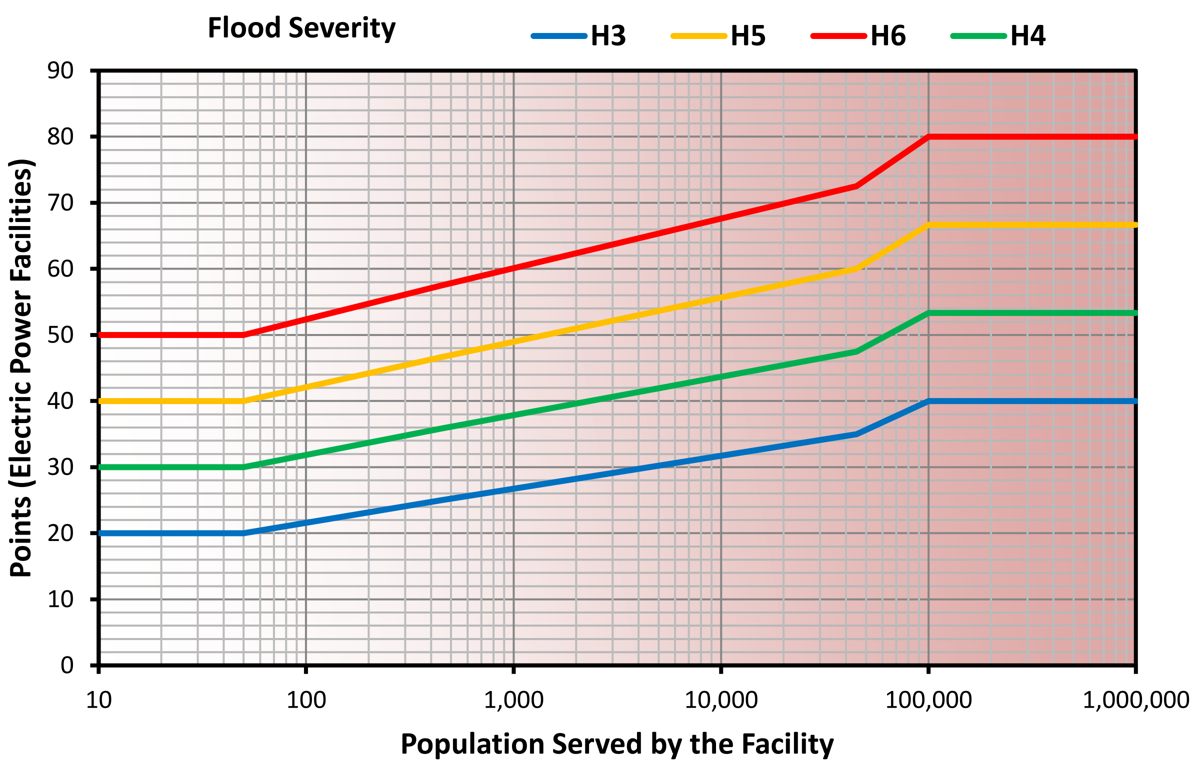

Figure C.10.- Utility Curves for Point Score Estimation of Electric Power Facilities

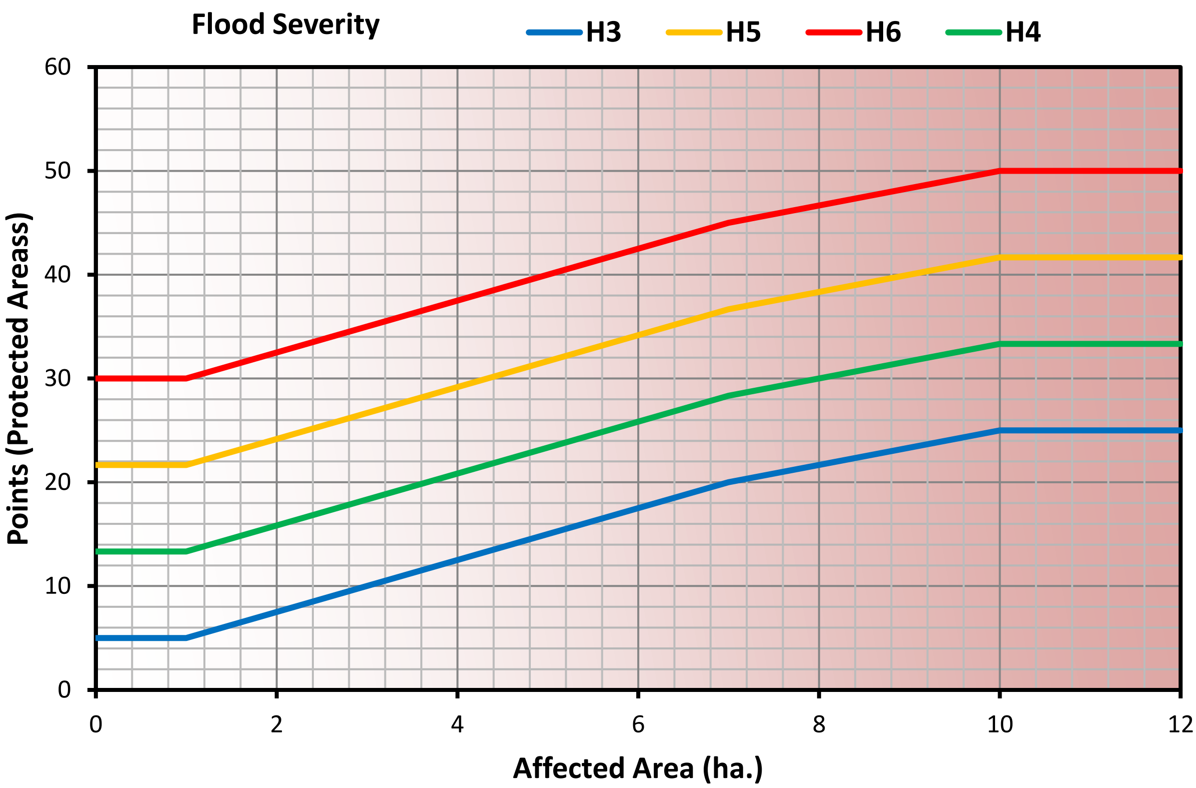

Figure C.11.- Utility Curves for Point Score Estimation of Protected Areas

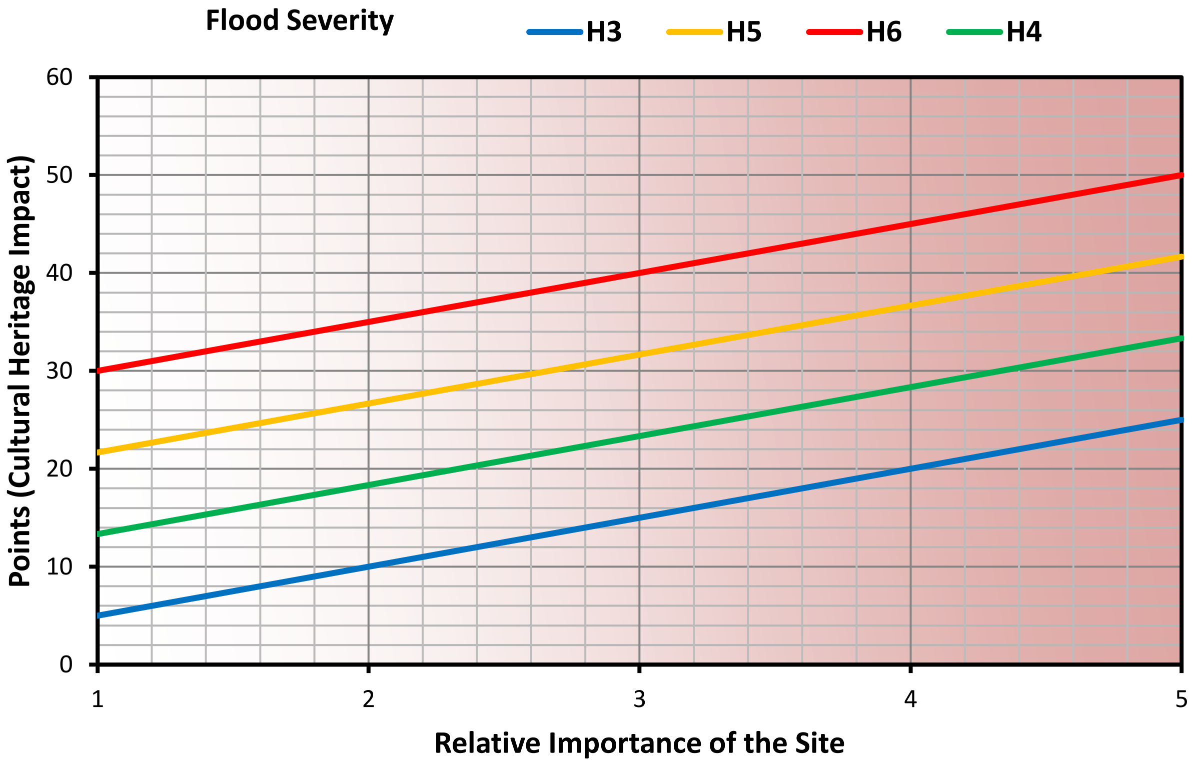

Figure C.12.- Utility Curves for Point Score Estimation of Cultural Heritage Sites

Appendix E. SOURCES OF INFORMATION FOR THE HAZARD CLASSIFICATION PROCESS

Disclaimer: The following sources represent a compilation of both public and commercial datasets available at the moment of publication of this Guideline. Therefore, The Central Dam Safety Organization or the Central Water Commission cannot be held responsible for outdated information during the period that this guidelines' version remains published. Also, please be aware that more accurate data as well as additional sources may become available after publication of this document

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Digital Elevation Models							
Data Type	Organisation / Satellite	Product Name	Cell Resolution[1] (m)	Vertical Accuracy[2] (m)	Planimetric Accuracy[3] (m)	Link to Download	Public /Commercial Use
DSM	NRSC/ Cartosat-1	CartoDEM[4]	10	8	15	https://www.nrsc.gov.in/	Commercial
DSM	NRSC/ Cartosat-1	CartoDEM[5]	30	8	15	https://bhuvan-app3.nrsc.gov.in/data/download/index.php	Public
DSM	JAXA / ALOS-Prism	AW3D30[6]	30	5.3	5	https://www.eorc.jaxa.jp/ALOS/en/aw3d30/index.htm	Public
DSM	NASA/ Terra (EOS AM-1)	ASTER GDEM v3[7]	30	15-20	15-20	https://search.earthdata.nasa.gov/search	Public
DSM	NASA & USGS /SRTM	SRTM 1arc sec[8]	30	6-9	7-12	https://earthexplorer.usgs.gov/	Public

Notes:

1 Values are approximate at the equator.

2 Vertical accuracy expressed as Liner Error with 90% confidence interval (LE90)

3 Planimetric accuracy expressed as Circular Error with 90% confidence interval (CE90)

4 Source: https://bhuvan-app3.nrsc.gov.in/data/download/tools/document/cartodem_bro_final.pdf

5 Source: https://bhuvan-app3.nrsc.gov.in/data/download/tools/document/technicaldoc_cartosatv3.pdf

6 Source: https://www.isprs-ann-photogramm-remote-sens-spatial-inf-sci.net/III-4/25/2016/isprs-annals-III-4-25-2016.pdf

7 Source: https://asterweb.jpl.nasa.gov/gdem.asp

8 Source: https://www2.jpl.nasa.gov/srtm/

Land Cover – Land Use								
No.	**Data Format**	**Data Type**	**Organisation**	**Dataset Name / Date**	**Reso-lution / scale**	**No. The-matic Classes**	**Link to Download**	**Public/Com-mercial Use**
1	Vector File	Land Use and Land Cover	National Remote Sensing Centre	Datasets No. 2 to 5 below (in vector file format)	-	-	https://www.nrsc.gov.in/	Commercial
2	Web-service (image)	Land Use and Land Cover	National Remote Sensing Centre	LULC 50K / 2015-16	1: 50K	24	https://bhuvan-app1.nrsc.gov.in/thematic/the-matic/index.php	Public
3	Web-service (image)	Land Use and Land Cover	National Remote Sensing Centre	LULC 250K / every year	1:250K	18	https://bhuvan-app1.nrsc.gov.in/thematic/the-matic/index.php	Public
4	Web-service (image)	Land Use & Land Cover	National Remote Sensing Centre	LULC SIS-DP (only 637 districts)	1:10 K	19	https://bhuvan-app1.nrsc.gov.in/thematic/the-matic/index.php	Public
5	Web-service (image)	Urban Land Use & Land Cover	National Remote Sensing Centre	LULC NUIS (only 637 districts)	1:10 K	39	https://bhuvan-app1.nrsc.gov.in/thematic/the-matic/index.php	Public
6	Raster (Geo-TIFF)	Land Use	Socioeconomic Data and Applications Center (SEDAC)	2011	1 Km	19	https://sedac.ciesin.colum-bia.edu/data/set/india-spatial-india-census-2011/data-download	Public
7	Raster (Geo-TIFF)	Land Use and Land Cover	The Oak Ridge Na-tional Laboratory Distributed Active Archive Center (ORNL DAAC)	2005	100 m.	19	https://daac.ornl.gov/cgi-bin/dsviewer.pl?ds_id=1336	Public
8	Raster (Geo-TIFF)	Land Cover	European Space Agency (ESA)	Glob Cover 2009 v2.3	300 m.	22	http://due.esrin.esa.int/page_glob-cover.php	Public

Population Data						
Data Format	**Organisation**	**Data Source**	**Remarks**	**Resolution / Scale**	**Link**	**Public/Commercial Use**
Handbooks	Ministry of Home Affairs	Census 2011	Official Publications from Government of India	-	https://censusindia.gov.in/2011census/dchb/DCHB.html	Public
Microsoft Excel File and Web Data Viewer	NRSC	Census 2011	Official Census 2011 Data presented on Indian Geoplatform of ISRO (Bhuvan)	-	https://bhuvan-app1.nrsc.gov.in/social_justice/socialjustice_census.php	Public
Raster (GeoTIFF)	School of Geography and Environmental Science, University of Southampton	United Nation (UN) Estimates and India Census 2011	National totals adjusted to match United Nations (UN) population division estimates (http://esa.un.org/wpp/). Data extrapolated to 2020	100 m.	https://www.worldpop.org/	Public
Raster (GeoTIFF)	Socioeconomic Data and Applications Center (SEDAC)	India Census 2011	The Spatial Data from the 2011 India Census contains gridded estimates of India population at a resolution of 1 kilometre The input data are extrapolated to produce population estimates for the years 2000, 2005, 2010, 2015, and 2020	1 Km	https://sedac.ciesin.columbia.edu/data/set/gpw-v3-population-density/data-download	Public

Dam Salient Features, Project Benefits and Floodplain Impact				
Data required	**Data Source**	**Data Format**	**Link**	**Public/ Commercial Use**
Salient Features and Project benefits	Concerned dam authorities/Central Water Commission (CWC)	Not specified	It varies	Public
	Dam Health and Rehabilitation Monitoring Application	Web Data Viewer	https://damsafety.in/dharma/Home1/index.php	Public
Road and Railway network	Concerned state government departments	Not specified	It varies	Public
	National Highways Authority of India	Not specified	https://nhai.gov.in/indian-road-network.htm	Public
	Socioeconomic Data and Applications Center (SEDAC)	Vector data	https://sedac.ciesin.columbia.edu/data/set/groads-global-roads-open-access-v1/data-download	Public
	National Informatics Centre	Web Viewer	https://stategisportal.nic.in/stategisportal/	Public
	Digital Chart of the World	Vector data	https://www.diva-gis.org/gdata	Public
	Open Street Maps (open source)	Vector Data (*.osm file)	https://www.openstreetmap.org/	Public
Infrastructure d/s of dam (Water supply and treatment, emergency services)	Concerned state government departments	Not specified	It varies	Public
	Google Maps	Web Data Viewer	https://www.google.com/maps/	Public
	Open Street Maps (open source)	Vector Data (*.osm file)	https://www.openstreetmap.org/	Public

Protected areas (national parks, wildlife sanctuaries, conservation reserves, etc)	Concerned state government departments	Not specified	It varies	Public
	ENVIS Centre on Wildlife & Protected Areas	Image (*jpg)	http://www.wiienvis.nic.in/Database/Maps_PAs_1267.aspx	Public
	National Remote Sensing Centre (NRSC)	Web Data Viewer (Point Location)	https://bhuvan-app1.nrsc.gov.in/moef/ https://bhuvan-app1.nrsc.gov.in/envis/	Public
	National Informatics Centre	Web Viewer	https://stategisportal.nic.in/stategisportal/	Public
	Open Street Maps (open source)	Vector Data (*.osm file)	https://www.openstreetmap.org/	Public
Cultural heritage sites	Concerned Central & State government departments	Not specified	It varies	Public
	Archaeological Survey of India (ASI), Ministry of Culture (MoC)	Web Viewer	https://asi.nic.in/world-heritage-sites/	Public
	United Nations Educational, Scientific and Cultural Organisation (UNESCO)	Web Viewer	https://whc.unesco.org/en/statesparties/in	Public
	National Informatics Centre	Web Viewer	https://stategisportal.nic.in/stategisportal/	Public
	National Remote Sensing Centre (NRSC)	Web Data Viewer (Point Location of Monuments)	https://bhuvan-app1.nrsc.gov.in/culture_monuments/	Public

Population Data						
Data Format	**Organisation**	**Data Source**	**Remarks**	**Resolution / Scale**	**Link**	**Public/Commercial Use**
Handbooks	Ministry of Home Affairs	Census 2011	Official Publications from Government of India	-	https://censusindia.gov.in/2011census/dchb/DCHB.html	Public
Raster (GeoTIFF)	School of Geography and Environmental Science, University of Southampton	United Nation (UN) Estimates and India Census 2011	National totals adjusted to match United Nations (UN) population division estimates (http://esa.un.org/wpp/). Data extrapolated to 2020	100 m.	https://www.worldpop.org/	Public
Raster (GeoTIFF)	Socioeconomic Data and Applications Center (SEDAC)	India Census 2011	The Spatial Data from the 2011 India Census contains gridded estimates of India population at a resolution of 1 kilometre The input data are extrapolated to produce population estimates for the years 2000, 2005, 2010, 2015, and 2020	1 Km	https://sedac.ciesin.columbia.edu/data/set/gpw-v3-population-density/data-download	Public

Appendix F. GLOSSARY OF TERMS FOR HAZARD POTENTIAL CLASSIFICATION

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Glossary of Terms for Hazard Potential Classification

The purpose of this glossary is to establish a common vocabulary of hazard potential terms for use within and among Central and State Government agencies. Terms have been included that are generic and apply to all dams, regardless of size, owner, or location.

Abutment – Shall mean that part of a valley side against which a dam is constructed. An artificial abutment is sometimes constructed as a concrete gravity section, to take the thrust of an arch dam where there is no suitable natural abutment.

Abutment - That part of the valley side against which the dam is constructed. An artificial abutment is sometimes constructed, as a concrete gravity section, to take the thrust of an arch dam where there is no suitable natural abutment. The left and right abutments of dams are defined with the observer viewing the dam looking in the downstream direction unless otherwise indicated.

Active Storage – The volume of the reservoir that is available for some use such as power generation, irrigation, flood control, water supply, etc. The bottom elevation is the minimum operating level.

Adequacy of the Failure Modes analysis - The determination of ALARP should be based on no less than a contemporary, thorough and expert assessment of potential failure modes. The organisations in charge of management of the dams will need to remain informed of any changes to the body of knowledge regarding potential failure modes, which may result in new failure modes being considered or modifications to event trees associated with existing failure modes.

Adverse Consequences - Negative impacts that may result from the failure of a dam. The primary concerns are a loss of human life, economic loss (including property damage), lifeline disruption, and environmental impact.

Ambient - Surrounding or occurring before a location or before an activity occurs. Ambient temperature is the temperature of the surrounding air. Ambient water quality is the water quality in a river, lake, or another water body, as opposed to the quality of water being discharged. In a river or stream, ambient water quality usually refers to the water upstream of a discharge point.

Annual Exceedance Probability (AEP) - The likelihood that a natural event (i.e. storm/flood) will occur in any given year, reported as a percent. Calculated as the reciprocal of the Recurrence Interval (VAT, 2015).

Annual Exceedance Probability (AEP) - The probability that flooding will occur at a given location (such as a consequence area index point, a specific grid cell, or a fragility curve location (also referred to as system response probabilities) in any given year considering the full range of possible annual floods and project performance (USACE, 2017).

Annualised Failure Probability - Annualised failure probability is the probability of dam failure occurring in any given year. It is the product of the probability of the load and the probability of dam failure given the load. Annualised failure probability is sometimes equated with Individual Risk.

Annualised Life Loss - Annualised life loss is the product of the annualised failure probability and the life loss that is expected to result from failure. A guideline for annualised life loss is commonly shown on the f-N diagram as a line with a negative slope. That is, as the severity of the consequences increases, the probability of the event causing those consequences must decrease in order to meet the risk targets.

Appurtenant Work – Structures associated with the dam including the following:

Appurtenant Works – Shall mean structures, either in dams or separate therefrom, including but not be limited to, spillways; reservoirs and their rims; low-level outlet works; and water conduits including tunnels, pipelines, or penstocks, either through the dams or their abutments.

Aquatic Ecosystem - An aquatic area where living and non-living elements of the environment interact. This includes the physical, chemical, and biological processes and characteristics of rivers, lakes, and wetlands and the plants and animals associated with them (AE, 2008).

Arch Dam - A concrete, masonry, or timber dam with the alignment curved upstream so as to transmit the major part of the water load to the abutments.

Attenuation - A decrease in amplitude of the seismic waves with distance due to geometric spreading, energy absorption, and scattering, or decrease in the amplitude of a flood wave due to channel geometry and energy loss.

Auxiliary Spillway – Any secondary spillway that is designed to be operated infrequently, possibly in anticipation of some degree of structural damage or erosion to the spillway that would occur during operation.

Availability of Risk Reduction Options - In some situations, for some failure modes, it may not be possible to identify additional viable risk reduction options, thus justifying an ALARP determination. Authorities in charge of dam management will need to be mindful of technological and other developments and review this assessment periodically.

Axis of Dam - The vertical plane or curved surface, chosen by a designer, appearing as a line, in the plan or in cross-section, to which the horizontal dimensions of the dam are referenced.

Backwater - The increase in the upstream water surface level resulting from an obstruction to flow, such as a roadway fill with a bridge or culvert opening placed on the floodplain.

Backwater Curve - The longitudinal profile of the water surface in an open channel where the depth of flow has been increased by an obstruction, an increase in channel roughness, a decrease in channel width, or a flattening of the bed slope.

Baffle Block - A block, usually of concrete, constructed in a channel or stilling basin to dissipate the energy of water flowing at high velocity.

Bank Full Width - The distance between channel bank full elevations, which is the elevation at which flow first floods over the bank into the floodplain.

Base Flow - The amount of water in a stream that results from groundwater discharge. The fair-weather or sustained flow of streams; that part of stream discharge not attributable to direct runoff from precipitation, snowmelt, or a spring. Discharge entering streams channels as effluent from the groundwater reservoir. It is also referred to as Groundwater Flow.

Base Thickness/ Base Width - The maximum thickness or width of the dam measured horizontally between upstream and downstream faces and normal to the axis of the dam, but excluding projections for outlets or other appurtenant structures.

Baseline Data - An initial set of observations or measurements used for comparison; a starting point.

Basin - The area of land that drains to a particular river. The official name of the basin in which the river or stream on which the dam is built is located. It may also be the main river on which the dam is built.

Benchmarking - The process of identifying best practices indicating superior performance. Benchmarks are adopted as targets for optimal organizational performance and may include standards or environmental management processes.

Benchmarking - The state-wide annual dam safety report of the Department and database maintained by them help to provide information to benchmark dam safety risks, and this information should improve annually as data/reporting matures. Such benchmarking may provide helpful information about investment and rate of risk reduction, particularly as risk diminishes over time with increasing investment, and this feedback information could help inform about investment decisions. In addition, dam safety management systems, processes and procedures could also be benchmarked against established good practice.

Benefits - Benefits are a measure of direct net benefits that accrue in the study area and the rest of the country. Benefits (also referred to as project benefits) are defined as the beneficial purposes which a dam and its water supply provide. Benefits (or lost benefits) are measured for agriculture, M&I, fish and wildlife, recreation, and hydropower. These lost benefits are one component of the total economic consequences.

Benefits Transfer - A benefits transfer is an approach used to estimate values by transferring available information from studies and/or economic analyses already completed at other sites with contexts similar in nature and character to the study at hand. The transfer can be done as a unit value transfer or a function transfer (USDHS, 2011).

Berm - A nearly horizontal step in the sloping profile of an embankment dam. Also a step in a rock or earth cut.

Best Management Practices (BMPs) - Practices that are technically and economically feasible and for which significant water conservation or water quality benefits can be achieved (CSU, 2012).

Breach - An opening through a dam that allows the uncontrolled draining of a reservoir. A controlled breach is a constructed opening. An uncontrolled breach is an unintentional opening caused by discharge from the reservoir. A breach is generally associated with the partial or total failure of the dam.

Catchment Area (Square Kilometres) - Area that drains to a particular point (in this case, the dam) on a river or stream.

Channel - A general term for any natural or artificial facility for conveying water. The term is generally applied to a temporary arrangement, e.g., to bypass water around a dam site during construction. Channel is normally used instead of the canal when the waterway is short.

Check Dam - A small dam constructed in a gully or other small watercourse to decrease the streamflow velocity, reduce channel erosion, promote deposition of sediment, and to divert water from a channel.

Check Dam - A small dam constructed in a gully or other small watercourse to decrease the stream flow velocity, minimize channel erosion, promote deposition of sediment, and to divert water from a channel.

Cofferdam - A temporary structure enclosing all or part of the construction area that construction can proceed in the dry. A diversion cofferdam diverts a stream into a pipe, channel, tunnel, or another watercourse.

Collaboration(Partnership) - A process through which parties who see different aspects of a problem can explore constructively their differences and search for (and implement) solutions that go beyond their own limited vision of what is possible. Collaboration is a mechanism for leveraging resources; dealing with scarcities; eliminating duplication; capitalizing on individual strengths; building internal capacities; and increasing participation and ownership strengthened by the potential for synergy and greater impact (AE, 2008).

Command and Control Approach - A method of environmental management by government that involves specific statutory controls and associated regulatory offences which are generally prescriptive in terms of outcomes and behaviours. Examples of this approach include: acts, regulations, approvals, licenses, authorizations, Codes of Practice, and orders (AE, 2008).

Compaction – A mechanical action that increases the density by reducing the voids in a material.

Compliance Assessment - An activity undertaken to determine whether a regulated party's activity/operation complies with a statute, regulation, authorization or Code of Practice. Compliance assessments educate the regulated party on legislative requirements and also identify current or potential non-compliance. Compliance assessments include inspections, reviews, and audits (AE, 2008).

Compliance Assurance - Activities that ensure regulated parties comply with legislation, including the Water Act. These activities include promoting compliance through education and prevention initiatives, and compelling compliance through enforcement responses.

Comprehensive Reviews - Comprehensive Reviews are in-depth routine examinations of facilities (structures forming an individual reservoir) carried out on a recurring basis. In addition to a comprehensive examination and records review, evaluations of potential failure modes and estimation of risks are typically completed by a senior engineer and peer reviewer.

Concurrent floods - Flood flows expected at a point on the river system below a dam at the same time a flood inflow occurs above the dam.

Condition Assessment - Assessment that best describes the condition of the dam based on available information: Satisfactory; Fair; Poor; Unsatisfactory; Not Rated.

Condition Assessment Date - Date of the most recent assessment of the dam prior to the transmittal of the data by the submitting agency.

Condition Assessment Detail - A specific detail that best describes the reason for condition assessment. This field only applies to dams that were assigned the condition Satisfactory, Poor, or Not Rated. Satisfactory: (hydrologic and seismic regulatory criteria / tolerable risk criteria), Poor: (deficiency recognized / more analysis needed), Not Rated: (dam has not been inspected / not under state jurisdiction / other).

Condition Index - A scoring system ranging from 0 (failed) and 100 (excellent) that rates the relative level of performance of a component or a system (USACE, 2008).

Conduit - A closed channel to convey water through, around, or under a dam.

Confidence - Confidence is a qualitative measure of belief that an engineering analysis, risk estimate, or recommended action is correct. Confidence is used to describe how sure the estimator(s) is about the general location of a risk estimate (or cloud of Monte Carlo simulation values) on an f-N chart. Similarly, the level of confidence influences recommended actions (USBR, 2011).

Consensus - When a group of individuals in a decision-making process work towards a general agreement by all involved.

Consequences - Potential loss of life or property damage downstream of a dam caused by floodwaters released at the dam or by waters released by partial or complete failure of the dam. Also effects of landslides upstream of the dam on property located around the reservoir. Consequences of dam failure can include economic losses due to property damage, lost benefits, and ripple effects through the economy; environmental damages as a result of large downstream flows and release of reservoir sediment; damages to cultural resources; and socio-economic damages to the affected communities. Although these consequences can be considered in the decision-making process, the primary consequences considered with respect to dam safety are human fatalities or life loss.

Conservation - The planning, management, and implementation of activity with the objective of protecting the essential physical, chemical, and biological characteristics of the environment against degradation. The process of managing biological resources (e.g., timber, fish) to ensure replacement by regrowth or reproduction of the part harvested before another harvest occurs. A balance between economic growth and environmental and natural resource protection.

Conservation Storage (Million Cubic Metres) - Conservation storage, defined as the total storage space in a reservoir below the full reservoir level, excluding any flood or surcharge storage. It includes inactive storage and conservation storage.

Consideration of Standards-Based Approaches - Satisfaction of contemporary engineering standards may assist with justifying an ALARP determination. Having met standards, there may be additional simple, low-cost risk reduction measures that could also be considered by dam owners and managers to reduce risk further.

Construction Joint - The interface between two successive placements or pours of concrete where bond, and not permanent separation, is intended.

Contact Grouting - Filling, with cement grout, any voids existing at the contact of two zones of different materials, i.e., between a concrete tunnel lining and the surrounding rock.

Control Dam - A dam or structure with gates to control the discharge from the upstream reservoir or lake.

Control Dam - A dam or structure with gates to control the discharge from the upstream reservoir or lake.

Conveyance - A measure of the flow capacity of a channel.

Core - A zone of low permeability material in an embankment dam. The core is sometimes referred to as the central core, inclined core, puddle clay core, rolled clay core, or impervious zone.

Core wall - A wall built of relatively impervious material, usually of concrete or asphaltic concrete in the body of an embankment dam to prevent seepage.

Corrective Action Study - A Corrective Action Study is a detailed investigation undertaken to evaluate potential alternatives and risk reduction options. A corrective action study may be performed after a decision has been made that action is justified to reduce risks at a particular facility.

Cost-Effectiveness - In general terms, this is the amount of risk reduction achieved per unit of money spent.

Crack Monitors - Measure movements transverse and along a joint or crack.

Creation of New Risks - Risk reduction may itself be risky. In some cases reducing dam safety risks cannot be done without creating new and poorly understood risks. In such a situation, evaluation of ALARP may conclude that it is better to leave things as they are.

Credible Potential Failure Mode - A potential failure mode that is considered to affect the total risk at a given dam and for which action could potentially be taken to reduce risk. A non- credible potential failure mode is a potential failure mode which is judged to have very low risks and for which a strong case can be made to that effect.

Non-credible potential failure modes are often judged to represent a risk that is well below tolerable risk guidelines and orders of magnitude less than that of the more dominant potential failure modes at a given dam (FEMA, 2015).

Crest – Shall mean the top of the dam, usually provides a road or path across the dam.

Crest Gate (Spillway Gate) - A gate on the crest of a spillway to control the discharge or reservoir water level.

Crest Length - The measured length of the dam along the crest or top of the dam.

Crest Width (Metre) - The thickness or width of a dam at the level of the top of the dam (excluding corbels or parapets).

Critical Elevation - The highest level above a stormwater feature that water can rise before causing unacceptable inundation of travel lanes or adjacent property (VAT, 2015).

Critical Flow - The type of flow that occurs when the Froude number has a value of 1.0, indicating that the inertial forces and gravitational forces are equal.

Critical Velocity - The flow velocity above which the bed material of particle size, D, and smaller will be transported.

Cross Section - An elevation view of a dam formed by passing a plane through the dam perpendicular to the axis.

Cumulative Effects - The combined effects on the aquatic environment or human developments arising from the combined environmental impacts of several individual projects.

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Cut-off Trench - A foundation excavation later to be filled with impervious material so as to limit seepage beneath a dam.

Cut-off wall - A wall of impervious material usually of concrete, asphaltic concrete, or steel sheet piling constructed in the foundation and abutments to reduce seepage beneath and adjacent to the dam.

Dam – Any artificial barrier including appurtenant works constructed across rivers or tributaries thereof with a view to impound or divert water; includes barrage, weir and similar water impounding structures but does not include water conveyance structures such as canal, aqueduct and navigation channel and flow regulation structures such as flood embankment, dyke and guide bund.

Dam Crest Elevation / Top of the Bank Level (Metre) - The lowest elevation at which water can flow over the top of the dam, not including flow through the spillway. If crest elevations for the masonry/concrete and earthen sections are different, it may be recorded accordingly.

Dam failure - Catastrophic type of failure characterized by the sudden, rapid, and uncontrolled release of impounded water or the likelihood of such an uncontrolled release It is recognized that there are lesser degrees of failure and that any malfunction or abnormality outside the design assumptions and parameters that adversely affect a dam's primary function of impounding water is properly considered a failure. These lesser degrees of failure can progressively lead to or heighten the risk of a catastrophic failure. They are, however, normally amenable to corrective action.

Dam Former Name - Any previous reservoir or dam name(s), if changed.

Dam Height (Metre) - Height of the dam, defined as the vertical distance between the lowest point on the crest of the dam and the lowest point in the original streambed at the downstream toe of the dam.

Dam Inspection – On-site examination of all components of dam and its appurtenances by one or more persons trained in this respect and includes examination of non-overflow portion, spillways, abutments, stilling basin, piers, bridge, downstream toe, drainage galleries, operation of mechanical systems (including gates and its components, drive units, cranes), interior of outlet conduits, instrumentation records and record-keeping arrangements of instruments.

Dam Length (Metre) - Length of the dam, defined as the length along the top of the dam. This also includes the spillway, navigation lock, fish ladder, etc., where these form part of the length of the dam. If detached from the dam, these structures should not be included.

Dam Name - Official name of the dam.

Dam Owner – The Central Government or a State Government or public sector undertaking or local authority or company and any or all of such persons or organisations, who own, control, operate or maintain a specified dam.

Dam Safety - Dam safety is the art and science of ensuring the integrity and viability of dams such that they do not present unacceptable risks to the public, property, and the environment. It requires the collective application of engineering principles and experience, and a philosophy of risk management that recognizes that a dam is a structure whose safe function is not explicitly determined by its original design and construction. It also includes all actions taken to identify or predict deficiencies and consequences related to failure and to document, publicize, and reduce, eliminate, or remediate to the extent reasonably possible, any unacceptable risks.

Dam Safety Priority Rating - The dam safety priority rating is a categorisation scheme that is intended to guide and prioritize appropriate actions at a structure or facility, particularly with regard to the urgency of actions, using risk as a component of the considerations.

Dam Safety Program Purposes - The purposes of a dam safety program are to protect life, property, and the environment by ensuring that all dams are designed, constructed, operated, and maintained as safely and as effectively as is reasonably possible. Accomplishing these purposes requires commitments to continually inspect, evaluate, and document the design, construction, operation, maintenance, rehabilitation, and emergency preparedness of each dam and the associated public. It also requires the archiving of documents on the inspections and histories of dams and the training of personnel who inspect, evaluate, operate, and maintain them. Programs must instil an awareness of dams and the hazards that they may present to the owners, the users, the public, and the local and national decision-makers. On both local and national scales, program purposes also include periodic reporting on the degree of program implementation. Key to accomplishing these purposes is to attract, train, and retain a staff proficient in the art and science of dam design (FEMA, 2004a).

Dam Type - Type of dam, viz., Earth, Rockfill, Gravity, Buttress, Arch, Multi-Arch, Concrete, Masonry, Stone, Roller-Compacted Concrete.

Date of Maximum Pool Elevation (DD / MMM / YYYY) - The date on which the highest maximum pool elevation occurred.

Dead Storage – The storage that lies below the invert of the lowest outlet and that, therefore, cannot readily be withdrawn from the reservoir.

Decision Process - Procedures and administrative responsibilities for the operation of spillway gates.

Degradation - Decrease in land elevation due to erosion.

Design Event - The physical counterpart to Design frequency. The representation of natural processes that have the potential to affect the performance and use of an engineered structure. The simulated storm or flood used to predict the behaviour of a proposed hydraulic system (VAT, 2015).

Design Flood – Maximum flood which a dam is designed to pass safely. Full spilling capacity of a spillway.

Design Frequency - An event with a designated Annual Exceedance Probability (AEP) that a proposed hydraulic system must be hydraulically capable of conveying without flooding and becoming impassable.

Design Water Elevation (Metre) - Maximum attainable water surface elevation, including flood surcharge, that a dam is designed to withstand.

Design Wind - The most severe wind that is possible at a particular reservoir for generating wind setup and run-up. The determination will generally include the results of meteorological studies that combine wind velocity, duration, direction and seasonal distribution characteristics in a realistic manner.

Detention - The temporary storage of water.

Detention Basin - A facility that temporarily detains stormwater with an outlet that restricts the outflow to a pre-project development rate.

Deterministic Methodology - A method in which the chance of occurrence of the variable involved is ignored and the method or model used is considered to follow a definite law of certainty and not probability.

Dike (Levee) - A long low embankment dam. The term is usually applied to auxiliary dams used to close off areas that would otherwise be flooded by the reservoir.

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Direct Economic Consequences - Direct economic consequences are defined for the purpose of this reference document as the costs of lost project benefits, downstream property damages, and repair/replacement costs.

Direct Economic Effects - In a multiplier type of analysis, direct effects are the initial changes in the industry to which there is a change in final demand. The direct effects are equal to the value of the change in final demand used to estimate regional impacts. For example, the direct effects of a management action resulting in water delivery changes may be changes in the value of agricultural production due to changes in irrigated acreage.

Discharge - Refers to the outflow, and is used as a measure of the rate at which a volume of water passes a given point. Therefore, the use of this term is not restricted as to course or location, and it can be used to describe the flow of water from a pipe or a drainage basin.

Distance to Nearest Downstream City/Town (Kilometres) - Distance from the dam to nearest affected downstream city/town/village to the nearest kilometre (and tenth if appropriate).

District/State Information - If the main features of the project (impounding structure, navigation locks, etc.) are located across District/State lines, please provide all relevant District/State information.

Diversion – Interception of a partial or full flow that takes the water to a different channel across a watershed or subarea divide. Removal of water from its natural course or location by canal, pipe, or another conduit.

Diversion Channel, Canal, or Tunnel - A waterway used to divert water from its natural course.

Downstream – Shall mean the high side of the dam, the side opposite the upstream side.

Downstream Hazard Potential - A potential hazard to the downstream area resulting from failure or mis-operation of the dam (L:

Low, S: Significant, H: High, U: Undetermined).3

Drain, Blanket - A layer of pervious material placed to facilitate drainage of the foundation and/or embankment.

Drain, Chimney - A vertical or inclined layer of pervious material in an embankment to facilitate and control drainage of the embankment fill.

Drain, Toe - A system of pipe and/or pervious material along the downstream toe of a dam used to collect seepage from the foundation and embankment and convey it to a free outlet.

Drainage Area - The area that drains to a particular point on a river or stream.

Drainage Basin - All the land that serves as a drainage for a specific stream or river.

Drainage Curtain - A line of vertical wells or boreholes to facilitate drainage of the foundation and abutments and to reduce water pressure.

Drainage Wells or Relief Wells - Vertical wells downstream of or in the downstream shell of an embankment dam to collect and control seepage through and under the dam. A line of such wells forms a drainage curtain.

Drawdown - The difference between a water level and a lower water level in a reservoir within a particular time. Used as a verb, it is the lowering of the water surface.

Duration that the Risk Applies - A greater focus on risk reduction may be prudent for failure modes associated with enduring risks compared to shorter term risks. Short duration of risk here is not to be confused with rare events or low failure probability. In principle though, risk is expressed as an intensity (that is, as likelihood of consequences per annum) and intensity is not affected by duration.

Earth Dam/ Earth-fill Dam - An embankment dam in which more than 50% of the total volume is formed of compacted earth layers with particles that are generally smaller than 75-millimetre size.

Earthquake - A sudden motion or trembling in the earth caused by the abrupt release of accumulated stress along a fault.

Economic Consequences - Economic consequences are the direct and indirect economic impacts associated with a dam failure or disruption event.

Economic Instruments (Market-Based Instruments) - Policies, programs, or initiatives that provide financial motivation to achieve environmental and resource management objectives. Economic instruments encourage firms and/or individuals to undertake pollution control efforts that are in their own interests and that collectively meet policy goals by providing monetary or near-monetary rewards for polluting less or by imposing costs for polluting more, thus supplying the necessary motivation for polluters to change their behaviour. A few examples of economic instruments include pollution taxes, tax credits, and deposit refund systems (like the beverage container recycling program), among many others (AE, 2008).

Ecosystem - A community of interdependent organisms together with the environment they inhabit and with which they interact.

Ecosystem Functions - Processes that are necessary for the self-maintenance of an Ecosystem such as primary production, nutrient cycling, decomposition, etc. The term is used primarily as a distinction between values.

Efficiency – The need for society to distribute and use available resources for the greatest benefit.

Embankment Dam – Any dam constructed of excavated natural materials, such as both earth-fill and rock-fill dams, or of industrial waste materials, such as a tailings dam.

Emergency - A condition that develops unexpectedly, which endangers the structural integrity of a dam and/or downstream human life or property, and requires immediate action.

Emergency action plan (EAP) – A plan of action to be taken to reduce the potential for property damage and loss of life in an area affected by a dam failure or large flood. A written document prepared by the dam owner or the owner's professional engineer describing a detailed plan to prevent or lessen the effects of a failure of the dam or appurtenant structures. A code is used to indicate whether the dam has an Emergency Action Plan.

Emergency Action Plan (EAP) Exercise - An activity designed to promote emergency preparedness; test or evaluate EAPs, procedures, or facilities; train personnel in emergency management duties; and demonstrate operational capability. Exercises consist of the performance of duties, tasks, or operations very similar to the way they would be performed in a real emergency. However, the exercise performance is in response to a simulated event.

Emergency Alert System - A network of radio stations that voluntarily provide official emergency instructions or directions to the public during an emergency.

Emergency Gate - A standby or auxiliary gate used when the normal means of water control is not available for use.

Emergency Preparedness Plan - Formal plan of procedures to alleviate hazards during construction of or after completion of a dam or to reduce damages if conditions develop in which dam failure is likely or unpreventable. These emergency plans related to dam safety do not include flood plain management for the controlled release of floodwater for which the project is designed.

Emergency Spillway – An auxiliary spillway designed to pass large, but infrequent, the volume of flood flow, with a crest elevation higher than the principal spillway or normal operating level.

Endorsement - The act of partners within a partnership formally expressing their assent, publicly and definitively, to proceed with a policy, plan, or initiative.

Enforcement - Those activities that compel and/or force adherence to legal requirements.

Enforcement Authority - State regulatory organization, has the authority to issue notices, when applicable, to require owners of dams to perform necessary maintenance or remedial work, revise operating procedures, or take other actions, including breaching dams when necessary.

Environment - The components of the earth, including air, land, and water, all layers of the atmosphere, organic and inorganic matter, living organisms, and their interacting natural systems.

Environmental Assessment - A formal review of the impacts of a proposed development project to support the goals of environmental protection and sustainable development, as required by the Environmental Protection and Enhancement Act.

Equity – The right of individuals and society to be protected, and the right that the interests of all are treated fairly.

Erosion - The natural breakdown and movement of soil and rock by water, wind, or ice. The wearing off of a surface (bank, streambed, embankment, or another surface) by floods, waves, wind, or any other natural process. The process may be accelerated by human activities.

Facility Contact(s) – Owner/operator representative(s) designated as facility point of contact (e.g., project manager) and qualified to answer technical questions regarding project characteristics and its different operations

Failure Mode - A potential failure mode is a physically plausible process for dam failure resulting from an existing inadequacy or defect related to a natural foundation condition, the dam or appurtenant structures design, the construction, the materials incorporated, the operations and maintenance, or ageing process, which can lead to an uncontrolled release of the reservoir.

Filter (Filter Zone) - One or more layers of granular material graded (either naturally or by selection) so as to allow seepage through or within the layers while preventing the migration of material from adjacent zones.

Flashboards - Structural members of timber, concrete, or steel placed in channels or on the crest of a spillway to raise the reservoir water level but intended to be quickly removed, tripped, or fail in the event of a flood.

Flip Bucket - An energy dissipater located at the downstream end of a spillway and shaped so that water flowing at a high velocity is deflected upwards in a trajectory away from the foundation of the spillway.

Flood - An overflow of water onto lands that are used or usable by man and not normally covered by water. Floods have two essential characteristics: it is temporary; and the land is adjacent to and inundated by overflow from a river, stream, lake, or ocean. A temporary rise in water surface elevation resulting in inundation of areas not normally covered by water. Hypothetical floods may be expressed in terms of average probability of exceedance per year such as one-percent-chance-flood or expressed as a fraction of the probable maximum flood or another reference flood.

Flood Damage Reduction or Flood Reduction - Due to practical limitations, structural and non-structural measures can only reduce flood damages by lowering flood levels or removing houses and businesses from flood-prone areas. Floods can neither be prevented nor controlled (HCFCD, 2009).

Flood Fringe - The part of a floodplain where, during a flood, the water is shallower (<1 m in depth) and moves more slowly (<1m/sec).

Flood Fringe - The part of a floodplain where, during a flood, the water is shallower (<1 m in depth) and moves more slowly (<1m/sec).

Flood Hydrograph – A graph showing, for a given point on a stream, the discharge, height, or another characteristic of a flood with respect to time.

Flood Plain - An area adjoining a body of water or natural stream that may be covered by floodwater. Also, the downstream area that would be inundated or otherwise affected by the failure of a dam or by large flood flows. The area of the floodplain is generally delineated by a frequency (or size) of the flood.

Flood Routing - A process of determining progressively over time the amplitude of a flood wave as it moves past a dam or downstream to successive points along a river or stream.

Flood Storage (Million Cubic Metres) - The retention of water or delay of runoff either by the planned operation, as in a reservoir, or by the temporary filling of overflow areas, as in the progression of a flood wave through a natural stream channel. Storage space available in a reservoir between the normal pool elevation and the maximum operating pool elevation (top of active storage).

Flood Surcharge – The storage volume between the top of the active storage and the design water level.

Flood, 100-Year - A 100-year flood does not refer to a flood that occurs once every 100 years, but to a flood level with a 1 percent or greater chance of being equalled or exceeded in any given year.

Flood, Inflow Design (IDF) - The flood flow above which the incremental increase in downstream water surface elevation due to the failure of a dam or other water impounding structure is no longer considered to present an unacceptable threat to downstream life or property. The flood hydrograph used in the design of a dam and its appurtenant works particularly for sizing the spillway and outlet works and for determining maximum storage, the height of the dam, and freeboard requirements.

Flood, Probable Maximum (PMF) - The flood that may be expected from the most severe combination of critical meteorological and hydrologic conditions that are possible in the drainage basin under study.

FloodGate - A gate to control flood release from a reservoir.

Floodway - The part of the floodplain that, during a flood, has the deepest, fastest, and most destructive flow of water.

Flow Measurement Devices (Flow Meters, Weirs, and Calibrated Bucket and Stopwatch) - Instruments that measure leakage quantities.

Flume - An open channel constructed with masonry, concrete or steel, rectangular or U shaped cross-section and designed for medium or high-velocity flow. Also, a channel in which water is accelerated for purposes of measurement.

Fluvial - Of or pertaining to rivers and streams; growing or living in streams ponds; produced the action of a river or stream.

f-N Chart/ f-N Diagram - An f-N chart is composed of individual f-N pairs, where each pair typically represents one potential failure mode (or in the case of total risk, the summation of all potential failure modes). On the f-N chart, f represents the annualized failure probability over all loading ranges. N represents the estimated life loss or number of fatalities associated with an individual failure mode, or the weighted equivalent number of fatalities associated with the summation of failure modes.

Foundation - The portion of the valley floor that underlies and supports the dam structure. The material upon which dam is founded.

Framework - An organized structure of policies, legislation, programs, and tasks created to achieve a specific outcome. There can be frameworks for broad policies and strategic initiatives at various scales (e.g. provincial, regional, sector, media); programs and program delivery; and short-term tasks and projects.

Freeboard – Vertical distance between a specified Stillwater (or other) reservoir surface elevation and the top of the dam, without camber. For example, freeboard above the maximum surface or freeboard above the normal reservoir level.

Froude Number - A dimensionless parameter representing the ratio of inertia forces to gravity forces.

Full Supply Level - The maximum storage level of a reservoir when it is full. This level usually corresponds to the level of the spillway crest for an un-gated spillway, or to the water level for which the dam is designated.

Gallery - A passageway in the body of a dam used for inspection, foundation grouting, and/or drainage.

Gantry Crane - A fixed or travelling bent-supported crane for handling heavy equipment.

Gate - A movable water barrier for the control of water.

Gate Chamber (Valve Chamber) - A room from which a gate or valve can be operated, or sometimes in which the gate is located.

Gauging/ Gauge Station - A location along a stream where measurements of stage or discharge are customarily made. The location includes a reach of the channel through which the flow is uniform, a control downstream from this reach, and usually a small building to house the recording instruments.

Geotextiles - Any fabric or textile (natural or synthetic) when used as an engineering material in conjunction with soil, foundations, or rock. Geotextiles have the following uses: drainage, filtration, separation of materials, reinforcement, moisture barriers, and erosion protection.

Gravity Dam – A dam constructed of concrete and/or masonry that relies on its weight and internal strength for stability.

Groin - The area along the contact (or intersection) of the face of a dam with the abutments.

Grout - A fluidized material that is injected into soil, rock, concrete, or other construction material to seal openings and to lower the permeability and/or provide additional structural strength. There are four major types of grouting materials: chemical; cement; clay; and bitumen.

Grout Curtain - One or more zones, usually thin, in the foundation into which grout is injected to reduce seepage under or around a dam.

Guideline - A specific performance measure that is not legally binding unless designated in legislation. It is a guide or indication of a future course of action. It describes how something will be accomplished. It may contain numerical performance measures and may deal with multiple uses of water.

Gumbel Distribution - A skewed statistical distribution for extreme value analysis.

Habitat - The natural home of a living organism. The three components of wildlife habitat are food, water, shelter.

Hazard - A situation that creates the potential for adverse consequences such as loss of life, property damage, or other adverse impacts. Potential loss of life or property damage downstream of a dam from floodwaters released at the dam or waters released by partial or complete failure of the dam, and upstream of the dam from effects of rim slides. A hazard is considered significant if there is a potential to cause loss of life or major damage to permanent structures, utilities, or transportation facilities.

Hazard Potential – The possible adverse incremental consequences that result from the release of water or stored contents because of failure or incorrect operation of the dam or appurtenances. Impacts may be for a defined area downstream of a dam from flood waters released through spillways and outlet works of the dam or waters released by partial or complete failure of the dam. There may also be impacts for an area upstream of the dam from effects of backwater flooding or landslides around the reservoir perimeter.

Hazard Potential Classification – A measure of the potential for loss of life, property damage, or economic impact in the area downstream of the dam in the event of a failure or malfunction of the dam or appurtenant structures. The hazard classification does not represent the physical condition of the dam.

Head Cut - The sudden change in bed elevation at the leading edge of a gully.

Head Gate - A control structure or gate upstream of a lock or canal; A floodgate that controls the flow of water, as in a ditch.

Head, Static - The vertical distance between two points in a fluid.

Head, Velocity - The vertical distance that would statically result from the velocity of a moving fluid.

Headwater - The water immediately upstream from a dam. The water surface elevation varies due to fluctuations in inflow and the amount of water passed through the dam.

Headwaters - The source and upper tributaries of a stream or river.

Headworks - All structures and associated facilities located at the beginning (upstream end) of a water management project. In the case of the headworks owned by Alberta Environment, this includes structures for diverting water from the river (e.g. dams or weirs) and facilities for carrying and storing water (e.g. canals or reservoirs).

Heel - The junction of the upstream face of a gravity or arch dam with the ground surface. For an embankment dam, the junction is referred to as the upstream toe of the dam.

Height, Above Ground - The maximum height from the natural ground surface to the top of a dam.

Height, Structural - The vertical distance between the lowest point of the excavated foundation to the top of the dam.

Height/ Head, Hydraulic - The vertical difference between the maximum design water level and the lowest point in the original streambed.

High Hazard Potential - Dams assigned the high hazard potential classification are those where failure or mis-operation results will probably cause huge loss of human life.

Historical Maximum Pool Elevation (Metre) - The highest elevation attained in the Reservoir since construction.

Hydraulic Grade Line (HGL) - The level to which water in a pipe would rise when exposed to atmospheric pressure. If the HGL is below the crown of a pipe, open channel flow is occurring. If the HGL is above the crown of a pipe, pressure flow is occurring (VAT, 2015).

Hydraulic Head (Metre) - Hydraulic head of the dam, defined as the vertical difference between the maximum water level upstream of the dam and the water level at the downstream end of the low-level outlet during the passage of average annual flood. In case the outlets are located in the saddle / above the river bed, the average annual flood level in the main river has to be considered. As an alternative, it is also defined as the vertical difference between the full reservoir level (normal conservation level) and the lowest water level in the main river channel downstream of the dam.

Hydraulics - Study of practical applications of liquid in motion.

Hydrograph, Breach or Dam Failure - A flood hydrograph resulting from a dam breach.

Hydrograph, Flood - A graph showing, for a given point on a stream, the discharge, height, or another characteristic of a flood with respect to time.

Hydrograph, Unit - A hydrograph with a volume of one inch of runoff resulting from a storm of a specified duration and areal distribution. Hydrographs from other storms of the same duration and distribution are assumed to have the same time base but with ordinates of flow in proportion to the runoff volumes.

Hydrologic Cycle - The cycle of water movement from the atmosphere to earth and back again through evaporation, transpiration, condensation, precipitation, percolation, runoff, and storage. See water cycle.

Hydrology - One of the earth sciences that encompasses the natural occurrence, distribution, movement, and properties of the waters of the earth and their environmental relationships. The science dealing with the waters of Earth - their distribution and movement on the surface and underground; and the cycle involving evaporation and precipitation.

Hydro-mechanical Equipment - Gates, valves, hoists, and elevators.

Hydrometeorology - The study of the atmospheric and land-surface phases of the hydrologic cycle with emphasis on the interrelationships involved.

Impervious Surfaces - Land where water cannot infiltrate back into the ground such as roofs, driveways, streets, and parking lots.

Total imperviousness means the actual amount of land surface taken up with impervious surfaces, often stated as a percentage.

Impoundment - Storage of water.

Inactive Storage or Dead Storage – The storage volume of a reservoir between the crest of the lowest outlet and the reservoir bottom.

Inclinometer - An instrument, usually consisting of a metal or plastic casing inserted in a drill hole and a sensitive monitor either lowered into the casing or fixed within the casing. This measures at different points the casing's inclination to the vertical. The system may be used to measure settlement.

Incremental - Under the same conditions (e.g., flood, earthquake, or another event), the difference in impacts that would occur due to failure or mis-operation of the dam over those that would have occurred without failure or mis-operation of the dam and related structures.

Incremental Potential Loss of Life - The estimated potential loss of life for a flood event with dam failure minus the estimated potential loss of life for the same flood event without dam failure (ANCOLD, 2012).

Indicator - A direct or indirect measurement of some valued component or quality in a system, including an ecosystem or organization. For example, an indicator can be used to measure the current health of the watershed or to measure progress toward meeting an organizational goal.

Indirect Economic Consequences - Also called indirect impacts, refer to the changes in the valuation of business output estimated for a failure scenario.

Indirect Economic Effects - Indirect economic effects are the secondary economic effects on regional and local economies that occur as a result of the direct impacts (USDHS, 2011).

Individual Risk - Often considered equivalent to the annualized failure probability. In essence, this term is associated with the most exposed individual who is placed in a fixed relation to a hazard such as a dam. Individual risk is the sum of the risks from all failure modes associated with the hazards that affect that person. The similarity to annualized failure probability is apparent when life loss of that individual is virtually certain (because the failure probability multiplied by a life loss of 1 is equal to the failure probability).

Inflow Design Flood – The flood hydrograph used in the design of a dam and its appurtenant works particularly for sizing the spillway and outlet works and for determining maximum storage, the height of the dam, and freeboard requirements.

Inspection Authority - State regulatory organization, has the authority to require or perform the inspection, at least once every five years, of all dams and reservoirs that would pose a significant threat to human life and property in case of failure to determine the continued safety of the dams and reservoirs.

Inspection Date - Date of the most recent inspection of the dam.

Inspection Frequency (Years/Months) - Scheduled frequency interval for periodic inspections.

Instrumentation - An arrangement of devices installed into or near dams that provide for measurements that can be used to evaluate the structural behaviour and performance parameters of the structure.

Instrumentation - In relation to a dam, means instruments and equipment used to measure the following: hydrological and hydraulic characteristics in relation to the dam, including, without limitation, water levels in the dam and reservoir and at the weirs, and water flow throughout the dam, water clarity in the reservoir and below the dam, seismic, geological and geotechnical characteristics in relation to the dam, including, without limitation, movement of the dam, seismic activity, pore pressures and stresses applied to the dam, temperature variations of the dam, weather conditions that may affect the operation of the dam, other parameters in relation to the dam.

Intake - Any structure on the upstream face of a dam or within a reservoir created for directing water into a confined conduit, tunnel, canal, or pipeline. Placed at the beginning of an outlet-works waterway (power conduit, water supply conduit), the intake establishes the ultimate drawdown level of the reservoir by the position and size of its opening(s) to the outlet works. The intake may be vertical or inclined towers, drop inlets, or submerged, box-shaped structures. Intake elevations are determined by the head needed for discharge capacity, storage reservation to allow for siltation, the required amount and rate of withdrawal, and the desired extreme drawdown level.

Intensity, Seismic - A numerical index describing the effects of an earthquake on man, manmade structures, or other features of the earth's surface.

Inundation Map – A map showing areas that would be affected by flooding from releases from a dam's reservoir. The flooding may be from either controlled or uncontrolled releases or as a result of a dam failure. A series of maps for a dam could show the incremental areas flooded by larger flood releases. For breach analyses, this map should also show the time to flood arrival, and maximum water-surface elevations and flow rates.

Inundation Zone - Envelope of the maximum areal extent of a flood.

Invert - The inside bottom of the structure; for an open- bottom culvert or bridge, the invert is the elevation of the channel's low point at the location of analysis.

Irrigation - The controlled application of water for agricultural purposes through man-made systems to supply water requirements not satisfied by rainfall.

Issue Evaluation (IE) Risk Analysis - Issue Evaluation level risk analyses are detailed team estimates of risks often focused on a small number of specific issues at a single facility, and facilitated by an experienced facilitator.

Joint Meters - An embedded instrument that uses electrical principles to measure movement across a joint or crack.

Lagoon - A shallow pond or lake. In Alberta, the term often refers to a small, artificial body of water usually composed of several cells or compartments used to treat wastewater to a secondary level of treatment.

Landslide - The unplanned descent (movement) of a mass of earth or rock down a slope.

Latitude - Latitude at dam centreline as a single value in decimal degrees (up to the fourth place).

Leakage - Uncontrolled loss of water by flow through a hole or crack.

Left – Shall mean the area to the left when looking in the downstream direction.

Legislation - Laws such as Acts and Regulations that are established by an elected official.

Length of Dam - The length along the top of the dam. This also includes the spillway, power plant, navigation lock, fish pass, etc., where these form part of the length of the dam. If detached from the dam, these structures should not be included.

Length of Navigation Locks (Metre) - Length of the main lock chamber.

Lining - With reference to a canal, tunnel, shaft, or reservoir, a coating of asphaltic concrete, reinforced or unreinforced concrete, shotcrete, rubber or plastic to provide water tightness, prevent erosion, reduce friction, or support the periphery of the outlet pipe conduit.

Liquefaction - A condition whereby soil undergoes continued deformation at a constant low residual stress or with low residual resistance, due to the build-up and maintenance of high pore water pressures, which reduces the effective confining pressure to a very low value. Pore pressure build-up leading to liquefaction may be due either to static or cyclic stress applications, and the possibility of its occurrence will depend on the void ratio or relative density of a cohesionless soil and the confining pressure.

Live Storage – The sum of the active and the inactive storage. The volume of water stored between the minimum drawdown level and the full reservoir level.

Lock Width (Metre) - Width of the main lock chamber.

Longitude - Longitude at dam centreline as a single value in decimal degrees (up to the fourth place).

Loss of life – Human fatalities that would result from a failure of the dam, without considering the mitigation of loss of life that could occur with evacuation or other emergency actions.

Low Hazard Potential - Dams assigned the low hazard potential classification are those where failure or mis-operation results in no to negligible probable loss of human life and low economic and/or environmental losses. Losses are principally limited to the owner's property.

Low-Level Outlet (Bottom Outlet) – An opening at a low level from a reservoir generally used for emptying or for scouring sediment and sometimes for irrigation releases or water supply.

Maintenance - Maintaining structures and equipment in intended operating condition; equipment repair and minor structure repair.

Maintenance – Those tasks that are generally recurring and are necessary to keep the dam and appurtenant structures in a sound condition and free from defect or damage that could hinder the dam's functions as designed, including adjacent areas that also could affect the function and operation of the dam.

Maintenance Inspection – Visual inspection of the dam and appurtenant structures by the owner or owner's representative to detect apparent signs of deterioration, other deficiencies, or any other areas of concern.

Masonry Dam – Any dam constructed mainly of stone, brick, or concrete blocks pointed with mortar. A dam having only a masonry facing should not be referred to as a masonry dam.

Maximum Discharge (Cubic Metres per Second) - Spillway discharge capacity when the reservoir is at its maximum designed water surface elevation.

Maximum Flood Control Level - The highest elevation of the flood control storage.

Maximum Operating Pool Elevation or Maximum Water Level (Metre) - The upper limit or top of active storage. This is the reservoir elevation that would be attained when the reservoir is fully utilized for all purposes, including flood control. It represents the highest elevation achieved in the reservoir under normal operating conditions.

Maximum Storage (Million Cubic Metres) - Maximum storage, defined as the total storage space in a reservoir below the maximum attainable water surface elevation, including any surcharge storage.

Maximum Storage Capacity – The volume, in millions of cubic metres (Mm^3), of the impoundment created by the dam at the effective crest of the dam; only water that can be stored above natural ground level or that could be released by failure of the dam is considered in assessing the storage volume; the maximum storage capacity may decrease over time due to sedimentation or increase if the reservoir is dredged.

Maximum Wind - The most severe wind for generating waves that is possible at a particular reservoir. The determination will generally include results of meteorological studies that combine wind velocity, duration, direction, fetch, and seasonal distribution characteristics in a realistic manner.

Meteorology - The science that deals with the atmosphere and atmospheric phenomena, the study of weather, particularly storms and the rainfall they produce.

Minimum Operating Pool Elevation or Minimum Operating Level or Minimum Draw Down Level (Metre) - The lower limit or bottom of active storage. It represents the lowest elevation to which the reservoir is drawn down under normal operating conditions.

Modified Puls Method – A method of flood routing through a reservoir that ignores the slope of the water surface in the reservoir.

Multipurpose Project - A project designed for irrigation, power, flood control, municipal and industrial, recreation, and fish and wildlife benefits, in any combinations of two or more. Contrasted to single-purpose projects serving only one need.

National/ State Disaster Management Authority - The national and state agencies responsible for emergency operations, planning, mitigation, preparedness, response, and recovery from all hazards.

Natural Levee - A build-up of sediment, sand, or debris on the sides of a river or stream's floodplain that occurs during flooding.

Nearest City/Town - Name of nearest downstream city, town, or village that is most likely to be affected by the failure or disruption of the dam.

Non-Compliance - Where legislative requirements, such as those found in an Act, regulation, Code of Practice, or authorization are not met.

Non-overflow Dam (Section) - A dam or section of dam that is not designed to be overtopped.

Non-uniform Flow - Flow in which the velocity and depth vary in the direction of motion. Non-uniform flow can occur either in a prismatic channel or in a natural channel with variable properties.

Normal Flow - Occurs in a channel reach when the discharge, velocity, and depth of flow do not change throughout the reach. The water surface profile and channel bottom slope will be parallel.

Normal Pool Elevation or Normal Reservoir Level or Full Reservoir Level (Metre) - The reservoir elevation at the normal or conservation storage level (excluding flood and surcharge storage). For a reservoir with a fixed overflow sill the lowest crest level of that sill. For a reservoir whose outflow is controlled wholly or partly by movable gates, siphons or other means, it is the maximum level to which water may rise under normal operating conditions, exclusive of any provision for flood surcharge.

Normal Storage Capacity – The volume, in millions of cubic meters (Mm^3), of the impoundment created by the dam at the lowest uncontrolled spillway crest elevation, or at the maximum elevation of the reservoir at the normal (non-flooding) operating level.

Normal Water Surface - The water surface in a channel the majority of the time produced by normal flow when there is no direct rainfall runoff or drought conditions. The normal water surface is usually at or near the vegetation line. Secondary tributaries usually have a normal water surface at or near the channel bottom. Main channels and primary tributaries usually have normal water surface 0.3 metres to 1 metre above the channel flow line, excluding areas of erosion or deposition.

Notification - To inform appropriate individuals about an emergency condition so they can take appropriate action.

Number of Navigation Locks - Number of existing navigation locks for the dam.

Observation Well - A hole used to observe the groundwater-surface at atmospheric pressure within soil or rock.

Off-stream Use - Water is withdrawn from a surface water source for uses such as irrigation, municipal and industrial water supply, steam-electric power generation, etc.

Orographic - Physical geography that pertains to mountains and to features directly connected with mountains and their general effect on storm path and generation of rainfall.

Other Dam Names - Other names (i.e., reservoir name) of the dam in common use.

Outcome - The result of either planned or unplanned actions. For planning purposes, "outcomes" are the desired endpoint and should guide the development and implementation of related programs. Outcomes can be broad and long-term in nature or focused. They are used in both direction setting and performance measurement.

Outfall - The point at which a pipe or channel discharges to a water body.

Outlet - An opening for releasing discharge that is lower than the spillway crest. Designed to release reservoir water through or around a dam. An opening through which water can be freely discharged from a reservoir to the river for a particular purpose. A conduit or pipe controlled by a gate or valve, or a siphon, that is used to release impounded water from the reservoir.

Outlet Gate – A gate controlling the flow of water through a reservoir outlet.

Outlet Works – A dam appurtenance that provides release of water (generally controlled) from a reservoir.

Overflow Dam/ Overflow Section - A section or portion of a dam designed to be overtopped.

Owner Name - Name of the dam owner.

Parapet wall – A solid wall built along the top of a dam (upstream or downstream edge) used for ornamentation, for the safety of vehicles and pedestrians, or to prevent overtopping caused by wave run-up.

Partnership (Collaboration) - A relationship in which individuals or organizations share resources and responsibility to achieve a common objective, as well as any resulting rewards or recognition. It often includes a formal contract, new resources, and shared risks and rewards. The structure includes a central body of decision-makers whose roles are defined. The links are formalized. Communication is frequent, the leadership is autonomous, and the focus is on specific issues. Partnerships are a form of collaboration.

Peak flow – The maximum instantaneous discharge that occurs during a flood. It is coincident with the peak of a flood hydrograph.

Perennial Stream - A watercourse or a portion, segment, or reach of a watercourse, generally exceeding 0.5 square miles in watershed size, in which surface flows are not frequently or consistently interrupted during normal seasonal low flow periods. Perennial streams that begin flowing subsurface during low flow periods, due to natural geologic conditions, remain defined as perennial. All other streams, or stream segments of significant length, shall be termed intermittent. A perennial stream shall not include the standing waters in wetlands, lakes, and ponds.

Performance Assessment - The linkage of inputs (e.g., funding, staff, equipment, supplies), actions (e.g., advice, projects, programs, services) and outputs (e.g., reports, plans, policies) to outcomes or results (e.g., an increase in awareness, a change in behaviour, or the achievement of an outcome or end result, such as a healthy environment).

Permanent Population at Risk – The population at risk is ordinarily located in the dam-breach inundation zone [e.g., as permanent residents]; three consequence classes [high, very high, extreme] are proposed to allow for more detailed estimates of potential loss of life [to assist in decision-making if the appropriate analysis is carried out] (DSP, 2017).

Pervious Zone - A part of the cross-section of an embankment dam comprising material of high permeability.

Phreatic Surface - The free surface of water seeping at atmospheric pressure through soil or rock.

Piezometer - An instrument used for measure water levels or pore water pressures in embankments, foundations, abutments, soil, rock, or concrete.

Piping - The loss of finer soil particles through the coarser material. The progressive development of internal erosion by seepage.

Plumb Lines - Measures the movement of a concrete dam due to applied reservoir water pressures and temperature changes. Installations consist of a formed shaft, suspension assembly, wire, plumb bob, dashpot and reading stations.

Plunge Pool - A natural or artificially created pool that dissipates the energy of free-falling water.

Policy - A governing principle, plan, or consistent course of action developed in order to meet recognized needs and to achieve specific measurable outcomes. Policies are normally broad, conceptual documents that outline approaches and/or considerations to be taken into account by decision-makers. Policies do not act as constraints but provide information. A statement of intent that is not legally binding. It sets direction and expectations for activities.

Policy Analysis - The comparison of the viability and effects of an existing or proposed set of operating rules to the impact of some other option.

Policy Development - The process of shaping policy, from issue recognition and analysis to implementation and evaluation. While the Alberta Public Service's role is to undertake the necessary steps to develop policy options, it is the role of elected officials to decide policy. This process includes defining the roles of government, citizens (individuals and corporate), communities, and markets will a given policy of policy field.

Policy Instruments - The means and tools available to achieve policy goals, including both regulatory and non-regulatory tools.

Potential Failure Mode - A way that dam failure can occur (i.e., the full sequence of events from initiation to failure) for a given loading condition. A condition of a potential failure mode is that it results in an uncontrolled release of the reservoir.

Pressure Relief Pipes - Pipes used to relieve uplift or pore water pressure in a dam foundation or in the dam structure.

Principal Spillway – The primary or initial spillway engaged during a rainfall-runoff event that is designed to pass normal flows.

Prior Appropriation (Prior Use) - A water law doctrine under which users who can demonstrate the earlier use of a particular water source are given right that takes precedence over all future users of water.

Priority - The concept that the person first using water has a better right to it than those commencing their use later. An appropriator is usually assigned a "priority date". However, the date is not significant in and of itself, but only in relation to the dates assigned other water users from the same source of water. Priority is only important when the quantity of available water is insufficient to meet the needs of all those having a right to use water.

Probability - The likelihood of an event occurring.

Probable - Likely to occur; reasonably expected; realistic.

Probable Maximum Flood – The flood that may be expected from the most severe combination of critical meteorological and hydrologic conditions that are possible in the drainage basin under study.

Probable Maximum Precipitation – Theoretically, the greatest depth of precipitation for a given duration that is physically possible over a given size storm area at a particular geographical location during a certain time of the year.

Proposed dam – Any dam not yet under construction.

Public and Stakeholder Involvement - The process used by the government to obtain advice or recommendations from a community and engage them in decision-making. Public and stakeholder involvement is an umbrella term that includes a range of interactive approaches, including information and education, consultation, collaboration, partnerships, and delegated authority.

Purposes – Project purposes for which the reservoir is used.

Radial Gate (Tainter Gate) – A gate with a curved upstream plate and radial arms hinged to piers or other supporting structure.

Rainfall - (1) Point precipitation: that which registers at a single gage. (2) Area precipitation: Adjusted point rainfall for area size.

Rapidly Varied Flow - Flow in which there is a pronounced curvature of the streamlines, and the assumption of hydrostatic pressure is no longer valid.

Reach - A group of river segments with similar biophysical characteristics. Most river reaches represent simple streams and rivers, while some reaches represent the shorelines of wide rivers, lakes, and coastlines.

Recurrence Interval (Return Period) - The average interval of time expected to pass before a natural event (i.e. storm/flood) of the same magnitude occurs again.

Regime - The length, width, depth, slope, or other physical condition that define a body of water.

Regulating Gate (Regulating Valve) - A gate or valve that operates under full pressure flow conditions to regulate the rate of discharge.

Regulation (Legislation) - Created under authority granted by a law, a regulation presents more specific requirements than the legislation itself.

Regulator - An entity delegated the power to regulate a specific activity or set of activities.

Regulatory Instruments - Rules-based tools that focus on enforcing compliance with minimum standards. Their goal is compliance with the law and their driving mechanism is deterrence. Regulatory tools include laws and regulations.

Rehabilitation or Improvement - Repair of structure deterioration to restore original condition; alteration of structures to improve dam stability, enlarge reservoir capacity, or increase spillway and outlet works capacity; replacement of equipment.

Repairs – Any work is done on a dam that may affect the integrity, safety, and operation of the dam.

Reservoir – Any water spread which contains impounded water. A body of water impounded by a dam and in which water can be stored. A man-made lake that collects and stores water for future use. During periods of low river flow, reservoirs can release additional flow if water is available.

Reservoir Area - The total surface of a reservoir measured in a horizontal plane at an elevation corresponding to the full supply level of the reservoir. The area that would be flooded due to backwater elevations or surcharge is not included.

Reservoir Capacity – The total volume of water a reservoir is capable of holding when filled up to the full supply or normal water level. Storage derived from temporary flash-boards, surcharge, or backwater curve is not included. Reservoir capacity usually is reported as of the date of construction of the dam. The sum of the dead and live storage of the reservoir.

Reservoir Regulation Procedure (Rule Curve) - The compilation of operating criteria, guidelines, and specifications that govern the storage and release function of a reservoir. It may also be referred to as operating rules, flood control diagram, or water control schedule. These are usually expressed in the form of graphs and tabulations, supplemented by concise specifications and are often incorporated in computer programs. In general, they indicate limiting rates of reservoir releases required or allowed during various seasons of the year to meet all functional objectives of the project.

Reservoir Rim - The boundary of the reservoir including all areas along the valley sides above and below the water surface elevation associated with the routing of the IDF.

Reservoir Storage – The retention of water or delay of runoff in a reservoir either by the planned operation, as in a reservoir, or by temporary filling in the progression of a flood wave. Specific types of storage in reservoirs are (a) dead storage, (b) conservation storage, (c) flood storage.

Reservoir Surface Area - The area covered by a reservoir when filled to a specified level.

Residual Risk - The risk remaining after risk reduction measures have been implemented.

Return Flow - Water that has been diverted under the terms of a Water Act licence for a specific purpose but does not get consumed in the process and is returned to the environment. Typically, this is water that results from a temporary use, such as water cycling through a cooling pond, but it can also result from consumptive uses, such as municipal wastewater, that is treated and returned to the environment. (GWMT)

Right – Shall mean the area to the right when looking in the downstream direction.

Riparian - Pertaining to the banks of a river, stream, waterway, or other, typically, flowing body of water as well as to plant and animal communities along such bodies of water.

Riprap - A layer of large dressed stone, pre-cast blocks, bags of cement, or other suitable material, generally placed on the slope of an embankment or along a watercourse as protection against wave action, erosion, or scour. Riprap is usually placed by dumping or other mechanical methods, and in some cases is hand placed. It consists of pieces of relatively large size, as distinguished from a gravel blanket.

Risk - A measure of the likelihood and severity of adverse consequences. The risk is estimated by the mathematical expectation of the consequences of an adverse event occurring, i.e., the product of the probability of occurrence and the consequence, or alternatively, by the triplet of scenario, probability of occurrence, and the consequence.

Risk Analysis – A procedure to identify and quantify risks by establishing potential failure modes, providing numerical estimates of the likelihood of an event in a specified time period, and estimating the magnitude of the consequences. The risk analysis should include all potential events that would cause the unintentional release of stored water from the reservoir.

Risk Assessment – The process of deciding whether existing risks are tolerable and present risk control measures are adequate and, if not, whether alternative risk control measures are justified. Risk assessment incorporates the risk analysis and risk evaluation phases.

Risk-Based - This term implies that a comparison of a risk estimate to risk criteria is the basis for decision-making.

Risk Evaluation - The qualitative or quantitative description of the nature, magnitude, and likelihood of the adverse effects associated with a hazard. A risk evaluation often includes one or more estimates of risk, a risk description, risk management options, economic and other evaluations, and estimates of changes in risk attributable to the management options.

Risk Governance - The process of risk-informed decision making and the process by which risk-informed decisions are implemented.

Risk-Informed - This term implies that decisions are made considering risk estimates and many other contributing factors that might include confidence in the risk estimates, risk uncertainty, deterministic analyses, and the overall dam safety case in addition to other local or regional considerations.

Risk Management - Actions implemented to communicate the risks and either accept, avoid, transfer, or control the risks to an acceptable level considering associated costs and benefits of any action taken.

Risk Reduction Actions - These are actions taken to reduce risks, based on the evaluation of a number of prudent alternative actions. The appropriate actions are based on the magnitude of the risk and the risk reduction, the degree of confidence in the estimated risk and/or the risk reduction, the likelihood of additional information providing a significantly different understanding of the risks, and the costs of taking the actions.

Risk-Neutral - Implies that there is no appreciable increase in risk due to changes in operation, or modifications to the dam or appurtenant structures. (Note: this is different than the definition typically used in the industry, where risk-neutral refers to an equal decrement in probability for a given increment in consequences.)

River Basin - The drainage area for a river above a particular point. The land area surrounding one river from its headwaters to its mouth; the area drained by a river and its tributaries.

River or Stream - Official name of the river or stream on which the dam is built.

Rock Fill Dam – An embankment dam in which more than 50% of the total volume is comprised of compacted or dumped cobbles, boulders, rock fragments, or quarried rock generally larger than 75-millimetre size.

Roller Compacted Concrete Dam – A concrete gravity dam constructed by the use of a dry mix concrete transported by conventional construction equipment and compacted by rolling, usually with vibratory rollers.

Rubble Dam – A stone masonry dam in which the stones are not shaped or are coarse.

Runoff - Water that runs off at the surface during a precipitation or snowmelt event when infiltration and/or storage is exceeded or unavailable. Drainage or flood discharge after a rainfall or snowmelt event which leaves an area as surface flow or as piped flow and is not infiltrated.

Saddle Dam - An auxiliary dam constructed across a saddle or low point on the perimeter of the reservoir of the primary or main dam.

Saddle Dam (or Dyke) – A subsidiary dam of any type constructed across a saddle or low point on the perimeter of a reservoir.

Safe Manner – Operating and maintaining a dam in sound condition, free from defect or damage that could hinder the dam's functions as designed.

Sediment - Eroded soil, rock and plant debris, transported and deposited by water.

Sedimentation - The process of material settling out of the water.

Seepage - The internal movement of water that may take place through the dam, the foundation or the abutments.

Sensitivity Analysis - An analysis in which the relative importance of one or more of the variables thought to have an influence on the phenomenon under consideration is determined.

Settlement - The vertical downward movement of a structure or its foundation.

Settlement Sensors (Pneumatic and Vibrating-wire) - Monitors the difference in elevation between the sensor unit and its reservoir.

Shared Responsibility - The recognition that resource and environmental management is not solely the responsibility of government. Good resource and environmental management are based on cooperation, collaboration, and partnerships among parties that have an interest in achieving resource and environmental outcomes. Shared responsibility recognizes the role that parties outside of government can play in resource and environmental management, but understands that management must be done within clear governance and accountability frameworks.

Sheet Flow - Any flow spread out and not confined; i.e. flow across a flat open field.

Significant Hazard Potential - Dams assigned the significant hazard potential classification are those dams where failure or misoperation results in some probable loss of human life but can cause economic loss, environmental damage, disruption of lifeline facilities, or can impact other concerns. Significant hazard potential classification dams are often located in predominantly rural or agricultural areas but could be located in areas with population and significant infrastructure.

Significant Wave Height - Average height of the one-third highest individual waves. Maybe estimated from wind speed, fetch length, and wind duration

Slide Gate – A gate that can be opened or closed by sliding in supporting guides.

Slope - Inclination from the horizontal. It is sometimes referred to as batter when measured from vertical.

Slope Protection - The protection of a slope against wave action or erosion. See Riprap.

Sluice - An opening for releasing water from below the static head elevation.

Societal Risk - Societal risk is generally equivalent to Annualized Life Loss. Societal risk is defined as the probability of adverse consequences from hazards that impact on society as a whole and create a social concern and potential political response because multiple fatalities occur in one event. Society is increasingly averse to hazards as the magnitude of the consequences increases.

Spillway - A structure over or through which flow is discharged from a reservoir. If the rate of flow is controlled by mechanical means, such as gates, it is considered a controlled spillway. If the geometry of the spillway is the only control, it is considered an uncontrolled spillway. A chute, weir, conduit, tunnel, channel, or other structure designed to permit discharges from a reservoir. The primary purpose of a spillway is to discharge flood flows safely past a dam, but they may also be used to release water for other purposes. A spillway may be gated (controlled) or not. Gates are used to regulating the level of the reservoir above the spillway crest. In an un-gated (uncontrolled) spillway, the discharge occurs automatically when the water level rises above the level of the spillway crest.

Spillway – Shall mean a structure over or through which water flows are discharged. If the flow is controlled by gates or boards, it is a controlled spillway; if the fixed elevation of the spillway crest controls the level of the impoundment, it is an uncontrolled spillway.

Spillway Capacity - The maximum flow a spillway is capable of discharging when the reservoir is at its highest water surface elevation. The maximum spillway outflow that a dam can safely pass through the reservoir at its maximum level.

Spillway Channel/ Spill Channel - An open channel or closed conduit conveying water from the spillway inlet downstream.

Spillway Chute - A steeply sloping spillway channel that conveys discharges at super-critical velocities.

Spillway Crest - The lowest level at which water can flow over or through the spillway.

Spillway Crest Elevation (Metre) - The lowest elevation at which water can flow over or through the spillway.

Spillway Type - Type of spillway – controlled or uncontrolled.

Spillway Width (Metre) - Length of the spillway control section available for discharge when the reservoir is at its maximum designed water surface elevation.

Spillway, Auxiliary - Any secondary spillway that is designed to be operated infrequently, possibly in anticipation of some degree of structural damage or erosion to the spillway that would occur during operation.

Spillway, Fuse Plug - A form of auxiliary spillway consisting of a low embankment designed to be overtopped and washed away during an exceptionally large flood.

Spillway, Service - A spillway that is designed to provide continuous or frequent regulated or unregulated releases from a reservoir, without significant damage to either the dam or its appurtenant structures. This is also referred to as principal spillway.

Spillway, Shaft - A vertical or inclined shaft into which water spills and then is conveyed through, under, or around a dam by means of a conduit or tunnel. If the upper part of the shaft is splayed out and terminates in a circular horizontal weir, it is termed a bell mouth or morning glory spillway.

Spur Dikes - A structure used to protect stream banks from erosion and to encourage stable pools along a stream. It is a linear structure with one end projecting into the stream and the other end on the bank of the stream.

Stability - The condition of a structure or a mass of material when it is able to support the applied stress for a long time without suffering any significant deformation or movement that is not reversed by the release of the stress.

Stage - The elevation of a water surface above its minimum; also above or below an established low water plane; hence above or below any datum of reference; gage height.

Stakeholder - An individual, organization, or government with a direct interest in a particular process or outcome.

Standard - A definite rule established by authority. They are legally enforceable numerical limits or narrative statements found in a regulation, statute, contract, or another legally binding document, which have been adopted from a criterion or objective. Environmental standards often take the form of prescribed numerical values that must be met.

State or Central ID - Official State or Central identification number for the dam.

State Regulatory Agency - Name of the primary state agency with regulatory or approval authority over the dam.

Steady-state Flow - Flow that occurs when the discharge passing a given cross-section is constant with respect to time. The maintenance of steady flow in any reach requires that the rates of inflow and outflow be constant and equal.

Stilling Basin - A basin constructed to dissipate the energy of rapidly flowing water, e.g., from a spillway or outlet, and to protect the riverbed from erosion. A pond or reservoir, riprapped or in a natural state, formed downstream of a dam, usually by means of a small auxiliary dam or weir. Its purpose is to protect the streambed from scouring caused by spillway and outlet discharges. The basin serves to dissipate energy.

Stillwater Level - The elevation that a water surface would assume if all wave actions were absent.

Storage - The retention of water or delay of runoff either by the planned operation, as in a reservoir, or by the temporary filling of overflow areas, as in the progression of a flood wave through a natural stream channel. Definitions of specific types of storage in reservoirs are:

Storm - A disturbance of the ordinary, average conditions of the atmosphere which, unless specifically qualified, may include any or all meteorological disturbances, such as wind, rain, snow, hail, or thunder.

Storm Water - Water discharged from a surface as a result of rainfall or snowfall.

Stormwater Drainage System - Any structure for collecting, storing, or disposing of stormwater and the connections between them. The system includes stormwater sewers, pumping stations, storage areas, management facilities, treatment facilities, and outfall structures.

Strain Meters (Carlson type and Vibrating-Wire) - An instrument that uses electrical principles to measure the strain at the location of the strainmeter.

Strategy - A perspective, position, or plan developed and undertaken to achieve goals. It is the bridge between policy and concrete actions that outlines how a policy will be implemented to achieve its goals.

Stream - Water flowing in a channel or conduit, ranging in size from small creeks to large rivers.

Streambed Elevation (Metre) - The elevation at the dam corresponding to the lowest point in the original streambed.

Structural Height (Metre) - Structural height of the dam, defined as the vertical distance from the lowest point of the excavated foundation to the top of the dam.

Sub-basin - Official name of the sub-basin of which the river or stream on which the dam is built is a tributary. It may also be the main river on which the dam is built. Part of a river basin drained by a tributary or with significantly different characteristics than the other areas of the basin.

Subcritical Flow - Flow that occurs when the Froude number has a value that is less than 1.0, indicating that the gravitational forces are greater than the inertial forces.

Sub-Watershed - A smaller watershed that is a piece of a much larger watershed.

Sunny Day Dambreak flood - A failure of the dam with its storage at Full Supply Level without concurrent flood flow either into or downstream of the dam.

Supercritical Flow - Flow that occurs when the Froude number has a value that is greater than 1.0, indicating that the inertial forces are greater than the gravitational forces.

Supply Management - Managing the supply of water to change the timing of water availability such as water storage, or other measures to increase the supply of water to meet the quantity of water demanded.

Surcharge - The volume or space in a reservoir between the controlled retention water level and the maximum water level. Flood surcharge cannot be retained in the reservoir but will flow out of the reservoir until the controlled retention water level is reached.

Surcharge Storage or Flood Storage – The volume or space in a reservoir between the controlled retention water level and the maximum water level. Flood surcharge cannot be retained in the reservoir but will flow out of the reservoir until the controlled retention water level is reached.

Surface Area (Square Kilometres) - Surface area of the impoundment at its normal retention level / full reservoir level (normal storage conditions).

Surface Runoff - The movement of water on earth's surface, whether the flow is over the surface of the ground or in channels.

Surface Water - Water bodies such as lakes, ponds, wetlands, rivers, and streams, as well as groundwater with a direct and immediate hydrological connection to surface water (for example, water in a well beside a river).

Surveillance - The continual examination of the condition of a dam and its appurtenant structures.

Surveys (Triangulation, trilateration, Global Positioning System (GPS), photogrammetric, and collimation) – Measurement of external vertical and horizontal movement on the surface of the dam.

Suspended Solids - Material, such as fine particles of soil, that neither dissolve nor settle out of the water, but instead are held or carried along in the water.

Sustainability - The balancing of opportunities for growth with the need to protect the environment. It reflects a vision of a vibrant economy and a healthy environment. Regarding renewable resources (e.g., water, timber, fish, and wildlife), sustainability involves managing renewable natural resources so that their status, condition, or use is maintained over time. In this context, the use of a renewable resource, or impacts on it from other human activities, should not exceed its capacity to maintain itself through re-growth, reproduction, and management practices. Regarding non-renewable resources (e.g., coal, oil, gas, and minerals), sustainability involves the development of resources in a responsible manner. This means protecting the environment during the construction and operation phases and ultimately reclaiming the land disturbed by development. In this context, non-renewable resource development is a temporary land use.

Tail Water - The water immediately downstream from a dam. The water surface elevation varies due to fluctuations in the outflow from the structures of a dam and due to downstream influences of other dams or structures. Tailwater monitoring is an important consideration because a failure of a dam will cause a rapid rise in the level of the tailwater.

Temporary Population at Risk – People are only temporarily in the dam-breach inundation zone [e.g., seasonal cottage use, passing through on transportation routes, participating in recreational activities] (DSP, 2017).

Thalweg - The line of lowest elevation along a stream bottom.

The height of Dam – The difference in elevation between the natural bed of the watercourse or the lowest point on the downstream toe of the dam, whichever is lower, and the effective crest of the dam.

The Number of Separate Structures - Number of secondary impounding structures associated with this project (saddle dams or dykes).

Thermometers (resistance temperature devices, thermistors, and thermocouples) - Measures temperature using electrical principles of changing resistance in a copper wire as temperature changes, a semiconductor material that changes its resistance very markedly with temperature, or when two dissimilar metal wires are joined together, a change in temperature produces a change in voltage.

Threshold - The value of an indicator that reflects a problem condition.

Tilt Meters - An instrument that monitors the horizontal or vertical tilt of structures and rock masses.

Time of Concentration - The time required for storm runoff to flow from the most remote point of a drainage area to the point under consideration (design point).

Toe of The Dam – The junction of the downstream slope or face of a dam with the ground surface; also, referred to as the downstream toe. The junction of the upstream slope with ground surface is called the heel or the upstream toe.

Tolerable Risk - A risk within a range that society can live with so as to secure the benefits provided by the dam. It is a risk that is not to be regarded as negligible or ignored, but needs to be kept under review and reduced further if possible.

Top of a Dam - The elevation of the uppermost surface of a dam, usually the roadway or walkway or the non-overflow section of the dam.

Top Thickness (Top Width) - The thickness or width of a dam at the level of the top of the dam (excluding corbels or parapets). In general, the term thickness is used for gravity and arch dams, and width is used for other dams.

Topographic Map - A detailed graphic delineation (representation) of natural and man-made features of a region with particular emphasis on relative position and elevation.

Total Energy Head - The specific energy head plus the elevation of the channel bottom with respect to a datum.

Total Risk - Total risk is the sum of the annualised life loss for all potential failure modes associated with a structure.

Trash Rack - A device located at an intake to prevent floating or submerged debris from entering the intake.

Tributary - A stream that flows into a larger stream or body of water. A tributary is generally regarded as a surface water drainage system which is interconnected with a river system.

Uncertainty - The result of imperfect knowledge about the present or future state of a system, event, situation, or population under consideration. Uncertainty is a qualitative or quantitative measure of the range or spread of reasonable outcomes of a risk estimate. Uncertainty is used to portray variability or a range of values for loads, consequences, and risk estimates, rather than relying solely on single-point estimates.

Uniform Flow - Flow that occurs in a channel with a constant cross-section, roughness, and slope in the flow direction.

Unquantified Risk - Typically, risk is evaluated for a few potential failure modes and for loadings up to the maximum level to which the hazard studies were carried. Additional risk can be accumulated for loading levels higher than the maximum portrayed by the hazard curves, but analyses might not be available at these higher loading levels. Typically, these unquantified risks are assumed to be small, but they may not actually be in all cases. Therefore, they should be evaluated when the potential consequences are large.

Unsteady-state Flow - Flow that occurs when the discharge passing a given cross-section varies over time.

Upstream – Shall mean the side of the dam that borders the impoundment.

Upstream Blanket - An impervious blanket placed on the reservoir floor and abutments upstream of a dam. For an embankment dam, the blanket may be connected to the core.

Velocity Head - The kinetic energy of flowing water expressed as a height of water. The velocity head is also known as the dynamic head.

Vertical Datum - A reference point, surface, or axis on an object against which measurements are made.

Vicinity Map – A map that shows the location of the dam and surrounding roads that provide access to the dam. This map should display the location of the dam in relation to major roads and streets and should include a north arrow and scale bar.

Village, Panchayat, and Taluka Location - Village, Panchayat and Taluka Location on the database.

Volume of the Dam – The total space occupied by the materials forming the dam structure computed between abutments and from top to bottom of the dam. No deduction is made for small openings such as galleries, adits, tunnels, and operating chambers within the dam structure. Portions of power plants, locks, spillway, etc., are included only if they are needed for structural stability of the dam.

Water Allocation - The permitted volume, rate, and timing of a diversion of water outlined in a water licence. When water is permitted to be redirected for a use other than for domestic purposes, it is referred to as an allocation. Agricultural, industrial, and municipal water users must apply for a licence to use a set allocation of water.

Water Body - Any location where water flows or is present, whether or not the flow or the presence of water is continuous, intermittent, or occurs only during a flood. This includes, but is not limited to, wetlands and aquifers.

Water cycle - Transition and movement of water involving evaporation, transpiration, condensation, precipitation, percolation, runoff, and storage.

Water Development - The process of building diversion, storage, pumping, and/ or conveyance facilities.

Water Harvesting - The capture and use of runoff from rainfall and other precipitation (e.g., the collection of rainwater in cisterns).

Water Management - The protection and conservation of water and aquatic ecosystems, including their associated riparian area. Water Conservation Objectives may be set to protect minimum flow and aquatic ecosystem health. Stakeholders may take part in improvements to Water Management Plan.

Water Management Plan - A document developed under the Water Act that provides broad guidance regarding water conservation and management, sets clear and strategic directions regarding how water should be managed or results in specified actions. A Framework for Water Management Planning may outline the process for water management planning and the components required for water management plans. The process may apply to all water bodies, including streams, rivers, lakes, aquifers, and wetlands.

Water Meter - A device that measures the quantity of water used in a house, business, factory, etc. Cities that have implemented a water meter system and charge people according to the amount of water consumed use less water than those cities that charge a flat rate for water.

Water Right - A right to use, in accordance with its priority, a certain amount of water. A legal claim to water when the water is available.

Water Storage - The locations in which water is stored. They can be above ground in lakes, rivers, and other waterways or below ground as groundwater.

Watercourse - The bed and shore of a river, stream, lake, creek, lagoon, swamp, marsh or another natural body of water, or a canal, ditch, reservoir or other artificial surface feature made by humans, whether it contains or conveys water continuously or intermittently.

Watershed – The area drained by a river or river system or portion thereof. The watershed for a dam is the drainage area upstream of the dam.

Watershed divide – The divide or boundary between catchment areas (or drainage areas).

Watershed Management - The protection and conservation of water and aquatic ecosystems, including their associated riparian area. Because land use activities on the uplands of a watershed can affect ground and surface water quality and quantity, a broader, more comprehensive approach to planning is often required. A Watershed Management Plan may look at water quantity, water quality, aquatic ecosystems, riparian area, as well as a variety of land use issues as they impact water. Watershed management plans require water and land-use managers to work together to ensure healthy watersheds.

Watershed Management Plan - A comprehensive document that addresses many issues in a watershed including water quantity, water quality, point and non-point-source pollution, and source water protection. It may or may not include a Water Management Plan. It may also examine ways to better integrate land and resource management within a watershed.

Watershed Management Planning - A comprehensive, multi-resource management planning process involving all stakeholders within the watershed, who, together as a group, cooperatively work toward identifying the watershed's resource issues and concerns as well as develop and implement a watershed plan with solutions that are environmental, socially and economically sustainable.

Watershed Planning and Advisory Council - Collaborative, independent, volunteer organizations with representation from all key partners within the watershed. Their mandate is to engage governments, stakeholders, other partnerships, and the public in watershed assessment and watershed management planning while considering the existing land and resource management planning processes and decision-making authorities.

Wave Protection - Riprap, concrete, or other armouring on the upstream face of an embankment dam to protect against scouring or erosion due to wave action.

Wave Run-up - Vertical height above the still water level to which water from a specific wave will run up the face of a structure or embankment.

Weir – A barrier across a stream designed to alter its flow characteristics. In most cases, weirs take the form of obstructions smaller than conventional dams, pooling water behind them while also allowing it to flow steadily over their tops.

Weir, Broad-crested – An overflow structure on which the nappe is supported for an appreciable length in the direction of flow.

Weir, Measuring – A device for measuring the rate of flow of water. It consists of a rectangular, trapezoidal, triangular, or another shaped notch, cut into a vertical, thin plate over which water flows. The height of water above the weir crest is used to find the rate of flow.

Weir, Ogee – A reverse curve, shaped like an elongated letter "S." The downstream faces of overflow spillways are often made to this shape.

Year Completed - Year when the original main dam structure was completed.

Year Modified - Year when major modifications or rehabilitation of dam or major control structures were completed, and type of modification.

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Central Dam Safety Organisation
Central Water Commission

Vision

To remain as a premier organisation with best technical and managerial expertise for providing advisory services on matters relating to dam safety.

Mission

To provide expert services to State Dam Safety Organisations, dam owners, dam operating agencies and others concerned for ensuring safe functioning of dams with a view to protect human life, property and the environment.

Values

Integrity: Act with integrity and honesty in all our actions and practices.

Commitment: Ensure good working conditions for employees and encourage professional excellence.

Transparency: Ensure clear, accurate and complete information in communications with stakeholders and take all decisions openly based on reliable information.

Quality of service: Provide state-of-the-art technical and managerial services within agreed time frame.

Striving towards excellence: Promote continual improvement as an integral part of our working and strive towards excellence in all our endeavours.

Quality Policy

We provide technical and managerial assistance to dam owners and State Dam Safety Organisations for proper surveillance, inspection, operation and maintenance of all dams and appurtenant works in India to ensure safe functioning of dams and protecting human life, property and the environment.

We develop and nurture competent manpower and equip ourselves with state of the art technical infrastructure to provide expert services to all stakeholders.

We continually improve our systems, processes and services to ensure satisfaction of our customers.

Dam Rehabilitation & Improvement Project